Chapter 4

GPS Surveys

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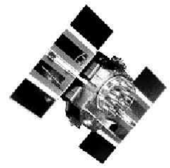


GPS Surveys

4.1 General

Navigation Satellite Timing And Range Global Positioning System (NAVSTAR GPS) is a space-based radio-positioning and time transfer, passive, all weather, 24-hour global navigation satellite system operated and maintained by the United States Department of Defense (DoD). GPS as utilized for positioning is a three-dimensional (3-D) measurement system based on the observations of radio signals of the NAVSTAR GPS. The GPS observations are processed to determine station positions in Earth-Centered Earth-Fixed (ECEF) Cartesian Coordinates (X, Y, Z), which are centered on the World Geodetic System 1984 (WGS-84) reference ellipsoid (the best mean fit to the Earth). In turn, the (X, Y, Z) can be converted to geodetic coordinates (latitude, longitude, and height-above-reference ellipsoid).

With adequate connections to vertical control network points and the determination of the geoidal separation, orthometric heights or elevations can be computed. GPS can be also be classified as a linear measurement technique that determines vectors between points, instead of just a direct distance. A vector has a magnitude and a direction (orientation) in space, whereas, a direct distance is only the magnitude component of a vector. Thus, a GPS vector contains a horizontal and vertical angle, and a distance between two points.

This chapter is a continuation of Chapter 3, except that it is devoted to GPS. GPS is a current state-of-the-art surveying technology with its prominence in contemporary and future surveys. GPS has several major advantages such as both day and night operation, intervisibility between stations is not required, mostly weather independent, geodetic accuracy, and is very productive with a possible one man operation. GPS is becoming the first choice surveying technique for all types of surveys. GPS is the “tool of choice” for surveyors, except in those circumstances where it cannot be utilized due to obstructions or other restricting factors.

In this chapter, GPS will be discussed with the same approach that other surveying techniques were discussed in Chapter 3. The discussion will include a short introduction to GPS, error issues, and field procedures

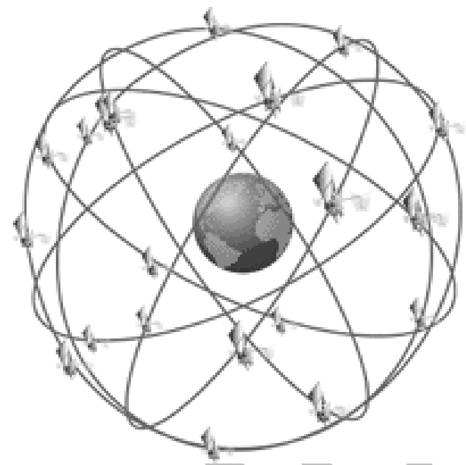
GPS surveying is an evolving technology. As GPS hardware and processing software are improved, and state-of-the-art new techniques are developed, new guidelines and specifications will be considered. The specifications contained herein are referred to as of the date of this issue.

Disclaimer: *The specifications included in this chapter are general recommendations. Contractors should follow their specific contractual agreement with NJDOT.*

4.2 Introduction to GPS

4.2.1 GPS Background

The system was originally designed for military use only, providing sea, air and ground forces of the United States and NATO with an all weather, high-precision, worldwide real-time positioning system. NAVSTAR GPS is maintained by the United States DoD. Though initially designed as a military system, it became freely available for international civil use with certain restrictions to civilians for positioning. The U.S. Air Force Space Command (AFSC) formally declared the GPS satellite constellation as having met the requirement for Full Operational Capability (FOC) as of April 27, 1995. The system has at least a complete set of at least 24 satellites orbiting the earth in a carefully designed pattern.



4.2.2 The Fundamental Components of GPS

The NAVSTAR GPS has three basic segments: Space, Control, and User.

- **The Space Segment** consists of the orbiting satellites making up the constellation. The initial design was for a 24 satellite constellation, each orbiting at an altitude of approximately 20,200 km above the earth, in one of six orbital planes. Each satellite broadcasts a unique "bar code", known as Pseudo Random Noise (PRN) code, which enables GPS receivers to identify the satellites from where the signals came, and makes positioning possible.

- **The Control Segment**, under DoD's direction, oversees the building, launching, orbital positioning, monitoring, and providing GPS positioning services. A master control station updates the information (message) component of the GPS signal with satellite ephemeris data and other announcements to the users. This information is then decoded by the receiver and used in the positioning process.

- **The User Segment** is the most important segment of the system and is comprised of all users making observations with GPS receivers. The civilian GPS user community has increased dramatically in recent years, due to the emergence of low cost, portable GPS receivers and the ever-expanding areas of applications in which GPS has been found to be very useful. Some of these applications are: surveying, mapping, navigation and vehicle tracking. There are two classes of GPS service; the Precise Positioning Service (PPS) which is available only to users authorized by the military, and the Standard Positioning Service (SPS), which is available for civilian use. On December 8, 1993, the DoD formally declared that the NAVSTAR GPS was capable of sustaining SPS.

4.2.3 GPS Limitations

Though GPS can provide a worldwide 3-D position, 24 hours a day, in any type of weather, the system does have some limitations. First, there must be a (relatively) clear "line of sight" between the receiver's antenna and several orbiting satellites. Buildings, trees, overpasses, and other obstructions that block the line of sight between the satellite and the observer (GPS antenna) make it impossible to work with GPS. Anything shielding the antenna from a satellite can potentially weaken the satellite's signal to such a degree that it becomes too difficult to make reliable positioning. Any obstruction that can block or interfere with a radio signal can effectively block or interfere with GPS signals.

Bouncing of the signal off nearby objects may present another problem, that of distinguishing between the signals coming directly from the satellite and the "echo" signal that reaches the receiver indirectly. This phenomenon is referred to as multipath. Multipath refers to the existence of signals reflected from objects in the vicinity of a receiver's antenna that corrupt the direct line-of-sight signals from the GPS satellites, thus degrading the accuracy of both code-based and carrier phase–based measurements. Particularly difficult is close-in multipath in which the reflected secondary signals arrive only slightly later (within about 100 nanoseconds) than does the direct-path signal, having been reflected from objects only a short distance from the receiver antenna. In areas that possess these types of characteristics, longer observational times or traditional surveying techniques must be used instead of GPS positioning or to complement the GPS positioning.

The receiver must receive signals from at least four satellites to be able to make reliable position measurements. In addition, these satellites must be in a favorable geometrical arrangement. The four satellites used by the receiver for positioning must be fairly spread apart. In areas with a relatively open view of the sky, this will almost always be the case because of the way these satellites were placed in orbit.

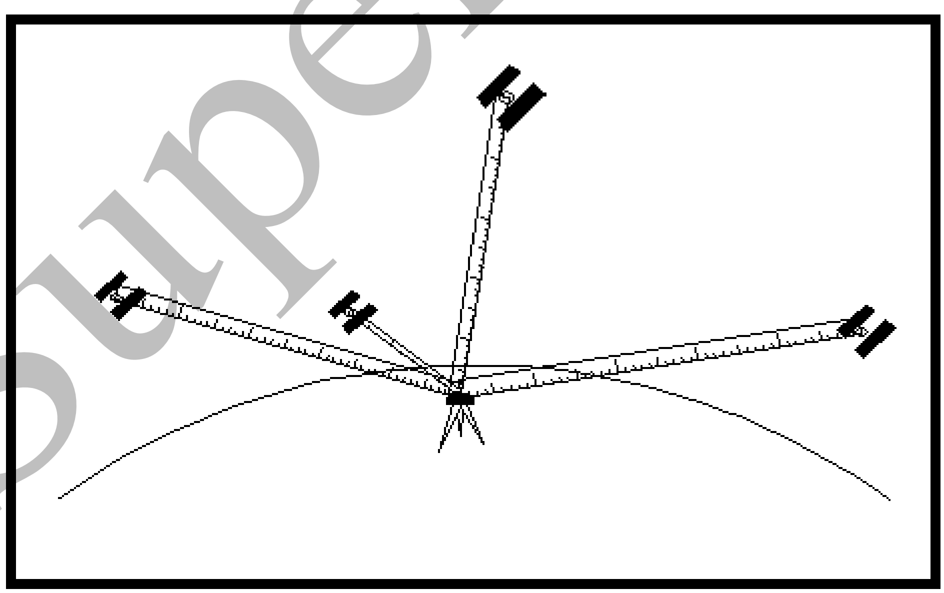


Figure 4.1. Position Determination by Measuring Distances to Satellites

4.2.4 GPS Point Positioning

The position of a point is determined by measure distances or pseudo ranges from the receiver to at least four satellites (see figure 4.1). The GPS receiver "knows" where each of the satellites is at the instant in which the distance was measured. These distances will intersect only at one point, the position of the GPS receiver (antenna). The receiver "knows" the position of the satellites, because this information comes from the broadcast ephemeris that is downloaded when the GPS receiver is turned on. The GPS receiver performs the necessary mathematical calculations, then displays and/or stores the position, along with any other descriptive information entered by the operator from the keyboard.

