CHAPTER SIX

GLOBAL POSITIONING SYSTEM (GPS)

6

OVERVIEW

Global Positioning System (GPS) is a tool that the construction industry has adopted from the United States Military. It is a constellation of at least 24 satellites that provide accurate position coordinates. GPS uses satellites and computers to compute positions anywhere on the Earth.

There are three main segments to the GPS. The first being space. This medium encompasses a minimum of 24 satellites that orbit the earth every 12 hours at an altitude of about 12,551 miles. The second segment is control. There is a master station located at Schriever Air Force Base in Colorado Springs, Colorado. Each satellite passes over one of four monitoring stations twice a day. The master station calculates corrections and synchronizes the atomic clocks aboard the satellites. The third and final segment is the user. The user is, simply put, anyone who has a GPS receiver and can access the signal.

GPS survey methods include, but are not limited to:

- Static GPS surveys
- Fast-static GPS surveys
- Real-Time GPS surveys (RTK)
- Post-Processed kinematic GPS surveys

The type of GPS survey used mostly for construction is Real-Time GPS survey (RTK). RTK is similar to a Total Station radial survey. RTK surveys measure the baselines from the reference station to the roving receivers point. A radio at the reference station broadcasts the position of the reference point to the rovers, and the system processes the baselines in "Real Time" allowing for project coordinate information to be gathered and analyzed during the actual field survey. RTK surveying provides centimeter-level precision without post-processing. There are three types of survey methods in RTK surveys: topo points, continuous surveys, and stakeouts. Topo points are short (usually 3-15 second) occupations, e.g., over a sample site or survey marker. Continuous survey mode allows ongoing data collection at a specified logging interval, e.g., every 5 seconds, or a specified distance interval, e.g., 1 meter. Continuous mode is used for mapping. Stakeout mode allows navigation to predetermined coordinates.

The following are some of the items that will affect the accuracy of a GPS survey:

- Satellite Geometry. A minimum of four satellites are required to survey with GPS. A minimum of five satellites is recommended. The configuration of the visible satellites the receiver is able to track in relation to each other will make a significant difference in the data that is being collected. Satellite geometry is expressed as a numeric value known as Dilution of Precision (DOP). Good satellite geometry will have small DOP values while poor satellite geometry will have large DOP values. As a guideline, DOP values of six or lower are required for NDOT GPS surveys. The ideal satellite geometry is one which has the visible satellites distributed throughout the sky. Good satellite geometry will yield a higher precision. Satellite geometry factors that must be considered when planning a GPS survey are:
    - Number of satellites available.
    - Minimum elevation angle above the horizon (elevation mask).
    - Obstructions limiting satellite visibility.
    - Position Dilution of Precision (PDOP).
    - Vertical Dilution of Precision (VDOP).
    - Horizontal Dilution of Precision (HDOP).
    - Geometric Dilution of Precision (GDOP).

- **Weather Conditions.** Generally, weather conditions do not affect GPS surveying; however, the following conditions must be considered when planning a GPS survey:
  - GPS observations should never be conducted during an electrical storm.
  - Significant changes in weather or unusual weather conditions should be noted either in the field notes, data collector, or receiver.
  - Horizontal and vertical GPS observations can at times be affected by severe snow, hail and rain storms. Therefore, high accurate GPS surveys should not be conducted during these periods.
  - Sunspots or magnetic storms can affect GPS observations; care needs to be taken to avoid GPS surveying during these periods.
- **Elevation Mask Angle.** Nearly all GPS receivers, inexpensive or expensive, have a “Mask Angle” setting. This means that the receiver can be set to ignore any satellite signals that come from below a user-definable angle above the horizon, or “mask” them out. The most typical mask angle is usually somewhere between 10 and 15 degrees. The drawback here is that setting the mask angle too high might exclude satellites needed to acquire the necessary minimum of four. It’s a trade-off. Are you so desperate for a position at that exact time that you’re willing to accept a degraded signal? It does happen. In that case, the mask angle could be set to maybe 5 degrees, or even to zero if there’s a clear view of the horizon, such as at sea, and simply accept a degraded signal and possibly (probably) a poorer accuracy as a result. In most cases, it’s better to keep the mask angle at that upper end of around 15 to (at most) 20 degrees and just wait for a sufficient number of satellites to become available above the mask.

