Chapter 8 Global Positioning System (GPS) Survey Specifications

8-01 General

Survey specifications describe the methods and procedures needed to attain a desired survey accuracy standard. The specifications for Post Processed GPS Surveys described in 8-02 are based on Federal Geodetic Control Subcommittee (FGCS) standards and specifications. The FGCS standards and specifications have been modified to meet the specific needs and requirements for various types of primary, secondary, tertiary- and general-order GPS surveys typically performed by WSDOT. The specifications for Real Time Kinematic (RTK) GPS surveys described in 8-03 are based on accepted WSDOT Department of Transportation standards. For complete details regarding accuracy standards, refer to Chapter 7, "Accuracy Classifications and Standards."

WSDOT GPS survey specifications are to be used for all WSDOT-involved transportation improvement projects, including special-funded projects.

GPS surveying is an evolving technology. As GPS hardware and processing software are improved, new specifications will be developed and existing specifications will be changed. The specifications described in this chapter are not intended to discourage the development of new GPS procedures and techniques.

Note:
Newly developed GPS procedures and techniques, which do not conform to the specifications in this chapter, may be employed for production surveys if approved by WSDOT HQ. Newly developed procedures are to be submitted to the WSDOT Geo-Services and Computer Aided Engineering (CAE) Survey Support Offices for distribution and review by other regions.

Note:
The specifications in 8-02, "Post Processed GPS Survey Specifications," are separate and distinct from the specifications in 8-03, "Real-Time Kinematic (RTK) GPS Survey Specifications."

8-02 Post Processed GPS Survey Specifications

8-02.1 Methods

8-02.1(a) Static GPS Surveys

Static GPS survey procedures allow various systematic errors to be resolved when high-accuracy positioning is required. Static procedures are used to produce base lines between stationary GPS units by recording data over an extended period of time during which the satellite geometry changes. All measurements exceeding 6 miles (10 km) must utilize static techniques with longer observation times.

8-02.1(b) Fast-Static GPS Surveys

Fast-static GPS surveys are similar to static GPS surveys, but with shorter observation periods (approximately 5 to 15 minutes). Fast-static GPS survey procedures require more advanced equipment and data reduction techniques than static GPS methods.

8-02.1(c) Kinematic GPS Surveys

Kinematic GPS surveys make use of two or more GPS units. At least one GPS unit is set up over a known (reference) station and remains stationary, while other (rover) GPS units are moved from station to station. All base lines are produced from the GPS unit occupying a reference station to the rover units. Kinematic GPS surveys can be either continuous or "stop and go." Stop and go station observation periods are of short duration, typically under two minutes. Kinematic GPS surveys are employed where tertiary or lower accuracy standards are applicable.

8-02.1(d) Real Time Kinematic (RTK) GPS Surveys

Real-time GPS surveys are kinematic GPS surveys that are performed with a radio or cellular telephone data link between a reference receiver and the roving receiver. The field survey is conducted like a kinematic survey, except measurement data from the reference receiver is transmitted to the roving receiver, enabling the rover to compute it's position in real time. RTK surveys produce a radial network. The distance between the reference receiver and the rover should not exceed 6 miles (10 km).

8-02.2 Equipment

Post processed GPS surveying equipment generally consists of two major components: the receiver and the antenna.

8-02.2(a) Receiver Requirements

Primary, secondary and tertiary post processed GPS surveys require GPS receivers that are capable of recording data. When performing specific types of GPS surveys (i.e. static, fast-static, and kinematic), use receivers and software that are suitable for the specific survey, as specified by the manufacturer. Dual frequency receivers are used for observing base lines over 9 mi (15 km) long.

8-02.2(b) Antennas

Whenever feasible, use all-identical antennas. For vertical control surveys, use identical antennas unless software is available to accommodate the use of different antennas, including Continuous Operating Reference Stations (CORS) antennas. Use identical antennas and receivers, regardless of software accommodations, for WSDOT Primary Reference Network (PRN) surveys.

For primary and secondary horizontal surveys, use antennas with a ground plane attached, and mount the antennas on a tripod or a stable supporting tower. When tripods or towers are used, optical plummets or collimators are required to ensure accurate centering over marks.

The use of range poles and/or stake-out poles to support GPS antennas may only be employed for tertiary horizontal and general-order surveys.

8-02.2(c) Miscellaneous Equipment Requirements

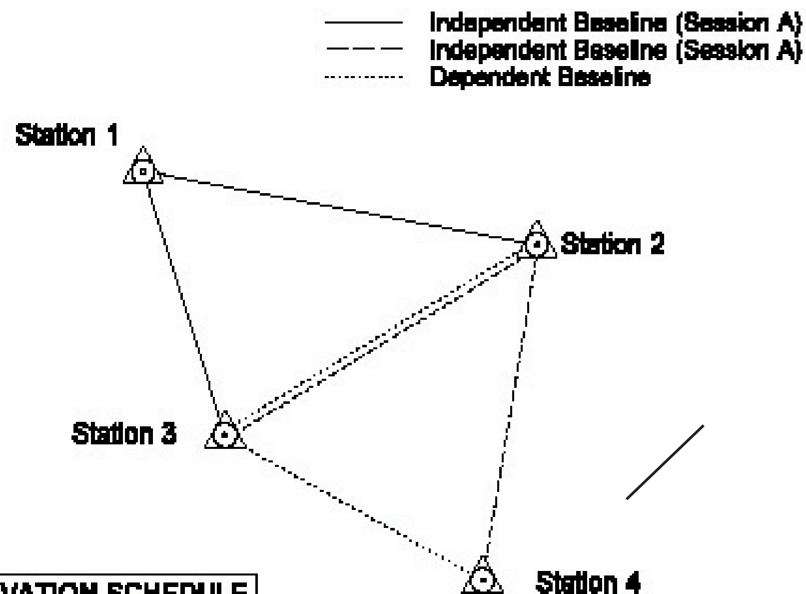
Maintain all equipment to ensure valid survey results. Regularly check equipment for accuracy: calibrate level vials, optical plummets, and collimators at the beginning and end of each GPS survey. If the survey duration exceeds a week, repeat these calibrations weekly for the duration of the survey. For details regarding equipment repair, adjustment, and maintenance refer to Chapter 3, "Survey Equipment."

8-02.3 General Post Processed GPS Survey Specifications

8-02.3(a) Network Design

Base Lines (Vectors)

Base lines are developed by processing data that is collected simultaneously by GPS units at each end of a line. For each observation session, there is one less independent (nontrivial) base line than the number of receivers collecting data simultaneously during the session. Notice in Figure 8-1 that three receivers placed on stations 1, 2, and 3 for Session “A” yield two independent base lines and one dependent (trivial) base line. Magnitude (distance) and direction for dependent base lines are obtained by separate processing, but use the same data used to compute the independent base lines. Therefore, the errors are correlated. Dependent base lines must not be used to compute or adjust the position of stations



OBSERVATION SCHEDULE	
Session	Session
A	1, 2, 3
B	2, 3, 4

.

Observation Schedule
Figure 8-1

Loops

A loop is a series of at least three independent, connecting base lines that start and end at the same station. Each loop has at least one base line in common with another loop. Each loop contains base lines collected from a minimum of two sessions.

Networks

Networks only contain closed loops. Each station in a network is connected with at least two different independent base lines. Avoid connecting stations to a network by multiple base lines to only one other network station. Primary and Secondary GPS control networks consist of a series of interconnecting closed-loop, geometric figures.

Redundancy

Design Primary, Secondary and Tertiary GPS control networks with sufficient redundancy to detect and isolate blunders and/or systematic errors. Redundancy of network design is achieved by:

- Connecting each network station with at least two independent base lines
- Observing a series of interconnecting, closed loops
- Repeating base line measurements

Refer to Figures 8-3 through 8-7 for the maximum number of base lines per loop, the number of required repeat independent base line measurements, and least squares network adjustment specifications. If a Post-Processed GPS survey lacks sufficient network or station redundancy to detect disclosures in an unconstrained (free) least squares network adjustment, it will be considered a general-order GPS survey.

