Chapter 2 - RTK GPS

Policy Statement

Any survey which incorporates Real Time Kinematic GPS (RTK) shall conform to the specifications as defined in this document.

General Notes

In performing an RTK survey, a GPS receiver occupies a known Reference Station and remains stationary (**Base Station**), while another roving GPS unit is moved from point to point (**Rover**). A Real Time Network provides permanently mounted, continuously operating Base Stations, while a traditional Base/Rover configuration requires physical set-up of the Base Station. In either case, baselines are computed between the Base Station GPS receiver and the Rover GPS receiver, which then computes a real-time position relative to the Reference Station position.

Although uses of RTK are limited when higher accuracies are required, RTK is ideally suited to the following types of surveys:

- Setting of slope stakes, rough grade stakes, limits of grading stakes, etc. (see ***Chapter 3 – Construction Staking***)
- Performing a topographic survey of a dirt area (see ***Chapter 6 – Topographic Surveys***)
- Performing a scour study survey (see ***Chapter 8 – Scour Study Surveys***)
- Performing a hydrographic survey (see ***Chapter 9 – Hydrographic Surveys***)
- Searching for monuments (which will subsequently be tied-in using a higher-order methodology)
- Flagging or painting City/County boundary lines (to establish limits of resurfacing, etc.)
- Layout of conceptual alignments for visual inspection
- Positioning aerial targets

Limitations of RTK

Beyond the uses listed above, it is important to recognize that RTK is generally not to be used as a stand-alone measurement tool when performing a boundary or control survey. RTK is best used to bolster a control network, not define it. In order to ensure realization of the **1:10,000** combined (relative) positional accuracy standard required by these types of surveys, the network should be adjusted using RTK measurements together with conventional traverse data. RTK occupation points are selected in such a way as to maximize strength of figure, while leaving the bulk of the data to be captured by conventional traverse. The occupation scheme will be determined by the Party Chief.

The minimum recommended spacing for points in RTK surveys shall be dictated by the following criteria:

- Trimble R10 receivers, rated for RTK surveys at 8mm + 1 ppm at 68% confidence level (1 sigma): a minimum spacing of **1200 feet** when tied to OCRTN Stations at an average distance of 32,000 feet; a minimum spacing of **700 feet** when tied to published legacy control or local project control in a Base-Rover configuration at an average distance of 4,000 (see the formula shown in "***Appendix A, Section 1***")

- Minimum spacing for GPS receivers with RTK survey ratings different from those listed above can be computed using the formula shown in "***Appendix A, Section 1***"

OCRTN vs. Base/Rover Configuration

There are two basic options when performing an RTK survey within Orange County: the Orange County Real Time Network (OCRTN) and a traditional Base/Rover configuration. Each method has advantages and disadvantages and both are currently acceptable for use, as directed within the bounds of this document. In most cases, conditions on the ground will make the decision an obvious one. This decision must occur before planning and design of the survey. Design of the network and occupation scheme will be determined by the Party Chief.

OCRTN

Advantages:

Use of the OCRTN offers the luxury of an essentially "free" continuously operating Base Station, thus a survey may be conducted with a single GPS receiver. Stations within the OCRTN are of a known integrity. There is no set-up time associated with the Base Station. Link between the Base and Rover is established via cellular modem and thus not limited to line of sight or by distance.

Disadvantages:

Due to the wide spacing of OCRTN Stations, the nearest Station may be up to 10 miles from an individual project location, resulting in longer initialization times and more importantly, a significantly larger PPM error. Correct modeling of errors associated with atmospheric conditions is critical to achieving accurate results, and as the Rover moves farther from the Base Station, the modeling of these atmospheric errors becomes less certain. Some of the OCRTN Stations rely on solar power and may become non-operational during periods of prolonged inclement weather. A robust cellular connection is required to connect to the server which broadcasts corrections. Corrections broadcast from OCRTN Stations do not include data from GNSS satellites: working with fewer satellites reduces horizontal and vertical accuracy and may make it difficult to obtain and maintain initialization.