  Now that the full GPS constellation is complete, there will rarely be times with too few satellites sufficiently high in the sky to get a good position. Another potential source of error is receiver noise, or electronic noise produced by the receiver itself that interferes with the very weak incoming signal. While this error is highly variable among receiver brands, most have some kind of internal filtering designed to minimize the problem some better than others. Elevation mask also helps to minimize the atmospheric noise in the data. Satellites that are high in the sky will have less atmospheric noise than satellites low in the sky and very close to the observer’s horizon. By having an elevation mask set, the noise in the GPS satellite signal is kept to a minimum.
- **Multi-Path Errors.** Another potential, though relatively minor, source of signal error is Multi-Path. Multi-Path is simply the reception of a reflected satellite signal. With multi-path reception, the receiver collects both the direct signal from the satellite and a fractionally delayed signal that has bounced off of some nearby reflective surface then reached the receiver. This is the same kind of thing seen in television “ghosts.” The problem is that the path of the signal that has reflected off some surface is longer than the direct line to the satellite. This can “confuse” some lower-end receivers resulting in an incorrect range measurement and, consequently, an incorrect position. Most receivers have some way of “seeing” and comparing the correct and incorrect incoming signal. Since the reflected multi-path signal has traveled a longer path, it will arrive at a fraction of a second later, and a fraction weaker than the direct signal. By recognizing that there are two signals one right after another, and that one is slightly weaker than the other, the receiver can reject the later, weaker signal, minimizing the problem. This ability is referred to as the receiver’s multi-path rejection capability.
- **Dilution of Precision (DOP).** The DOP is a measure of the geometry of the visible satellite. The ideal orientation of four or more satellites would be to have them equally spaced all around the receiver, including one above and one below. Because we’re taking our position from only one side of the Earth, that’s really not possible since that part of space is blocked by the planet itself. The next best orientation is to have one satellite directly above and the other three evenly spaced around the receiver and elevated to about 25 to 30 degrees (to help minimize atmospheric refraction). This would result in a very good DOP value. If all the satellites are clustered together, it would result in a poor DOP value and your readings could be suspect. A low numeric DOP value represents a good satellite configuration, whereas a higher value represents a poor satellite configuration. The DOP at any given moment will change with time as the satellites move along their orbits. When the satellites are widely spaced, the overlap area of the two zones of possible satellite range error is relatively small. The diagram below on the left illustrates a pair of widely spaced satellites which would result in a good or low DOP value. The diagram on the right in Figure 6-1 illustrates poor satellite geometry resulting in poor or high DOP.

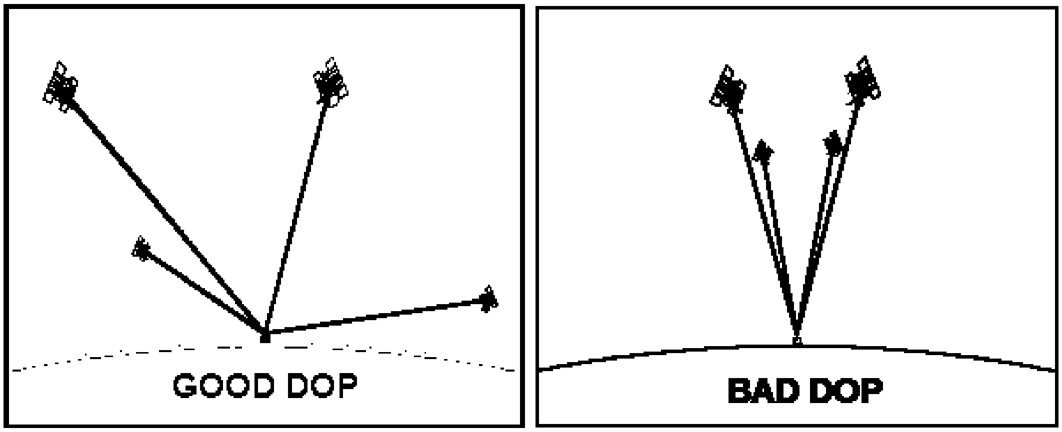

Figure 6-1: Dilution of Precision (DOP)