The way in which a GPS receiver determines distances (called pseudo ranges) to the satellites depends on the type of GPS receiver. Basically, there are two broad classes: carrier phase based and code based.

4.2.4.1 Carrier Phase Receivers

Carrier phase receivers, mainly used in surveying, are capable of centimeter (cm) accuracy or better. These receivers measure distances or pseudo ranges to visible satellites by determining the number (N) of whole wavelengths (λ) and measuring the partial (phase) signal wavelength (Φ) between the satellites and the receiver's antenna. Once the number (N) of wavelengths is known, a pseudo range may be calculated by multiplying 'N' by the wavelength of the carrier signal (L1 and/or L2, 19cm and 24.4cm respectively) plus the partial wavelength. Figure 4.2 illustrates this ranging method. It is then a straight forward, albeit complex task to compute a baseline distance and azimuth between any pair of receivers operating simultaneously. With one receiver placed on a point with precisely known 3-D position and with the calculated baseline (distance between 2 points), the coordinate for the unknown point may be determined.

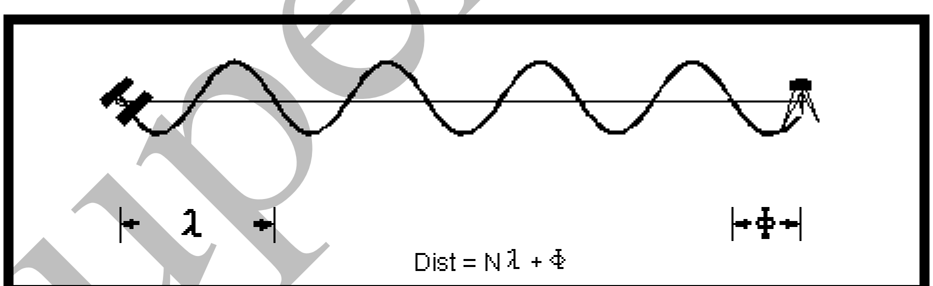


Figure 4.2. Carrier Phase Based Ranging

Carrier phase receivers come in two models: single-frequency (using L1 only) and dual-frequency (using both, L1 and L2). Dual-frequency receivers are required for all NJDOT projects where observations are greater than 10kms. Dual-frequency receivers are the preferred type of receiver for ALL observations, regardless of length.

4.2.4.2 Code Based Receivers

Code based receivers use the speed of light and the time interval that it takes for the signal to travel from the satellite to the receiver to compute the distance to the satellites (see figure 4.3). The time interval (Δt) is determined by comparing the time in which a specific part of the "bar code" left the satellite with the time it arrived at the antenna. The pseudo range is computed by multiplying the time interval by the speed of light constant (c=299,792 Km/second). Pseudo ranges from at least four satellites are needed in order for a receiver to perform essentially a triangulation and produce a position fix. Position fixes are made by the receiver roughly every second, and the more advanced receivers enable the user to store the position fixes in a file that can be downloaded to a computer for post processing.

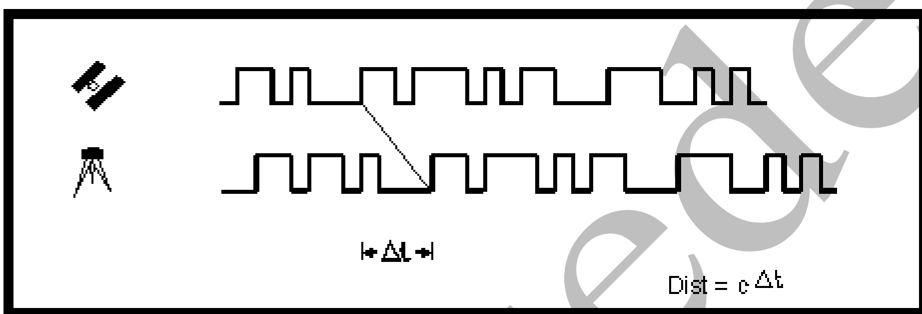


Figure 4.3. Code Based Pseudo Ranging

4.2.5 Advantages of GPS

Probably the most advantageous aspects of GPS are its accuracy, precision, and efficiency, particularly in survey tasks that span a large area. Traditional terrestrial survey activities that would have normally taken months to complete, now take only a few days utilizing GPS. Real-time applications of GPS enable surveyors to perform quick data collection and construction stakeout activities. In fact, a complete construction design plan can be loaded into a receiver and staked out by following the guidance of the receiver.

GPS is used exclusively to densify control networks. The New Jersey Geodetic Survey (NJGS) Unit of NJDOT has been actively using GPS since 1989 to develop a geodetic control network which contains approximately +/-3,000 GPS suitable horizontal control stations in New Jersey which can be utilized for GPS surveying activities.

GPS is a positioning system that can also be used as a real world digitizer for mapping point and line features, such as roads or wetland boundaries. However, for large volume data collection which includes measuring many points, mapping, contouring, etc., one should consider photogrammetry as a more efficient data collection tool.

4.3 Differential GPS Error Sources

GPS has inherited errors that are unique to this technology. GPS, as a surveying tool, has many standard (traditional) surveying errors as well. For example, an instrument setup error applies across the board to all surveying measurements regardless of the instrument or technique used. It does not make a difference what instrument is used, if a GPS receiver, a total station or a range pole is on the wrong point, or not properly set up on the proper point, the survey is erroneous. There are two major categories of error sources in GPS surveys. The first is System Errors and the other is Operational Errors.

4.3.1 System Errors

System errors are those errors that will affect every positioning activity regardless of the specific location of a particular receiver. System errors originate from inaccuracies in the positions of the satellites, the GPS signal and the propagation of the signal through the earth's atmosphere. Most of these errors can be eliminated if GPS positioning is performed in a relative mode and with dual frequency receivers. GPS surveys are always made relative to a known control point, thus, many system errors cancel out. System errors include:

- **Ephemerides Errors** – To compute a position with GPS, it is necessary to know the exact position of each observed satellite. The positions of the satellites derived from the broadcast navigation message (broadcast orbits), are predictions of where the satellites are expected to be. These predictions could have an error of a few meters. For most practical purposes these errors are insignificant in a relative (differential) positioning mode. Precise orbits that have typically sub-decimeter orbital accuracy may be required for specific projects.

- **Satellite Clock** – Precise GPS positioning depends on precise timing devices since one of the GPS observables is time. The double-differencing data processing technique (processing observation data from 2 satellites and 2 receivers simultaneously) can eliminate the impact of this error. In GPS surveying, the standard positioning computation is double-differencing.