Reference Stations

The following are the requirements for reference (controlling) stations for a GPS survey:

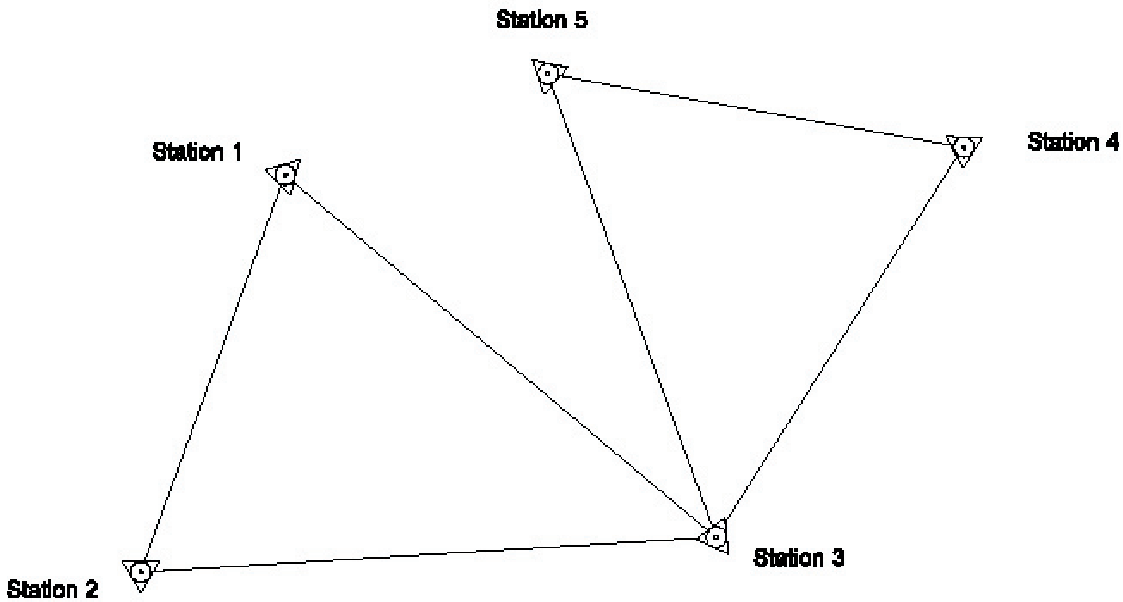
- All have the same, or higher, order of accuracy as that intended for the project.
- All are on the NAD83/91 datum. See Chapter 6, "Survey Datums."
- All are included in, or adjusted to, the Washington High Accuracy Reference Network (HARN) with coordinate values that are current and meet reference network accuracy standards.
- All are evenly spaced throughout the survey project and in a manner that no project station is outside the area encompassed by the exterior reference stations.
- All of the same epoch, or adjusted to the same epoch using National Geodetic Survey (NGS) procedures (NAD 83/91 or subsequent adjustments as tied to the HARN or CORS).

Refer to Figures 8-3 through 8-7 for the number and type of reference stations, and distances between stations.

Adjacent Station Rule (20 Percent Rule)

For primary and secondary GPS surveys, an independent base line is produced between stations that are closer than 20 percent of the total distance between those stations traced along existing or new connections. For example, in Figure 8-2, if the distance between Station 5 and Station 1 is less than 20 percent of the distance between Station 1 and Station 3 plus the distance between Station 3 and Station 5, an independent base line is produced between Station 1 and Station 5. If the application of the adjacent station rule is not practical, include an explanation in the survey notes and/or project report.

Also make direct connections between adjacent intervisible stations.



Adjacent Station Rule (20 Percent Rule)
Figure 8-1

8-02.3(b) Satellite Geometry

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

- Number of satellites available
- Minimum elevation angle for satellites (elevation mask)
- Obstructions limiting satellite visibility
- Positional Dilution of Precision (PDOP)
- Vertical Dilution of Precision (VDOP) when performing vertical GPS surveys

Refer to Figures 8-3 through 8-7 for specific requirements.

8-02.3(c) Field Procedures

Reconnaissance

Thorough field reconnaissance is essential to the execution of efficient, effective GPS surveys. Reconnaissance includes:

- Station setting or recovery
- Checks for obstructions and multipath potential

- Preparation of station descriptions (monument description, to-reach descriptions, etc.)
- Development of a realistic observation schedule

Station Site Selection

The most important factor for determining GPS station location is the project's requirements (needs). After project requirements, consideration must be given to the following limitations of GPS:

- Situate stations in locations that are relatively free from horizon obstructions.

  In general, a clear view of the sky is required. Satellite signals do not penetrate metal, buildings, or trees and are susceptible to signal delay errors when passing through leaves, glass, plastic and other materials.
- Avoid locations near strong radio transmissions because radio frequency transmitters, including cellular phone equipment, can disturb satellite signal reception.
- Avoid locating stations near large flat surfaces, such as buildings, large signs, and fences, as satellite signals can be reflected off these surfaces causing multipath errors.

Some obstructions near a GPS station might be acceptable. For example, station occupation times can be extended to compensate for obstructions.

Multipath

Multipath describes an error affecting positioning that occurs when the signal arrives at the receiver from more than one path. Multipath normally occurs near large reflective surfaces, such as a metal building or structure, but can be in effect by the presence of trees, grass, water, or roadway surfaces. Obviously, a vehicle parked nearby will represent a reflective surface. GPS signals received, because of multipath, give inaccurate GPS positions when processed. The effects of multipath as an error source can be reduced with the newer receiver and antenna designs and sound prior mission planning to eliminate possible causes of multipath. Averaging of GPS signals over a period of time can also help minimize the effects of multipath. With the short occupation times allowed by fast static and real-time techniques, multipath can become problematic.

Weather Conditions

Generally, weather conditions do not affect GPS survey procedures with the following exceptions:

- Never conduct GPS observations during electrical storms.
- Note significant changes in weather or unusual weather conditions in the observation log (field notes).
- Generally, avoid horizontal GPS surveys during periods of significant weather changes.
- Do not attempt vertical GPS surveys during periods of significant weather changes.
- Include GPS observation planning information on current solar activity, as well as DoD-planned satellite outages.
- During periods of moderate solar activity, dual frequency receivers may be used for observing base lines over 6 mi (10 km) long. Do not attempt measurements during intense activity.

Antenna Height Measurements

Blunders in antenna height measurements are a common source of error in GPS surveys because all GPS surveys are three dimensional whether the vertical component will be used or not. Antenna height measurements determine the height from the survey monument mark to the phase center of the GPS antenna. With the exception of permanently mounted GPS antennas, independent antenna heights must be measured in both feet and meters at the beginning and end of each observation session. Use a height hook or slant rod to make these measurements. Record all antenna height measurements on the observation log sheet and enter them in the receiver data file. Antenna height measurements in both feet and meters must check to within ± 0.01 ft (3 mm).

When a station is occupied during two or more observation sessions back to back, break down the antenna/tripod, reset it, and replumb the antenna/tripod between sessions.

When adjustable antenna staffs are used (e.g., kinematic surveys), adjust them so that the body of the person holding the staff does not act as an obstruction. Check the antenna height for staffs in extended positions continually throughout each day.

On-Site Observations

Include the following procedures when making field observations.

- Verify stamping on monument, insuring proper station occupation
- Position antenna so that arrow is pointing north
- Move vehicle away from GPS equipment a minimum of 100 feet
- Check receiver for satellite tracking (minimum of 4), then start session
- Record monument stamping and enter station and file name
- Measure height of antenna in Metric units, check in English, record and enter into receiver

Documentation

Include the following information in the final GPS survey project file:

- Project report
- Project sketch or map showing independent base lines used to create the network
- Station descriptions
- Station obstruction diagrams
- Observation logs
- Raw GPS observation (tracking) data files
- Base line processing results
- Loop closures
- Repeat base line analysis
- Least squares unconstrained adjustment results

- Least squares constrained adjustment results
- Final coordinate list

For details regarding field notes and other survey records, see Chapter 16, “Monumentation and Survey Records.”

8-02.3(d) Office Procedures

General

For primary, secondary and tertiary Post-Processed GPS surveys, raw GPS observation (tracking) data is collected and post processed for results and analysis. Post processing and analysis are required for primary and secondary GPS surveys. The primary post-processed results that are analyzed are:

- Base line processing results
- Loop closures
- Repeat base line differences
- Results from least-squares network adjustments

Post-processing software must be capable of producing relative-position coordinates and corresponding statistics that can be used in a three-dimensional least squares network adjustment. This software must also allow analysis of loop closures and repeat base line observations.

Data Analysis Specifications

Before performing a minimally constrained and fully constrained adjustment, analyze the network for possible outliers using loop closures, analysis of repeat base lines, and comparison of known and observed base lines. To facilitate in detecting the source of blunder (height of instrument, centering errors, etc.), display vectors in northing, easting, or azimuth, height, and distance, or geodetic latitude, longitude, and height.

Data Processing and Verification

It is strongly recommended that base lines be processed daily as related to any given project, allowing the user to identify problems that might exist. Once the base lines are processed, review each base line output file. The procedures used in base line processing are manufacturer-dependent. Certain computational items within the base line output are common among manufacturerers and may be used to evaluate the adequacy of the base line observation in the field. A list of the triple difference, float double difference, and fixed double difference vectors (*dx-dy-dz*) are normally listed.

