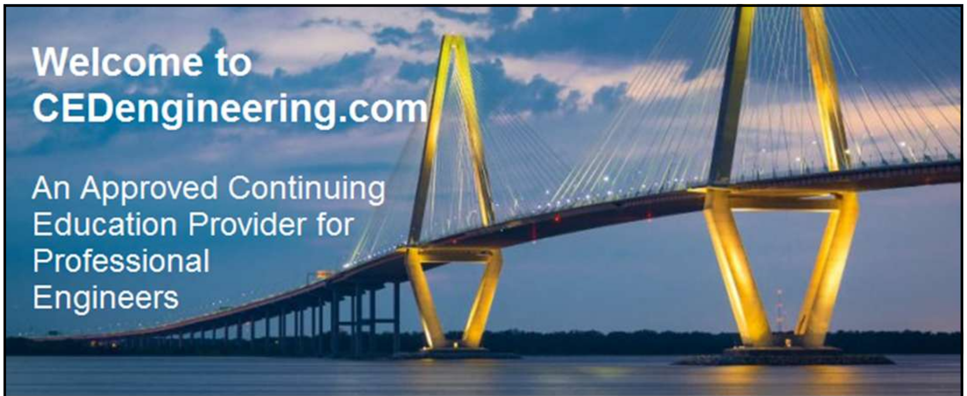


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# CONTROL AND TOPOGRAPHIC SURVEYING

Course No: L03-307 - Course Credit: 3 PDH

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## LEARNING OBJECTIVES

1. To understand the operation, features, and error sources of total stations, and their application in topographic surveys, trigonometric leveling, and traverse techniques.
2. To explain the principles and field procedures of GPS Real-Time Kinematic (RTK) surveying, including ambiguity resolution, site calibration, and observing standards for topographic and construction control surveys.
3. To explore the capabilities, accuracy, and data processing procedures of terrestrial 3D laser scanners, and their application on Corps of Engineers civil and military projects.
4. To examine the methods for transferring topographic survey data into CADD and GIS platforms, including data flow, geospatial data definitions, feature coding, and quality control procedures.
5. To analyze the requirements for survey documentation and submittals, including field note keeping procedures, monument descriptions, and final survey report formats for civil and military projects.
6. To understand the deliverable components and quality assurance criteria required for topographic survey project submittals, including coordinate files, design files, metadata, and QA checklists.

# TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES

## Purpose

- This chapter provides general guidance on the use of total stations on topographic surveys.
- This chapter includes information on reflectorless/robotic systems and prism-only systems.
- Use and operation of internal and external data collectors with a total station are covered.





**Figure 1: Wild TC-1010 Total Station with TDS-HP48GX Data Collector 1998 Levee Survey at Bayou Segnette.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Total Stations

- Total stations combine electronic theodolites and EDM into a single unit.
- They digitally observe and record horizontal directions, vertical directions, and slope distances.
- These digital data observations can be adjusted and transformed to local X-Y-Z coordinates using an internal or external microprocessor.
- Various atmospheric corrections, grid and geodetic corrections, and elevation factors can also be input and applied.
- The total station may internally perform and save the observations or (more commonly) these data may be downloaded to an external data collector.
- With the addition of a data collector, the total station interfaces directly with onboard microprocessors, external PCs, and software.
- Electronic theodolites operate in a manner similar to optical theodolites.
- Angles can be electronically encoded to one arc-second with a precision down to 0.5 arc-second.
- Digital readouts eliminate the uncertainty associated with reading and interpolating scale and micrometer data.
- The electronic angle-measurement system minimizes some of the horizontal and vertical angle errors that normally occur in conventional theodolites.
- Angular measurements are based on the reading of an integrated signal over the surface of an electronic encoder that produces a mean angular value and completely eliminates the inaccuracies from eccentricity and circle graduation.
- These instruments also are equipped with a dual-axis compensator, which automatically corrects both horizontal and vertical angles for any deviation in the plumb line.



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**Figure 2: Leica TCR-705 Reflectorless Total Station.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

**Figure 3: Trimble TSC and HP48 Data Collectors.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





- a. The development of the total station has made it possible to accurately gather enormous amounts of survey measurements quickly.
  - In the last 20 years, total stations and data collectors have become common field equipment, and have largely replaced the traditional survey methods that utilized transits, theodolites, and alidades.
  - Digital theodolites and EDM instruments were perfected during the 1970s.
  - In the early 1980's the surveying instrument manufacturers introduced what has become the total station, redefining the term by creating an entirely electronic instrument that combined the heretofore separate digital theodolites and EDM devices.
  - Directly storing direction and distance observations to a microprocessor helped eliminate many of the reading errors that can occur with an optical theodolite or traditional EDM where observations are hand recorded.
  - Along with the advent of the electronic theodolite came the electronic data collector, thus minimizing both the reading errors and the writing errors.
  - Modern total stations can measure a distance to an accuracy of better than 5 millimeters plus 1 part per million, with some variation depending on the type of reflecting surface or prism used.
  - Electronic angles can be resolved to about one-half arc second, although models used for construction may have a resolution of only 30 seconds.
  - In most land surveying situations, the normal crew size can be reduced to two persons when equipped with a standard total station, and one person when using robotic total stations.

- b. Traditionally, surveying has used analog methods of recording data.
  - Digital data collection methods using electronic total stations are far more efficient.
  - Total stations have dramatically increased the amount of topographic data that can be collected during a day and are well suited for topographic surveys in urban landscapes and busy construction sites.
  - Modern total stations are also programmed for construction stakeout and highway centerline surveys.
  - When proper procedures are performed, total stations have made trigonometric leveling nearly as accurate as many of the differential level techniques in areas possessing large relief landforms.
  - Total station instruments and associated data collectors can quickly transfer 3D coordinates and are capable of storing unique mapping feature codes and other parameters which in the past could only be recorded on paper media such as field books.





### Total Station Features and Operation

- There are less than a dozen manufacturers of total stations that commonly market in the US.
- Each manufacturer may have varied models, with optional features that can be tailored to local operating conditions, such as accuracy requirements, project size (EDM distances), and available crew size.
- Selection of a particular model, along with the associated data collector and CADD software, requires some research.
- A good place to start would be viewing periodic surveys by trade publications.
- Discussions with users at other Districts, local survey suppliers, and AE survey contractors are also recommended.
- Exhibitor demonstrations at state survey society meetings is another good place to observe and test new equipment.
- In some cases, vendors will offer to come to the district and demonstrate their equipment in your local working environment

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- a. General operation.
  - Total station surveys are performed similarly to transit-stadia or plane-table-alidade surveys.
  - Total stations are set up over control points similarly to traditional transits, theodolites, or EDM.
  - Most employ a three-screw, forced-centering Wild-type tribrach mount to fasten and align the total station with the tripod.
  - Heavy wooden or fiberglass tripods are best for supporting total stations.
  - Leveling over a point is performed no differently than traditional instrument methods.
  - The tribrach is roughly centered over the point first using the standard tripod leg adjustment technique.
  - The total station is then mounted in the three-pin tribrach and internally leveled using either level vials or electronic dualaxis methods, depending on the type of instrument.
  - Either optical or laser plummets are used for final centering over a point.
  - Some total stations provide out of level warnings to the operator.
  - All plummets, optical or digital, should periodically be checked, adjusted, and calibrated.
  - A conventional plumb bob provides such a check if used in ideal conditions.





## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- b. Prism poles.
  - A variety of target poles are used for the remote rod to which topographic observations are made.
  - Both adjustable and fixed height poles are common.
  - Extendable rods (to 20 feet and higher) may be used--especially on beach profiling surveys and in canopy areas.
  - For most applications, a retro-reflector prism is attached to the top of the prism pole such that there is no eccentric offset correction required.
  - If not, then the retro-reflector offset correction must be determined and applied to observed distances.
  - Use of a fixed height pole helps minimizes HR blunders.
  - A shoe for the pole point may be needed in soft ground.
  - A standard rod level is used to plumb the prism pole over a point.
  - Many poles have built-in rod levels to facilitate plumbing the prism.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)




**Figure 4: Prism pole.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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- c. EDM range and accuracy.
  - Ranges with standard prisms and reflectorless models vary widely between manufacturers.
  - Both infrared and laser EDMs are used.
  - Distance resolution is either pulsed (low accuracy) or phase comparison (typical ± 2 to ± 5 mm accuracy).
  - One and three array prism ranges can vary from one mile to over 5 miles.
  - Ranges of reflectorless total stations are specified relative to 90% and 18% Kodak grey cards, and can vary from 300 ft to over 3,000 ft.
  - Reflectorless accuracies are not as good as prism accuracies given the variability of the reflecting terrain, and may therefore may not be suitable for more accurate surveys such as FEMA first floor elevation certificates.
  - At the outer range limits, bicycle reflector tape or a prism rod with a retroreflector may be needed.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- d. Instrument controls.
  - Focus and plate control tangent and locking screws vary widely between total station brands.
  - A 30X optical zoom is common on most total stations.
  - These controls should be operated in accordance with the manufacturer's instructions.
- e. Cost.
  - Total station costs obviously will vary with the accuracy and added features.
  - A simple digital theodolite (no data collection) will cost less than $1,500.
  - A basic total station survey package (including tripod and prism pole) will cost about $7,500 and reflectorless or robotic units can cost upwards of $20,000.
  - A data collector and software must be purchased separately--a $1,500 to $4,000 additional cost.
  - A field laptop computer will run $2,000 to $3,000.
  - Miscellaneous survey equipment can easily exceed another $3,000--e.g., extra tripods, total station batteries, 25-ft telescoping rod, additional prisms, magnetic locater, etc.





## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- f. Angular accuracy.
  - Angle standard errors range from ± 1" to ± 5" based on a Direct and Reverse set.
  - Less accurate models are available for construction layout application--e.g., 1-minute instruments.
- g. Data collectors.
- h. Other features.
  - Other factors to be considered in the selection of a particular total station include: robotic search controls, measurement time, integrated laser scanners, integrated GPS, internal digital camera, internal data storage capacity, internal COGO and stakeout capabilities, compatibility with existing data collector (if not purchased with the total station), weight (including batteries and battery life), ease of operation, and training needs.

**Figure 5: TOPCON GPT-8200 Series Reflectorless-Robotic Total Station can make reflectorless measurements out to 4,000 ft and prism measurements to 23,000 ft.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





## Reflectorless and Robotic Total Stations

- Reflectorless and robotic total stations have an unlimited number of applications.
- They allow one-man survey crew operation.
- Reflectorless total stations can position objects that cannot be positioned with a reflector prism, such as towers, tanks, roof eaves, overhead cables or power lines, overhead pipes, stockpiles, traffic areas, and potentially hazardous areas (unexploded ordinance).
- Robotic total stations have the advantage of one-man crew operation.
- In addition, they allow the instrument to be left unattended at secure sites.
- The instrumentman then records data at the rod/prism point, where a particular feature can be better identified.
- Typical units are shown in Figure 5 and Figure 6.

- The data collector shown in the figure here is a Trimble ACU Survey Controller, which contains a color graphical display and uses a Windows CE operating system.
- This data collector can be used with the total station as shown, with a RTK topographic system, or as a robotic rover.

**Figure 6: Trimble 5600 DR Reflectorless-Robotic Total Station with ACU Survey Controller.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





## Field Equipment Inventory and Maintenance

- Modern electronic survey equipment requires surveyors to be maintenance conscious of their equipment.
- Special concerns include power sources and whether or not the instruments and accessories are accurately adjusted and in good repair.
- When setting up a crew to work with a total station and data collector, it is helpful to supply the party chief with a checklist to help the crew maintain its assigned equipment and handle the collected data upon returning to the office.
- It is also important that each crew be supplied with all necessary equipment and supplies.
- These should be stored in an organized and easily accessible manner.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- a. Typical equipment inventory for a two-man crew.
  - Listed below is equipment list that would support a two-person crew, consisting of a party chief/rodperson and a notekeeper/instrument person.
  - This should be a sufficient equipment inventory to meet the general needs of boundary, layout, and topographic surveys.
  - It is assumed that this crew has a regular complement of supplies such as hammers, shovels, cutting tools, ribbon, stakes, lath, and safety equipment.
    - Total station
    - Data collector
    - Batteries for 14 hours of continuous operation plus backup supply
    - 3 tripods
    - 2 tribrachs
    - 2 target carriers
    - 1 fixed height range pole and 1 adjustable pole
    - 2 target holders
    - 2 reflectors
    - 2 two-way radios



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- b. Additional equipment.
  - With this basic equipment inventory, a two-person field crew will be able to handle most survey tasks that are routinely encountered in day-to-day operations.
  - An additional tripod, range pole, carrier, tribrach, and reflector would give the crew even greater flexibility, and allow them to handle many projects more efficiently.
  - It is also helpful for the field crew to have a convenient place to store their assigned equipment.
  - Crews should be equipped with briefcase-sized cases that will hold tribrachs, reflectors with holders, carriers, and target plates.
  - A hard camera case or pistol case works well for this purpose.
  - With all the components stored in one place, it makes inventory of the equipment easy and reduces the chance of equipment being left at the job site.
  - This also allows for proper equipment maintenance.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- c. Equipment maintenance.
  - The following checklist will aid each crew in properly maintaining and keeping inventory of their assigned equipment.
  - At the end of each workday the party chief should check that the following duties have been performed:
    - Clean all reflectors and holders.
      - A cotton swab dipped in alcohol should be used on the glass surfaces.
      - A crew member can do this during the trip back to the office.
    - Clean tribrachs.
      - They should be dusted daily.
    - Remove dust from all instruments.
      - A soft paintbrush or a shaving brush works well.
      - If an instrument has been exposed to moisture, thoroughly dry it and store in an open case.
    - Download the data collector to the computer.
    - Backup all files generated from the download and check the integrity of the backup files before erasing the field data from the data collector.
    - Clean batteries and connect to charger.
      - Some batteries require a 14- to 20-hour charge, so one set of batteries may have to be charged while a second set is in operation.