A DOP value of less than 2 is considered excellent-about as good as it gets, but it doesn't happen often, usually requiring a clear view of the sky all the way to the horizon. DOP values of 2 to 3 are considered very good. DOP values of 4 or below are frequently specified when equipment accuracy capabilities are given. DOP values of 4 to 5 are considered fairly good and would normally be acceptable for all but the highest levels of survey precision requirements. A DOP value of 6 would be acceptable only in low precision conditions, such as in coarse positioning and navigation. Position data should not be recorded when the DOP value exceeds 6.

It's important to carefully consider where the data is to be collected. Is the area of interest on Main Street of a large city? If so, the receiver is likely to be surrounded by tall buildings that restrict satellite visibility resulting in poor DOPs, since the only satellites that the receiver can see will be nearly straight up. That is, provided it's even possible to see enough satellites to get a position at all. In addition, the glass-sided structures all around the receiver act as nearly perfect multi-path reflectors. It's possible that, because of the efficiency of the buildings to reflect the incoming satellite signal, the receiver's multi-path rejection capability may actually be overloaded. These are very difficult problems to overcome, particularly in dense urban areas with many tall buildings. And the problems aren't just in the cities. Even out in the country with wide open spaces there are conditions to be considered. Close proximity to high-power lines is a problem. The electromagnetic radiation surrounding the lines can interfere with the satellite signal, contributing an error that is nearly impossible to compensate for or model. Forests with dense canopy cover can obscure the sky and interfere with the incoming satellite signal. The problem is even worse if the vegetation is wet, since the liquid water itself can also interfere with the signal.

- Human Error. The greatest contributor to error in GPS measurement is human error. Care must be taken while performing any GPS survey to keep human error to a minimum by proper procedures, redundant checks, repeat measurements and GPS observation log reports. The following are some common examples of human error:
  - Misreading antenna height measurements
  - Transposing numbers entered electronically
  - Rushing observations
  - Poor centering and leveling over points
  - Observing the wrong survey point (for example, observing a reference mark instead of the actual mark itself)
  - Incorrect equipment configuration settings

EQUIPMENT

NDOT is currently using GPS equipment from various manufacturers such as Leica and Trimble and also various generations of old and new. Therefore, you will need to refer to the operating manuals on the actual setup and operation of your equipment.

RECEIVERS

RTK surveys utilize two or more receivers. One is used as a reference or base station over a control monument. The other receiver or (rover) is moved from point to point collecting data. Additional receivers can be employed to achieve better productivity.

BASE RADIO

A radio or cellular link between the receiver and the rover is required. Some receivers utilize an internal radio while others need an external base radio to transmit to the rovers. The rover has a built-in radio to receive data from the base. Most external base radios include an antenna that mounts on a standard tripod and are powered by its own battery. The rover units have a small whip antenna and do not require an external power source.