The geodetic azimuth and the distance between the two stations are also listed. The Root Mean Square (RMS) is a quality factor that helps the user to determine which vector solution (triple float, or fixed) to use in the adjustment. The RMS is dependent on the base line length and the length of time the base line was observed. In some cases, the vector passes the RMS test, but does not fit into the network. If this occurs, ensure the stations were occupied correctly, then if necessary, check for multipath or other interference sources and reprocess data sets.

The first step in data processing is to transfer the observational data to a storage device for archiving and/or further processing.

Once the observational data has been downloaded, preprocessing of data can be completed. Pre-processing consists of editing files info, station names, HI's, equipment types, etc. to ensure data quantity and quality.

Root Mean Square Error Measures

Two-dimensional (2D/horizontal) GPS positional accuracies are normally estimated using a root mean square (RMS) radial error statistic. A 1-8 RMS, 1 sigma error, equates to the radius of a circle in which the position has a 63 percent probability of falling. A circle of twice this radius (i.e., 2-8 RMS or 2DRMS) represents approximately a 97 percent, 2 sigma, positional probability circle. This 97 percent probability circle or 2DRMS, is the most common positional accuracy statistic used in GPS surveying. In some instances, a 3DRMS or 99+ percent probability is used. This RMS error statistic relates to the positional variance-covariance matrix, used in adjustments of GPS networks. Note that an RMS error statistic represents the radius of a circle and therefore is not preceded by a ± sign.

Post Processing Criteria

The success of an observation session based on data processing done by a differencing process can be determined in several ways.

RMS is a measurement (in units of cycles or meters) of the quality of the observational data collected during a given session. RMS is dependent on line length, observation strength, ionosphere, troposphere, and multipath. In general, the longer the line and the more interference by other electronic gear, ionosphere, troposphere, and multipath, the higher the RMS will be (commonly referred to as "noisy data"). A low RMS factor indicates good results, and is one indication to be taken into account. RMS can generally be used to judge the quality of the data used in the post processing and the quality of the post-processed vector.

Redundant lines should agree to the level of accuracy that GPS is capable of measuring to. For example, if GPS can measure a 6 mile (10 km) base line to 0.03 ft (1 cm) +/- 1 ppm, the expected ratio of misclosure is:

$$\frac{0.01\text{ m} + 0.01\text{ m}}{10{,}000\text{ m}} = 1{:}500{,}000$$

Repeated base lines should be near the corresponding:

$$\frac{1\text{ cm} + 1\text{ ppm}}{\text{base line}} = \text{ratio}$$

Loop Closure and Repeat Base Line Analysis

Compute loop closures and differences in repeat base lines to check for blunders and to obtain initial estimates of the internal consistency of the GPS network. Tabulate and include loop closures and differences in repeat base lines in the project documentation. Failure of a base line in a loop closure does not automatically mean that rejection is required, but it is an indication that a portion of the network requires additional analysis.

Least Squares Network Adjustment

Remove blunders from the network and perform a minimally constrained adjustment, to verify the base lines of the network. After a satisfactory standard deviation of unit weight (network reference factor) is achieved using realistic "a priori error estimates" (statistical quality indicator derived from the base line processor that is utilized in the adjustment of each base line), a constrained adjustment is performed.

The constrained network adjustment fixes the coordinates of the known reference stations, thereby adjusting the network to the datum and epoch of the reference stations. For details regarding least squares adjustments, refer to Chapter 7 for "Least Squares Adjustment."

Accuracy Reporting

When providing geodetic coordinate data, include a statement that the data meets a particular accuracy standard for both the *local accuracy* and *network accuracy.* For example: these geodetic data meet the 0.07 ft (2 centimeter) local accuracy standard for the horizontal coordinate values and the 0.16 ft (5 centimeter) local accuracy standard for the vertical coordinate values (heights) at the 95% confidence level. Provide a similar statement for these same data reporting the network accuracy.

Accuracy Determination

The procedure leading to classification involves four steps:

1. Examine the survey measurements, field records, schematics, and other documentation to verify compliance with the specifications for the intended accuracy of the survey. This examination might lead to a modification of the intended accuracy.
2. Examine the results of a minimally constrained, least squares adjustment of the survey measurements to ensure correct weighting of the observations and freedom of blunders.
3. Local and network accuracy measures computed by random error propagation determine the provisional accuracy. In contrast to a constrained adjustment where coordinates are obtained by holding fixed the datum values of the existing network control, accuracy measures are computed by weighting datum values in accordance with the network accuracy's of existing network control.
4. Check the survey accuracy by comparing minimally constrained adjustment results against established control. The result must meet a 95% confidence level. This comparison takes into account the network accuracy of the existing control, as well as systematic effects such as crustal motion or datum distortion. If the comparison fails, then scrutinize both the survey and the network measurement to determine the source of the problem.

8-02.4 Order A and B GPS Surveys

8-02.4(a) Applications

High Accuracy Reference Network (HARN) Surveys

HARN surveys establish high-accuracy geodetic control stations throughout the State of Washington. HARN and related stations are part of the NGS National Spatial Reference System (NSRS). The HARN consists of Federal Base Network (A order, 1:10,000,000) and Community Base Network (B order- 1:1,000,000) stations.

8-02.4(b) Specifications

HARN surveys are performed using Order A and B specifications published by the FGCS. All HARN surveys are planned and coordinated through the HQ Geographic Services Office and submitted to NGS.

8-02.5 Primary (Horizontal) GPS Surveys

8-02.5(a) Applications

Primary Reference Network Surveys

The Washington State Department of Transportation (WSDOT) Primary Reference Network (PRN) is designed to serve as a "first level of densification" from the Washington State High Accuracy Reference Network (HARN). The PRN provides a cost effective, systematic approach, which advocates conducting precise geodetic surveys along entire corridors, multiple corridors, or, in some cases, entire counties. In addition to increased efficiency, improvements in accuracy, because large high-order survey network adjustments are superior to that of forcing the adjustment of a succession of previously unconnected smaller projects, is a major benefit.

All WSDOT PRN monuments must meet NGS standards for geodetic control. All new PRN monuments, established by WSDOT, utilize a special brass disk designating it as a part of the PRN. All PRN positions meet National Spatial Data Infrastructure Standards of less than five centimeters (0.15 ft) (<5 cm) for Network Accuracy and less than two centimeters (0.07 ft) (<2 cm) for Local Accuracy.

All monuments in the PRN Monumentation History include a written "to reach" description following NGS format, a digital picture and are included in the WSDOT Monument Database (www.wsdot.wa.gov/monument). The Monument Database is an Internet application that allows the public at large to access geodetic information gathered by WSDOT.

The GPS measurements include static as well as fast static techniques. The geodetic networks are designed to take advantage of the vast number of HARN stations surrounding and within the project areas. The new stations are installed at an average of 6.8 mi (11 km) intervals to make use of efficient but accurate fast static techniques. Secondary surveys, to reference WSDOT projects, benefit greatly from the selected interval.

8-02.5(b) Specifications

Methods

- Static
- Fast- static

Generally, static GPS survey methods are employed when base line lengths are greater than 6 mi (10 km). Specifications for primary/PRN accuracy using static and fast-static GPS procedures are listed in Figures 8-3a and 8-3b.

Specification	Static	Fast-Static
General Network Design		
Size of project and number of HARN stations included	Minimum size: County-wide, includes all HARN stations	Minimum size: County-wide, includes all HARN stations
Distance between the survey boundary and network reference control stations (1)	>9 mile (>15km)	<9 mile (<15km)
Minimum percentage of all base lines contained in a closed network	100%	100%
Direct connection between survey stations that are closer than 20 percent of the distance between those stations traced along existing or new connections (adjacent station rule)	Yes	Yes
Minimum number of independent occupations per station	100% (2 times) 10% (3 or more times)	100% (2 times) 10% (3 or more times)
Vectors to be measured on the 2nd day	33%	33%
Vectors to be triple redundant	100%	100%
Vectors to be septuple redundant	60%	60%
Minimum # of vectors from encompassing directions on exterior stations	4	4
Minimum # of vectors from encompassing directions on interior stations	5	5
Direct connection between intervisible azimuth pairs	Yes	Yes
Field		
Maximum PDOP during station occupation	3)	3
Minimum observation time on station	150 minutes	15 minutes (PRN)
Minimum number of satellites observed simultaneously at all stations	5 (75% of time)	5
Maximum epoch interval for data sampling	15 seconds	15 seconds
Antenna height measurements in feet and meters at beginning and end of each session (2)	Yes	Yes
Minimum satellite mask angle above the horizon (3)	10 degrees	10 degrees

Primary (Horizontal) GPS Survey Specifications
Figure 8-3a

Specification	Static	Fast-Static
Office		
Fixed integer solution required for all base lines	Yes	Yes
Ephemeris	Precise	Precise
Initial position: maximum 3-d position error for the initial station in any base line solution	33 ft (10 m)	33 ft (10 m)
Maximum misclosure per loop, in terms of loop length	10 ppm	10 ppm
Maximum misclosure per loop in any one component(x, y, z) not to exceed	0.10 ft (3 cm)	0.10 ft (3 cm)
Repeat base line length not to exceed (dual frequency)	31 mi (50 km)	6 mi (10 km)
Repeat base line difference in any one component (x, y, z)not to exceed	10 ppm	10 ppm
Maximum length misclosure allowed for a base line in a properly-weighted, least squares network adjustment	10 ppm	10 ppm
Maximum allowable residual in any one component (x, y, z) in a properly-weighted, least squares network adjustment	0.07 ft (2 cm)	0.07 ft (2 cm)

Notes:

1. Network independent base lines are required to all “existing primary (or better) GPS established NSRS stations” located within 6 mi (10 km) of the project exterior boundary.
2. Antenna height measurements are not required when using fixed-height antenna poles.
3. During office processing, start with a 15-degree mask. If necessary, the angle may be lowered to 10 degrees.