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## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- d. Battery maintenance.
  - One of the biggest problems faced by the users of total stations with data collectors is maintaining an adequate power supply.
  - Most total stations have small, removable, rechargeable Ni-Cad or gel-cell batteries.
  - There are several factors that should be considered when assessing power needs:
    - (1) Type of survey.
      - A topographic survey usually entails much more data collection in a day than a boundary survey.
      - Determine the number of measurements that you would normally make in a day and consult the manufacturer's specifications to determine the number of shots you can expect from a fully charged new battery.
      - In general, some 4 to 8 hours of continuous use is available, based on one EDM measurement every 30 seconds.
      - Larger batteries are available to extend observation time.

- (2) Age of batteries.
  - Keep in mind that batteries will degrade over a period of time.
  - This means that a new battery, with sufficient power for 500 measurements when new, may only be capable of 300 measurements after a year of use.
  - With an inverter, extra backup batteries can be charged in the survey vehicle.
- (3) Time needed to charge batteries.
  - Total station batteries take 3 to 5 hours to fully charge.
  - Multiple battery chargers should be obtained in order to keep a sufficient supply of batteries on hand each morning.





- (4) In addition to the proper assessment of power need, a record of the history and current status of the power supply should be readily available.
  - When batteries begin to get weak there is generally a rapid deterioration in their performance.
  - To monitor the performance of a particular battery record the serial number in a battery log book.
  - If problems arise with a particular unit, check the log to see when the battery was purchased or when it was last recelled.
  - Next try discharging and recharging the battery.
  - If performance is still not up to speed, have it checked to determine the weak cell and replace it.
  - If the battery was not new or was recelled in the last year, recell the entire unit.
  - When one cell goes the next one is usually only a charge or two from failure.
  - The cost of having a battery recelled is minimal when considering the cost of lost work time due to power failure.

- (5) Also record the date the battery was charged on the shipping label that is attached to the battery box.
  - When the battery is fully used simply cross out the date, thus eliminating the confusion of not knowing which battery needs to be charged.
  - Monitor the shelf time of the battery, and if it exceeds 10 days, recharge it.
  - This keeps the power supply at peak performance.
  - Always consult the operator's manual for recharge specifications.



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- e. Backup power.
  - It is always a good idea to have backup power available for that last 15 minutes of work.
  - Most manufacturers can provide cabling for backup to an automobile battery.
  - Some can even supply a quick charge system that plugs into the cigarette lighter.
  - Power pointers are:
    - Assess power needs for the particular job
    - Assess power usage of the equipment
    - Monitor performance of each battery
    - Monitor battery age, usage, and recell information
    - Have one day's worth of backup power readily available

## Total Station Job Planning

- An often-asked question when using a total station with a data collector is "How do I plan a project?"
- To answer this question, first examine the productivity standards expected of field crews.
- a. Most crews will make and record hundreds of observations per day.
  - This includes any notes that must be put into the system to define what was measured.
  - When creating productivity standards keep in mind that a learning curve is involved.
  - Usually it takes a crew some four to five projects to become familiar with the equipment and the coding system to start reaching the potential productivity of the system.





- b. A two-person crew is most efficient when the nominal spacing of the measurements is less than 50 feet.
  - When working within this distance the average rod person can acquire the next target during the time it takes the instrument operator to complete the measurement and input the codes to the data collector.
  - The instrument operator usually spends 20 seconds (±) sighting a target, recording a measurement, and another 5-10 (or more) seconds coding the measurement.
- c. When the general spacing of the data exceeds 50 feet, having a second rod person will significantly increase productivity.
  - A second rod person allows the crew to have a target available for measurement while the first rod person is moving.
  - If the distance of the move is 50 feet or greater, the instrument will be idle with only one rod person.

- d. When dealing with strip topographic situations, it may be necessary to acquire data every 3 feet along the length of the job.
  - In urban areas the data may seem to be denser, but the rights-of-way are generally wider.
  - Some feel that one measurement for every 3 feet of linear topography works very well for estimating purposes.
  - Using this estimate, an average field crew can make and record between 350- 500 measurements or 1,000-1,500 feet of strip topography per day.
  - A two-person crew equipped with recording total station and data collector can pick up 1,250 feet a day.
  - Depending on the office/field reduction software being used, these data can produce both the planimetric and contour maps as well as transfer the data to an engineering design package with very little additional manipulation.





### Total Station Error Sources

- All theodolites measure angles with some degree of imperfection.
- These imperfections result from the fact that no mechanical device can be manufactured with zero error.
- In the past very specific measuring techniques were taught and employed by surveyors to compensate for minor mechanical imperfections in theodolites.
- With the advent of electronic theodolites, the mechanical errors still exist but are related to in a different way.
- One must now do more than memorize techniques that compensate for errors.
- One must clearly understand the concepts behind the techniques and the adjustments for errors that electronic theodolites now make.
- The following paragraphs provide the major sources of error when using a theodolite and also the particular method employed to compensate for that error.

- a. Circle eccentricity.
  - Circle eccentricity exists when the theoretical center of the mechanical axis of the theodolite does not coincide exactly with the center of the measuring circle.
  - The amount of error corresponds to the degree of eccentricity and the part of the circle being read.
  - When represented graphically circle eccentricity appears as a sine wave.
  - Circle eccentricity in the horizontal circle can always be compensated for by measuring in both faces (opposite sides of the circle) and using the mean as a result.
  - Vertical circle eccentricity cannot be compensated for in this manner since the circle moves with the telescope.
  - More sophisticated techniques are required.





- (1) Some theodolites are individually tested to determine the sine curve for the circle error in that particular instrument.
  - Then a correction factor is stored in ROM that adds or subtracts from each angle reading so that a corrected measurement is displayed.
- (2) Other instruments employ an angle-measuring system consisting of rotating glass circles that make a complete revolution for every angle measurement.
  - These are scanned by fixed and moving light sensors.
  - The glass circles are divided into equally spaced intervals which are diametrically scanned by the sensors.
  - The amount of time it takes to input a reading into the processor is equal to one interval, thus only every alternate graduation is scanned.
  - As a result, measurements are made and averaged for each circle measurement.
  - This eliminates scale graduation and circle eccentricity error.

- b. Horizontal collimation error.
  - Horizontal collimation error exists when the optical axis of the theodolite is not exactly perpendicular to the telescope axis.
  - To test for horizontal collimation error, point to a target in face one then point back to the same target in face two; the difference in horizontal circle readings should be 180 degrees.
  - Horizontal collimation error can always be corrected for by meaning the face one and face two pointings of the instrument.



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- (1) Most electronic theodolites have a method to provide a field adjustment for horizontal collimation error.
  - Again, the manual for each instrument provides detailed instruction on the use of this correction.
- (2) In some instruments, the correction stored for horizontal collimation error can affect only measurements on one side of the circle at a time.
  - Therefore when the telescope is passed through zenith (the other side of the circle is being read), the horizontal circle reading will change by twice the collimation error.
  - These instruments are functioning exactly as designed when this happens.
- (3) When prolonging a line with an electronic theodolite, the instrument operator should either turn a 180-degree angle or plunge the telescope and turn the horizontal tangent so that the horizontal circle reading is the same as it was before plunging the telescope.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- c. Height of standards error.
    - In order for the telescope to plunge through a truly vertical plane the telescope axis must be perpendicular to the standing axis.
    - As stated before there is no such thing as perfection in the physical world.
    - All theodolites have a certain degree of error caused by imperfect positioning of the telescope axis.
    - Generally, determination of this error should be accomplished by a qualified technician because horizontal collimation and height of standards errors interrelate and can magnify or offset one another.
    - Horizontal collimation error is usually eliminated before checking for height of standards.
    - Height of standards error is checked by pointing to a scale the same zenith angle above a 90-degree zenith in "face-one" and "face-two."
    - The scales should read the same in face one as in face two.





## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- d. Circle graduation error.
    - In the past, circle graduation error was considered a major problem.
    - For precise measurements surveyors advanced their circle on each successive set of angles so that circle graduation errors were “meaned out.”
    - Current technology eliminates the problem of graduation errors.
    - This is accomplished by photo-etching the graduations onto the glass circles and making a precise master circle and photographing it.
    - An emulsion is then applied to the circle and a photo-reduced image of the master is projected onto the circle.
    - The emulsion is removed and the glass circle has been etched with very precise graduations.

- e. Vertical circle error.
  - It is important to check the vertical circle indexing adjustment on surveying instruments on a routine basis.
  - When direct and indirect zenith angles are measured to the same point, the sum of the two angles should equal 360°.
  - Over time, the sum of these two angles may diverge from 360° and consequently cause errors in vertical angle measurements.
  - While averaging the direct and indirect zenith angles easily eliminates this error, on many jobs it may not be cost effective to make two readings.
  - Acceptable accuracy may still be maintained for many applications with only a direct reading; however, as long as the index error is kept to a minimum by periodically performing a vertical adjustment, such as TOPCON's "Vertical Angle 0 Datum Adjustment."
  - Most total stations are provided with some type of electronic adjustment to correct the vertical circle indexing error.
  - This adjustment takes just a few seconds and will insure that you get good vertical angle readings with just one measurement.
  - Consult the manufacturer's manual for instructions on making this adjustment.



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- f. Pointing errors.
  - Pointing errors are due to both human ability to point the instrument and environmental conditions limiting clear vision of the observed target.
  - The best way to minimize pointing errors is to repeat the observation several times and use the average as the result.
- g. Uneven heating of the instrument.
  - Direct sunlight can heat one side of the instrument enough to cause small errors.
  - For the highest accuracy, utilize an umbrella or pick a shaded spot for the instrument.
- h. Vibrations.
  - Avoid instrument locations that vibrate. Vibrations can cause the compensator to be unstable.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- i. Collimation errors.
  - When sighting points a single time (e.g., direct position only) for elevations, check the instrument regularly for collimation errors.
- j. Vertical angles and elevations.
  - When using total stations to measure precise elevations, the adjustment of the electronic tilt sensor and the reticule of the telescope becomes very important.
  - An easy way to check the adjustment of these components is to set a baseline.
  - A line close to the office with a large difference in elevation will provide the best results.
  - The baseline should be as long as the longest distance that will be measured to determine elevations with intermediate points at 100- to 200-ft intervals.
  - Precise elevations of the points along the baseline should be measured by differential leveling.
  - Set up the total station at one end of the baseline and measure the elevation of each point.
  - Comparing the two sets of elevations provides a check on the accuracy and adjustment of the instrument.
  - Accuracy requirements may dictate that more than one set of angles and distances is measured to each point.
  - Some examples are distances over 600 feet, adverse weather conditions, and steep observations.





## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- k. Atmospheric corrections.
  - Meteorological data corrections to observed EDM slope distances may be significant over longer distances.
  - Usually for most topographic surveying over short distances, nominal (estimated) temperature and pressure data is acceptable for input into the data collector.
  - Instruments used to measure atmospheric temperature and pressure must be periodically calibrated.
  - This would include psychrometers and barometers.
- l. Optical plummet errors.
  - The optical plummet or tribrachs must be periodically checked for misalignment.
  - This would include total stations with laser plummets.

- m. Adjustment of prism poles.
  - When using prism poles, precautions should be taken to ensure accurate measurements.
  - A common problem encountered when using prism poles is the adjustment of the leveling bubble.
  - Bubbles can be examined by establishing a check station under a doorway in the office.
  - First, mark a point on the top of the doorway.
  - Using a plumb bob, establish a point under the point on the doorway.
  - If possible, use a center punch to make a dent or hole in both the upper and lower marks.
  - The prism pole can now be placed into the check station and easily adjusted.





- n. Recording errors.
  - The two most common errors are reading an angle incorrectly and/or entering incorrect information into the field book.
  - Another common (and potentially disastrous) error is an incorrect instrument or rod height.
  - Although electronic data collection has all but eliminated these errors, it is still possible for the surveyor to identify an object incorrectly, make a shot to the wrong spot, or input a bad target height (HR) or HI.
  - For example, if the surveyor normally shoots a fire hydrant at the ground level, but for some reason shoots it on top of the operating nut, erroneous contours would result if the program recognized the fire hydrant as a ground shot and was not notified of this change in field procedure.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- o. Angles.
  - As a rule, a surveyor will turn a doubled angle for move-ahead, traverse points, property corners, or other objects that require greater accuracy.
  - On the other hand, single angles are all that are required for topographic shots.
  - Refer to the total station operating instructions for repeating angle methods where required.



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## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

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- p. Slope to grid and sea level EDM corrections.
  - Slope distances will be reduced to horizontal distances in the data collector, and then reduced to a grid distance if a grid scale factor (or combined scale sea level factor) is input into the data collector.
  - For most topographic survey applications involving short side shots, the grid scale factor is ignored (e.g., 1.000 is used).
  - This would not be correct for control traverses covering larger distances.
  - Scale factors can be obtained directly in CORPSCON.
- q. EDM calibration.
  - All EDM instruments should be periodically (at least annually) checked over a NGS Calibration Baseline or a baseline established by local state surveying societies.