- **Tropospheric Delay** – The troposphere is the lower part of the atmosphere extending from the Earth's surface to a height of approximately 15 km. This is an electrically neutral and non-dispersive medium for frequencies as high as about 30 GHz. Within this medium, group and phase velocities of the GPS signal on both L1 and L2 frequencies are equal. The GPS satellites transmit on two L-band frequencies: L1 = 1575.42 MHz and L2 = 1227.6 MHz.

An electromagnetic signal propagating through the neutral atmosphere is affected by the constituent gases. The effect of the troposphere on GPS signals appears as an extra delay in the measurement of travel time from the transmitter to the receiver. This delay is caused at the lower part of the atmosphere and is a function of the atmospheric conditions such as barometric pressure, temperature, and humidity. GPS signals are refracted due to moisture in the lower atmosphere. Reasonably established models for the index of refraction and other atmospheric models can correct this error.

- **Ionospheric Delay** – An error introduced by the outer region of the atmosphere, which causes the GPS signal to disperse and change its traveling speed. The magnitude of the impact of the Ionosphere on the GPS signal depends on the intensity of the sun spot activity or the solar radiation. Solar activity has an 11-year epicycle. At that time, accurate positioning with GPS will become more difficult. Dual frequency receivers are more useful in handling this error because they can compute it and apply the necessary corrections. Single frequency receivers must rely on an external correction model to overcome this error and may produce poor results at the peak of the solar activity.

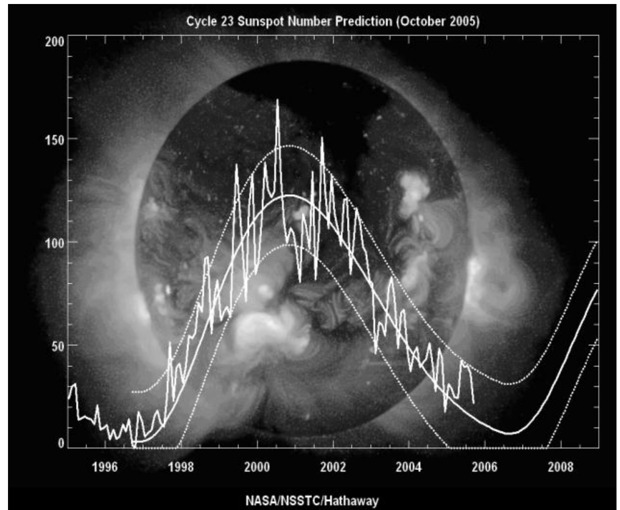


Figure 4.4. Sunspot Predictions

http://solarscience.msfc.nasa.gov/

4.3.2 Receiver Dependent Errors

- **Receiver Clock Error** – As mentioned earlier, precise timing is essential for GPS positioning. High quality clocks are very expensive and even they are subject to errors. Receiver clock errors can be eliminated by utilizing the double differencing computation method.

- **Receiver Noise** – GPS receivers are not perfect devices. Some level of noise always contaminates the observations and produces positioning errors. The "carrier to noise power density ratio C/N_o" value determines how well the tracking loops in the receiver can track the signal and, hence, the precision of the observation. Nominal GPS receiver C/N_o values are in the 40 50 dB-Hz range.

- **Antenna Phase Center** – The cross hair of a GPS receiver is the antenna phase center. The position that is determined with GPS is the position of the antenna phase center. Every antenna is calibrated by the vendor to determine the offset between the center of the physical center of the antenna (used to place the antenna directly above a point) and the phase center. Each antenna has a setup orientation mechanism to enable the user to orient all antennas used in a given session to the same (usually north) direction. If this is done and the same type of antenna is used in the session, the antenna phase error can be eliminated. This is one of the reasons why it is not recommended to mix antennas from different manufacturers in a given session, unless this error is known and corrected for.

- **Bulls-Eye Level Bubble Collimation Error** – The integrity of the bulls-eye level bubble on the 2-meter fixed height pole and the rover bi-pod pole must be checked before, after and during the project (if suspect). The findings must be documented in the final survey report. An out of adjustment bubble can cause an antenna centering error of several centimeters.

- **Tribrach Misalignment** – This is the same error that can be committed when setting up a total station or a theodolite over a point. The GPS antenna is mounted on a tribrach and, in turn, the tribrach is used to place the antenna directly above a point on the ground. If the tribrach is misaligned, the position determined by GPS is not exactly the one of the intended point, but has a small offset which depends on the misalignment error. This error is usually larger than in the case of total station misalignment because GPS antennas are mounted higher than total stations to avoid low obstructions. The verification of both the bulls-eye level bubble and reticular sighting components of the tribrach must be documented.

4.3.3 Errors Due to Point Selection

The selection of points to be measured with GPS is not a trivial matter. The rules of point selection in traditional surveying, mainly maintaining line of sight, do not apply in GPS surveys. Since the direct line of sight has to be with the satellites, points have to be selected in such a way that the clearest signal is received at that point. The following are errors that can impact the results of GPS surveys:

- **Multipath** – Multipath is receiver-satellite geometry dependent, hence the effect of the multipath error on positioning will generally repeat on a daily basis for the same baseline. A signal can arrive at a receiver directly from the satellite, but also from a nearby reflective surface. The reflected signal travels a longer path than the direct one, which results in an observation error. The point to be GPS occupied must be selected in such a way that it is not adjacent to a reflective surface. If possible, avoid locations of stations near large flat surfaces such as buildings and large signs.

For this reason, the vehicle used during the survey should not be parked near the GPS antenna, or the antenna should be mounted higher than the vehicle. Longer observation times can help "average out" multi-path error.

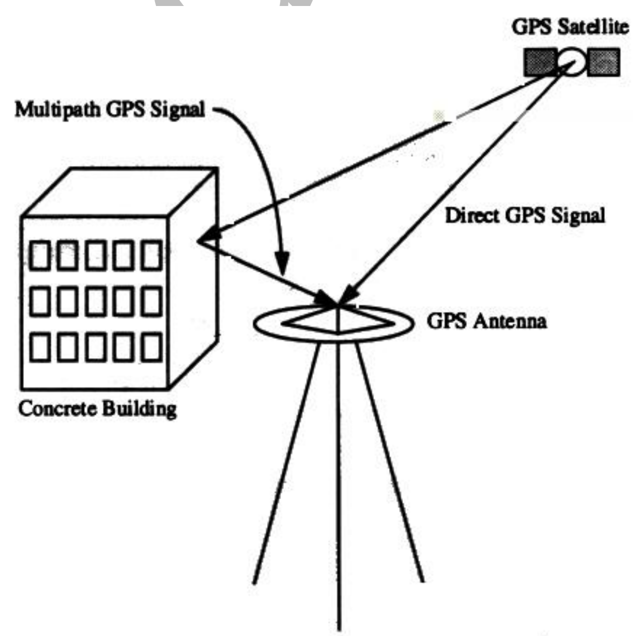


Figure 4.5. Multipath Example

- **Obstructions** – There are two types of obstructions that may interfere with GPS signals. The first is a solid obstruction that completely blocks the antenna from the incoming signal. This will cause fewer actual observations to fewer satellites than planned and a weaker positioning solution. Every point to be GPS surveyed must be inspected for such obstructions and the obstructions must be properly mapped. The observation planning software should be updated with these obstructions to provide better session planning and, eventually, better results. Generally, some GPS obstructions can be tolerated to the north of the station due to the orientation of the satellite orbital planes coming into view in the south.

The second types of obstructions are those that do not completely block the signal but may hamper integer fixing, such as tree canopy. If the location of the point cannot be altered, longer observation sessions are required to assure quality results.

- **Interference** – Electromagnetic signal interference can cause lower C/N_o values and less reliable observations. Areas with very high wireless communication traffic or nearby high voltage power lines should be avoided. Longer sessions could overcome some of the effect of the interference.

