Chapter 4
GPS Surveys

Chapter 4 GPS Surveys

4.1 General

GPS, as utilized for surveying, can 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. The reason why a separate chapter is dedicated to GPS is because of its prominence in contemporary and future surveys. GPS is becoming the first choice surveying technique for all types of surveys. In the near future, all surveys will be done with GPS, 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.

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 What Is GPS?

The Navigation Satellite Timing And Range Global Positioning System, or NAVSTAR GPS, is a satellite based radio navigation system that is capable of providing extremely accurate, worldwide, 24 hour, 3 dimensional locational data (latitude, longitude, and elevation). The system was designed and is maintained by the US Department of Defense (DOD) as an accurate, all weather, navigation system. Though designed as a military system, it is freely available with certain restrictions to civilians for positioning. The system is now fully operational, which means that the system has 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. This constellation is comprised of 24 satellites, 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, that 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.

  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.

- 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.

4.2.3 GPS Limitations

Though GPS can provide worldwide, 3D positions, 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. As a rule of thumb, an obstruction that can block sunlight can effectively block GPS signals.

Bouncing of the signal off nearby objects may present another problem, that of distinguishing between the signal coming directly from the satellite and the "echo" signal that reaches the receiver indirectly. In areas that possess these types of characteristics, traditional surveying techniques must be used instead of GPS positioning or to complement 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.

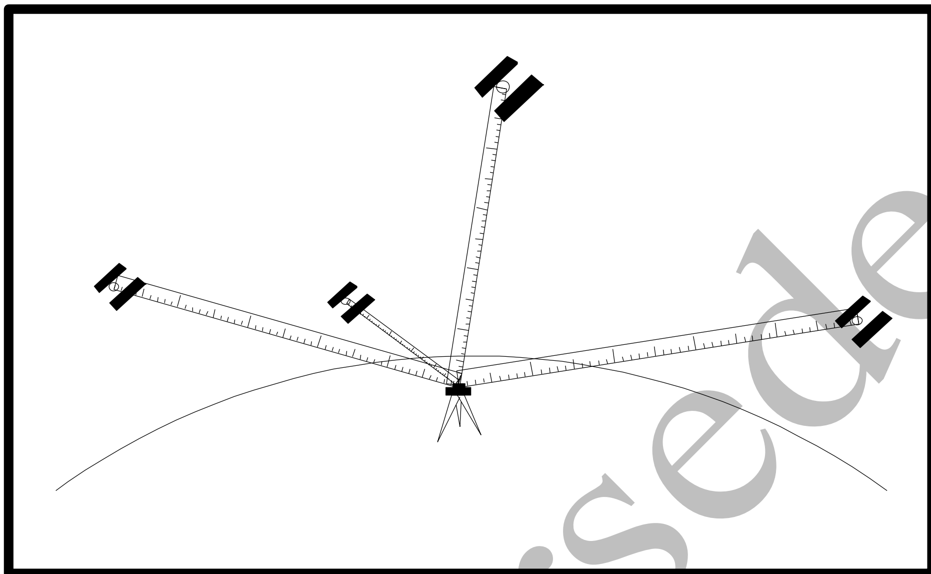

Figure 4.1. Position Determination by Measuring Distances to Satellites

4.2.4 How Does A GPS Receiver Determine Positions?

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 millimeter (mm) 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 latitude, longitude, and elevation, and with the calculated baseline (distance between 2 points), the coordinate for the unknown point may be determined.

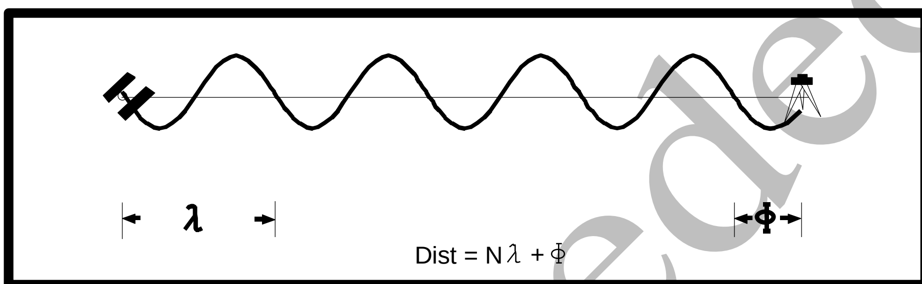

Figure 4.2. Carrier Phase Based Ranging

Carrier phase receivers come in two models: single frequency (using L1 only) and dual frequency (using both, L1 and L2). Dual frequency receivers are more efficient and accurate than the single frequency receivers, but are more expensive. Some type of control surveys must be done only with dual frequency receivers. NJDOT utilizes only dual frequency receivers.