## General Total Station Operating Procedures

- A set routine should be established for a survey crew to follow.
- Standard operating procedures should require that control points be measured and noted immediately on the data collector and/or in the field book after the instrument has been set up and leveled.
- This ensures that the observations to controlling points are established before any outside influences have had an opportunity to degrade the setup.
- In making observations for an extended period of time at a particular instrument location, reobserve the control points from time to time.
- This ensures that any data observed between the control shots are good, or that a problem has developed and appropriate action can be taken to remedy the situation.
- As a minimum, require survey crews to observe both vertical and horizontal control points at the beginning of each instrument setup and again before the instrument is picked up.





- One of the major advantages of using a total station equipped with data collection is that some errors previously attributed to blunders (e.g., transposition errors) can be minimized or eliminated.
- Even if the wrong reading is set on the horizontal circle in the field or the wrong elevation is used for the bench, the data itself may be precise.
- To make the data accurate, many software packages will allow the data to be rotated and/or adjusted as it is processed.
- The only way to assure that these corrections and/or observations have been accurately processed is to compare the data to control points.
- Without these observations in the recorded data, the orientation of that data will always be in question.
- The use of a total station with a data collector can be looked upon as two separate and distinct operations.
- The following procedure is typical of most total stations and data collectors:

- a. Total Station
  - If EDM is modular, mount it on instrument.
  - Connect data collector.
  - Set up and level instrument.
  - Turn on total station.
  - Set atmospheric correction (ppm). This should be done in the morning and at noon.
  - Set horizontal circle.
  - Set coordinates.
  - Observe backsight (check whether azimuth to backsight is 180 degrees from previous reading).
  - Observe backsight benchmark (obtain difference in elevation). This may require factoring in the height of reflector above benchmark.
  - Compute relative instrument height (benchmark elevation +/- difference in height). Note height of rod (HR) and note computations in field book.
  - Input Z (elevation) value in instrument or data collector.
  - Observe backsight benchmark (check elevation).
  - Invert and repeat (check elevation).



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- b. Data Collector
  - Record date and job number.
  - Record crew number and instrument serial number.
  - Record field book number and page number.
  - Record instrument location (coordinates).
  - Record backsight azimuth.
  - Record standard rod height.
  - Record height of instrument.
  - Observe and record measurement to backsight benchmark.
  - Enter alpha or numeric descriptor of above point into data collector.
  - Observe and record measurement backsight benchmark or check benchmark (if setting benchmark, note in field book and repeat with instrument inverted).
  - Enter alpha or numeric descriptor of above point into data collector.
  - Observe and record measurement to backsight.
  - Enter alpha or numeric descriptor of above point into data collector.
  - Invert and repeat the above two steps.
  - Observe and record measurement to foresight.
  - Enter alpha or numeric descriptor of above point into data collector.
  - Invert and repeat the above two steps.
  - Observe and record measurement to side shot.
  - Enter alpha or numeric descriptor of above point into data collector (repeat the above two steps as needed).
  - When setup is complete, or at any appropriate time, repeat shots on vertical and horizontal control. Observe the displays and record in data collector.

- c. Precautionary guidance and recommendations on total stations.
- The following guidance from the CALTRANS Surveys Manual (CALTRANS Surveys Manual 2001-2004) is applicable to total station operation.
  - Never point the telescope directly at the sun as the sun's rays may damage the diodes in an electronic distance measuring instrument (EDMI).
  - If possible, shade the instrument from direct sunlight as excess heat may reduce the range of the sender diodes in the EDMI.
  - To maintain maximum signal return at longer ranges, shade prisms from direct sunlight.
  - Avoid multiple unrelated prisms in the same field of view; this can cause blunders in distance observations.
  - Do not transmit with a two-way radio near the total station during EDMI measurements.
  - Most total stations are equipped to detect and correct various instrumental errors. If such errors exceed program limits, error codes will indicate the error. Consult the operator's manual for exact procedures and error codes.
  - Do not carry tripod-mounted instruments over the shoulder.
  - Whenever possible, select instrument setup locations to minimize the exposure of the instrument operator, other members of the crew, and the instrument to danger. Select stable ground or footing for the tripod feet. Do not set an instrument directly in front of or behind a vehicle or piece of construction equipment that may suddenly move.
  - Don't leave instruments unprotected or unattended.
  - In the event that the instrument or any personnel are required to be in an area subject to traffic, protection procedures must be followed.



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## Total Station Angle Measurement and Traverse Techniques

- Most total stations provide a variety of methods for observing traverse or sideshot angles (or directions).
- Generally, three modes are available, depending on the angular accuracy required.
- The following modes are available on typical data collectors when configured with a total station.
  - Single - a single horizontal angle shot will be taken.
  - Directional - the sequence of shots to determine the horizontal angle for each point is as follows: direct to the backsight; direct to the foresight; reverse (invert) the scope; reverse to the backsight; reverse to the foresight.
    - Multiple "sets" may be selected--e.g., two or four sets might be turned on a Third-Order traverse.
  - Repeating - multiple angles (windings) are taken to determine each horizontal angle.
    - The value of the circle angle from each foresight reading is used as the circle angle for the next backsight; thus, accumulating the readings.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- a. Vertical angles.
  - Similar options are available for vertical angles (or zenith distances).
  - Either a single zenith distance is observed, or multiple (repeated) sets are observed in both circle faces.
  - The number of positions (sets) is a function of the accuracy required.
  - For topographic sideshots, a single zenith distance is all that is necessary.
  - Multiple zenith distances (in face right and face left) should be observed when running a traverse with long distances between setups.
- b. Distance measurements.
  - On most data collectors, options are available to take either single or multiple EDM distances.
  - Multiple distances are then averaged for each shot.



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- c. Tolerance alarms.
  - When multiple sets are observed, a tolerance can be specified in the data collector to alert high misclosures in angles or distances.
  - A tolerance factor on reflectorless observations will indicate potential erroneous settings or poor reflectivity at the target.
- d. Traverse procedures.
  - Total station data collectors will automatically update traverse angle and distance observations at each sequential setup.
  - Most collectors will compute angular and position misclosures, and perform a simple (Compass) traverse adjustment.
  - More sophisticated data collectors can perform rigorous least squares adjustments, including vertical network adjustments.
  - Adjusted traverse points are stored for use in densifying topography by radial methods.

## Total Station Leveling Field Procedures

- Accurate trigonometric leveling is perhaps one of the most important applications of a total station.
- Trigonometric leveling error sources must be considered when using a total station to set vertical control or to define feature elevations.
- The table here depicts relative elevation errors over varying distances and differing total station angular accuracies.

| Sight Distance | Vertical Angle Uncertainty (seconds) | | | |
|---|---|---|---|---|
| | 1 Sec | 5 Sec | 10 Sec | 60 Sec |
| 100 ft | 0.0005 ft | 0.0024 ft | 0.005 ft | 0.03 ft |
| 200 | 0.0010 | 0.0048 | 0.010 | 0.06 |
| 400 | 0.0019 | 0.0097 | 0.019 | 0.12 |
| 500 | 0.0024 | 0.0121 | 0.024 | 0.15 |
| 1,000 | 0.0048 | 0.0242 | 0.049 | 0.29 |

**Table 1: Elevation Errors (in feet) due to Errors in Trigonometric Zenith Angles.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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- Knowledge of the limitations of trigonometric leveling, together with means (instrumentation and procedures) to account for such limitations, is essential.
- Over short lines, total station trigonometric leveling can approach accuracies similar to those reached using a spirit level.
- Third-Order accuracy can be achieved over short lines.

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- To obtain Third-Order vertical accuracies with a total station, the following field procedures should be rigorously followed:
  - Careful setup and leveling
  - Use Face I and Face II observations
  - Reciprocal measurements
  - Take multiple observations
  - Protect instrument from sun and wind
  - Use proper targetry based on Inst/EDM configuration
    - Tilting target if necessary
    - Good quality reflectors
    - Correct prism offsets
    - Unambiguous target
    - Maintain targetry in good adjustment
  - Limited sight distances
    - 300 meters max
    - Reduce atmospheric-related error
    - Improves vertical angle accuracy
  - Accurately measure temperature and pressure
    - At least twice a day
    - If long steep line measurements at both ends, use averages
  - Watch for adverse refraction



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- The following error sources impact the accuracy of trigonometric leveling with electronic total stations:
  - Instrument
    - Distances
    - Vertical angle accuracy
    - Vertical compensator important, dual axis compensation
    - No boost to vertical angle accuracy
  - Nature
    - Curvature and refraction
    - Temperature/pressure correction
    - Wind, sun, and weather
  - Operator
    - Accurate pointing
    - Lots of measurements
    - Reciprocal measurements
    - Measure HI and HT or HR

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- Errors due to curvature and refraction can become significant at distances greater than 500 ft.
- At 1,000 ft, a 0.02 ft error due to curvature and refraction is possible.
- At one mile, a 0.6 ft error results.
  - *h (feet) = 0.0206 (F)* $^2$
- where
  - h = combined correction for curvature and refraction in feet
  - F = length of observed line in thousands of feet



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- Data collectors should have built in options for making the above correction for each shot taken.
- The table here shows the precision resulting from horizontal distance and vertical angular measurements as needed to resolve differences in elevations from trigonometric observation.

Errors in Vertical Angle Measurement

| Source | Type | Nominal Amount |
| --- | --- | --- |
| Instrument accuracy | Random | +/- 3 sec |
| Collimation | Systematic | +/- 3 sec |
| Measure HI and HT | Random | +/- 0.005 to 0.1 ft |
| C and R | Systematic | +/- 0.005 ft |
| Hand-held prism pole | Random | +/- 0.005 ft |
| 30-mm prism offs error | Random | +/- 3 mm |
| Heat waves | Random | +/- 0.01 ft |
| Unshaded instrument | Random | +/- 5 to 10 sec |

Combined angular and linear error is between -0.024 ft and 0.048 ft.
Vertical angle precision for the 500-ft line is therefore in the range 1:10,000 and 1:210,000.

Errors in Distance Measurement

| Source | Type | Nominal Amount |
| --- | --- | --- |
| Nominal accuracy | Random | +/-(5 mm + 5 ppm) |
| Temp estimation | Random | +/- 10 degrees F |
| Pressure estimation | Random | +/- 0.5 in Hg |
| Prism and instr cal. | Systematic | +/- 2 mm |
| Prism mispointing | Random | +/- 0.35 mm |
| Hand-held prism pole | Random | +/- 5 ft (fore/ft lean) |

Combined error is between -0.0414 ft and +0.0546 ft.
On this 500-ft line, this gives a range in precision of 1:9,000 to 1:12,000.

**Table 2: Combining Sources of Error over a 500-foot line.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- The following guidance from the Oregon Department of Transportation's Geometronics Unit (Oregon DOT 2000) applies to trigonometric elevation observations:
  - Due to the effects of curvature and refraction, the instrument to target distance must be kept relatively short.
    - A good rule of thumb is not to exceed 1000 feet.
  - Make sure you understand your equipment's capabilities.
    - Instruments that can measure zenith angles and slope distances to a high order of accuracy will produce good trigonometric elevations.
  - Setup and level your instrument and target carefully.
    - Measure the height of instrument and height of target accurately.
  - Measure several slope distances and use a representative or mean value.
    - Make sure that your EDM is correcting for the appropriate atmospheric conditions.
  - Measure direct and reverse zenith angles, and use the adjusted value for your calculations.
  - For lines longer than 500 feet, correct for curvature and refraction.





## Positioning Topographic Features with a Total Station

- Topographic features are usually cut in by multiple radial sideshots from a primary project control point.
- This is usually a straightforward process: the remote point is occupied with the prism pole, the HR and feature (code) recorded, and the angle and slope distance observed and recorded.
- If necessary, supplemental feature attributes may be added.
- The process is similar when using a reflectorless total station or robotic total station where the data collector is at the prism pole.
- The following sideshot sequence for the TDS-48GX is typical of most total stations:

**DIRECT SIDE SHOTS:**

| | |
|---|---|
| => P-SHF "MAIN" | |
| => enter "J" | [trav/side shot] |
| => enter "HR" | [height of reflector ... eg "5.0"] |
| => SIDES | (measures side shot point) |
| => enter side shot descriptor plus attributes eg "CTR TWR GRD" "TOP OF TWR" | |
| => press ENTER | |
| => [repeat for additional side shots] | |

## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- The figure here shows 305 radial total station observations made during a survey at Fort McCoy by the Louisville District.

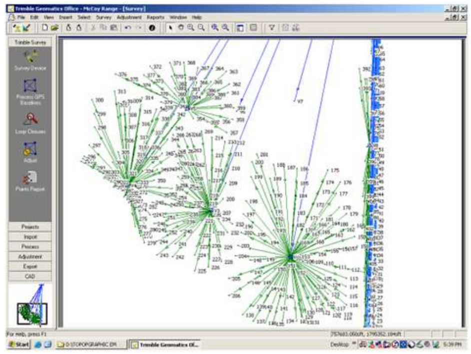

**Figure 7: Direct radial side shots with a Total Station and RTK control surveys at Fort McCoy Range.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





## TOTAL STATION TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- These terrestrial radial observations are in green.
- Each of the five occupied points was established by fast static GPS observations from the local NSRS point on the installation--a point about a half mile to the north as shown in the lower left insert box on the TGO plate.
- In addition to the radial total station observations, some 106 RTK topographic points were shot on the easterly side of the site--as indicated in blue radials from the primary GPS base station.