4.3.4 Operation Errors

- **Satellite Geometry** – There are several satellite geometry factors to be considered when planning a GPS survey. These factors influence the geometry of the satellites in space at the time of observations is an important factor of GPS positioning accuracy. These factors include the number of satellites available, the minimum elevation angle for the satellites (elevation mask), obstructions that limit satellite visibility, and the various locations of each satellite with respect to the receiver. The best geometry is when the satellites are evenly distributed around the horizon and at least one satellite is at the zenith. The worst geometry is when all the satellites are bunched together in a small region of the sky.

Dilution of Precision (DOP) is a purely geometrical contribution to the uncertainty in a position fix. It is a unit-less number that indicates the error in position determination as a function of the relative satellite geometry. GPS derived positions uses four parameters: position (*X, Y, Z)* and time *t*. The DOP for all four parameters is called Geometric DOP (GDOP). The DOP for a three coordinate position (*X, Y, Z)* is called PDOP, the DOP for two horizontal coordinates (*X, Y*) is called the HDOP, and for vertical position only is called the VDOP. For surveys, it is recommended to use GDOP as the indicator for favorable observation geometry. Observations should be done at times when the GDOP is less than 4. One should never perform GPS surveys when GDOP is more than 8.

GDOP information is computed by an observation planning software. It is based on the predicted location of the satellites relative to the observer. One should be aware of two factors which may change the actual value of GDOP at the time of observation. These factors are obstructions blocking the satellite signals and unanticipated operational problem of satellites. If obstructions are not mapped properly, the software assumes that all the satellites are visible and the computed GDOP may not reflect the actual situation.

Similarly, if the observation sessions are planned in advance and one of the satellites has since stopped operating properly (or temporarily turned off), the actual GDOP at the time of observation may not be the same as predicted. Always check the actual GDOP, as indicated on the receiver, to ensure quality observations.

- **Length of Session** – The length of a session is the maximum time interval at which data is collected from all the receivers simultaneously. This means that it is not enough to collect data at a point, but this data collection must be coordinated with other receivers. Longer sessions can provide better results, but are more expensive. The length of a particular session depends on the type of receivers used, the length of the measured baseline, project specifications etc. One should consult the user's manual of the receiver for determining the optimal length of an observation session.

- **Instrument Setup** – The GPS antenna must be placed directly above the point on the ground with the same attention to detail as in any other survey. A setup error translates directly into a position error. See the total station setup procedure in this manual for details on how to minimize setup errors.

- **Antenna Height** – One of the most common errors in GPS surveys is the incorrect reading or recording of the height of the antenna. Antenna height error affects all three position parameters (*X, Y, Z),* but is more critical for elevation surveys. The height of the antenna should be measured for every setup at least twice, once before the first observation and immediately after the last observation. If the height of the antenna is measured manually, then it must be measured with two independent measuring systems (Metric/English) to eliminate blunders. This measurement is then reduced to the reference point (ARP). The use of a fixed-height 2-meter pole is highly recommended, thus eliminating the antenna measurement and the possibility of an incorrectly recorded height.

4.3.5 Data Processing Errors

Data processing errors are those errors which can be identified only when the field work has been completed. During the processing of the field data certain "poor" observations have to be filtered while others can be corrected with the software.

- **Loop Closures** – Closed loops of baselines are used for the quality control of the measurements and their respective errors in a similar way as used in traversing and leveling. A loop is defined as a series of at least three independent, connecting baselines, which start and end at the same station. Each loop shall contain baselines collected from a minimum of two independent sessions. The acceptable closure for a given survey task should be specified at its planning stage. Survey tasks that require higher accuracies will have more stringent acceptable closures and vice versa.

- **Ambiguity Resolution Error** – The ambiguity in GPS surveys is an integer number of full carrier wave cycles between the receiver and the satellite. An inaccurate ambiguity determination results in a position error because the computed distance between the receiver and the satellite is incorrect. This value cannot be measured directly, but must be computed (resolved) using sophisticated algorithms. Longer sessions and low GDOP values will reduce the potential for ambiguity resolution errors.

- **Cycle Slip** – A cycle slip is a discontinuity in GPS carrier phase observations caused by signal loss, usually due to obstructions. If a GPS receiver loses a signal temporarily, when the signal is reacquired there may be a jump in integer number of full carrier phase cycles (ambiguity). This jump must be identified and corrected; otherwise the position determination may be in error. Most GPS software have cycle slip repair tool to correct short cycle slips. If the cycle slip cannot be repaired, some of the observations may have to be discarded.

- **Station Coordinate and Transformation Errors** – Since GPS surveys are made relative to known control points, an error in the coordinate values of these control points will translate into errors in the newly determined points. The same applies to elevations and benchmarks. This error can be detected if a GPS survey is tied into several control points. Erroneous coordinate or elevation values will result in an inconsistent fit between the survey and the control points.

4.4 GPS Surveys

4.4.1 Network Design and Connections

In accordance with contract documents, policy and procedures, and articles, prior to contract award, physically contacting NJGS must be done before starting any GPS-type survey for a NJDOT project. Additional information for these publications can be obtained from the NJDOT Division of Procurement/Bureau of Professional Services at (609) 530-2452. The web link is: http://www.state.nj.us/transportation/business/procurement/. Project specifics and any additional up-to-data survey related (horizontal/vertical) information by NJGS, (609) 530-5642, fax: (609) 530-3689, can be utilized if available.

All GPS network survey projects will be established horizontally to National Spatial Reference System (NSRS) stations with minimum accuracy of a First-Order (1:100,000). Typically, orthometric vertical control values are a same-survey requirement. Usually, NJDOT projects are linear or corridor in character. As a result, the proper geometric locations of the NSRS GPS control stations, in particular benchmarks, with respect to the project would stabilize any possible rotational error. Specific locations of the new control points depend on the optimum layout to carry out the required needs of the survey.

Checks shall be made to ensure that no existing network control points have been moved or disturbed. If any are doubtful, additional existing points shall be tied into the network. All control stations which are in agreement for the intended accuracy will be used as constraints in the final adjustment. If any control station does not fit, then a report of the reason(s) for not constraining it must be highlighted in the project report.

The minimum number of horizontal network constraints is stated herein, with their location being distributed in at least three different quadrants relative to the center of the project. Where existing National Geodetic Survey (NGS) published horizontal control on a common datum is present, all such stations lying within two kilometers of the survey's boundaries must be included in the survey.

Horizontal control networks shall be based on the North American Datum of 1983 (NAD83). All stations must be published with a common datum tag and agree with each other for the required accuracy of the survey. The use of eccentric points, without direct connections to the NSRS, as horizontal control stations is not permitted. The project horizontal network will be connected to the NSRS in one of the following methods:

- A minimum of three NSRS stations, one of which must be an "A or B-Order" Federal Base Network station (FBN) or Cooperative Base Network (CBN) station and the remaining stations shall be, at a minimum, First-Order accuracy. The three control stations will lie in three separate quadrants from the center of the project.

- Two A/B-Order FBN/CBN stations which are located in separate quadrants about the center of the project, preferably in diagonally opposite quadrants from the center of the project.

- In lieu of one of the A/B-Order stations, a horizontal network ties to a NSRS Continuously Operating Reference Stations (CORS) and an A/B-Order station. The CORS station should preferably be positioned in diagonally opposite quadrants about the center of the project from the other A/B-Order station.

The A/B-Order FBN/CBN, in New Jersey, as it currently stands, contains about 117 stations. The spacing of these stations was originally designed to be within 20-25 km of each other. This allows for any GPS survey, utilizing dual frequency receivers, to be easily connected to the NSRS via this route.

Vertical control networks shall be based on the North American Vertical Datum of 1988 (NAVD88) and connected to a minimum of four NGS stations, with published NAVD88 orthometric elevations, preferably a minimum of Second-Order accuracy or higher. Three vertical control stations (benchmarks) determine the plane of the geoid but provide no redundancy. The fourth bench mark shall be included to provide this redundancy.