Primary (Horizontal) GPS Survey Specifications
Figure 8-3b

8-02.6 Secondary (Horizontal) GPS Surveys

8-02.6(a) Applications

Project Control Surveys

Secondary accuracy standards are acceptable for horizontal Project Control Surveys. See Chapter 13.04.3, “Project Control Surveys.”

8-02.6(b) Specifications

Methods

- Static
- Fast-static

Dual-frequency receivers are required for observing base lines over 9 miles (15 km) in length. Figures 8-4a through 8-4c list the specifications for secondary accuracy using static and fast-static GPS procedures.

Specification	Static	Fast-Static
General Network Design		
Minimum number of reference stations to control the project (1)	3 PRN or 3 primary (horiz.) or better	3 PRN or 3 primary (horiz.) or better
Maximum distance between the survey project boundary and network reference control stations	31 mi (50 km) if PRN does not exist	6 mi (10 km)
Minimum percentage of all base lines contained in a loop	100%	100%
Direct connection between survey stations that are closer than 20 percent of the distance between those stations traced along existing or new connections (adjacent station rule)	Yes	Yes
Minimum number of independent occupations per station	100% (3 or more times)	100% (3 or more times)
Direct connection between intervisible azimuth pairs:	Yes	Yes
Field		
Maximum PDOP during station occupation	5	5
Minimum observation time on station	70 minutes	10 minutes
Minimum number of satellites observed simultaneously at all stations	4	(5 sat/15min, 6 sat/ 10 min) 4
Maximum epoch interval for data sampling	15 seconds	10 seconds
Time between repeat station observations	45 minutes	45 minutes
Antenna height measurements in feet and meters at beginning and end of each session (2)	Yes	Yes
Minimum satellite mask angle above the horizon (3)	15 degrees	15 degrees
Minimum number of vectors from encompassing directions to all stations	3	3

Secondary (Horizontal) GPS Survey Specifications
Figure 8-4a

Office		
Fixed integer solution required for all base lines	Yes	Yes
Ephemeris (4)	Broadcast	Broadcast
Initial position: maximum 3-d position error for the initial station in any base line solution	66 ft (20 m)	66 ft (20 m)
Maximum misclosure per loop in any one component (x,y,z) not to exceed	0.10 ft (3 cm)	0.10 ft (3 cm)
Repeat base line length not to exceed (dual frequency)	31 mi (50 km)	31 mi (50 km)
Repeat base line length not to exceed (single frequency)	N/A	6 mi (10 km)
Maximum length misclosure allowed for a base line in a properly-weighted, least squares network adjustment	10 ppm	10 ppm
Maximum allowable residual in any one component (x, y, z) in a properly-weighted, least squares network adjustment	0.10 ft (3 cm)	0.10 ft (3 cm)

Secondary (Horizontal) GPS Survey Specifications
Figure 8-4b

Notes:
1. Network independent base lines are required to all "existing primary (or better) GPS established NSRS stations" located within 6.2 mi (10 km) of the project exterior boundary.
2. During office processing, start with a 15-degree mask. If necessary, the angle may be lowered to 10 degrees.
3. Precise ephemeris may be used.

Secondary (Horizontal) GPS Survey Specifications (Notes)
Figure 8-4c

8-02.7 Tertiary (Horizontal) GPS Surveys

8-02.7(a) Applications

Tertiary horizontal accuracy is acceptable for the following typical WSDOT survey operations:

- Supplemental control for engineering and construction surveys
- Photogrammetry control
- Controlling land net points
- Construction survey setup points for radial stakeout
- Setup points for engineering and topographic survey data collection
- Controlling stakes for major structures
- Monumentation surveys

8-02.7(b) Specifications

Methods

- Static
- Fast-static
- Kinematic

Figures 8-5a and 8-5b lists the specifications for tertiary accuracy using static, fast-static and kinematic GPS procedures.

Specification	Static	Fast-Static	Kinematic	RTK
General Network Design				
Minimum number of reference stations to control the project (1)	3 secondary (horiz.) or better	3 secondary (horiz.) or better	3 secondary (horiz.) or better	5 secondary (horiz.) or better
Maximum distance between the survey project boundary and network control stations	9 mi (15 km)	6 mi (10 km)	6 mi (10 km)	6 mi (10 km)
Location of reference network control (relative to center of project); minimum number of "quadrants," not less than	3	3	2	4 + Center Pt.
Minimum percentage of all base lines contained in a loop	100%	100%	100%	0%
Direct connection between survey stations that are less than 20 percent of the distance between those stations traced along existing or new connections (adjacent station rule)	Yes	Yes	Yes	Yes
Minimum percentage of repeat independent base lines	100%	100%	100%	100% Antenna dump
Percent of stations occupied 2 or more times	100%	100%	100%	100%
Direct connection between intervisible azimuth pairs	Yes	Yes	Yes	No
Field				
Maximum PDOP during station occupation	5	5	5	5
Minimum observation time on station	70 minutes	10 minutes	5 Epochs	30 Epochs
Minimum number of satellites observed simultaneously at all stations)	4	4	5 (100% of time)	5 (100% of time)
Maximum epoch interval for data sampling	15 seconds	15 seconds	1 - 15 seconds	1 seconds
Minimum time between repeat station observations			45 minutes	After antenna dump
Antenna height measurements in feet and meters at beginning and end of each session (2)	Yes	Yes	Yes	Yes
Minimum satellite mask angle above the horizon (3)	15 degrees	15 degrees	15 degrees	15 degrees

Tertiary (Horizontal) GPS Survey Specifications
Figure 8-5a

Specification	Static	Fast-Static	Kinematic	RTK
Office				
Fixed integer solution required for all base lines	Yes	Yes	Yes	Yes
Ephemeris (4)	Broadcast	Broadcast	Broadcast	Broadcast
Initial position: max. 3-d position error for the initial station in any base line solution	330 ft (100 m)	330 ft (100 m)	330 ft (100 m)	-
Maximum misclosure per loop in any one component (x, y, z) not to exceed	0.16 ft (5 cm)	0.16 ft (5 cm)	0.16 ft (5 cm)	0.16 ft (5 cm)
Maximum allowable residual in any one component (x, y, z) in a properly-weighted, least squares network adjustment	0.33 ft (10 cm)	0.33 ft (10 cm)	0.33 ft (10 cm)	-

Notes:

1. Network independent base lines are required to existing primary (or better) GPS established NSRS stations within 3.1 mi (5 km) of the project exterior boundary.
2. During office processing, start with a 15-degree mask. If necessary, the angle may be lowered to 10 degrees.
3. Precise ephemeris may be used.

Tertiary (Horizontal) GPS Survey Specifications
Figure 8-5b

8-02.8 WSDOT General-Order (Horizontal and Vertical) Post Processed GPS Survey Specifications

8-02.8(a) Applications

General-order horizontal accuracy is acceptable for the following typical WSDOT survey operations:

- Collection of topographic and planimetric data
- Supplemental design data surveys: borrow pits, utility, drainage, etc.
- Construction staking
- Environmental surveys
- Geographic Information System (GIS) surveys.

8-02.8(b) Specifications

Method

- Real Time Kinematic
- Kinematic

Figure 8-6 lists the specifications for general-order accuracy using kinematic GPS procedures.