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.

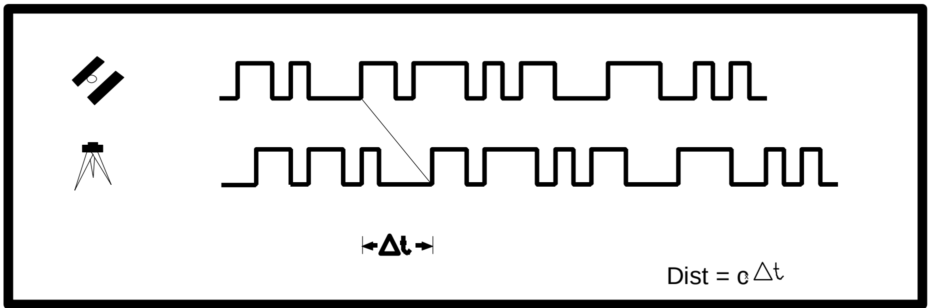

Figure 4.3. Code Based Pseudo Ranging

4.2.5 Advantages of GPS

Probably the most advantageous aspects of GPS are its accuracy and efficiency, particularly in survey tasks that span a large area. 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.

Another advantage of GPS is in densification of the control network. The need to maintain a dense network of monumented control points can somewhat be alleviated because establishing new control with GPS is much easier and less expensive than it used to be. The Geodetic Survey Section of NJDOT is using GPS to develop a geodetic control network for New Jersey which will be utilized for GPS 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 Sources of Errors

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, 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 systems errors cancel out. NJDOT has only dual frequency receivers, which assures that system errors are held at minimum. 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, 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.

- **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.

- **Selective Availability** – The Department of Defense introduces a clock "dithering" error to degrade the attainable positioning accuracy by unauthorized users. This error has a similar effect to a satellite clock error and is eliminated by differential or double differencing computation techniques.

- **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 cycle which will peak around the year 2001. 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.

- **Tropospheric Delay** – An error caused at the lower part of the atmosphere and is a function of the atmospheric conditions, such as: barometric pressure, temperature, and humidity. Reasonably established models for the index of refraction and other atmospheric models can correct this error.

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.

- **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.

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** – 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. 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.

- **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.

  The second type of obstructions are those that do not completely block the signal, 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** – The location or the geometry of the satellites in space at the time of observations is an important factor of GPS positioning accuracy. 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 number that indicates the error in position determination as a function of the relative satellite geometry. GPS can be used for determining four parameters: position X,Y,Z and time t. The DOP for all four parameters is called Geometric DOP (GDOP.) The DOP for position X,Y,Z is called PDOP, for horizontal position X,Y, HDOP and for vertical position Z, 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 thoroughness 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. It is recommended to measure the height of the antenna in feet and in meters so that potential blunders can easily be detected.

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 in a similar way as used in traversing and leveling. 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 a cycle slip repair tool to overcome 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

A. The location of the new control points depend on the optimum layout to carry out the required needs of the survey.

B. 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.

C. Horizontal networks shall be connected to a minimum of three National Geodetic Survey (NGS) first order stations, or four stations if any NGS second order stations are used. At least one benchmark shall be used (held fixed) if only a horizontal survey is being done. The use of eccentric horizontal stations is not permitted.

D. Vertical networks shall be connected to three or more NGS elevation marks of first or second order accuracy. In areas of sparse NGS vertical control, contact the Geodetic Survey unit of NJDOT for alternative benchmarks. The use of eccentric vertical stations is permitted provided they are located within 100 meters of the original mark and three wire leveling is used to determine the elevation of the eccentric point.

E. The existing control, both horizontal and vertical, used to control a network shall lie in a minimum of three quadrants using the geographic center of the project as the reference point.

F. Depending on the project requirements, azimuth marks can be established by GPS procedures. Station pairs (station and reference station) to provide azimuths shall be established at intervals no greater than 10 kilometers along the project length. Station pairs shall be intervisible at normal tripod heights and spaced not less than 500 meters apart.