Direct GPS connections must be made to a minimum of two NSRS benchmark stations. One highly recommended vertical connection is to a FBN/CBN station. Communication with NJGS must be made before surveys are started because of the possibility of additional benchmarks that may be available due to on-going level projects being surveyed by NJGS to establish new NAVD88 heights within the State. If authorized from NJGS and used, these "benchmarks" must be documented in the final project report. The use of eccentric vertical stations is permitted provided they are located within 100 meters of the original mark and three wire/digital leveling is used to determine the elevation of the eccentric point(s). All eccentric vertical connections must be documented.

GPS derived ellipsoidal height differences, when combined with geoidal height differences, can give usable orthometric height differences. The latest version of the NGS provided geoid model (currently GEOID03) must be used and documented in determining the orthometric heights for any points established by GPS done for NJDOT. Figure 4.6 illustrates the large number of existing NSRS benchmarks used to model GEOID03 in New Jersey. The Internet link for the illustration is:

http://www.ngs.noaa.gov/PC_PROD/WorkShops/PPT/GeodeticandTidalDatums.ppt#407,24,Ellipsoid, Geoid, and Orthometric Heights

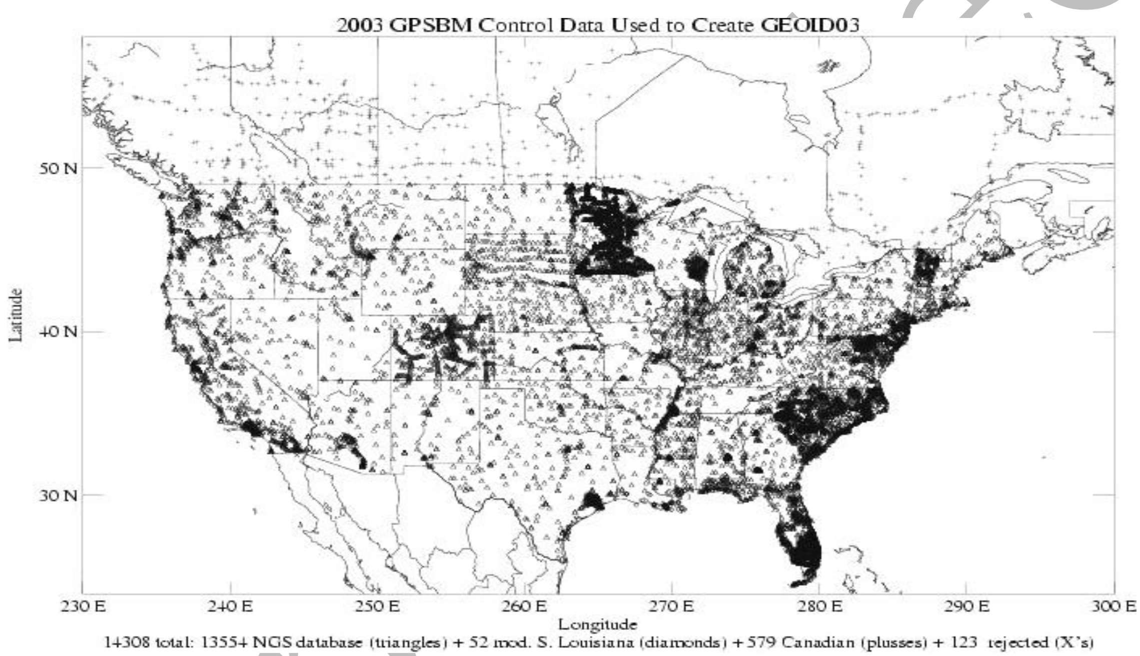


Figure 4.6. 2003 GPSBM Control Data Used To Create **GEOID03**

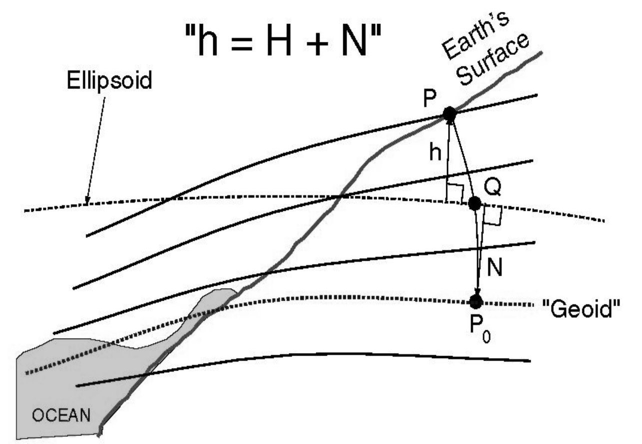
The use of GPS for vertical network surveys requires an understanding of the relationship between conventional and GPS height systems, and of problems unique to the vertical component of a GPS measurement.

Conventional leveling measures the relative elevations of points above an undulating equipotential surface called the geoid, which is close to, but not the same as, "mean sea level." An approximate example of a geoidal reference surface is NAVD88. The leveling observations used by NGS in NAVD88 were corrected for rod scale and temperature, level collimation, and astronomic, refraction, and magnetic effects. Geopotential differences were generated and validated, using interpolated gravity values based on actual gravity data. An orthometric correction is then applied to the elevations to correct for the error introduced by the fact that level surfaces at different elevations are not exactly parallel.

In contrast, GPS measures the relative elevations of points above a smooth, mathematically simple surface called an ellipsoid. An example of an ellipsoidal reference surface is GRS80, the defining surface for NAD83. Elevations derived from GPS measurements are ellipsoidal heights

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

The height equation h=H+N is only an approximation, as orthometric height is measured along a curved plumb line normal to the geoid surface, while the ellipsoidal and geoid heights are measured along straight lines normal to the ellipsoid surface.



h (Ellipsoid Height) = Distance along ellipsoid normal (Q to P)
N (Geoid Height) = Distance along ellipsoid normal (Q to P_0)
H (Orthometric Height) = Distance along Plumb line (P_0 to P)

http://www.ngs.noaa.gov/PUBS_LIB/DRAFTGuidelinesforEstablishingGPSderivedOrthometricHeights.pdf

Figure 4.6. Surface Relationships

When comparing the GEOID03 model with GPS ellipsoidal heights in the NAD83 reference frame and leveling in the NAVD88 vertical datum, it is seen that GEOID03 has roughly a 2.4 cm absolute accuracy (one sigma) in the regions of GPS on benchmark coverage. For further GEOID03 information see the NGS reference link: http://www.ngs.noaa.gov/GEOID/GEOID03/

The height component of a GPS survey measurement is also affected by relatively poor geometric strength for trilateration, as the earth blocks all satellite signals from the hemisphere below the horizon. This imbalance makes height measurements more susceptible than horizontal measurements to signal path errors from multipath or atmospheric conditions. Accordingly, GPS height accuracies for a survey are typically 1.5-3 times worse than GPS horizontal accuracies, depending on data quality and base line length.

Depending on the project requirements, intervisible pairs can be established by GPS procedures. Station pairs (station and reference station) are provided for any terrestrial survey needs. These azimuth pairs shall be established at regular intervals in order to provide sufficient control along the project length with spacing, if possible, of 100-400 meters between stations so as to be accurate to within fifteen seconds (+/-10”) of arc.

Table 4-6: Guidelines for Minimum Spacings for Establishing Pairs of Intervisible Stations to Meet Azimuth Reference Requirements

SPACING BETWEEN A “PAIR” OF STATIONS, NOT LESS THAN (METERS)	AZIMUTH ACCURACY REQUIRED IN SECONDS OF ARC (95 PERCENT CONFIDENCE LEVEL				
	1	2	4	6	10
	GPS RELATIVE POSITION PRECISION (MM) (95) PERCENT CONFIDENCE LEVEL)				
100	-	-	2	3	5
200	-	2	4	6	10
300	-	3	6	9	14
400	2	4	8	12	19
500	3	5	10	14	24
600	3	6	12	18	29

Example: If the expected relative position precision from a GPS survey between two marks spaced less than 1 000 meters apart is 2 MM at the 95 percent confidence level, then to achieve an azimuth accuracy of 2 seconds at the 95 percent confidence level, the minimum spacing between the pair of stations is 200 meters.
1-01-86

(GLOBAL POSITIONING (GPS) Standards and Specifications By the Federal Geodetic Control Committee. (Version # 5.0). Reprint.)