Specification	Kinematic	Real-time Kinematic
Minimum number of reference stations to control the project	3 Tertiary or better	3 Tertiary or better
Minimum number of check stations	2	2
Maximum distance between the survey project boundary and the network reference control stations	6mi (10 km)	Within project boundary/ radio range/6mi (10 km) max
Maximum PDOP during station occupation	5	5
Minimum observation time on station	5 epochs	As indicated by the system
Minimum number of satellites observed simultaneously at all stations	5 (100% of time)	5 (100% of time)
Maximum epoch interval for data sampling	1 – 15 seconds	1 second
Minimum satellite mask angle above the horizon	10 degrees (1)	13 degrees

Note:
1. During office processing, start with a 15-degree mask. If necessary, the angle may be lowered to 10 degrees.

General-Order (Horizontal) GPS Survey Specifications
Figure 8-6

8-02.9 Vertical GPS Surveys

8-02.9(a) General

The following guidelines are intended for use on local transportation projects, and are not applicable to larger area networks.

Introduction

Because vertical positioning techniques using GPS are still under development, these guidelines are preliminary and will be updated as improved techniques and procedures are developed. GPS-derived orthometric heights (elevations) are compiled from ellipsoid heights (determined by GPS observations) and modeled geoid heights (using an acceptable geoid height model for the area). (For more detail see Chapter 6-03, "Vertical Datum.")

Because of distortions in vertical control networks and systematic errors in geoid height models, results can be difficult to validate; however, results comparable to those obtained using differential leveling techniques are obtainable.

Geoid Height Modeling Methods

Two basic geoid modeling methods are used to develop the geoid heights:

- Published National and Regional Geoid Models: For relatively large areas (areas exceeding 6 mi (10 km) by 6 mi (10 km), geoid heights use the applicable national or regional geoid model published by NGS. Generally, use the latest published model. If there are indications that the existing published geoid model does not provide adequate geoid heights, the procedures listed in the following paragraph may be substituted.
- Local Geoid Models Based on Existing Vertical Control: For smaller areas, (and where the published geoid model proves inadequate) if there are sufficient existing vertical control stations, a local geoid model applicable to the specific survey can be developed. With this method, geoid heights are determined at new stations by interpolating between the geoid heights at the known vertical control stations. The interpolation can be accomplished automatically during the least squares adjustment process by entering the known orthometric heights as ellipsoid heights for each vertical control station in the adjustment software. The horizontal positions might change slightly. Evaluate the amount of change to decide if separate adjustments need to be performed and documented. If an independent vertical adjustment is performed, include a minimum of constraints (one position) in the horizontal dimension.

Accuracy Standards

When performing vertical control work using conventional methods, accuracy is expressed as a proportional accuracy standard based on the loop or section length (See Chapter 7, “Accuracy Classifications and Standards.”). GPS survey accuracies, both horizontal and vertical, are expressed in the form of allowable station positional variance. This variance is basically independent of the base line lengths, although base line lengths do affect procedures and the accuracies attainable. For horizontal GPS surveys, base line proportional accuracies are computed during the adjustment process, so a comparison of positional and proportional accuracy standards is provided; but, for GPS vertical surveys, only station positional accuracies are obtainable. A comparable relative measure of accuracy based on base line length is not readily available during the adjustment process. The GPS guidelines included in this chapter are designed to achieve an orthometric height accuracy standard of 0.07 ft (20 mm) or 0.15 ft (50 mm) at the 95 percent confidence level relative to the vertical control used for the survey. This means that 95 percent of the orthometric height determinations will be within plus or minus 0.07 ft (20 mm) or 0.15 ft (50 mm) (whichever is applicable) of the “true” relative value, provided the network is designed with sufficient redundancy and validation checks.

8-02.9(b) Applications

Vertical GPS survey methods are an emerging technology. This is particularly true where orthometric heights (elevations) rather than ellipsoid heights are required, as is the case for most WSDOT surveys. Factors to consider when evaluating the use of vertical GPS survey methods are:

- Accuracy requirements for the survey
- Equipment availability
- Distance between survey stations
- Survey station locations (sky view obstructions, etc.)
- Specifications to be employed for the vertical GPS survey
- Whether elevations are required or only relative differences (over time) required
- Time and resources required in comparison to conventional surveys

- Availability and density of suitable reference control
- Future survey efforts in the vicinity

Vertical Project Control Surveys

GPS surveys can be an effective means to establish vertical control (e.g., NAVD88) for a Vertical Project Control Survey, providing the required secondary and tertiary accuracy standard is achieved. The achievable accuracy standards will depend on the guidelines employed and the distance to the vertical reference control network. See 8-02.9(c), "Guidelines." Differential leveling is used throughout the project corridor and strategic locations to aid in geoid modeling for Project Geometric Framework surveys.

Other Surveys

See the list of possible applications Chapter 8-02.8(a).

8-02.9(c) Guidelines

Guidelines for vertical control surveys using GPS are similar to those for primary GPS horizontal control surveys with additional requirements to limit the errors in GPS ellipsoid height determination. Guidelines for GPS vertical control surveys to achieve 0.07 ft (20 mm) or 0.15 ft (50 mm) accuracy standards, relative to existing vertical control are shown in Figures 8-7a and 8-7b.

In addition to the tabular specifications, in complex areas (mountainous, lack of control, need for greater precision, and longer distances to good control), contact the NGS State Geodetic Advisor to obtain the latest information and specifications for vertical GPS surveys.

Specification	0.07 ft (20 mm)	0.15 ft (50 mm)
General		
Minimum number of horizontal control stations for the project (latitude, longitude, ellipsoid height)	3 primary (HPGN-D) or better	3 primary (HPGN-D) or better
Location of horizontal control stations (relative to center of project); minimum number of "quadrants," not less than	3	3
Minimum number of vertical control stations (benchmarks) for the project	4 see 8-02.9(d)	4 see 8-02.9(d)
Location of vertical control stations (relative to center of project); minimum number of "quadrants," not less than	4	4
Maximum distance between project survey stations	6.2 mi (10 km) [avg. 4.3 mi (7 km)]	12.4 mi (20 km) [avg. 7.5 mi (12 km)]
Minimum percentage of all base lines contained in a loop	100%	100%
Minimum percentage of repeat independent base lines (adjacent station rule)	100% of total	100% of total
Field		
Dual frequency GPS receivers required	Yes	Yes
Maximum VDOP during station occupation	4	4
Minimum observation time per adjacent station base line	30 minutes	see note 1
Minimum number of satellites observed simultaneously at all stations	5	5
Maximum epoch interval for data sampling	15 seconds	5 seconds
Time between repeat station observations	see 8-02.9(d)	see 8-02.9(d)
Minimum satellite mask angle above the horizon	15 degrees	15 degrees
Required number of receivers	3	3

** Relative to the existing vertical control*

Vertical GPS Survey Guidelines (Local Projects)
Positional Accuracy Standard –
0.07 ft (20 mm) and 0.15 ft (50 mm)*
Figure 8-7a

Specification	0.07 ft (20 mm)	0.15 ft (50 mm)
Office		
Antenna height measurements in feet and meters at beginning and end of each session	N/A	Yes see note 2
Fixed integer solution required for all base lines	Yes	Yes
Ephemeris	Precise	Broadcast
Initial position: maximum 3-d position error for the initial station in any base line solution. See note 3 below.	33 ft (10 m)	33 ft (10 m)
Loop closure analysis, maximum number of base lines per loop	6	6
Maximum ellipsoid height difference for repeat base lines	0.07 ft (20 mm)	0.16 ft (50 mm)
Maximum RMS values of processed base lines (2)	0.05 ft (15 mm) (typically <0.03 ft (10 mm))	0.05 ft (15 mm) (typically <0.03 ft (10 mm))

Notes:
1. Minimum time on adjacent station base lines must ensure that all integers can be resolved and the root mean square error will not exceed 0.05 ft (15 mm).
2. Antenna height measurements are required at the beginning and end of each observation period and must be made in both feet and meters.
3. Start with HARN stations.

** Relative to the existing vertical control*

Vertical GPS Survey Guidelines (Local Projects)
Positional Accuracy Standard –
0.07 ft (20 mm) and 0.15 ft (50 mm)*
Figure 8-7b

8-02.9(d) General Notes

Observations

Collect data at the vertical control stations continuously and simultaneously with the new project survey station observations. Observe adjacent survey stations simultaneously. Observations at the new project survey stations are continuous for the times specified and must be repeated on a different day and at a different time. Complete the repeated observations on different days either four hours before the starting time of the first day's observations or four hours after the ending time of the first day's observations.

Datums/Network/Epoch

Reference stations must be the same datum, included in (or adjusted to) one consistent geodetic network, and of the same epoch (or adjusted to the latest epoch), especially in areas of known or suspected subsidence. For reference stations, use the most recent epoch NAD83 latitude, longitude, and ellipsoidal height. Vertical control surveys in subsidence areas might require special procedures.