Methodology:

A detailed explanation of how to use the OCRTN is given on the OC Public Works website.

The survey must be constrained to a minimum of 4 existing control stations. These control stations are selected so as to create a polygon which fully encompasses the project area. If positions will be needed in real-time, the data collected at these control stations is used to compute a Site Calibration (see ***Appendix B*** for Site Calibration procedures). If positions are not needed in real-time, data is still collected as described in ***Appendix B*** but will be processed later (see ***Adjustment of the Network***, below).

After a link is established between Base and Rover and data is collected at the existing control stations, collection of topographic survey data or establishment of new control points may begin.

Each new control point shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 2 hours. These time differentials are required in order to ensure significantly different satellite geometry. Each of these occupations shall consist of either one measurement of 180 epochs, or three sequential measurements of 60 epochs each.

Each topographic data point shall consist of a single measurement of at least 5 epochs.

Additional Notes:
All survey data collected for a project shall be tied to the same OCRTN Base Station and epoch.

Base/Rover Configuration

Advantages:
The Base/Rover configuration can be used in areas where no cellular service exists. Corrections broadcast from the Base Station include data from GNSS satellites, thus constellations of 12 or more satellites are not uncommon. This is especially beneficial for 3D surveys. The Base and Rover are rarely more than 1 mile apart, resulting in insignificant PPM errors. Orientation of the Base Station on an existing project control point may eliminate the need for Site Calibration.

Disadvantages:
The Base/Rover configuration requires utilization of an additional GPS receiver and potentially an additional crew member. Care must be taken to mitigate the theft risk created when this stationary receiver is located in an area of public access. Additional set-up and break-down time must be factored into the daily work flow. Link between the Base and Rover is established via radio signal and is limited to line of sight, at a maximum range of about 1 mile.

Methodology:
Two of the possible methods for conducting a conventional Base/Rover RTK survey are detailed below:

A. **Placing the Base receiver on a published legacy control point:**

   The legacy control point must be of the same epoch date as the current project.

   This method eliminates the need for Site Calibration.

   After a link is established between Base and Rover, a second published legacy point is checked and stored as described above, and collection of topographic survey data or establishment of new control points may begin.

   Each new control point shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 2 hours. These time differentials are required in order to ensure significantly different satellite geometry. Each of these occupations shall consist of either one measurement of 180 epochs, or three sequential measurements of 60 epochs each.

   Each topographic data point shall consist of a single measurement of at least 5 epochs.

Additional Notes: All subsequent survey data shall be tied to the same legacy control point.

B. Placing the Base receiver on a control point within a local control network:

This method may be used when the current survey is to be tied to the control network of a previous survey, and *may* eliminate the need for Site Calibration.

After a link is established between Base and Rover, two additional points within the network are checked and stored as described above, and if these additional control points meet acceptable tolerance for the current survey and it is apparent that no rotation exists, collection of topographic survey data or establishment of new control points may begin.

Each new control point shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 2 hours. These time differentials are required in order to ensure significantly different satellite geometry. Each of these occupations shall consist of either one measurement of 180 epochs, or three sequential measurements of 60 epochs each.

Each topographic data point shall consist of a single measurement of at least 5 epochs.

Additional Notes: All survey data need not be tied to the same point within the existing project control network, however if the Base Station is moved, check shots must be measured and stored as above to two additional existing network control points, one of which being the first Base point.

Additional Field Procedures

- A known point shall be checked at the beginning and end of each session. Prudent practice would indicate additional checks, particularly after initialization is lost. Check shots should be coded with a unique numbering system which makes them easy to sort and verify. For example, a check shot on point #207 could be named “CHK207”.
- Conditions which may generate multipath or obstruct view of the satellites, such as overhead power lines, nearby trees, or adjacent buildings, should be avoided.
- GPS receivers occupying the Base position shall be mounted on a tripod/tribrach configuration. Receiver HI is measured two times, one measurement in feet and one in meters, and a unit conversion applied to verify the HI **before** the receiver is moved.
- Roving GPS receivers occupying new or existing control points may be mounted either on a tripod/tribrach configuration or on a standard layout rod with supporting bipod. If this configuration is used, the session should be split, with the rod being turned 180 degrees between sessions, so as to cancel out error introduced by improper adjustment of the plumb bubble.
- Topographic data points may be collected using a standard layout rod without the aid of a supporting bipod.
- Elevation mask shall be set to 15 degrees.
- Data should not be collected when PDOP exceeds 5.0.