Figure 4.7. Guidelines For Minimum Spacing of Intervisible Pairs

All station pairs must receive double simultaneous independent occupations. An independent occupation is defined as an occupation whereby the 2-meter pole, bi-pod, or tribrach is physically moved and releveled. The use of 2-meter fixed height poles is recommended for all observations. Substantially permanent, durable and recoverable physical marks should be established for these intervisible pairs.

4.4.2 Reconnaissance

A key to any successful GPS survey is comprehensive reconnaissance. The basis for survey control will be the NSRS as contained in the NGS Integrated Data Base (IDB). These existing published survey stations (horizontal (NAD83) and vertical (NAVD88)) are required by NJDOT projects to ensure proper integration of the GPS project within the accepted data base. The recommended site for published survey data is the NGS website homepage found at: http://www.ngs.noaa.gov/. The NJGS can also be contacted for further directions.

Proper reconnaissance consists of appropriate station selection, identification of existing stations, monumentation or marking of new stations, estimation of travel time between stations and scheduling. A careful reconnaissance at the initiation of the project will save a lot of resources, as well as make the field and office operation much more efficient.

Good reconnaissance plans include, but are not limited to the following procedures:

- Inventory existing control as obtained from and their relationship to the survey task.
- Organize and plot possible tie marks before leaving the office. This will help the field crew to identify the points easily.
- Recover control before using it and mark them discretely.
- Obtain permission to enter property. Do not offend land owners, private, public, or unknown.
- Check the stations for GPS suitability. If necessary make an obstruction diagram that will be used in the session planning software. Any eccentric point must be included in the network design. Eccentric points should be established for stations that have insufficient open skies.
- Avoid selecting locations for new stations which have difficult tripod setups and are close to power sources; microwave or TV transmitters etc. and reflective environments.
- If a station is at a busy location determine the best time to occupy the station.
- Determine the best way to get to the station and write clear and concise directions to the station. If possible, provide alternative routes to the station. Remember that the schedule of the observations sessions must be strictly kept strictly otherwise, some observation session may become useless.
- Draw maps/sketches to help observers to identify the station.
- Supply contacts for site access, keys, etc.
- Determine if there are special setup requirements.

4.4.3 Field Procedures

4.4.3.1 General

As discussed in the previous section of this manual, the precision of the GPS vector baseline results depends (among other) on the following:

- The number of satellites visible simultaneously from each station during an observing session.
- The geometric relationships between the satellites and the receiver (GDOP.)
- The duration of the period when the desired number of satellites can be observed simultaneously.
- The uncorrected effects of ionospheric and tropospheric refraction.
- Weather conditions do not generally affect GPS survey procedures. However, GPS observations should never be conducted during electrical storms. Significant changes in weather or unusual weather conditions should be noted in the observation log.
- The length of line.

The number of possible observing sessions per day is a function of the required survey accuracy, satellite availability, type of survey method utilized, and project logistical considerations, such as travel and set up time required between observing sessions.

The specifications for field procedures depend on the survey methods utilized. In general, there are two general methods, static and kinematic, using carrier phase tracking. Both methods have similar observation and initialization requirements, and differ mainly in their initialization procedures and whether the positional computations are preformed in real-time or post-processed. Three techniques under the static method are Classical Static, Rapid Static (Fast) Static, and Static Reoccupation. Three techniques used under kinematic surveying are, Stop and Go Kinematic, Continuous Kinematic, and Real-Time Kinematic (RTK). Regardless of the particular observation method selected, the following specifications must be met:

- A minimum of five satellites shall be observed simultaneously. At no time during the observing session shall the Geometric Dilution of Precision (GDOP) be greater than 8. The Position Dilution of Precision (PDOP) shall not be greater than 5.
- Satellite signals shall be observed from a minimum of two quadrants that are diagonally opposite each other.
- Obstructions that are 20 degrees or more above the horizon should be noted on an obstruction diagram. The effect of obstructions should be minimized by proper reconnaissance prior to observations.
- Satellite data below an elevation mask of 10 degrees shall not be used in baseline measurements.

Each one of these methods has advantages and disadvantages for different types of surveys.

4.4.3.2 Observation Methods

4.4.3.2.1 Static Observations

4.4.3.2.1.1 Classical Static Technique (Typically For Baselines > 20 km)

Static GPS survey procedures allow various systematic errors to be resolved when high accuracy positioning is required. Static procedures are used to produce baselines between stationary GPS units by recording data over an extended predetermined period of time during which the satellite geometry changes. This is the classical GPS survey method for long lines and higher accuracy, typically 1:100,000 or greater. In order to resolve integer ambiguities between satellite and receiver, points are occupied for long sessions (30 minutes to 6+ hours), depending on the number of visible satellites, baseline length, intended accuracy, etc. Baselines are re-observed in different sessions according to a predetermined observation scheme.

Specifications:

- Static observations are required for all baselines greater then 20 kilometers in length. Static observations may be required for lines less than 20 kilometers depending on particular project requirements.
- A minimum of three receivers (a CORS connection can be used as an independent receiver) shall be used simultaneously during all static GPS sessions.
- A minimum of five satellites shall be observed simultaneously for a minimum of 30 minutes, plus one minute per kilometer of base line length per session. Remember, sessions that are a bit longer than this minimum will provide worthwhile redundancy that could make data processing more robust and improve project results.
- Data sampling shall have an epoch time interval of 15 seconds or less.
- Typical achieved accuracy: sub-centimeter level (5 mm + 1 ppm).

4.4.3.2.1.2 Fast-Static Technique (Typically For Baselines 0-20 km)

Fast-Static GPS surveys are similar to static GPS surveys, but with a shorter observation period and usually with a faster epoch rate. This technique utilizes shorter observation times for shorter baselines with accuracies usually < 1:100,000. It can be done with a classical network design or as radial surveys.

Specifications:

- Rapid static procedures may be used on baselines up to 20 kilometers in length.
- A minimum of three receivers (a CORS connection can be used as an independent receiver) shall be used simultaneously during all rapid static GPS sessions.
- A minimum of 5 satellites shall be observed simultaneously for a minimum of 5 minutes, plus one minute per kilometer of base line length per session. Sessions that are slightly longer than this minimum could prove rewarding during data processing stage. Typical observation times range from 5-20 minutes.
- Data sampling shall have an epoch time interval of 5 seconds or less.
- Typical achieved accuracy: centimeter level (10 mm + 1 ppm).

4.4.3.2.1.3 Reoccupation Technique

Reoccupation surveys are similar to Fast-Static, except that the length of each session is short. Each point is re-visited after at least an hour, when the geometry of the satellites becomes significantly different.

Specifications:

- A minimum of three receivers (a CORS connection can be used as an independent receiver) shall be used simultaneously during all Reoccupation GPS sessions.
- Minimum of 5 satellites shall be observed simultaneously for a minimum of 5 minutes plus one minute per kilometer of base line length per session. All points surveyed shall be re-occupied after at least one hour has elapsed to allow for a different alignment of the satellites. This method is not recommended unless the satellite configuration or site conditions do not permit FAST Static procedures.
- Data sampling shall have an epoch time interval of 5 seconds or less.
- Typical achieved accuracy: 5 to 10 mm + 1 ppm.

4.4.3.2.2 Kinematic Observations

4.4.3.2.2.1 Stop and Go Technique (For Baselines < 10 km)

A temporary reference station is tracking constantly. The roving receivers are initialized to establish an accurate relative position between them and the reference station. Following the initialization each new point is occupied for a minimum of 10 minutes. Lock on the satellites must be maintained at all times or a new initialization must be performed.