- a. Off center sideshots.
  - Quite often objects cannot be directly occupied with a prism pole or targeted with a reflectorless total station.
  - Off center (or eccentric) corrections are automatically available in most data collectors to cover these situations.
  - Offset cases include trees or circular tanks where only a point on the circumference can be sighted, high objects that are beyond the reach of a prism pole, or invert elevations.
  - The following off center options taken from the TDS-48GX data collector are typical of most data collectors.





- The "Off Center Shot Menu" covers five common situations that are encountered in the field when it is not convenient or not possible for the rod to occupy the point that needs to be stored.
  - Those five situations are selected from the Off Center Shot menu.
  - The Offset routines require that the data is collected as Zenith angles and Slope distances.
  - The Traverse / sideshot screen will be automatically set to this mode when an offset shot routine is used.

- HORIZONTAL ANGLE OFFSET SCREEN
  - This screen allows you to shoot the center of a large object such as a big tree.
- HORIZONTAL DISTANCE OFFSET SCREEN
  - The Horizontal Distance Offset routine allows you to collect a point that is in-line with the rod but on which the rodman cannot occupy; e.g., the middle of a river.
  - To use this routine, place the rod in line with where the point should be placed.
  - Shoot to the rod and enter the distance to add to the measured slope distance.
  - Enter a negative distance to subtract from the slope distance.





- VERTICAL ANGLE OFFSET SCREEN
  - The purpose of the Vertical Angle Offset Screen is to allow you to store a point that is too high for the rod; e.g., the cross-member of a power pole.
  - This routine is used by placing the rod directly above or below the desired point and shooting the rod.
  - Then, move the scope up or down to sight the true point, and press [ZEN] key to read the zenith angle.
- RIGHT ANGLE OFFSET SCREEN
  - The Right Angle Offset Screen allows you to shoot a point that is at a right angle to your rod position; e.g., around the corner of a building.
  - Place the rod at a 90° offset to the point you want to store.
  - Shoot the rod and enter the offset distance.
  - From the Instrument man's point of view, enter + for offsets to the right of the rod and - for offsets to the left of the rod.

- VERTICAL DISTANCE OFFSET SCREEN
  - The purpose of the Vertical Distance Offset Screen is to allow you to collect data for a point that you cannot obtain the zenith angle on, but to which you can measure the vertical distance; e.g., down a manhole.
  - Place the rod above or below the desired point and shoot the rod.
  - Then enter the distance to the actual point: + for up and - for down.





- b. Horizontal distance offset example.
  - The following is an example of applying a horizontal offset to a target.
  - In this example, the target is a Leica GPS antenna mounted in a tribrach atop a tripod.
  - The antenna is set over a PK nail marked point.
  - The Total station sights and measures a slope distance to the outside horizontal edge of the antenna--to a point horizontal with the antenna phase center.
  - From published measurements of the GPS antenna, the distance from the outside of the antenna to the phase center is 0.330 feet.
  - This is the offset distance entered into the data collector--a positive value since the offset must be added to the measured slope distance.
  - The following sequence is used to perform a horizontal offset measurement on the TDS 48GX:

**HORIZONTAL DISTANCE OFFSET:**
=> P-SHF "HDOFF"
=> enter offset distance ... eg radius of cir object *["+0.330 ft" for Leica antenna]*
=> CNTR *[takes shot at center face of object & adds offset]*
=> ENTER
=> enter side shot description *[eg "CENTER OF TANK" CTR TWR" "PK_NAIL"]*

- The following data collector string illustrates the raw data saved for a horizontal offset distance sequence- -in this example a +0.330 ft offset.
- The second line in the string is the initial shot on the edge of the antenna.
- The horizontal angle is zero since this is the backsight for a default local coordinate system with the instrument set at 5,000-5,000-100.
- The fourth line ("SS") is the offset corrected zenith distance and slope distance to the center of the antenna.
- Both the zenith distance and slope distance are larger to account for the offset.
- The last line (Sideshot 2) is the solved coordinates for the center of the GPS antenna at the station mark (a PK nail)

```
-- HD offset
OF,AR0.0000,ZE89.3505,SD47.427        initial horiz angle, zenith dir, & slope distance
OF,DD0.330                            horizontal offset distance of 0.330 feet
SS,OP1,FP2,AR0.00000,ZE89.35153,SD47.757,--PK NAIL     offseted sideshot to Point 2

2, 5047.755754, 5000.000000, 100.053746, PK NAIL  solved coordinates Point 2
```





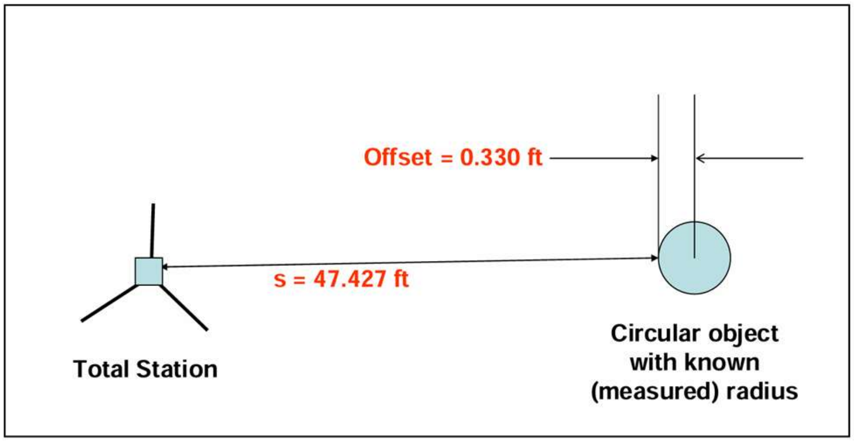


**Figure 8: Horizontal distance offset measurement to circular object (pole, tree, tank).**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- c. Vertical angle offset measurement.
  - The following is an example of observing a vertical angle offset.
  - In this example, a reflectorless total station is attempting to measure the elevation at the top of a 640-ft antenna.
  - Since this distance is beyond the range of the reflectorless return, or the object at the top does not provide sufficient reflectivity, an offset angle observation is required to obtain the elevation.
  - The following sequence is used to perform a vertical angle offset measurement on the TDS 48GX:

**VERTICAL ANGLE OFFSET SHOTS:**

=> P-SHF "VAOFF"
=> (sight reflector or reflectorless return point at bottom of object)
=> CNTR (measures)
=> (sight top of antenna)
=> ZEN (computes elev of top)





- In the example TDS-48GX raw data string below, the total station is set over an arbitrary coordinate point ("PK_NS-1"-10,000 ft-10,000 ft-100 ft), with an HI = 5.39 ft.
- An intermediate point on the tower directly below the highest-most point is selected at which a reflectorless slope distance can be made.
- On the second line of the string below, observations to the intermediate point are: horizontal angle right (AR) of 338º 00' 40", zenith distance of 31º 39' 30", and a slope distance of 329.52 ft.
- The instrument is then elevated to point on the top of the antenna--a zenith distance of 15º 14' 35" is observed.
- (For such a high vertical angle, a 90-degree solar prism is needed for the eyepiece).
- The final corrected "SS" line has computed the slope distance as 657.81 ft to the top of the antenna, and the solved X-Y-Z coordinates of the antenna are shown in the last line.
- The elevation of the antenna is 640.06 ft above the elevation of the total station point (assumed elevation 100.0 ft).

```
OC,OP1,N 10000.0,E 10000.0,EL100.0,--PK_NS-1 ... LS,HI5.39

OF,AR338.0040,ZE31.3930,SD329.520659
OF,ZE15.1435,--Vert Angle Offset
SS,OP1,FP11,AR338.0040,ZE15.1435,SD657.818349,--TOP ANTENNA

11,10160.3689,9935.2429,740.0658,TOP ANTENNA    solved elevation
```

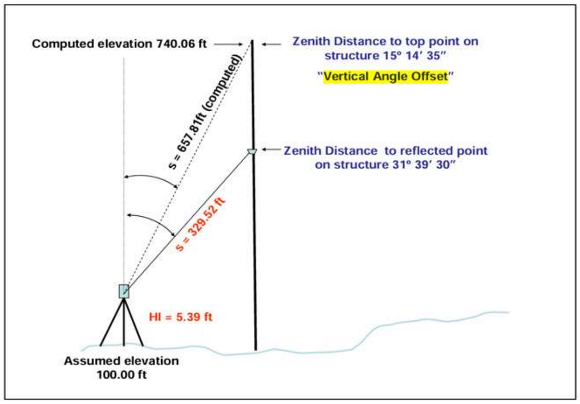


**Figure 9: Vertical Angle Offset.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

Check the next slide to explore an interactive GIF about common total station errors, their sources, and how they can be corrected



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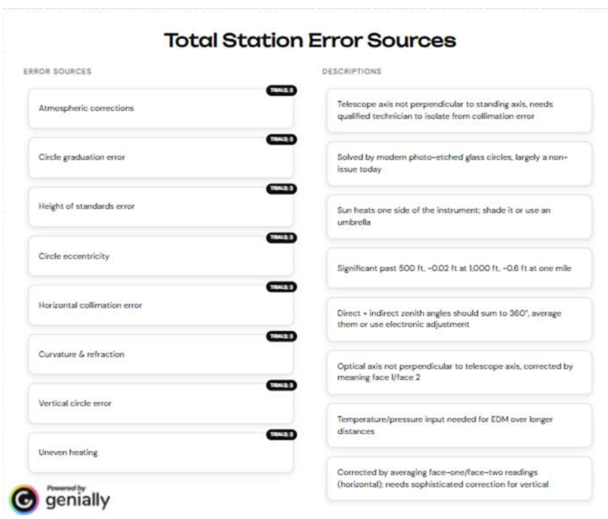

# GPS REAL TIME KINEMATIC TOPOGRAPHIC SURVEY PROCEDURES

## Purpose and Scope

- This chapter provides guidance on the use of GPS Real-Time Kinematic (RTK) positioning methods for performing topographic surveys of terrain, facilities, and infrastructure. RTK and total station methods provide identical output coordinate data.
- The only difference is that a total station must perform a visual observation from a reference station to some remote point to obtain a coordinate, whereas an RTK system derives the coordinates of the remote point by reducing carrier phase data over a GPS baseline between the reference (base) station and the remote point.
- The RTK base/reference point need not be visible and may be miles distant from the project site.
- Both systems employ similar (or identical) data collector devices, feature coding, attribution of features, stakeout methods, COGO functions, etc.
- Some data collectors (e.g., the Trimble TSC) can be connected to either a total station or a GPS receiver for RTK operation.
- Thus, this chapter will cover only those RTK survey functions that are unique to real-time GPS surveying.
- Only detailed site plan mapping applications with RTK will be covered.






**Figure 10: Real-Time kinematic survey of Corps lock and dam project--hand-held fixed height antenna pole.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## RTK Field Techniques

- Unlike GPS static survey methods used for precise control surveys, RTK methods provide real-time positioning results; thus, it can be used like a total station for real-time construction stakeout, setting project control, or topographic mapping.
- To obtain real-time coordinates at a remote ("rover") point, a communication link (radio, cell phone, or satellite) is required between the reference base station and the roving receiver.
- The remote/rover receiver is mounted on a range pole, similar to a prism pole for a total station.
- The operator at the remote receiver performs all survey and data collection functions at that point (the reference station is unattended).
- Thus, one-man survey crew operation is feasible if the reference station can be placed in a secure location.
- RTK surveying requires both the reference and remote receivers simultaneously recording observations. Periodic losses of the communication link can also be tolerated and/or corrected for in post-processing (e.g., PPRTK solutions).
- Unlike total station shot methods, the RTK rover receiver can be continuously moving--used for marking linear continuous features.
- RTK surveys require dual-frequency (L1/L2) GPS observations.





**Figure 11: Static or Fast-Static survey techniques. Rover is set on a tripod accurately centered over a control point or feature such as a photo target. 5 minutes to 2 hours of static data may be collected whereas an RTK solution may have only a few seconds using a hand-held antenna pole.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- a. Ambiguity resolution.
  - Carrier phase integer ambiguity resolution is required for successful RTK baseline formulations.
  - A fixed solution is essential for RTK surveys--float solutions over short distances are not accurate enough for engineering surveys.
  - RTK surveys can be initialized at a known point.
  - However, most systems employ "on-the-fly" (OTF) initialization technology, where the remote receiver can initialize and resolve integers without a period of static initialization.
  - With OTF capability, if loss of satellite lock occurs, initialization can occur while in motion.
  - OTF integers can usually be resolved at the rover within 10-30 seconds, depending on the distance from the reference station.
  - This initialization is automatically performed by the survey controller device.
  - OTF makes use of the L2 frequency in resolving the integer ambiguity.
  - A minimum of 5 satellites are required for OTF initialization, and after initialization, at least 4 satellites must be tracked.
  - After the integers are resolved, only the L1 C/A is used to compute the positions.
  - If no OTF capability is available, then initialization should be made at a known point and 4 satellites must be kept in view at all times and loss of satellite lock would require reinitialization.
  - For QA purposes, OTF initialization may be made at a known location (control monument).