4.4.2 Reconnaissance

A key to a successful GPS survey is a thorough reconnaissance. Reconnaissance consists of station selection, identification of existing stations, monumentation or marking of new stations, estimation of travel time between stations and scheduling. A thorough reconnaissance could save a lot of money, as well as make the field and office operation much more fluent and efficient. A good reconnaissance plan includes the following procedures:

1. Inventory existing control and their relationship to the survey task.

2. Organize and plot possible tie marks before leaving the office. This will help the field crew to identify the points easily.

3. Recover control before using it and mark them discretely.

4. Obtain permission to enter property. Do not offend land owners, private, public, or unknown.

5. Check the stations for GPS suitability. If necessary make an obstruction diagram that will be used in the session planning software. Eccentric points should be established for stations that have insufficient open skies.

6. Avoid selecting locations for new stations which are close to:
   - power sources; microwave or TV transmitters etc.
   - Reflective environment.
   - Impossible tripod setups.

7. If a station is at a busy location determine the best time to occupy the station.

8. Determine accessibility to 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.
- The length of line.

The number of possible observing sessions per day is a function of the required survey accuracy, satellite availability, 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 six different GPS survey methods: static, rapid static, stop and go, reoccupation, kinematic and real time kinematic. 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° 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 15° shall not be used in baseline measurements.

Each one of these methods has advantages and disadvantages for different types of surveys. Next, these field procedures will be discussed in detail.

4.4.3.2 Observation Methods

4.4.3.2.1 Static Observations

This is the classical GPS survey method for long lines and high accuracy. Points are occupied for long sessions and are re-observed in different sessions according to a predetermined observation scheme.

- Static observations are required for all baselines over 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 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.

4.4.3.2.2 Rapid (Fast) Static Observations

Short observation time for shorter lines. It can be done with a classical network design or as radial surveys. This is the most common GPS survey method.

Specifications:

- Rapid static procedures may be used on baselines up to 20 kilometers in length.

- A minimum of three receivers 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.

- Data sampling shall have an epoch time interval of 5 seconds or less.

4.4.3.2.3 Stop and Go Observations (For Baselines < 5 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 only a short period of time. Lock on the satellites must be maintained at all times or a new initialization must be performed.

Specifications:

- A minimum of three 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.

4.4.3.2.4 Reoccupation Observations

Same as rapid 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 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 rapid static procedures.

- Data sampling shall have an epoch time interval of 5 seconds or less.

4.4.3.2.5 Kinematic Observations

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.

<u>Specifications:</u>

- A minimum of three 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.

4.4.3.2.6 Real Time Kinematic Observations (Baselines < 3 km)

This is the same as kinematics, except that instead of making measurements that have to be post processed, the positions are available in real time. To achieve real time positioning, a radio link between the reference receiver and the rovers must be established. The observations and/or the computed positions are transmitted from the reference station to the rover.

<u>Specifications:</u>

- A minimum of 2 receivers shall be used simultaneously during all real time kinematic GPS sessions. One receiver (master) shall occupy a reference point and one or more receivers shall be used as rovers.

- 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 unknown points. Lock on the satellites must be maintained at all times.

- Data sampling shall have an epoch time interval of 2 seconds or less. Real time coordinates must be recorded. The raw data shall be recorded for post processing.

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 pertains to static, rapid static and reoccupation procedures for network adjustments:

- Ten percent of all stations shall be occupied three times or more.
- Thirty percent of new stations shall be occupied two or more times.
- All vertical control stations shall be occupied two or more times.
- Twenty five percent of 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 vertical stations shall be occupied two or more times.
- When a station is occupied during back to back sessions, the antenna/tripod must be reset between the sessions to be classified as an independent occupation.

4.4.3.4 Making the Observations

A. 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 utensils (pens)
- Station descriptions
- Observing schedule and station lists
- Special equipment required
- Traffic cones, safety equipment
- Maps, keys, lock combinations.

B. Antenna set up.

- Check that tripod is stable.
- Check that antenna/tribrach is level.
- Keep signal path clear; heads, trucks, etc.
- Check for reflective objects (your car!).
- 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.