Specifications:

- A minimum of two receivers shall be used simultaneously during all stop and go GPS sessions. Two receivers shall occupy reference stations and one receiver will be the rover. This procedure shall be limited to baselines of 5 kilometers or less.
- A minimum of 5 satellites shall be observed simultaneously for a minimum of 5 epochs.
- Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation of at least 5 minutes on the first point and then moving to other points to be surveyed.
- Data sampling shall have an epoch time interval of 5 seconds or less. A minimum of 5 epochs must be recorded for each point located.
- Typical achieved accuracy: 1 to 2 cm + 1 ppm.

4.4.3.2.2.2 Continuous Kinematic Technique

The reference receiver and rovers are initialized as in stop and go. After initialization the rover is constantly moving and measuring positions. Lock on the satellites must be maintained at all times or a new initialization must be performed.

Specifications:

- A minimum of two receivers shall be used simultaneously during all kinematic GPS sessions. Two receivers shall occupy reference stations and one receiver shall be the rover.
- Initialization of the roving receiver can be accomplished by occupying a known point for a minimum of 5 epochs or making a rapid static observation on the first point and then moving to other points to be surveyed.
- Data sampling shall have an epoch time interval of 2 seconds or less.
- Post processed baseline solutions.
- Typical achieved accuracy: 1 to 2 cm + 1 ppm.

4.4.3.2.2.2.3 Real-Time Kinematic (RTK) Technique (Baselines < 10 km)

RTK is rapidly becoming widespread and the most commonly preferred GPS positioning technique. RTK is an advanced form of relative GPS carrier-phase surveying in which the base station transmits its raw measurement data to the rover(s), which then compute a vector baseline from the base station to the rover. The computation is done nearly instantaneously, with minimal delays between the time that the base station measures, and the time these data are used for baseline processing at the rover. RTK is only suitable for environments with reasonably good GPS tracking conditions (limited multipath, obstructions and RF noise), and with continuously reliable base station to rover communication. To achieve real-time positioning, a radio or other electronic data transmitting device (i.e. CDMA, cell phones) link between the reference receiver and the rovers must be established.

RTK surveys, by nature, result in a radial pattern of baselines from the base station to the rover(s). This does not produce strong network geometry. Depending on the distance from the base station, the positions as determined may result in poor local accuracy between the two closely established stations if a direct connection is not observed between the two. If a second base station is observed, two additional baselines should be formed to each RTK point. This will add redundancy and improve the positional reliability.

There are numerous and widespread applications for RTK-type GPS surveying. Typical applications include, but are not limited to hydrographic surveys, location surveys, real-time topographic surveys, construction stake out surveys, and photo control surveys.

Specifications:

- The project area shall contain and be enclosed with RTK control base stations.
- A minimum of two receivers shall be used simultaneously during all RTK GPS sessions. One base receiver shall occupy a reference point and one or more receivers shall be used as rovers.
- Initialization of the roving receiver shall be made on a known point to validate the initial vector solution.
- Each RTK point shall have 2 different independent occupations. Each occupation consists of at least 10 epochs. The second occupation shall be made under a different satellite constellation, offset from the first occupation by at least 1 hour.
- The second occupation is recommended to be made from a different base station.
- To ensure good local accuracies between new RTK points and nearby existing stations, all previously established base stations, control points, and stations pair are to be RTK positioned, as feasible, for consistency.
- Data sampling shall have an epoch time interval of 2 seconds or less. Real-time coordinates must be recorded.
- The use of a bipod for the rover unit is required.
- The use of a 2-meter fixed height pole is recommended for the base station.
- Typical achieved accuracy: 1 to 2 cm + 1 ppm (horizontal) and 1-1.5 times greater (vertical).

4.4.3.3 Independent Reoccupation of Stations.

GPS surveys require redundancy of observations which are used to detect blunders and to obtain statistically sound results. Redundancy is achieved by reoccupying some points in different sessions with different geometric combinations. The following criteria pertain to static, rapid static and reoccupation procedures for network adjustments:

- Ten percent of all stations shall be occupied three times or more.
- All vertical control stations shall be occupied two or more times.
- Twenty five percent of published horizontal control stations shall be occupied two or more times.
- All "station pairs" for azimuth control shall be occupied simultaneously two or more times.
- One hundred percent of new stations shall be occupied two or more times.
- For sessions where stations are occupied in succession, the antenna/tripod must be physically moved and reset between the sessions to be classified as an independent occupation.

4.4.3.3 Making the Observations

Pre-Observational Check-List

Every day, before leaving the office, the following equipment must be checked for inventory, as well as for proper functioning:

Receiver

- Antenna and cables
- Batteries and power cables
- Cigarette lighter adapter cable
- Tripods, tribrachs and adapters
- Tape measures
- Flashlights
- Radios
- Vehicles
- Station log sheets
- Writing apparatus (pens)
- Station descriptions
- Observing schedule and station lists
- Special equipment required
- Traffic cones, safety equipment
- Maps, keys, lock combinations

On-Site Occupational Procedures

- Antenna Set Up
- Check that tripod is stable
- Weights, such as sand bags, must be used to stabilize legs on hard paving surfaces
- Check that antenna/tribrach is level
- Keep signal path clear; heads, trucks, etc.
- Check for reflective objects (your vehicle!)
- Orient the phase center offset
- Follow the manufacturer's recommended procedure for determining the antenna height.
- Make at least two antenna height measurements per session.
- Verify the height at the end of station occupation.
- Measure the antenna height in meters and preferably in feet as well.

- Operate the receiver following the instructions of its manufacturer.
- Initialize the session according to the requirements of the survey method utilized.
- Key in all necessary station and session related information.
- Coordinate the length of the session with other stations.
- If other stations are not ready, you may start observing early.
- Check receiver and antenna frequently during observations. Check for power loss, tripod movement, etc.
- Record weather data and note any drastic changes during sessions.
- Monitor data logs and note unusual occurrences during sessions.

4.4.3.4 Monumentation

Where feasible, control points which are used as origin, intermediate check, and closure points such as but not limited to, photo control stations, intervisible station pairs and/or RTK base station points are recommended to be permanent in nature. Examples include and are not limited to, poured-in-place concrete monuments, meeting NJDOT specifications, with uniquely stamped disks, feno rods with disks, steel rods/re-bars with caps uniquely identifiable, and drill holes in solid foundations. The above installed stations must be either sketched to scale with recovery ties or contain descriptions in a text format to fully identify the station. If a permanent-type monument is not used for these stations, then prior authorization from NJDOT is needed.

Semi-permanent points, typically PK nails, can be used for all other recoverable survey points (i.e. photo targets and intermittent traverse points).

4.4.4 Office Procedures

4.4.4.1 General

Generally, there are two types of classifications for a GPS survey. The first is based on the internal consistency of the observed vectors and their local resultant positions. The method to assess these internal consistencies is to use a free adjustment, thereby holding only one arbitrary 3-D position and evaluate the vector derived positions. The second classification would be a fully constrained adjustment holding all pertinent 3-D published NSRS control stations.

Loop closures and differences in repeat baseline measurements are to be assessed to check for blunders and to obtain initial estimates for internal network consistencies.

Software used for processing the raw data must be capable of producing results that meet the accuracy standards specified for the survey.

The software must be able to produce, from the raw data, relative position coordinates and corresponding variance covariance statistics, which, in turn, can be used as input to three dimensional network adjustment programs.

The most current version of the geoid model as furnished by NGS shall be used for elevation determinations.

Evaluate a minimally constrained 3-D adjustment holding the latitude and longitude and the ellipsoidal height of one NSRS station. This will be used to analyze the internal quality of the field work.

A fully constrained 3-D least squares adjustment, at the 2-sigma (95%) level shall be made to provide final adjusted coordinates of the GPS network control stations. All NSRS control stations are to be held in the adjustment; unless it is proven that the station does not meet the required accuracy.