Vertical Control Stations

Three vertical control stations (bench marks) determine the plane of the geoid but provide no redundancy. Include at least one additional vertical control station in the project to provide this redundancy. If possible, include three additional vertical control stations, especially in areas where there are changes in the slope of the geoid as shown on gravity anomaly maps or where there are significant changes in the slope of the terrain. Note that reference stations with published orthometric heights (elevations) may be considered as meeting the requirement for vertical control stations.

Also, locate the vertical control stations so that the project survey stations are bracketed by the vertical control stations. Do not attempt to determine elevations through extrapolation outside the area encompassed by the reference stations.

Checks

Check the elevation difference between adjacent survey stations by conventional leveling (differential or trigonometric) methods for 10 percent or two sections (whichever is greater) of the project survey base lines (i.e., pairs of adjacent survey stations). Use the procedures and quality of observations/measurements that will produce results that meet tertiary standards.

8-03 Real Time Kinematic (RTK) GPS Survey Specifications

8-03.1 Method

8-03.1(a) RTK GPS Surveys

RTK GPS surveys are kinematic GPS surveys (8-02.1-.3) that are performed with a data transfer link between a reference GPS unit (base station) and rover units. The field survey is conducted like a kinematic survey, except data from the base station is transmitted to the rover units, enabling the rover unit to compute its position in real time.

8-03.2 Equipment

An RTK system consists of a base station, one or more rover units, and a data transfer link between the base station and the rover unit(s).

8-03.2(a) Base Station Requirements

A base station is comprised of a GPS receiver, an antenna, and a tripod. The GPS receiver and the antenna must be suitable for the specific survey as determined from the manufacturer’s specifications. Tripod requirements are specified in 8-03.3.

8-03.2(b) Rover Unit Requirements

The rover units are comprised of a GPS receiver, an antenna, and a rover pole. The GPS receiver and the antenna must be suitable for the specific survey as determined from the manufacturer’s specifications.

A rover antenna must be identical (not including a ground plane, if used at the base station) to the base station antenna unless the firmware/software is able to accommodate antenna modeling of different antenna types.

Rover pole requirements are specified in 8-03.3.

8-03.2(c) Data Transfer Link

The data transfer link can be either a UHF/VHF radio link or a cellular telephone link. The data transfer link must be capable of sending the base station's positional data, carrier phase information, and pseudo-range information from the base station to the rover unit. This information must be sufficient to correct the rover unit's position to an accuracy that is appropriate for the type of survey being conducted.

If the data transfer link uses a UHF/VHF radio link with an output of greater than 1 watt, a Federal Communications Commission (FCC) license is required.

All FCC rules and regulations must be adhered to when performing an RTK survey. These include but are not limited to the following:

- Title 47, Code of Federal Regulations (CFR) part 90, Chapter 173 (47 CFR 90.173): Obligates all licensees to cooperate in the shared use of channels.
- 47 CFR 90.403: Requires licensees to take precautions to avoid interference, which includes monitoring prior to transmission.
- 47 CFR 90.425: Requires that stations identify themselves prior to transmitting.

Voice users have primary authorization on the portion of the radio spectrum used for RTK surveying. Data transmission is authorized on a secondary and noninterfering basis to voice use.

Failure to comply with FCC regulations subjects the operator, and their employer, to fines, seizure of the surveying equipment, civil liability, and/or criminal prosecution. Failure to comply also jeopardizes the future use of RTK/GPS surveying by or for WSDOT.

8-03.2(d) Miscellaneous Equipment Requirements

Use RTK equipment that is suitable for the work being done.

All RTK equipment must be properly maintained and checked for accuracy. Conduct the accuracy checks before each survey or at a minimum of once a week to ensure valid survey results.

For details regarding equipment repair, adjustment, and maintenance refer to Chapter 3, "Survey Equipment."

8-03.3 General RTK Survey Specifications

In an RTK survey "radial" shots are observed from a fixed base station to a rover unit. A delta X, delta Y, and delta Z are produced from the base station to the rover unit on the WGS84 datum. From these values, coordinates of the points occupied by the rover unit are produced.

8-03.3(a) RTK Survey Design

RTK survey design differs from static and fast static GPS survey design. With static and fast static GPS surveys, a closed network design method is used. See 8-02.3(a), "Network Design," for more details on GPS network design. Use the following criteria for RTK survey design:

- "Surround" and enclose the project area consisting of Project Geometric Framework control stations. (For the definition of a Project Geometric Framework control station, see the definitions in this section.)
- If the Project Geometric Framework control station is used for horizontal control, the Project Geometric Framework control station must have horizontal coordinates that are on the same datum as the datum required for the project.
- If the Project Geometric Framework control station is used for vertical control, the Project Geometric Framework control station must have a height that is on the same datum as the datum required for the project.
- Include all Project Geometric Framework control stations in a GPS site calibration. (For the definition of a GPS site calibration, see the definitions in this section.)
- If the RTK equipment does not support the use of a GPS site calibration, use the Project Geometric Framework control stations for check shots.
- For tertiary RTK surveys, occupy each new station twice. The 2nd occupation of a new station uses a different base station location. If the new station is being elevated by RTK methods, the 2nd occupation of the new station has a minimum of 3 different satellites in the satellite constellation. This is generally achieved by observing the 2nd occupation at a time of day that is either 4 hours before or 4 hours after the time of the 1st occupation.
- Establish the new stations in areas where obstructions, electromagnetic fields, radio transmissions, and a multipath environment are minimized.
- Use the current geoid model when appropriate.

8-03.3(a)1 THE PROJECT GEOMETRIC FRAMEWORK

Comprehensive and Coordinated Reference Framework

To insure WSDOT projects do not contain mismatched data, a well planned geometric framework of control stations that specifically define the required datum and adjustment must be formed in advance of initiating project development. If coordinate-driven technologies are expected to function properly, a geodetic survey forming a geometric framework must be constructed in a manner that surrounds each individual project. "Calibration" of positioning systems used by WSDOT, consultants, and contractors must be based on the geometric framework survey and its gravity modeling for each project. Individual monuments representing the coordinates, datum, and adjustments must be defined early in the engineering process, utilize throughout the design, and detailed in all contracts as a required specification.

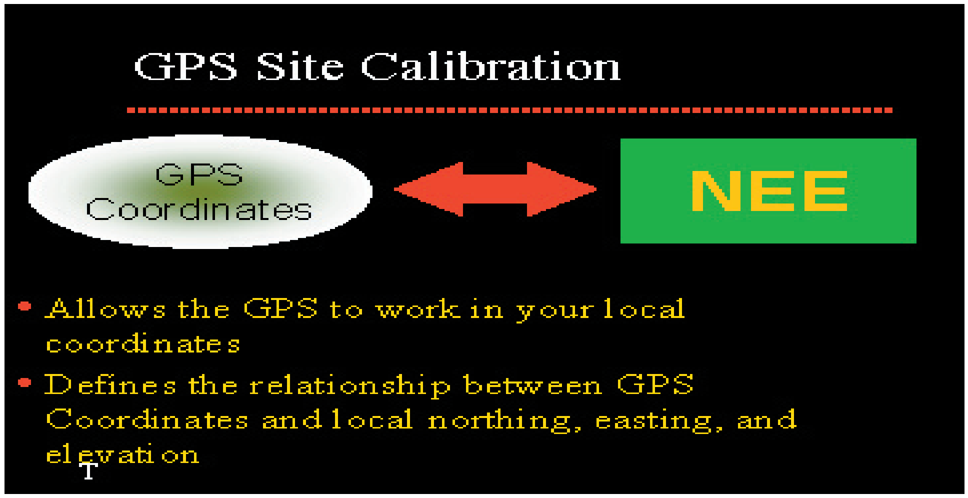
The Project Geometric Framework approach constitutes a "best business practice" for supplying survey control for WSDOT projects as it provides a comprehensive and coordinated reference "template" for new technologies utilized by planners, engineers, designers, consultants, and contractors.

Because the Global Positioning System provides location services for mapping, asbuilts, design, construction, and asset management the following elements need to be correctly addressed and implemented:

How is a Project Geometric Framework Constructed?