- While the receiver is logging data, a full description of the physical monument is recorded and a digital image is captured.
- Occupation session data is recorded on an ***RTK GPS Set-Up Sheet***.
- Considerable care should be given to point naming conventions. Each time a point is occupied, it is to be given the ***same*** name. There is no need to use A, B, C etc. for subsequent occupations of the same point.
- **Important Note:**
  If the data link utilizes a UHF/VHF radio with an output of greater than 1 watt, a Federal Communications Commission (FCC) license is required. A copy of the license shall be stored in the receiver case and must be presented to FCC personnel upon request. All FCC rules and regulations shall be adhered to when performing an RTK survey. These include but are not limited to the following:

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

Monumentation

Monuments set as control points during the course of a GPS survey shall meet the following requirements:

- Monuments which fall on concrete curbs or in the surface of concrete paving shall consist of a tag secured in a lead plug or set in epoxy.
- Monuments which fall on asphalt dikes or in the surface of asphalt paving shall consist of a spike or “MAG” nail with a washer.
- Monuments which fall in non-paved areas shall consist of an iron pipe with a tag or disk, or a rebar with an aluminum cap. Rebar must be set a minimum of 3 inches below the ground surface.
- All tags/washers/disks/caps referenced above shall be stamped with the agency name or the license number of the surveyor in responsible charge, and shall also be stamped “CP” or “CONTROL POINT”.
- Tags set in iron pipes shall be of a diameter less than that of the inside diameter of the pipe. Disks affixed to iron pipes shall be of a diameter equal to that of the outside diameter of the pipe.
- Under no circumstances are plastic plugs to be used with iron pipe or rebar.

Adjustment of the Network

All GPS data shall be adjusted by least squares adjustment software, in conformance with ***Chapter 12 – Network Processing***. Note that although an RTK network adjustment *may* be performed using only GPS vectors (stand-alone), combining conventional traverse data with GPS vectors will result in a network with higher relative positional accuracy.

Statistical analysis of the network adjustment shall be performed to ensure that a minimum combined (relative) positional accuracy of **1:10,000** has been achieved for all connected monument pairs (when RTK data is combined with conventional traverse data) or adjacent monument pairs (for stand-alone RTK data). Although this computation is automatically performed in most network adjustment software, the formula for this computation is shown in "***Appendix A, Section 2.***"

Connections of very short distances often will not meet this **1:10,000** standard. An alternative standard for distances of less than **330 feet** is shown in "***Appendix A, Section 3.***"

In the event one or more pairs of monuments fail to pass these relative positional accuracy criteria, the network adjustment shall be reviewed and a determination made by the Senior Land Surveyor (or Project Manager) as to whether or not additional observations will made in order to improve geometry, increase redundancy, or further isolate errors.

Important Note:
Once a network has been adjusted and coordinates are reported to another entity (e.g.: Boundary Analysis Unit or Mapping Unit), these coordinates shall be deemed final. Should supplemental control or boundary ties be needed, the primary coordinates shall be fixed in subsequent adjustments. Only in the event that erroneous data is discovered will previously reported coordinate values be changed.