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- b. Survey procedure.
  - Like the total station, RTK surveys are performed in a radial manner about a base station.
  - One of the GPS receivers is set over a known point (base station) and the other is placed on a moving or roving platform.
  - The survey controller will determine the amount of time required to lock in over each remote point.
  - If the survey is performed in real-time, a data link and a processor (external or internal) are needed.
  - The data link is used to transfer the raw data from the reference station to the remote.
  - If the radio link is lost, then post-processing techniques (PPRTK) are available to compute the survey, such as Trimble's "Infill" option, provided the raw GPS observations are collected during the survey.
  - Since most unlicensed radio frequencies have limited range (one mile ±), booster or repeater stations may be used if the job site is large.
  - Alternatively, multiple base stations may be set up to extend coverage.
  - Networked "virtual reference stations" are also available in some areas, allowing extended RTK coverage using cell phone modems in addition to adjusted solutions from the multiple bases.

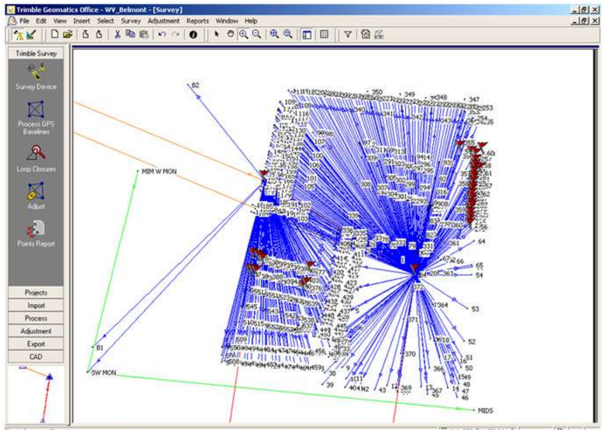

**Figure 12: RTK Radial Survey Method--Proposed USARC, Belmont Co., Ohio.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





- c. Accuracy of RTK surveys.
  - RTK surveys are accurate to within 3-10 cm (in 3D) when the distance from the reference to the rover does not exceed 10 k.
  - Expected 3D accuracies over short distances (less than one mile from reference base) are typically around the 0.1 ft range; provided that a good site calibration has been performed.

- d. General data collection operation.
  - The following functions are required to perform an RTK survey.
    - Set up horizontal and vertical projection grid
    - Establish coordinates of reference point
    - Configure reference and rover hardware
    - Establish radio link between reference and rover
    - Collect coordinate data at fixed monuments and benchmarks around survey site
    - Perform site calibration (or localization) with appropriate geoid model
    - Perform topographic or stakeout measurements--store points with descriptors and attributes
  - Some of the above items will be covered in the following sections.
  - They are covered in greater detail in the GPS receiver operation or reference manuals (e.g., Trimble 2001), or in training courses developed for specific receivers and/or RTK data collectors (e.g., "Survey Pro for Window CE--GPS RTK Training Guide").





- e. Receiver set up.
  - The figure here depicts the set up configuration for a GPS rover receiver, as set up for RTK surveys.

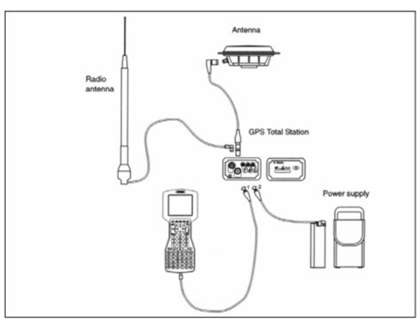


**Figure 13: Rover GPS receiver setup for RTK surveys--Trimble Navigation LTD.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## GPS REAL TIME KINEMATIC TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

- The radio link component must be set for maximum distance--and repeaters added if surveying a large site.
- Different channels may need to be tested to avoid interference.
- Once the system is set up and activated, the base station receiver must be initialized with the coordinates (and datum) of the point over which it is set.
- The rover receiver is then activated and initialized at a known point or by OTF methods.





## GPS REAL TIME KINEMATIC TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)

**Reference (Base) Station** **Remote (Rover) Station**

**Figure 14: Trimble RTK survey system.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Site Calibration

- A site calibration (also called a localization) must be performed before conducting a RTK survey.
- This is because the local georeferenced coordinate system is not planer with the GPS ellipsoid system.
- For example, a given project site may be on local NAD 83 horizontal coordinates and have a NGVD 29 vertical datum; RTK satellite observations are on the WGS 84 ellipsoid.
- A site calibration "best fits" horizontal and vertical variances (undulations) such that observed GPS positions on the ellipsoid are corrected to best fit the local datum at points within the site.
- Calibration of vertical geoid undulations is especially critical when RTK techniques are used for topographic ground shots or vertical stakeout.
- A calibration is needed in real-time kinematic surveying in order to relate GPS positions that are measured in terms of WGS-84 to local grid coordinate projections, such as SPCS, UTM, or a local station-offset-elevation system.
- In addition, a vertical calibration is needed to adjust the observed GPS ellipsoid elevations to a local vertical datum, and account for undulations in the local geoid over the project area.





- A calibration should be used on a project whenever new points are to be established.
- A calibration is based on a set of points that have 3D coordinates in both WGS-84 and the local grid coordinate projection system.
- The quality of the calibration will be affected by the accuracy and consistency of the GPS-derived coordinates of the points.
- Points tied to the NSRS are recommended as the basis of a calibration.
- The number of points that can be used in a calibration is manufacturer and software dependent.
- Smaller sized projects may be calibrated with one 3D point.
- However, for larger sized projects, three or four 3-D points are recommended.
- Calibration points should be well distributed around the project exterior.
- Projects may be calibrated by two methods: (1) in the field in the survey data collector or (2) in the network adjustment.
- The later procedure is recommended for large projects.
- The calibration computation summary should be examined for reasonable results in the horizontal scale, maximum vertical adjustment inclination, and the maximum horizontal and vertical residuals.

- a. The figure here illustrates the varied requirements for vertical site calibrations.

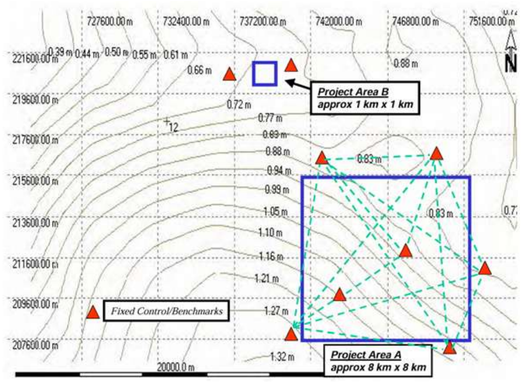


**Figure 15: Plot of geoid undulation contours over a local survey area.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





- This figure depicts a typical contour plot of a geoid model--height differences between the geoid relative to the WGS 84 ellipsoid.
- In the large (8 km x 8 km) Area A, the geoid undulation varies from 0.80 m to 1.27 m-- nearly a 50 cm variation.
- In order to determine accurate orthometric elevations from GPS ellipsoid elevation observations, this variation in the geoid must be accurately accounted for.
- In addition, the published orthometric elevations at each of the 7 established control benchmarks may not fit exactly with the geoid model--the geoid model may have been approximated from other NSRS points.
- Therefore, GPS observations over the 7 established control network points must be adjusted to further refine the geoid model so that subsequent GPS observations to any point in the project area can be "best-fitted" to the local vertical datum.
- Solely relying on a published geoid model is not recommended--connections with existing control should always be observed to refine the model.
- GPS adjustment software must be able to compensate for both the variations in the geoid model and variations in the established control benchmarks.
- In order to accomplish this, GPS observations need to be connected between the fixed control benchmarks, as shown in Area A.

## GPS REAL TIME KINEMATIC TOPOGRAPHIC SURVEY PROCEDURES (CONT'D)



- b. The small (1 km x 1 km) Area B in Figure 15 is more typical of local RTK topographic survey projects.
  - The geoid model shows a minimal undulation over this area--from 0.72 m to 0.75 m.
  - This 3 cm variation may or may not be significant, depending on the required elevation accuracy of the survey.
  - If this 3 cm geoid variation is not considered significant, then the geoid undulation at the selected reference station could be used over the entire area, and no geoid model correction used.
  - Alternatively, the 2 control benchmarks could be calibrated and the geoid model included in the adjustment.
  - When 2 control benchmarks are available, as shown around Area B, then a GPS check between the benchmarks is recommended.
  - If the geoid model is not used, the geoid correction could be interpolated from the check baseline observation results, holding the 2 control points fixed.



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- c. The figure here illustrates vertical calibrations over small local survey areas, which is typical of Corps topographic survey applications.

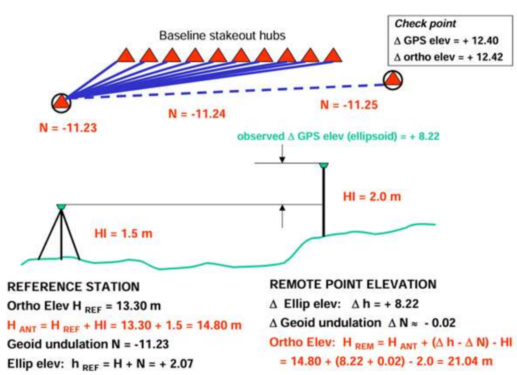


**Figure 16: Geoid elevation corrections for localized surveys.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- This area contains two fixed benchmarks with local datum elevations.
- A GPS reference receiver is set up over one benchmark and baseline hubs are staked out relative to this point, using kinematic techniques.
- The second fixed benchmark is used as a check point.
- A local geoid model shows estimated geoid heights varying between -11.23 and -11.25 m.
- Orthometric elevations on the individual baseline hubs are computed by correcting the observed ellipsoidal elevation differences with the local geoid undulation differences.
- This local geoid elevation difference (- 2 cm) could have been ignored if this error is acceptable to project accuracy requirements.
- This would, in effect, assume observed ellipsoidal elevation differences are equal to orthometric elevation differences and no geoid model corrections are applied to the observations.





- d. In Figure 16, a check point GPS elevation difference of +12.40 m is observed.
  - The published orthometric elevation difference between these points is +12.42 m.
  - This confirms the geoid model is accurate over this area since the computed geoid undulation difference ($\Delta N$) is - 0.02 m (+12.40 - 12.42).
  - Had a large misclosure existed at the check point, then either the published elevations are inaccurate or the geoid model is inaccurate.
  - A GPS baseline check to a third benchmark would be required, or conventional levels could be run between the two fixed points to resolve the problem.

- e. Manual site calibration procedure (Trimble).
  - The Trimble Survey Controller Reference manual outlines the following process for performing a site calibration.
  - This procedure is representative of other RTK systems.
    - Key in or upload grid coordinates of all the control/calibration points around the project site
    - Set calibration tolerances (acceptable adjustment levels)
    - Measure the control/calibration points using the GPS/RTK receiver
    - Pair local grid coordinates and WGS 84 coordinates for each control/calibration point
    - Activate the site calibration routine on the controller
    - Check residual errors v tolerances at each control/calibration point ... recheck points and reject as required
    - Apply the final site calibration to the controller
- f. Examples of site calibrations can be found in operating or training manuals for RTK equipment, e.g., Real-Time Surveying Workbook (Trimble) or Basic GPS Controller Workshop--Survey Pro for Windows CE (Tripod Data Systems).





### RTK Survey Field Data Collection Procedures and Checks

- Once a site calibration has been performed, field data collection (or stakeout) procedures are straightforward, and are detailed in GPS operation/reference manuals.
- The figure on the following slide is a Trimble TSC screen display in the "measure point" mode.
- This screen shows a topographic shot point (TOPO1001) being measured to.
- The GPS antenna on the rover is set on a fixed-height pole at 2.00 meters.
- The bottom of the screen displays the number of satellites being observed (5), the estimated errors in the horizontal (0.009 m) and vertical (0.014 m), and that the fixed solution has an RMS of 7.
- Optional screen displays will provide HDOP, VDOP, and other satellite related information.

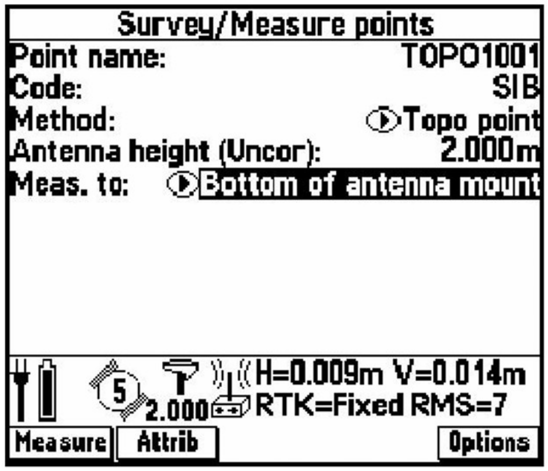


**Figure 17: Trimble TSC "Measure Points" screen.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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- The USFS and BLM Standards and Guidelines for Cadastral Surveys (USFS/BLM 2001) contains guidance for performing RTK surveys that is directly applicable to USACE RTK topographic mapping and construction control surveys.
- Some of the more significant field procedures recommended by the USFS/BLM are outlined below.
- These generally reduce down to (1) system checks, (2) measurement procedures, (3) and periodic calibration checks.

- a. RTK system check.
  - A RTK system check shall be made prior to any measurements.
  - RTK system checks may also be made at any time during the course of each RTK survey session or at any time the base receiver(s) and rover receiver(s) are set up and initialized per the manufacturer's recommended procedures.
  - This check is a measurement from the RTK base setup to another known project control monument.
  - The resulting observed position is then compared by inverse to the previously observed position for the known point.
  - This inverse should be within the manufacturer's recommended values for duplicate point tolerance measurements--typically within ± 2.5 cm in position and within ± 5 cm in elevation.
  - This RTK system check is designed to check the following system parameters:
    - The correct reference base station is occupied.
    - The GPS antenna height is correctly measured and entered at the base and rover.
    - The receiver antennas are plumb over station at base and rover.
    - The base coordinates are in the correct datum and plane projections are correct.
    - The reference base stations or the remote stations have not been disturbed.
    - The radio-communication link is working.
    - The RTK system is initialized correctly.
    - RMS values are within manufacturer's limits.