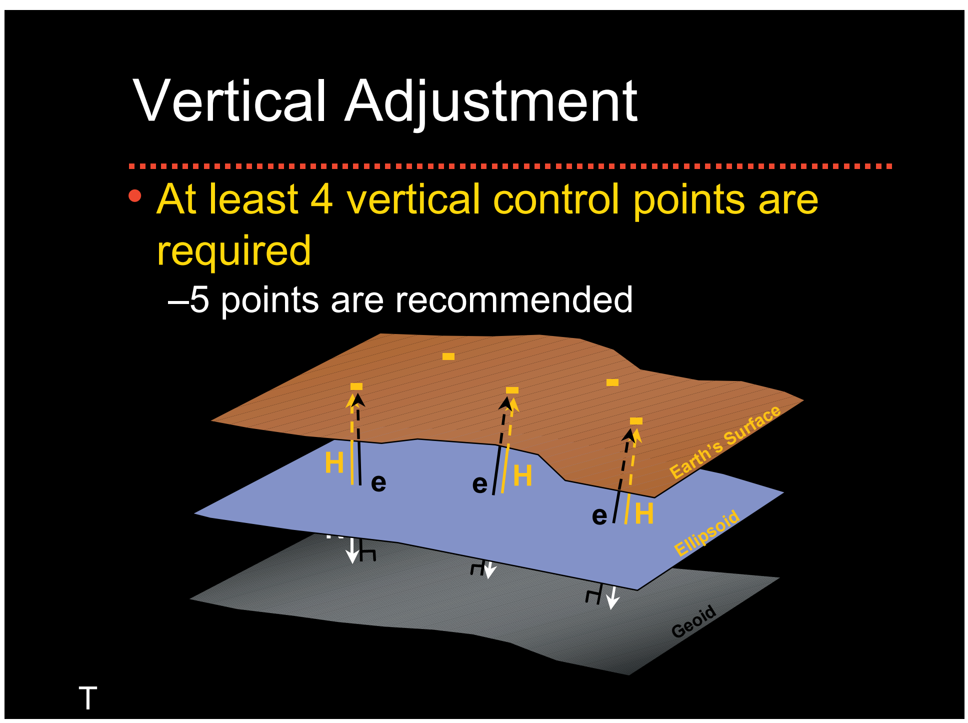
GPS-derived WGS84 Cartesian coordinates must be transformed to a local datum.

This process is called Site Calibration.



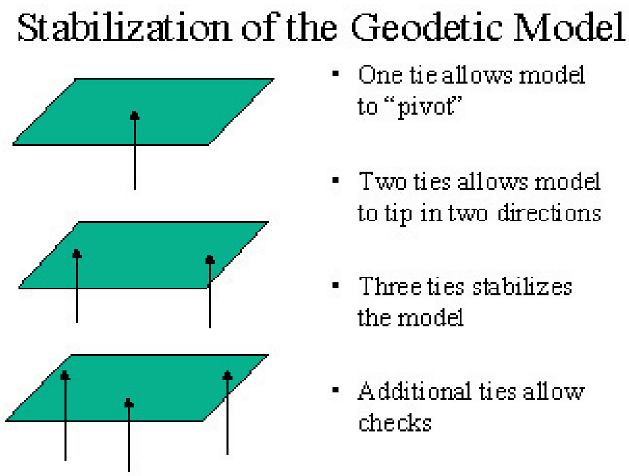
GIPS Site Calibration
Figure 8-8(a)

A geoid model must be utilized to transform earth-centered GPS-derived ellipsoid heights to a usable sea level referenced datum.



Vertical Adjustment
Figure 8-9

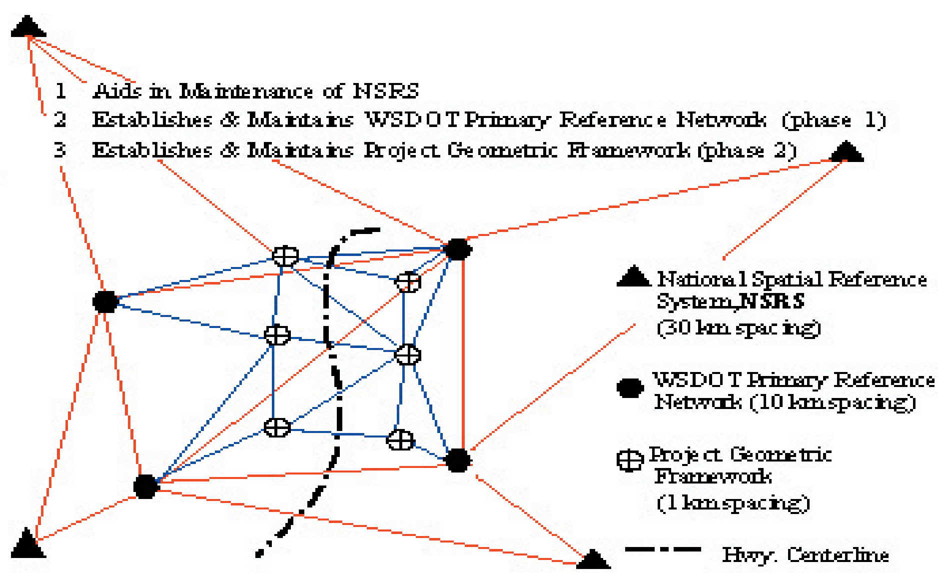
The need for geodetic control on WSDOT projects is based on the concept of stabilizing a plane. The following illustration demonstrates this need:



Stabilization Model
Figure 8-10

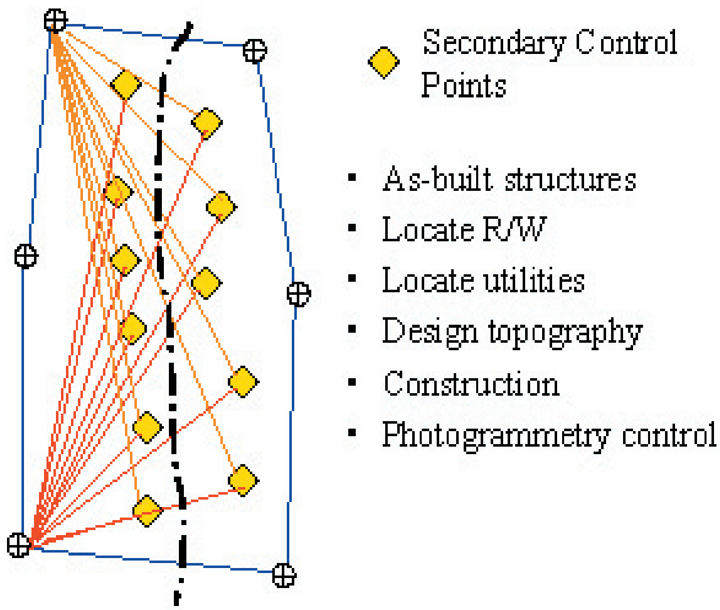
Geodetic principles require a hierarchy layer approach to survey control similar to familiar historical classifications of 1st, 2nd, 3rd Orders of Accuracy. Accuracy begins at the highest level (HARN/CORS) and works through a well-adjusted, widespread network to a dense project-specific framework.

While the scope of a Primary Reference Network is based on the number and location of prioritized WSDOT project corridors, as well as the coordinated needs of WSDOT partners, the scope of the Project Geometric Framework is based on specific needs of the infrastructure improvement.



Primary Reference Network
Figure 8-11

The Project Geometric Framework is delivered in the form of a "template" and used in the following manner:



Geometric Frame Work

Figure 8-12

Definition: A **Project Geometric Framework control station** is a station used to control a survey that uses RTK methods. The station has either horizontal coordinates, a height, or both. The order of accuracy of the horizontal coordinates and the height is at least tertiary.

Definition: A **GPS site calibration** establishes a relationship between the observed WGS84 coordinates and the known grid coordinates. This relationship is characterized by a translation, rotation, and scale factor for the horizontal coordinates and by an inclined plane for the heights. By applying a GPS site calibration to newly observed stations, local variations in a mapping projection are reduced and more accurate coordinates are produced from the RTK survey.

Note:
A GPS site calibration can be produced from RTK observations, an "office calibration," or from a combination of both. If the RTK control stations were established by static or fast static GPS techniques, then an office calibration may be used.

The procedures for an office calibration are:

- Do a minimally constrained adjustment before normalization holding only one WGS84 latitude, longitude, and ellipsoid height fixed.
- Associate the results of this minimally constrained adjustment with the final grid coordinates in a site calibration.

8-03.3(b) Satellite Geometry

Satellite geometry affects both the horizontal coordinates and the heights in GPS/RTK surveys. The satellite geometry factors to be considered for RTK surveys are:

- Number of common satellites available at the base station and at the rover unit.
- Minimum elevation angle for the satellites (elevation mask).
- Positional Dilution of Precision (PDOP) or Geometric Dilution of Precision (GDOP).
- Vertical Dilution of Precision (VDOP).

Refer to Figures 8-8a, 8-8b, and 8-9 for specific requirements.

8-03.3(c) Field Procedures

Proper field procedures must be followed in order to produce an effective RTK survey.