4.4.4.2 Loop Closure Analysis

The error of closure is the ratio of the length of the line representing the equivalent of the resultant errors in the GPS baseline vector components to the length of the perimeter of the figure of the analyzed survey loop. A loop is defined as a series of at least three independent, connecting baselines, which start and end at the same station. Each loop shall have at least one baseline in common with another loop. Each loop shall contain baselines collected from a minimum of two independent sessions. The following minimal criteria for baselines loops shall be used for static and rapid static procedures for First-Order classification (1:100,000) network adjustment:

- Baselines in the loop shall be from a minimum of two independent observation sessions. Loop closures incorporating only baselines determined for one common observation session are not valid for analyzing the internal consistency of the GPS network.
- Baselines in the loop shall not total more than 10.
- Loop length shall not exceed 100 kilometers.
- Percentage of base lines not meeting criteria for inclusion in any loop shall be less than 20% of all independent base lines.
- In any component (X. Y, Z) maximum misclosure shall not exceed 25 cm.
- In any component (X, Y, Z) maximum misclosure in terms of loop length shall not exceed 12.5 ppm.
- In any component (X, Y, Z) the average misclosure in terms of loop length shall not exceed 8 ppm.

4.4.4.3 Repeat Baseline Difference

- Baseline lengths shall not exceed 250 kilometers.
- In any component (X, Y, Z) maximum difference shall not exceed 20 ppm.

4.4.4.4 Project Documentation

The following information should be documented and filed upon completion of the horizontal and vertical control work:

- Original GPS raw data in digital form in both the receiver's proprietary format and RINEX format.
- Listings of loop closure analyses.
- Listing of geographic coordinates, ellipsoidal heights, and geoid separations for all stations.
- Listings of final New Jersey State Plane Coordinates (NJSPC) referenced to NAD83 shall be in U.S. Survey Feet, or meters depending on project requirements. The orthometric elevations of all stations shall be referenced to NAVD88.
- Map showing all measured baseline vectors.
- A report of the minimally constrained 3-D adjustment holding the latitude and longitude and the ellipsoidal height of one NSRS station. This will be used to analyze the internal quality of the field work. Once the internal vectors are acceptable, use all appropriate horizontal and ellipsoidal heights constraints as required for a fully constrained 3-D adjustment.
- A report of the fully constrained 3-D adjustment holding the NSRS all horizontal stations and all published orthometric heights of benchmarks used as constraints.
- A written report including obstruction charts and events logs.

4.5 GPS Specifications for Photogrammetric Control

4.5.1 Introduction

The specification details are referenced in NJDOT publication: *Minimum Guidelines for Aerial Photogrammetric Mapping, BDC98PR-009, Chapter 4-09.2.* The publication can be obtained via the Internet link:
http://www.state.nj.us/transportation/eng/documents/photogrammetry/

The guidelines for photogrammetric consultants performing mapping for NJDOT projects for the four levels of feasibility assessment mapping as currently issued by the New Jersey Bureau of Scope Development are under 4.5.2.

Recommended methods, such as RTK, for photogrammetric target positioning are previously outlined in Chapters 4.4.3.2.2.2 and 4.4.3.2.2.3. These RTK techniques, as an example, based on established control points are used for photo target points and other survey points as required. With a good geoid model (the latest NGS version) and good NSRS control stations for checks; this technique becomes an efficient way to survey, provided proper redundancy is maintained.

The horizontal coordinate reference datum shall be NAD83. The vertical reference datum shall be NAVD88 unless the project has special requirements. The latest NGS issued geoid model shall be used accordingly.

Unless otherwise specified, the de facto standard unit of measurement for any NJDOT photogrammetric project shall be U.S. Survey Foot. Currently, New Jersey has not legislated a specific conversion value between the meter/foot. The relationship of the meter/foot that will be used will be:

1 foot (U.S. Survey) = 1,200/3,937 meters (m) exactly.

1 meter = 3.28083333333333 U.S. Survey Feet.

4.5.2 Feasibility Assessment Levels Mapping

NJDOT BUREAU OF SCOPE DEVELOPMENT

MAPPING FOR FEASIBILITY ASSESSMENT (FA),

FINAL SCOPE DEVELOPMENT (FSD) and DESIGN DEVELOPMENT (DD)

Feasibility Assessment is considered to be the preliminary development of different engineering solutions to transportation problems. The concepts are to be developed on a mapped plan and the level of mapping required may differ for different projects for various reasons. Final Scope Development will further advance the selected concept, and Design Development will develop the construction documents. Below is a list of different levels of Feasibility Assessment mapping, a detailed description of the mapping and relative costs.

Level 1 - Aerial Photography (FA):

New aerial photography will be flown and obtained of the project area. The photography will be flown at an altitude allowing for the preparation of digital mapping in the future.

A digital image of the photograph with a minimum scanning rate of 25 microns will be created to plot larger scale prints.

Measurements will be performed if and where required only to scale the photograph, for concept use purpose.

Survey Control is not required, however documentation of the method of the measurements will be prepared. Also, NJ State Plane Coordinates Grids will be added to the Aerial Photography. Grid locations will be approximate and established utilizing USGS Quadrangle maps which are 1:24,000 scale.

All the alternatives will be developed electronically on the larger 1:1000 scale images (or 1:300 scale images if necessary).

Level 2 - Digital Mapping with Limited Ground Survey (FA):

New aerial photography of the project site will be obtained. Digital mapping of the project area will be prepared in MicroStation format conforming to the NJDOT CADD Manual, showing all features visible from above and contours at 1 foot (0.25 meter) intervals in flat terrain, 1.5 feet (0.5 meter) intervals in rolling terrain and 3 feet (1.0 meter) intervals in mountainous terrain. Project scale to be determined based on project specifics.

Horizontal and vertical control will be established for the photogrammetric control and a Primary Survey control report will be prepared in accordance with the NJDOT Photogrammetry Guidelines. Intervisible pairs of control points with 3-D values will be located along the project length so that they are visible between pairs to traverse the project and complete the traverse.

A DTM (digital terrain model) produced for this level of mapping will be sufficient for scoping purposes only.

For bridge projects, the field survey will be sufficient to establish elevations at the bridge abutments in order to obtain clearances below the bridges and other critical elements without performing field survey under the bridges. If directed, the consultant will measure the bridge underclearances.

All mapping information will be based on the U.S. Survey Foot and tied horizontally to the NAD83 and vertically to NAVD88. The mapping will conform to the NJDOT Photogrammetric Guidelines and general conditions such as article 44 and 51.

All the alternatives will be developed on the digital mapping at 1”=30’ (1:300) scale or specified scale.

If directed, the consultant may be required to establish the roadway baselines and obtain drainage information.

Level 3 - Digital Mapping with Ground Survey (FA):

Aerial Photography will be obtained; Digital Mapping and Survey Control will be prepared as described in Level 2.

Field survey shall be performed in the project limits, including a recoverable traverse and level bench run with the addition of a complete field edit to confirm and supplement the photogrammetric survey.

For bridge projects, the field survey will be sufficient to establish elevations at the bridge abutments in order to obtain clearances below the bridges and other critical elements with field survey under the bridge.

All existing visible utility features will be located and mapped accurately. If directed, the consultant will accurately locate the connecting utility lines between utility features.

If directed, the consultant may be required to establish the roadway baselines and obtain drainage information.

Level 4 - Complete Digital Mapping with Complete Field Editing (FA, FSD, DD):

Aerial photography will be obtained; digital mapping and survey control will be prepared as described in Levels 2 and 3.

A field survey and edit will be performed as described in Level 3 with the addition of the existing roadway baseline and the establishment of existing roadway ROW lines. Additional pavement elevations will be obtained to supplement and develop the design DTM. Location of the existing ROW lines assumes a combination of field and research effort and that record information that is useable and reliable is obtained. Individual property parcel research is not included.