- b. RTK measurements.
  - RTK topographic observations are usually made using one or more base stations and one or more rover receivers.
  - RTK measurements shall be made after the system setup check procedures have been completed.
  - Use manufacturer's recommended observation times for the highest level of accuracy when setting mapping or construction control points, for example, 180 seconds of time or when the horizontal (e.g., 2 cm) and vertical (e.g., 5 cm) precision has been met for a kinematic control point.
  - Under optimal conditions a deviation from the manufactures suggested times is appropriate; for example, a point may be observed using 30 seconds of time and 20 epochs of measurement data.
  - However, observation times should be set to account for field conditions, measurement methods (e.g., Trimble "topo point" or "kinematic control point") and the type of measurement checks being performed.

- Individual features can be quickly observed, as illustrated in the figure below.

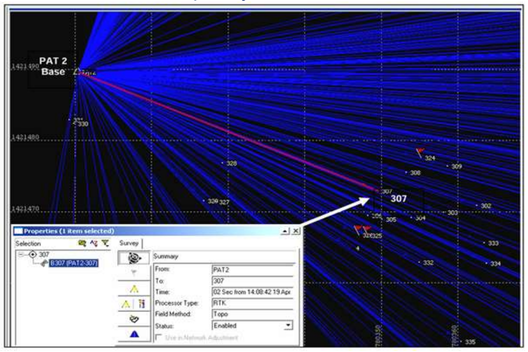


**Figure 18: Short-term (2-sec) RTK observation on a topographic point--# 307.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

Check the next slide to explore an interactive GIF about key GPS RTK concepts



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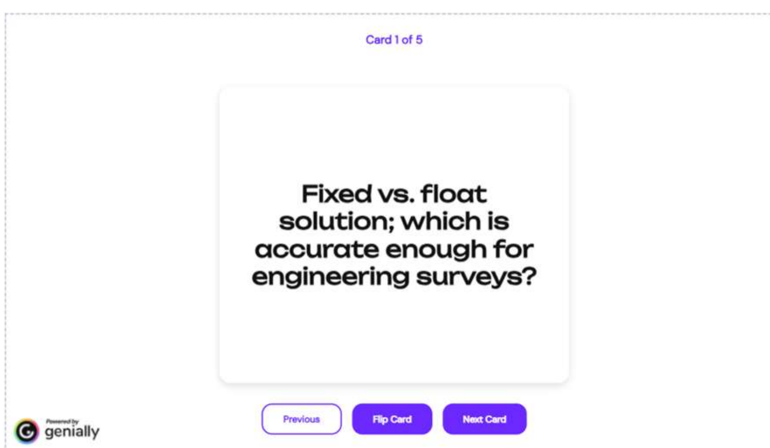

# TERRESTRIAL 3D LASER SCANNERS

## Purpose

- This chapter provides an overview of 3D laser scanners used for detailed mapping of facilities, structures, utilities, and ground planes.
- High-precision/high-definition tripod mounted laser scanners are covered.
- Examples of recent applications where these instruments have been used to map Corps facilities or structures are provided.





**Figure 19: Optech ILRIS 3D laser scanner--detailed mapping of structures and facilities at St. Lucie Lock and Dam, Jacksonville District.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Background

- Laser scanners operate similarly to reflectorless total stations.
- However, instead of a single shot point being observed, a full field-of-view scan is performed--at a speed upwards of 500,000 points per second.
- Unlike a total station, the location of the scanner is not usually a required input--resulting in points that are spatially referenced to the instrument and not real-world coordinates.
- This is somewhat analogous to an uncontrolled photogrammetric model.
- (Newer models allow input of the scanner coordinates from which all observed pixels may be directly georeferenced).
- The resultant imagery from a scan (termed a "point cloud") provides a full 3D model of the facility, utility, or terrain that was scanned.
- Objects can be scanned at a high density--with output pixels smaller than 5 mm.



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- Relative 3D accuracies approaching the millimeter level are claimed, based on redundant observations over a surface.
- However, 5 to 10 mm accuracy is more realistic in practice.
- Scans can be rapidly made--a full field-of-view scan of a site or structure can be performed in 5 to 15 minutes per setup (multiple setups generally are required to fully detail a given site or structure).
- Unlike a total station, however, laser scanners have no means of assigning feature codes or attributes to the measured points--this must be done in post-processing, and is often a tedious and time-consuming process.
- Laser scanners have increasing application to many Corps civil and military missions.
- They can be used to perform traditional topographic surveys (detailed planimetry and elevations) of project sites and facilities--providing ground elevations at a high density.
- These scanners are especially useful in detailed mapping of exposed (and hard to access) utility systems, such as those inside a hydroelectric power plant.
- They also have application in mapping archeological sites, HTRW sites, dams, rock faces, hazardous traffic areas, unexploded ordinance sites, or any other inaccessible location.

## TERRESTRIAL 3D LASER SCANNERS (CONT'D)



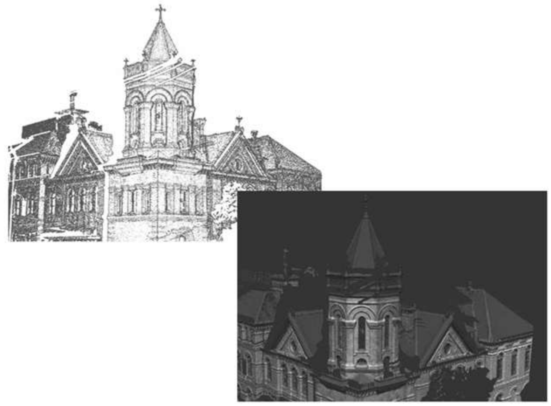

**Figure 20: Laser scanned image (upper left) and rendered image (lower right) of Corps Mississippi River Division headquarters building, Vicksburg, MS.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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## TERRESTRIAL 3D LASER SCANNERS (CONT'D)

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- a. Manufacturers.
  - Laser scanners have been on the market for only a few years--since the late 1990s.
  - As of 2005, there were about 12 manufacturers of laser scanners listed in trade publications.
- b. Cost.
  - A complete laser scanning system (including a high-end modeling software package and training) can cost between $150,000 and $200,000.
  - Thus, few, if any Corps Districts would have a sufficient number of applications to justify this level of expense.
  - In time, it is possible these prices will decrease to a level where 3D scanners may be cost-effective if the workload warrants.
  - Data processing and modeling software is typically expensive; however, it is essential in order to export scanned images to CADD platforms.
  - At present, Corps Districts contract for periodic 3D scanning services--many AE surveying contractors performing Corps work have acquired (or are acquiring) 3D scanners.
  - Given the limited amount of work, the hourly/daily rate is understandably high for these scanners (and data processing)--daily operating costs of $2,000 to $5,000 or more (including processing) are not uncommon, and can vary widely depending on the amount of processing required.
  - Most often, a project cost would be negotiated on a lump sum basis, factoring in the basic daily rental cost of the scanner plus the operator and CADD processor time estimates.

- c. Accuracy.
  - The accuracy of a scanned object can be relative or absolute.
  - Relative accuracies are very good (5 mm or better at close ranges).
  - Absolute accuracies depend on the accuracy of the control network developed for the site, how accurately the instrument is aligned to this network, and how well overlapping images (i.e., picture points or targets) are transferred and adjusted (best fit).
  - In general, absolute accuracies can be kept within 1 or 2 centimeters over a small project/structure site. In many cases, relative accuracies are far more important than absolute geospatial accuracies.
  - For example, measurement of a crack in a wall requires a high relative accuracy; however, the absolute geospatial coordinates of the crack are not significant.
  - Overall accuracy is a function of range, scan density, spot/footprint size, and single point accuracy.



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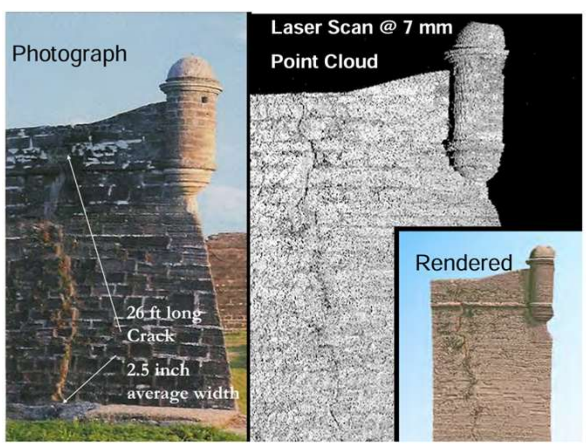


**Figure 21: Crack measurements with a 3D laser scanner. Castillo de San Marcos, Saint Augustine, FL.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- d. Density of scanned points.
  - Laser scanners can be set to any desired scan density, e.g., 5 mm to 1 meter, usually based on some short nominal distance.
  - The higher the density the larger the resulting dataset--and more time-consuming data editing and processing.
  - The purpose of the project determines the required density.
  - For general 3D planimetry or buildings or ground elevations, a low density can be set.
  - For detailed maps of structural members or concrete cracks, a high density is set.



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- e. Field-of-View.
  - Depending on the model and project requirements, scanners can be set to scan a full 360 deg field or zoomed (windowed) into a narrowly set field-of-view.
  - The Leica HDS4500 scanner has a field-of-view of 360 deg horizontal by 310 deg vertical.
  - The reality of scanning means that even a 360º field of view does not guarantee full area coverage; in fact, it rarely does.
  - Laser shadowing forces data to be collected from multiple angles for complete data coverage.
  - A large field of view does not alleviate this requirement.
  - Also, the angle of incidence of a measurement will have a profound impact on its accuracy and the resolution of the data in general.
  - Keeping this fact in mind, imagine surveying a long, flat wall.
  - If the scanner has a 180º horizontal field of view it will be able to survey the wall in a single scan.
  - Depending on the length of the wall, measurements may be collected from angles that approach 90º, but the reliability of these measurements will be very poor.

- f. Range.
  - Range of scans is a function of the laser intensity and reflectivity of the object scanned.
  - Some scanners are designed for only close up scans--i.e. 200 meters.
  - Others claim ranges of upwards of 1,000 meters--or more.
  - Obviously, the longer the range, the larger the footprint and less accurate the resultant measurement becomes.
  - In general, most detailed scans of facilities, buildings, and structures are kept at close range--usually less than 500 ft and not much beyond 1,000 ft.
  - The laser eye safety classification may also be a factor in longer-range scanners--a Class 3 type laser may not be desirable for surveying a populated beach but would be acceptable at a remote HTRW site.
  - (A Class 1 laser device "denotes exempt lasers or laser systems that cannot produce a hazard under normal operating conditions" and a Class 3a laser device "denotes visible lasers or laser systems that normally would not produce a hazard if viewed for only momentary periods with the unaided eye.
  - They may present a hazard if viewed using collecting optics.").





- The ranging capability of a laser scanner is more important than it first seems.
- In some cases, the lack of ranging ability will completely eliminate the ability to do certain projects.
- For example, let's examine the case of a bridge that crosses a body of water.
- A lack of certain characteristics (such as a 360º field of view) may force you to collect more scans but it doesn't prevent the project from being completed.
- The inability to range to the structure, with no provisional means of getting closer, will eliminate the potential of the scanner being used on the project.
- It is also true that a survey will rarely be conducted at a range greater then a few hundred meters (except in cases similar to the above example).
- However, long-ranging capability has other benefits that are not immediately identifiable.
- At the extreme limit of a scanners specified range, the accuracy of the measurements will begin to decrease in a nonlinear fashion.
- As such, let's consider the example of scanning a structure from 150 m away.
- The scanner whose maximum range is 150-200 m will struggle to collect the data.
- It may succeed, but the measurement quality will suffer and the dataset will contain a large number of "drop out" points (instances where no measurement was collected).
- Alternatively, the scanner that provides 1,000 m range will be collecting data from the ideal area of its total dynamic range.
- The data collected will be of optimum accuracy.

- g. Beam footprint size.
  - The footprint size will vary (increase) with the distance from the scanner to the object.
  - Typically, on close-range applications (less than 100 ft ranges), a 5 mm footprint is observed.





## Scanner Operation and Data Processing

- Scanners are normally mounted on a tripod, directly onto the plate or in a standard tribrach.
- The scanner is set up at any arbitrary location that affords the best view of the area or object to be mapped.
- No absolute geospatial orientation of the scanner is required (unless the scanner model is designed to incorporate geospatial references).
- Most structures require multiple scans in order to develop a complete 3D model, as illustrated in the figure here.

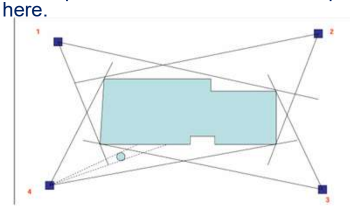

**Figure 22: Typical four scan locations needed to fully model a building and cover obscured areas. In practice, additional scan points may be needed.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- In addition, multiple scans are required to cover hidden, shadowed, or obstructed areas in a single scan.
- Thus, a rectangular building will require scans from four setups offset from each of the corners--each scan providing data covering two faces of the building, which will overlap with adjacent scan locations.
- These overlapping scans allow a full 3D model of the building to be generated using imagery correlation (optical recognition) software (similar to soft-copy photogrammetry).
- The scanned "point clouds" are saved on flash memory devices in the scanner, which can be later downloaded to a field or office computer.
- The overlapping "point clouds" from each scan are edited for data spikes--often a lengthy process.
- They are then merged to form the full 3D model.
- This merging is done in proprietary software that is usually sold separately with the laser scanner.
- This resultant 3D model is referenced only to a relative/internal coordinate system.