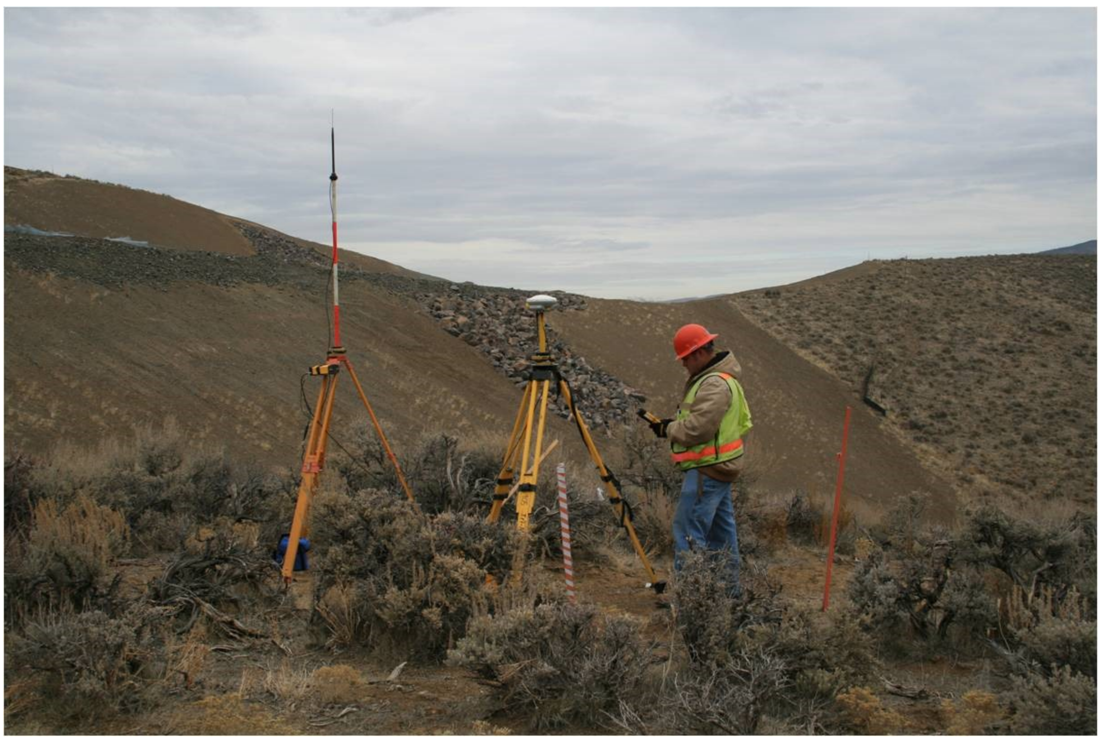

Figure 6-2: Trimble R8 GPS

DATA COLLECTOR

The Data Collector is needed for running the rover receiver. The Data Collector gives control over the survey and records data. It communicates with the rover by either cable or by Bluetooth. Most Data Collectors work exclusively on their manufacturer's equipment and will not communicate with other brands. Most Data Collectors have an internal battery. Each manufacturer has its own menu's and procedures. Therefore, the operator's manual must be referenced.

SOFTWARE

Each manufacturer has its own version of software for downloading data from the Data Collector and receiver. Data can then be manipulated from your personal computer and transferred back to the Data Collector for stakeout.

MISCELLANEOUS

Observe the following recommendations and precautions:

- Use a fixed height rod for both the base and the rover to eliminate height of instrument mistakes.
- Use bi-pod leg attachments when performing calibration shots.
- Check “fish eye” level bubbles frequently for plumb.
- Always take caution when winding up cords as they have glass encasements inside that if kinked will break and malfunction.

BATTERIES AND BATTERY CHARGERS

Supply the electricity required to run GPS equipment. Plan ahead to keep your batteries in the best condition and fully charged. Each supplier that delivers your GPS units include chargers that correspond with that equipment. Do not mix and match chargers and/or cables not meant for each particular unit. The life of the batteries can be affected by temperature. During very cold conditions, place hand warmers or other suitable devices inside the base/radio case. Keep rover batteries in a heated truck or in an inside pocket to keep them warm until needed. Conversely, when surveying in very hot conditions, keep the equipment off the direct surface of the ground by using a blanket and make sure to keep the equipment shaded as much as possible. It may be necessary to adjust your surveying times to reflect the coolest possible times.