For tertiary RTK Surveys:

- It is recommended that the base station occupy an RTK control station with known coordinates for horizontal RTK surveys and known heights for vertical RTK surveys.
- Use a fixed height survey rod or a survey rod with locking pins for the rover pole. A tripod and a tribrach may also be used. If a fixed height survey rod or a survey rod with locking pins is not used, independent antenna height measurements are required at the beginning and ending of each setup and must be made in both feet and meters. The antenna height measurements must check to within ±?3mm and ±?0.01 feet.
- Use a bipod/tripod with the rover unit's survey rod.
- Establish the data transfer link.
- Observe a minimum of five common satellites at the base station and the rover unit(s).
- Initialize the rover unit(s) before collecting survey data.
- The initialization must be a valid checked initialization.
- PDOP must not exceed 5.
- Collect data only when the root mean square (RMS) is less than 70 millicycles.
- Observe a check shot by the rover unit(s) immediately after the base station is set up and before the base station is taken down.
- The GPS site calibration must have a maximum horizontal residual of 0.07 ft (20 mm) for each horizontal RTK control station.
- The GPS site calibration must have a maximum vertical residual of 0.10 ft (30 mm) for each vertical RTK control station.
- Occupy the new stations for a minimum of 30 epochs of collected data.
- The precision of the measurement data must have a value less than or equal to 0.03 ft (10 mm) horizontal and 0.05 ft (15 mm) vertical for each observed station.
- Locate the rover unit(s) not more than 6 miles (10 km) from the base station.
- The 2nd occupation of a new station must have a maximum difference in coordinates from the 1st occupation of 0.07 ft (20 mm).

- The 2nd occupation of a new station must reinitialize by forcing loss of lock to satellites and radio link by inverting antenna (antenna dump)
- The 2nd occupation of a new station must have a maximum difference in height from the 1st occupation of 0.13 ft (40 mm).
- When setting supplemental control by RTK methods for conventional surveys methods, it is recommended that the new control points be a minimum of 1000 ft (300 meters) from each other. See Chapter 7, “Accuracy Classifications and Standards,” for minimum accuracy standards that must be achieved for specific surveys.
- When establishing set-up points for conventional survey methods, set three intervisible points instead of just an “azimuth pair.” This allows the conventional surveyor a check shot.)

For general-order RTK surveys:

- It is recommended that the base station occupy an RTK control station with known coordinates for horizontal RTK surveys and known heights for vertical RTK surveys.
- Independent antenna height measurements are required at the beginning and ending of each setup and must be made in both feet and meters. The antenna height measurements must check to within ± 0.01 feet and ±3 mm.
- Use a fixed height survey rod or a survey rod with locking pins for the rover poles. A tripod and tribrach may also be used. If a fixed height survey rod or a survey rod with locking pins is not used, independent antenna height measurements are required at the beginning and ending of each setup and must be made in both feet and meters. The antenna height measurements must check to within ± 0.01 feet and ±3 mm.
- Use a bipod/tripod with the rover unit’s survey rod.
- Establish the data transfer link.
- Observe a minimum of five common satellites by the base station and the rover unit(s).
- Initialize the rover unit(s) before collecting survey data.
- The initialization must be a valid checked initialization.
- PDOP must not exceed six.
- Collect data only when the root mean square (RMS) is less than 70 millicycles.
- Observe a check shot by the rover unit(s) immediately after the base station is set up and before the base station is taken down.
- The GPS site calibration must have a maximum horizontal residual of 0.07 ft (20 mm) for each horizontal RTK control station.
- The GPS site calibration must have a maximum vertical residual of 0.10 ft (30 mm) for each vertical RTK control station.
- The precision of the measurement data must have a value less than or equal to 0.05 ft (15 mm) horizontal and 0.07 ft (20 mm) vertical for each observed station.
- Locate the rover unit(s) not more than 6 miles (10 km) from the base station.

8-03.3(d) Office Procedures

Effective office procedures must be followed in order to produce valid results. These procedures include:

- Review the downloaded field file for correctness and completeness.
- Check the antenna heights for correctness.
- Check the base station coordinates for correctness.
- Analyze all reports.
- Compare the different observations of the same stations to check for discrepancies.
- After all discrepancies are addressed, merge the observations.
- Analyze the final coordinates and the residuals for acceptance.

8-03.3(e) General Notes

- At present, do not use RTK surveys for pavement elevation surveys or for staking major structures.
- If the data transfer link is unable to be established, the RTK survey may be performed with the intent of post processing the survey data.
- The data transfer link must not "step on" any voice transmissions.
- If a UHF/VHF frequency is used for the data transfer link, check it for voice transmissions before use.
- The data transfer link is to employ a method for ensuring that the signal does not interfere with voice transmissions.

8-03.4 Tertiary RTK Surveys

8-03.4(a) Applications

Tertiary horizontal accuracy is acceptable for the following typical WSDOT RTK operations:

- Supplemental control for engineering surveys and construction surveys
- Photo control
- Controlling land net points
- Construction survey set-up points
- Topographic survey set-up points
- Monument surveys
- Monument surveys (set)

Tertiary vertical accuracy is acceptable for the following typical WSDOT RTK operations:

- Supplemental control
- Photo control
- Construction survey set-up points
- Topographic survey set-up points

Figures 8-8a and 8-8b list the specifications for tertiary accuracy using RTK procedures.

8-03.5 General-Order RTK Surveys

8-03.5(a) Applications

General-order accuracy is acceptable for the following typical WSDOT RTK operations:

- Topographic surveys (data points)
- Supplemental design data surveys
- Construction surveys (staked points) excluding major structure points and finish grade stakes
- Environmental surveys
- Geographic Information System (GIS) surveys

Figure 8-9 lists the specifications for general-order accuracy using RTK procedures.

Specification	RTK Survey
Field	
Geometry of RTK control stations	Surround and enclose the RTK project
Minimum accuracy of RTK control stations	Tertiary
Minimum number of horizontal RTK control stations for horizontal RTK surveys	4
Minimum number of vertical RTK control stations for vertical RTK surveys	5
Base station occupies an RTK control station	Recommended
Percent of data collected with a valid checked initialization	100 %
Maximum PDOP during station observation	5
Minimum number of satellites observed simultaneously	5
Maximum epoch interval for data sampling	5 seconds
Minimum satellite mask above the horizon	15 degrees
Maximum RMS during a station observation	70 millicycles
Minimum number of epochs of collected data for each observation	30
Horizontal precision of the measurement data for each observation	Less than or equal to 0.03 ft (10 mm)
Vertical precision of the measurement data for each observation	Less than or equal to 0.05 ft (15 mm)

Tertiary-Order RTK Survey Specifications
Figure 8-8a

Specification	RTK Survey
Maximum residual of the horizontal coordinates for the horizontal RTK control stations in the GPS calibration	0.07 ft (20 mm)
Maximum residual of the height for the vertical RTK control stations included in the GPS calibration	0.10 ft (30 mm)
Maximum distance from the base station to the rover unit(s)	6 miles (10 km)
Percent of new stations occupied 2 or more times	100%
Percent of second occupations having a different base station	100%
Maximum difference in horizontal coordinates of the second occupation from the first occupation	0.07 ft (20 mm)
Maximum difference in height of the second occupation from the first occupation	0.13 ft (40 mm)
Establish stations to be used as conventional survey control in groups of 3	Yes
Office	
Check the data collector file for correctness and completeness	Yes
Check the base station WGS84 coordinates and ellipsoid height for correctness	Yes
Analyze the GPS site calibration for a high scale factor and high residuals	Yes
Compare check shots with the known values	Yes
Check all reports for high residuals	Yes

Tertiary-Order RTK Survey Specifications
Figure 8-8b

Specification	RTK Survey
Field	
Geometry of RTK control stations	Surround & enclose the RTK project
Minimum accuracy of RTK control stations	Tertiary
Minimum number of horizontal RTK control stations for horizontal RTK surveys	3
Minimum number of vertical RTK control stations for vertical RTK surveys	4
Base station occupies an RTK control station	Recommended
Percent of data collected with a valid checked initialization	100 %
Maximum PDOP during station observation	6
Minimum number of satellites observed simultaneously	5
Maximum epoch interval for data sampling	5 seconds
Minimum satellite mask above the horizon	13 degrees
Maximum RMS during station observation	70 millicycles
Horizontal precision of the measurement data for each observation	Less than or equal to 0.05 ft (15 mm)
Vertical precision of the measurement data for each observation	Less than or equal to 0.07 ft (20 mm)
Office	
Check the data collector file for correctness and completeness	Yes
Check the base station WGS84 coordinates and ellipsoid height for correctness	Yes
Analyze the RTK site calibration for a high scale factor and high residuals	Yes
Compare check shots with the known values	Yes
Check all reports for high residuals	Yes

General-Order RTK Survey Specifications
Figure 8-9