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- If real-world geographic X-Y-Z coordinates are required (and they are not always needed for many project applications), then targeted points need to be set in the scanned area/structure in order to perform a standard coordinate transformation.
- Once the model is generated, a variety of computer graphic enhancements can be performed.
- These include coloring, wire meshing, rendering, and smoothing objects.
- Rough point cloud images of solid objects can be smoothed using various software-fitting routines--e.g., items such as wall faces, cylindrical pipes, etc.
- If the resultant model is going to be exported to a CADD or GIS platform, then additional descriptor, attribute, or layer/level assignments may be required.
- Final data processing can represent a significant effort on some projects--a structure that is scanned in 4 hours may take as much as 40 hours or longer to process the data to a CADD compatible format.
- The software used for processing scanned datasets is a critical component in the overall efficiency and economy of the process.

**Corps of Engineers Project Application: St. Lucie Lock and Dam, Jacksonville District**

- The following figures illustrate an application of 3D laser scanning on a Corps civil works project-- mapping lock and dam structures and related grounds and facilities.
- This project (in 2001) involved both topographic and hydrographic surveying of the lock and dam site.
- An Optech laser scanner was used to capture images around the project.
- Given the complexity of the site, numerous instrument setups were required to fully cover the site.
- The individual point clouds were merged and a continuous 3D model of the lock and dam was created.
- Additional color rendering was also performed.
- The above ground Optech laser data set was subsequently merged with 3D hydrographic data obtained with a multibeam echo sounder.
- (This project was performed by Arc Surveying & Mapping, Inc. for the Jacksonville District).





**Figure 23: Typical scan location to cover downstream gate structures--instrument set up between 6th and 7th gates.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

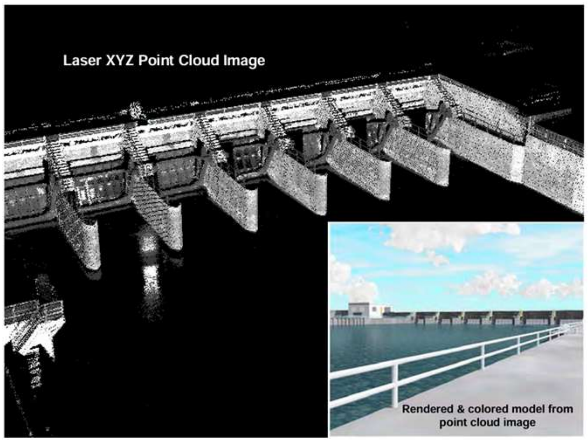


**Figure 24: Merged point cloud images of gate structures, from multiple scanning locations.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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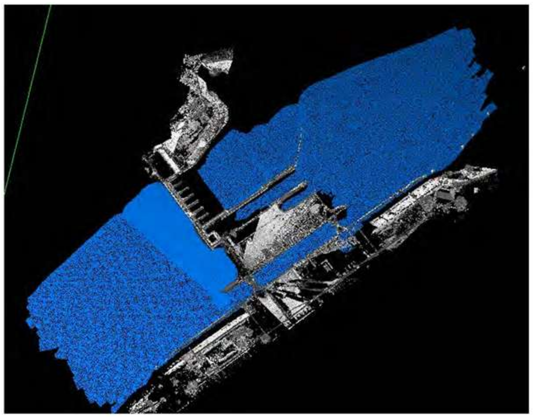

**Figure 25: Merged Optech laser scanned imagery with subsurface multibeam imagery--resultant 3D imagery model of entire lock and dam project.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Corps of Engineers Project Application: Portuguese Dam Foundation Construction, Ponce, PR, Jacksonville District

- The following figures depict a topographic survey of the foundation for the Portuguese Dam north of Ponce, Puerto Rico.
- These scans were made during grouting operations at the foundation.
- The entire area surrounding the foundation was scanned, and georeferenced to the local coordinate system using targeted reference points in the scans.
- A conventional total station survey on a 10 ft x 10 ft grid was performed over the same area and compared with the far denser matrix generated from the laser scan.
- Rappelling techniques had to be employed to reach many of the total station shot points in this rugged mountainous terrain--these same points were easily and safely tied in with a Cyrax 3D laser scanning system (Cyra Technologies--now Leica).
- These surveys were performed in 2000 by Arc Surveying & Mapping for the Jacksonville District.



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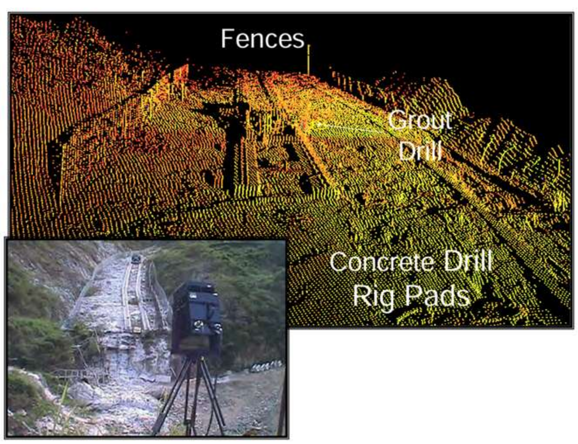


**Figure 26: Portion of Portuguese Dam foundation scanned by Cyrax laser.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

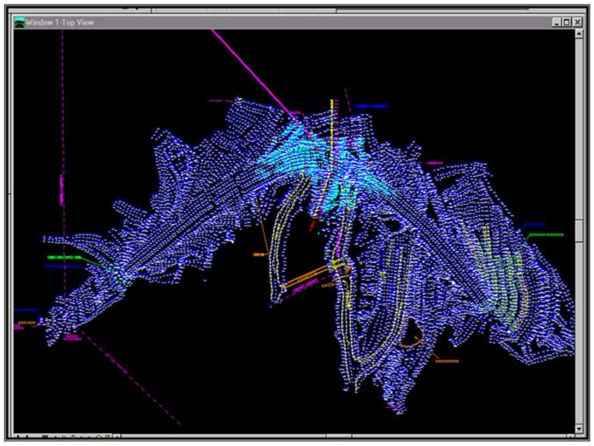

**Figure 27: Merged datasets: Conventional total station topography and 3D laser scanned model.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





### Corps of Engineers Application: Steel Bayou Levee Surveys, Vicksburg District

- The following figures depict a topographic survey of a levee using a 3D laser scanner.
- This was a demonstration project performed for the Vicksburg District; to assess the capabilities of terrestrial laser scanners for levee surveys.
- Comparisons were made between the scanned surveys and conventional topographic surveys performed by the Vicksburg District.
- A major problem with scanning flat terrain is the limited range when the scanner is set on a standard tripod.
- To be effective, an elevated platform is needed to obtain a more effective working range.
- Establishing georeferencing on the scanned images is also problematic in a linear scan over a flat area.
- Targeted control along the top of the levee is needed to reference each scan and may not be a cost-effective process.
- In addition, this demonstration project was conducted with 2-ft height grass on the levee.
- Since the laser picks up the top of grass, any practical use of 3D laser scanners must be performed immediately after vegetation is cleared--or in sites without vegetation.
- Effective use of laser scanners on flat terrain is marginal unless an elevated view site can be obtained.

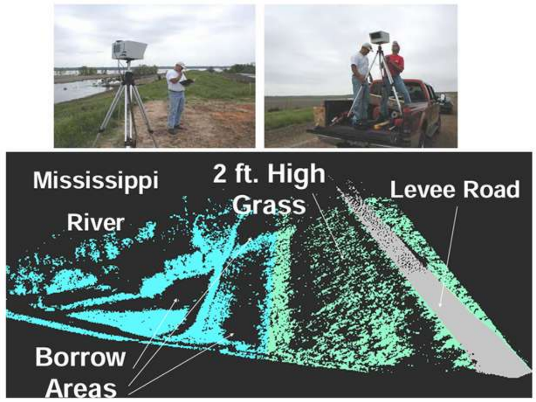


**Figure 28: Scanned images of Steel Bayou levee in Vicksburg District. Scanner elevated to maximum height in order to extend distance.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





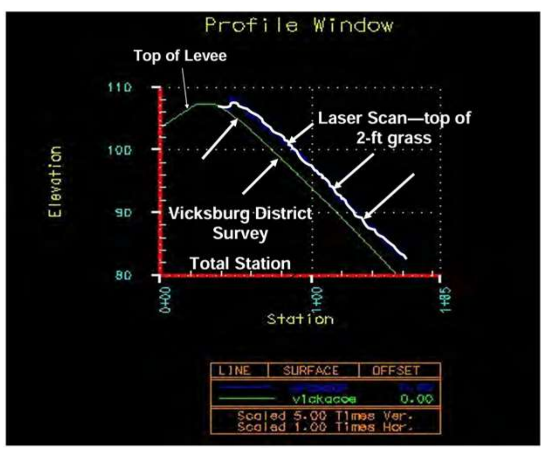


**Figure 29: Levee cross-section: comparison between conventional total station survey and 3D laser scanner.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Corps of Engineers Application: Structure Subsidence Survey, Philadelphia District

- The following figures illustrate another application of 3D laser scanning on a Corps civil works project-- monitoring subsidence for lock and dam structures.
- This was a demonstration project performed by TVGA Consultants for the Philadelphia District, to assess the capabilities of terrestrial scanners for subsidence monitoring.
- The location of dam outfall structure for the Francis E.
- Walter Dam makes access extremely difficult, time consuming and requires a detailed safety plan be prepared and followed.
- Given the complexity of the site conditions and instrument setup distance from the structure an Optech Ilris laser scanner was used.
- GPS observations on the local control monumentation was collected and tied in to independent offsite control.
- Using conventional reflectorless total stations, targeted control points were geo-referenced to the project control network.
- The individual point clouds were merged and a continuous 3D model of the outfall structure was created.
- Additional color rendering was also performed.





**Figure 30: Francis E. Walter Dam located in Whitehaven, Pennsylvania. Concrete outfall structure located on the downstream side of the dam is shown at bottom right.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

**Figure 31: Optech Iris Unit positioned in center of river bed at the Francis E. Walter Dam site located in Whitehaven, Pennsylvania.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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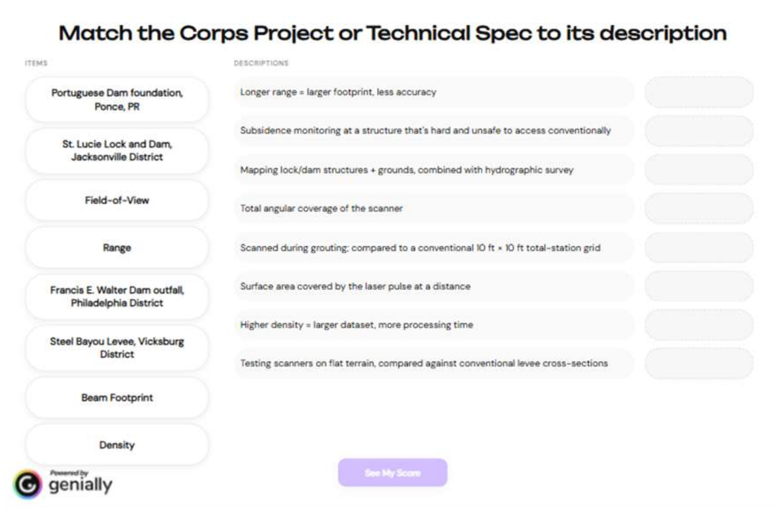
**Figure 32: Reflectorless Total Station was utilized to georeference scanner data to project control network.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

Check the next slide to explore an interactive GIF about 3D laser scanning

## TERRESTRIAL 3D LASER SCANNERS (CONT'D)







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# FINAL SITE PLAN OR MAP PRODUCTION

## Purpose

- This chapter provides general guidance on preparing final site plan maps from topographic survey data acquired in digital format in the field.
- Different methods of transferring data into CADD and GIS platforms are described.

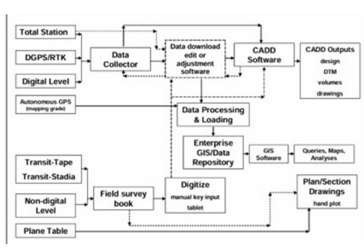


**Figure 33: Overview of survey data flow.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Overview of Topographic Survey Data Flow

- Figure 33 outlines the various routes by which topographic data are processed into a final site plan map format.
- As indicated in the figure, a number of processing options exist, depending on the software.
- a. Field instrument and data collector.
  - The field survey instrument may have an internal or external data collector.
  - Total stations can export internal data directly to a processing software package, without going through an external data collector.
  - GPS/RTK units typically record to an external data collector.
  - Manual data collection is recorded in a field book which must be reduced by hand.
  - If a digital file is desired, field book data must be manually keyed into a software program.
  - A plane table survey obviously is field-finish system in which a final drawing containing planimetric features and contours is generated directly in the field.