There is one other issue with batteries that might need to be mentioned. This is the slow deterioration that occurs over time. When battery life declines by half, get rid of the batteries and replace them with new ones. The lost time and maneuvering in the field to keep changing batteries is not cost effective.

EQUIPMENT MAINTENANCE

At the beginning of any survey and at least every 6 months, all survey equipment should be checked and adjusted if needed. Checks and adjustments shall include but are not limited the following:

- Tripods - nuts and bolts are tight, no loose or broken legs, tripod head is tight, flat, and not damaged.
- Fixed Height Tripods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, and legs are secure.
- Rods - level bubbles are in adjustment, rod is not bent or damaged, height of rod is correct as reportedly measured, and adjustable rod height clamps are secure.
- Tribrachs - optical plummets are in adjustment, level bubble is in adjustment, no loose legs, no loose or missing screws, bottom head is flat and not damaged.
- Cables - no cuts, breaks, pinch marks or damage.
- Receivers - no cracks or visible signs damage.
- Receiver Antennas - if equipped with a ground plane, it is not bent or warped, no cracks or visible signs of damage.

Follow the manufacturer’s recommendations on the care and storage of your equipment. Store the equipment in a secure area and do not store the equipment in a wet case.

PROCEDURES

Proper planning is an important step in an RTK survey. The first step in beginning a survey is to locate control monuments in your project area. These can be found in the contract plans project control sheets (refer to "Monument Identification", in Chapter 2, for more information). Use at least six to eight control points for a site calibration (the minimum is three for horizontal and four for vertical). Place the calibration points around the perimeter of the job site. Do not survey outside of the area enclosed by the calibration points as the calibration is not valid beyond this perimeter.

There are times of the day when the number of satellites available will vary. The positions of the satellites at various times of the day are also a factor. Planning your work around these times greatly increases productivity and the quality of your results. The selection of the base station sites will also affect the success of the RTK observations. The base should be situated in a location that minimizes obstructions. A problem at the base will affect all rovers. In general, a clear view of the sky above 15 degrees is desired. At least five healthy satellites must be observed and the PDOP shall not exceed six during any GPS survey observations.

Consider the following when choosing a site:

- Sites should be free of vertical obstructions blocking the horizon such as buildings, overhangs, terrain, trees, fences, utility poles, overhead lines, or any other visible obstructions. Non-obstructed skies 15 degrees above the horizon are best.
- Sites should not be located close to radio transmitters including cellular phone equipment, because they may disrupt satellite signal reception.
- Sites close to large flat surfaces such as signs, fences, glass, or utility boxes should be avoided.
- If feasible, sites should not be disturbed by future construction activities and should be outside the design construction limits and top of cuts for the contract.

PREPARING THE DATA COLLECTOR

- Set up the data collector for an RTK survey. The methods will vary depending on the manufacturer. Therefore, the operator's manual should be referenced. Trimble uses a feature called a "survey style" which is a template of settings for different types of surveys. Each style contains dozens of settings for receivers, base and rover radios, etc.
- A feature code library should be loaded into the data collector. (Refer to file:\\datsrv1\017Public\FeatureCodeLibraries\SUE for more information.)
- Set up a job on the data collector.
- Enter the names, coordinates and ortho elevations of the control points that were selected. When naming points, use different names for Grid and WGS-84 coordinates with grid being keyed in from the project control sheets and WGS-84 from 3-minute field observations. For example, a point named 997117 S use 997117 S for grid coordinates and G997117 S for WGS-84 coordinates.

BASE STATION SET-UP

To set up the base station for RTK survey:

1. Select a location over a control point where there is a clear and unobstructed view of the sky and preferably this location is higher than the area to be surveyed.

2. Set the GPS receiver antenna over the control point and face it to the north. GPS antennas should be set up over the points using fixed-height antenna tripods. When using standard tripods with a tribrach, the antenna slope-height will be measured multiple times (per manufacturer's directions) and the average recorded.