C. 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. Extra data cannot hurt.

D. Check receiver and antenna frequently during observations. Check for power loss, tripod movement, etc.

E. Record weather data and note any drastic changes during sessions.

F. Monitor data logs and note unusual occurrences during sessions.

4.4.3.5 Monumentation

- Permanent type monuments shall be placed at all "station pairs". Monuments shall meet NJDOT specifications. All permanently monumented stations shall be fully described with "how" descriptions and local connections.
- All new stations shall be described using sketches and local connections.

4.4.4 Office Procedures

4.4.4.1 General

- 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 1996 or later version of the Geoid Model shall be used for elevation determinations.
- A three dimensional least squares adjustment shall be made to provide final adjusted coordinates of the GPS network control stations. All NGS 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 following list of occupation rates shall be used for static and rapid static procedures for network adjusting:

- Baselines in the loop shall be from a minimum of two independent observation sessions.
- Baselines in the loop shall not total more than ten.
- Loop length shall not exceed 100 kilometers.
- Percentage of base lines not meeting criteria for inclusion in any loop shall be less than 30% of all independent base lines.
- In any component (XYZ) maximum misclosure shall not exceed 30 cm.
- In any component (XYZ) maximum misclosure in terms of loop length shall not exceed 20 ppm.
- In any component (XYZ) the average misclosure in terms of loop length shall not exceed 16 ppm.

4.4.4.3 Repeat Baseline Difference

- Baseline length shall not exceed 50 kilometers.
- In any component (XYZ) 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 of either the receiver's proprietary or RINEX format.
- Listings of loop closure analyses.
- Listing of geographic coordinates, ellipsoidal heights, and geoid separations for all stations.
- Listings of final State Plane Coordinates shall be in meters or U.S. Survey Feet, depending on project requirements, and shall be referenced to North American Datum of 1983. The elevations of all stations shall be referenced to the National Geodetic Vertical Datum of 1988.
- Map showing all measured baselines.
- A report of the minimally constrained three dimensional adjustment holding the latitude and longitude of one NGRS station and the ellipsoidal height of an existing bench mark. This will be used to analyze the internal quality of the field work.
- A report of the constrained 3D adjustment holding the latitude and longitude of all NGRS horizontal stations and all benchmarks. This will be used to analyze how

well this project fits within the NGRS from a three dimensional mapping standpoint.

- A written report including obstruction charts and events logs.

4.5 GPS Specifications for Photogrammetric Control

4.5.1 Introduction

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control used in photogrammetric mapping projects. The objective of this section is to provide specifications for photogrammetric consultants performing mapping for NJDOT projects.

4.5.2 Location Mapping (1:2500)

Only static and rapid static procedures, as outlined in Section 4.43 of this manual, shall be used to obtain the horizontal and vertical positions of aerial survey control points. All coordinates shall be established using the North American Datum of 1983 for the horizontal datum and the National American Vertical Datum of 1988 for the vertical reference datum unless the project has special requirements. The latest version available for the geoid model shall be used in determining the orthometric heights for the control points established for a photogrammetric project.

4.5.3 Design Mapping (1:300)

Static and rapid static procedures shall be used, as outlined in Section 4.43 of this manual, to establish the horizontal control positions for the aerial points. Vertical control can be established by GPS procedures provided 95% of all tested points meet or exceed the accuracy of 30 mm. Elevations of a minimum of 10% of the vertical control points shall be determined by conventional means to be used as a quality control measure.

4.5.4 Network Design

All points must be surveyed to allow loop closures to be calculated, using data from a minimum of two sessions, to form a loop. If control is required to be brought in to the project, a static or rapid static survey should be done to establish project base control. These base stations then are to be used to establish the project control points. A Least Squares adjustment is required to be completed for all control points established for a photogrammetric project.

4.5.5 Criteria for Establishing Project Control Points

4.5.5.1 Procedure 1: Project Framework Control

Control points should be established to create a framework around the project. This framework is used to control the project targets.

Specifications:

1 A framework point can be a NGS horizontal station, a NGS vertical station or another monumented station with confirmed coordinate values. If framework points do not already exist, then a network must be established to bring control into the project area to establish the required points.

2. Framework points shall have X, Y, and Z values. If the X, Y, and Z do not already exist, they should be established using a GPS network.