Appendix A – Formulas

1. Minimum spacing for new control points to be positioned using RTK GPS can be computed using the following formula:

   $\mathbf{D = 10{,}000 \times \sqrt{(2 \times \{ [(1.96)(a)]^2 + [(1.96)(b)]^2 + c^2 \})}}$
   where:

   - D = minimum spacing (in feet) between RTK occupation stations
   - a = manufacturer's millimeter rating at a 68% confidence level, (converted to feet)
   - b = manufacturer's ppm rating at a 68% confidence level, times the average distance (in feet) from legacy control stations, and divided by 1,000,000
   - c = estimated receiver positioning error (rod plumb or tribrach errors), commonly estimated to be 0.007 feet
   - 1.96 = the multiplier from a 68% confidence level (1 sigma) to a 95% confidence level (2 sigma)

2. All connected monument pairs shall pass the following mathematical test:

   $\mathbf{D \div \sqrt{(x^2 + y^2)} \geq 10{,}000}$ (or $\geq$ 20,000 where required above)
   where:

   - D = distance (in feet) between the pair of monuments being examined
   - x = error ellipse semi-major axis for monument #1 (at 95% confidence)
   - y = error ellipse semi-major axis for monument #2 (at 95% confidence)

3. Connections of very short distances often will not meet the **1:10,000** standard defined by the formula in Section 2 above. An alternative standard for distances of less than 330 feet follows:

   $\sqrt{(x^2 + y^2)} \leq 0.033$ **feet**
   where:

   - x = error ellipse semi-major axis for monument #1 (at 95% confidence)
   - y = error ellipse semi-major axis for monument #2 (at 95% confidence)

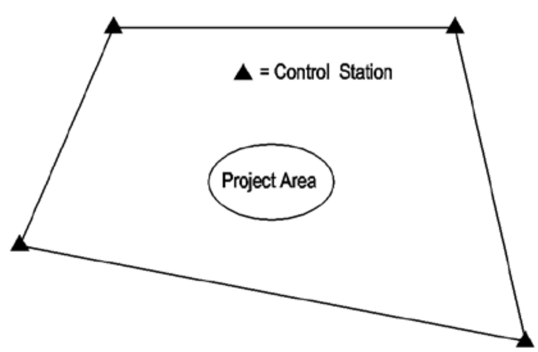
Appendix B - Site Calibration Procedure

A Site Calibration establishes a relationship between the observed WGS84 coordinates and the local grid coordinates.

General Requirements:

- The control stations shall be selected so as to create a polygon which fully encompasses the project area (see Figure 1). Selected control stations must be of the same epoch date as the current project and be located no more than six miles from the OCRTN Station or Base Station.
- Conditions which may generate multipath or obstruct view of the satellites, such as overhead power lines, nearby trees, or adjacent buildings, should be avoided.
- Elevation mask shall be set to 15 degrees.
- Each occupation shall consist of either one measurement of 180 epochs, or three sequential measurements of 60 epochs each.
- Upon computation of the Site Calibration, a control station with residual values greater than those defined below shall be discarded and another control station shall be used in place of this outlier.
- All subsequent measurements and staking activities shall use the same OCRTN Base Station or Base position as was used to generate the Site Calibration.

Figure 1 – Control Point Selection



2D Site Calibration:

- A minimum of 4 horizontal control stations shall be included in a 2D Site Calibration.

- Each horizontal control station shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 2 hours. These time differentials are required in order to ensure significantly different satellite geometry.
- The stations in a 2D Site Calibration shall not exceed a horizontal residual of 0.07 feet

3D Site Calibration:

- In addition to the requirements described above for a 2D Site Calibration, the following requirements shall be met for a 3D Site Calibration:
- A minimum of 5 vertical (or 3D) control stations shall be included in a 3D Site Calibration. To avoid creation of a distorted or tipped plane, the stations selected must have been tied together with one common leveling circuit. An alternative to this requirement is to collect data on these 5 vertical control stations but include just one of them in the Site Calibration. Analysis of the data will determine which vertical control station represents a best-fit solution for the project. This may be a better alternative when working with vertical control that has not been recently tied together (OC Survey Benchmarks).
- Each vertical control station shall be measured with 2 independent occupations, with a minimum time differential (time of day) of 4 hours.
- The stations in a 3D Site Calibration shall not exceed a vertical residual of 0.10 feet.