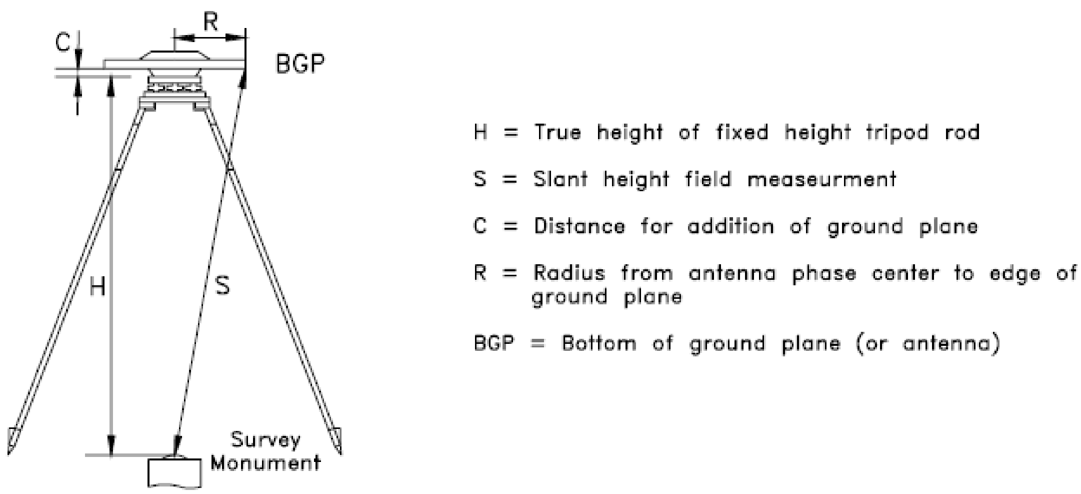

Figure 6-3: Base Station Setup

3. Attach the GPS antenna cable to the GPS antenna and then into the GPS receiver. (In some units, the receiver is built into the antenna. Therefore, this step is unnecessary).
4. Attach the data cable to the receiver.
5. Attach the battery to the base receiver.
6. Set up a tripod and place the radio antenna on it approximately 20 feet away from your GPS antenna.
7. Plug the radio antenna cable into the antenna port on the Trimmark 3 or other radio.
8. Attach the power cable to the external radio battery and plug the other end into the radio.
9. Plug one end of the radio cable into the base receiver and then the other into the radio.
10. Turn on the receiver.

To start a Trimble base receiver:

1. Start a file in your data collector by selecting Files from the main menu. Select New Job. Name your job and then tap coordinate system. Four choices will come up. For this time, select no projection/no datum. The screen will change and make sure the coordinates are selected Ground. Enter in the project height (can be found on the LPN sheet) and select Use Geoid Model. Select the proper geoid model and hit Store. Make sure your feature code library is selected (refer to file:\\datsrv1\017Public\FeatureCodeLibraries\SUE for more information) and that US survey feet is entered in the units category. Enter in the LPN number and your name and hit Accept.
2. Connect the data collector to the data cable already attached to the Trimble base receiver and select Survey. Then select the appropriate RTK survey style. Then select START BASE RECEIVER.

3. It will ask for a point number. Key in the point name and code. Select the Here button down on the bottom. This will give you a general location of your base station and allow you to calibrate on the control points.
4. Disconnect data cable and key in Grid Coordinates and ortho elevations of the control points that were selected. Use the point names from the project control sheets.
5. Turn on the rover and wait for it to initialize before you leave the base.