3. Framework points can be located from 1.6 km (1mile) to 5 km (3 miles) from the main line of the project. Spacing along the project can be up to 8 km (5 miles) apart.

4. Every fourth target (or photo identified point) must have at least one tie to a framework point.

5. A measurement must be made between consecutive targets to provide consistency checks.

6. If vertical control is going to be established for the targets (or photo identified points) using GPS, then all targets (or photo identified point) must be occupied at least twice.

7. All work within the area bounded by framework points can be done by rapid static procedures.

8. There should be enough redundancy in the measurements to be able to eliminate a few of them (up to 10%) and still compute the job without returning to the field.

9. At approximately 8 km spacing along the alignment, a tie should be made to two framework points.

10. All office procedures, in Section 4.442 "Loop Closure Analysis", must be met when using this procedure for photo control.

4.5.5.2 Procedure 2: Horizontal Targets Along Center of Corridor.

All horizontal targets (or photo identified points) shall be spaced along the centerline of a given corridor or centerline.

Specifications:

1. If first order NGS control lies within 30 km of the ends of the project, a traverse, like GPS survey, can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network must be established to bring control to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.

2. All distances between traverse stations shall be measured twice.

3. Two known benchmarks (preferably NGS) shall be occupied near the ends of the project.

4. It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.

5. If a measurement between two traverse stations proves to be in error during final analysis, it shall be remeasured and incorporated into the final adjustment before proceeding with the photogrammetric mapping.

6. All office procedures, in Section 4.442 "Loop Closure Analysis", shall be met when using this procedure for photo control.

4.5.5.3 Procedure 3: Full Control of Photo Wing Points

Horizontal and vertical information for photo control shall be placed along the outer edges of the aerial photography.

Specifications:

1. Any targets placed along the centerline of the mapping corridor shall be used as quality control points during the mapping process or set to establish horizontal control for other project purposes.

2. If first order NGS control lies within 30 km of the ends of the project, a GPS traverse can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network shall be established to bring control

to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.

3. All distances between traverse (target) stations shall be measured twice.

4. Two known benchmarks (preferably NGS) shall be occupied near the ends of the project. If the horizontal stations do not have vertical information, then benchmarks shall be occupied.

5. It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.

6. All office procedures, in Section 4.443 "Loop Closure Analysis", shall be met when using this procedure for photo control.

4.5.6 Project Documentation

See Section 4.4.4.4 of this manual, on project documentation, for GPS surveys.

4.6 GPS Specifications for Topographic Surveys

4.6.1 Introduction

These specifications set forth the minimum requirements for utilizing GPS techniques to establish horizontal and vertical control and the topographic data points for a NJDOT planning or design survey.

4.6.2 Network Design

If known control does not already exist within 30 km of the ends of a project, a static or a rapid static survey shall be done to establish second order control at the project site to be used for the topographic survey. All points must be surveyed to allow loop closures to be calculated using data from a minimum of two sessions to form a loop. These base stations then are to be used to establish the project data points. A Least Squares adjustment is required to be completed for all control points established when performing a static or rapid static survey.

4.6.3 Criteria for Establishing Project Control Points

1. If first order NGS control lies within 30 km of the ends of the project, a GPS traverse can be run between two first order NGS stations. If the monumentation does not meet the 30 km restrictions, a network must be established to bring control to the project site. Follow the procedures, as outlined in Section 4.42 of this manual, to do a network.

2. All distances between traverse stations must be measured twice.

3. Two known benchmarks (preferably NGS) must be occupied near the ends of the project. If the horizontal stations do not have vertical information, then benchmarks must be occupied.

4 It is recommended that wing points be set away from the main traverse line at 8 km (5 miles) spacing along the project corridor to help strengthen the horizontal coordinates.

5 All office procedures, in Section 4.443 "Loop Closure Analysis", must be met when using this procedure for base control.

4.6.4 Topographic Design and Mapping Data Collection

The GPS method of Stop and Go is the most efficient one to use in collecting topographic data for mapping and design purposes. Stop and Go procedures shall be used, as outlined in Section 4.42 of this manual, to establish the horizontal and vertical positions for the topo points. When collecting topo data, the roving receiver shall return to a known point, after every 50 data points, to perform a check on the system.

4.6.5 Project Documentation

See Section 4.4.4.4 of this manual, on project documentation, for GPS surveys.