CALIBRATION

To obtain a site calibration:

1. Attach the bipod legs to your rover rod (this is mandatory).
2. Face the antenna to the North for each measurement.
3. Go to control points that are outside the limits of your job usually before, after, in the middle and outside of the Right-of-Way if possible. You want to try and surround your jobsite if possible. Shoot at least six to eight control points for the calibration and remember that you should only shoot within 6 miles of your base. Always remember to name the shots you do in the calibration the number that is in the LPN sheet with a “G” placed in front of it to keep the points straight.
4. At the occupied point, face your predetermined direction and place the rod tip in the divet, firmly step on the bipod feet to sink them into the ground, level up, select Start Survey, then wait for the rover to initialize. Select Measure Points and select Observed Control Point for your choice of shot type.
5. After the 3-minute shot, collapse the legs and pick up and go to the other monuments for their shots.
6. Once you have completed all of the shots you want to do, you may start the field calibration in your data collector.
7. Select Key in / Points from the main menu. Set the type field to Coordinates. Check that the coordinate fields are North, East, and Elevation. Enter in any control points that have not been entered already.
8. Select the point pairs that you want to use for the calibration by selecting the LPN coordinates number and then your survey shots with the same name and the “G” prefix.
9. Once you select the point pairs, evaluate the vertical and horizontal residuals. You want to do the horizontal first. Try to hold the furthest points out from the job to get the widest calibration possible. Toggle on/off the horizontal portion of the selections on each of the pairs to determine if you get better residuals. Once you get the horizontal residual to be .03 or less, work on getting the vertical as low as possible. Once you get both as good as you can get them, fix the scale factor to 1 and then hit Apply.
10. Once the calibration is complete and you accept the results, never re-calibrate on this area as you do not want to change the relationship between all of the control points and the subsequent points you shoot. Multiple calibrations along a roadway should be connected at the ends by using one or two of the same control points in each of the associated calibrations. This enables the two calibrated surfaces to be held together at this point and removes the possibility of elevation breaks that can plague some contracts.
11. Once you have a calibrated site, you should be able to set up your base receiver on any of your control points you have in your data collector.

FIELD OBSERVATION

RTK GPS surveying is similar to a Total Station radial survey. The protocols used in point collection are the same in both methods of surveying.

Once the gear is set up and you have started the base receiver, you can initialize and start the survey. It is generally best to make sure you have a radio signal from the base, and the rover is initialized before leaving the area.

Measuring points can take a couple of different forms:

- Topo Point method is a shot that takes approximately three seconds to take once you hit measure. This is a very accurate shot and should be taken when shooting concrete and/or plantmix bituminous surfaces, flow lines of pipe or drop inlets, and basically any time that good elevation is required.
- Continuous Topo is another option where the vehicle or rod mounted rover can take a shot in a selected time or distance interval.
- Rapid Point has the least quality of the methods. It only takes about a second to take one of these shots, and this method should only be used on cross sections for borrow pits and original surfaces on dirt.
- Stake out. Once calibrated, the project's alignment can be entered into the data collector or downloaded from a personal computer in the office. Any point on the alignment can be staked out and offset as long as it is inside the calibrated area.

FEATURE CODES

Always remember to use the proper feature code on your points. (Refer to file:\\datsrv1\017Public\FeatureCodeLibraries\SUE for more information.) Improper coding is the number one problem when trying to create breaklines and surfaces and can lead to costly mistakes. Features should be shot sequentially whenever possible to reduce the amount of editing on breaklines in the office.

TROUBLESHOOTING

If you are having trouble getting your base and rover to communicate via radio link, consider the following:

- Are both the base and the rover set to CMR+ (in "Broadcast format" in the survey style on the controller)?
- Is the correct antenna type in the survey style for both the base and the rover?
- Is the correct radio type in the survey style for both the base and the rover?
- Is the power setting for the base radio appropriate for the distance between the base and rover?
- Does the base radio frequency and wireless mode settings match on the base and the rover?
- Is the coordinate system appropriate for the region?
- Is the base radio in the right broadcast mode?
- Check that all cables are correct.
- Check batteries.
- Power the receivers and Data Collector off and then back on and restart the base with the Data Collector. Sometimes a power cycle is all that is needed.

NOTE: Different manufacturers may refer to these methods by different names so read through the operator's manual for the correct procedures for your equipment. This guide was created with Trimble GPS equipment in mind.