- b. Data download, editing, and adjustment software.
  - Intermediate data download, edit, and adjustment software may be required for some data collectors.
  - GPS data may require processing at this stage, using software such as Trimble TGO.
  - Total station data is usually downloaded to an office PC using software compatible with that used on the data collector.
  - TDS SurveyPro is an example of this type of software.
  - Depending on the input format of data from the collector (*.raw, *.cr5, etc.), the software may have to create an X-Y-Z coordinate file from the raw data observations.
  - Feature and attribute editing may also be performed at this stage.
  - In addition, feature libraries can be backloaded to the data collector; including processed design files from the CADD software.

## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)



- c. CADD and GIS software.
  - Numerous software packages are used to process survey data into a final design or map product. All have various options and capabilities.
  - Bentley and AutoDesk are the most common CADD packages used in the Corps.
  - Each CADD vendor has a variety of optional packages which input survey data for use in a final design application.
  - Examples include AutoDesk Land Desktop, AutoDesk Field Survey, Bentley GEOPAC, AutoDesk CAiCE, TDS ForeSight, Trimble Terramodel, Carlsen SurvCadd XML, AutoDesk Land Development, ESRI Survey Analyst, and Bentley InRoads.
  - Some of these packages simply utilize fully processed and edited data to generate final products.
  - Others have survey editing, adjustment, and COGO options built in, along with final drawing capabilities.
  - Each package is generally tailored to a specific engineering discipline--e.g., CAiCE is used for highway design and construction.
  - Many CADD packages will import field data directly from the data collector.
  - Others are restricted to importing data only in certain formats or from specific data collector models.
  - CADD software display capabilities include 2D and 3D models, sheet layout, contours, etc.



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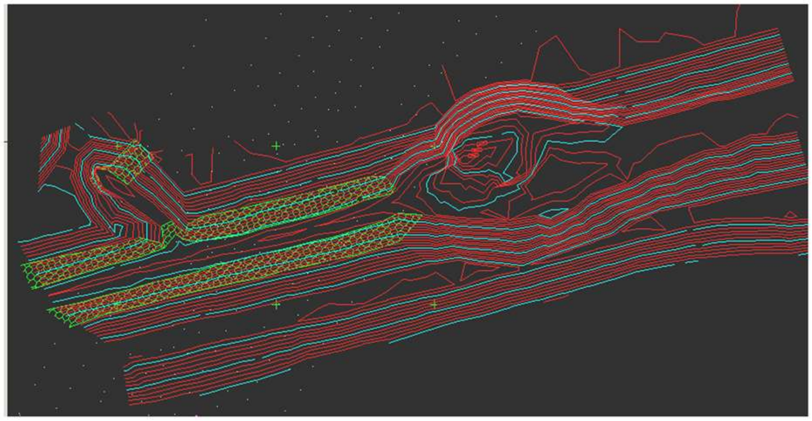

**Figure 34: MicroStation contour generation from topographic survey of scour erosion site along Sanders Creek, Pat Mayes Lake, Texas.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

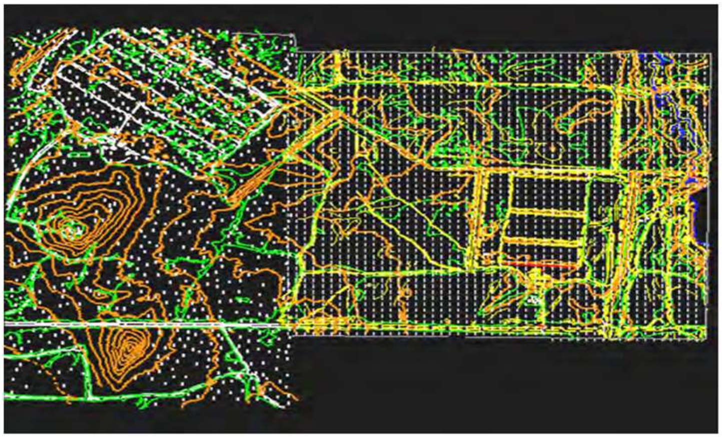

**Figure 35: MicroStation file Showing Planimetric and Topographic Mapping of 440 acre Range at Fort McCoy.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





## Basic Definitions of Geospatial Data used in CADD or GIS Databases

- The following subparagraphs detail some of the basic concepts and features required for field-collected topographic data that is exported to a CADD or GIS platform.
- These include descriptions of data dictionaries, types of feature codes and attributes, methods of feature code collection, and processing features with attributes.
- a. Data Dictionary.
  - A Data Dictionary contains the following information:
    - Feature and Attribute Library
    - Intelligent Features Codes
    - Data about Feature Codes
  - A data dictionary is created using software designed for that purpose.
  - Features and attributes are selected, along with attribute values and expected ranges.
  - The edited data dictionary is uploaded to the data collector.
  - Feature symbols can also be selected for display on the field data collector.
  - The data dictionary software should also have an ability to import a file containing existing GIS table structures or CADD layers and symbols.

- b. Feature Codes.
  - Feature Codes are descriptors identifying some unique property associated with a topographic feature.
- c. Cartographic data.
  - Cartographic data are observations (or shots) on spatially distributed features, activities, or events, which are definable as:
    - Points
    - Lines (Arcs)
    - Areas (Polygons)
- d. Attributes.
  - Attributes are descriptive information in a database about the cartographic features located on a map.
  - Attributes describe the characteristics of a feature--they are often referred to as noncartographic data.
  - Attributes can be any numeric or character value that describes the feature.
  - Examples of attributes assigned to a tree might include:
    - Height
    - Diameter
    - Species
    - Condition
    - Age





- e. Attribute Values.
  - Attribute values are sub details given to an attribute.
  - For example, possible values for the attributes of the above Tree feature might include:
    - Height = 15m
    - Diameter = 0.75m
    - Species = Oak
    - Condition = Good
    - Age = 8 years
  - When attribute data is collected in the field, the user may be prompted on the data collector when a particular feature is shot.
  - Attribute values can be classified as character, numeric, date, or temporal fields.
  - This prevents the input of an incorrect value into an attribute field; for example, preventing the entry of characters into a numeric field.
  - Attribute range limitations (or domains) are also held in the dictionary to prevent gross blunders in entering attribute data--e.g., a 0.1 ft or 1,500 ft height tree.

- f. Point Features.
  - A point feature represents a single geographical location (such as a latitude/longitude and altitude).
  - A point feature type is used to represent a feature that has no length or width.
  - Examples of point features are:
    - Tree
    - Lamp Post
    - Power Pole
    - Fire Hydrant
    - Manhole





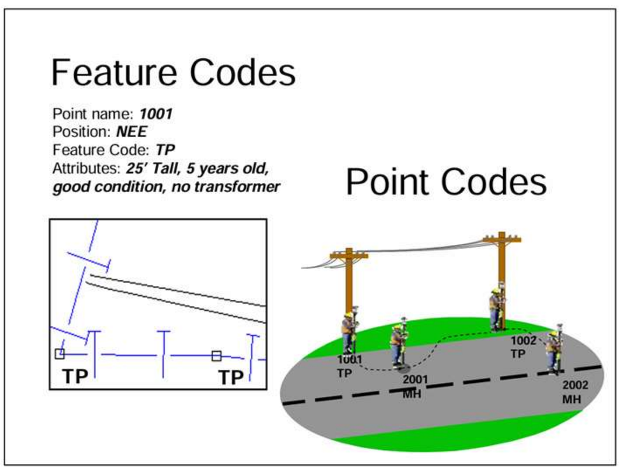


**Figure 36: Point Codes and Feature Codes.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- g. Line Features (breaklines, arcs, strings, or polylines).
  - A GIS line feature type is a series of geographical locations that are connected--so-called "arc-nodes."
  - A line feature type is also used to represent a feature which has a length but no width. Some GIS's refer to line features as arcs.
  - CADD software will mathematically define line strings as opposed to connected points in GIS.
  - Breaklines are connected strings.
  - Examples of line features are:
    - Roads/Railways
    - Streams
    - Animal trails
    - Routes
  - Line features will have various attributes similar to point features, e.g., storm sewer pipe diameter, type, thickness, date set, etc.





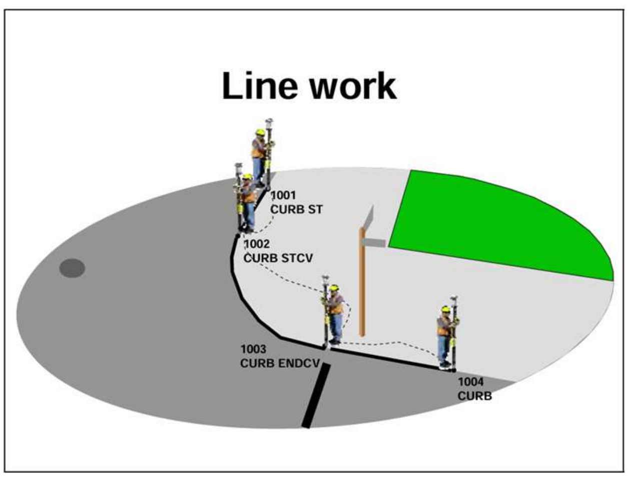


**Figure 37: Delineating line features.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

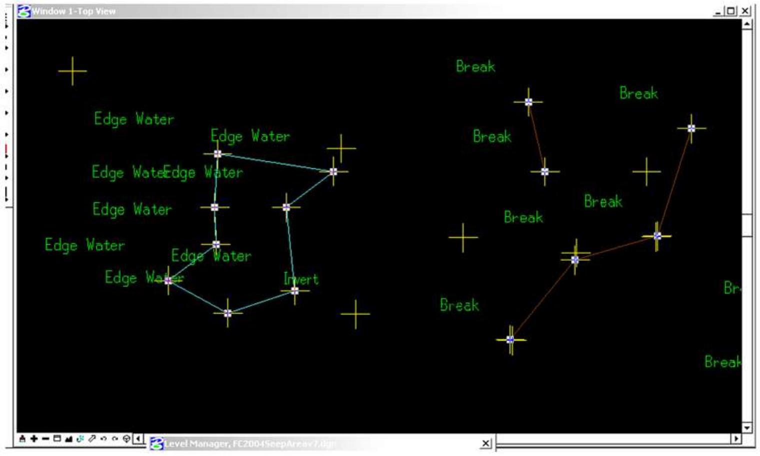


**Figure 38: Breaklines and connected line features.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





- h. Area Features.
  - Areas (polygons) are a series of geographic coordinates joined together to form a boundary.
  - An area feature type is a closed line.
  - An area feature has a length and a width and can have attribute data.
  - In GIS, area features are referred to as polygons.
  - A polygon is a single arc or a series of arcs that are connected together in order to enclose an area.
  - Examples of area features are:
    - Soil types
    - Wetlands
    - Flooded land
    - Lakes
    - Parking Lot
    - Building
    - Soil types

- i. ESRI Shapefiles.
  - A GIS shapefile stores nontopological geometry and attribute information for the spatial features in a data set.
  - The geometry for a feature is stored as a shape comprising a set of vector coordinates.
  - Because shapefiles do not have the processing overhead of a topological data structure, they have advantages over other data sources such as faster drawing speed and edit ability.
  - Shapefiles handle single features that overlap or that are noncontiguous.
  - They also typically require less disk space and are easier to read and write.
  - Shapefiles can support point, line, and area features.
  - Area features are represented as closed loop, double-digitized polygons.
  - Attributes are held in a dBASE® format file.
  - Each attribute record has a one-to-one relationship with the associated shape record.
  - Shapefiles are created using various ESRI products (e.g., ArcGIS).





## Data Collection and Processing Procedures for Topographic Surveys

- There is no standard process for moving digital field observations into a CADD platform.
- The steps taken vary with the type of total station used, including its internal or external data collector.
- Field data collection procedures can vary from simple single shot points to fully attributed polyline strings.
- A variety of data formats can be output from the different data collectors on the market.
- The field data may be imported directly into a CADD package or processed through intermediate survey software before being uploaded into the CADD package.
- Over 50 different survey software and CADD systems are listed in the most recent compilation by POB Magazine.
- Given this variety of CADD/survey software, there are numerous methods used to process data from the field to finished CADD or GIS product.
- Corps districts primarily use either MicroStation or AutoCAD, with MicroStation being more predominant.
- However, most data collector software is geared more towards export to AutoCAD than MicroStation.
- The following steps highlight a general process used in most systems.
- However, the trend today on some total station systems is to develop data on the data collector that imports directly into the CADD platform without all the intervening steps and varied format conversions described below.

- Step 1--Observations.
  - In the first step of the process, the field survey vertical and horizontal angles are measured along with slope distances using the total station.
  - The angles and distances are stored with a point number and description in the data collector.
  - Optionally, attribute data may also be stored with each point, including line/area string codes.
  - COGO routines in the data collector may be employed to convert raw observed data to local grid X-Y-Z coordinates; optionally, these conversions may be made on a PC after the data are downloaded.
  - If a RTK system is used, radial X-Y-Z coordinate data for each observed point is attached with a descriptor identifier code and saved in the data collector.





- Step 2--Transfer data from data collector to PC.
  - After completing the survey, the data are then transferred to a field or office computer via telephone, cable, or infrared modem for data processing and editing.
  - The computer is either an in-office desktop system or a laptop model that can be used on site.
  - A number of software systems contain modules for performing this data transfer process.
  - Data transfer programs were described back in Chapter 7.
  - One or more files may be downloaded from the data collector.
  - Depending on the data collector software, these downloaded datasets might include:
    - Raw data files in ASCII format containing all original survey, project, and attribute observations keyed or processed in the data collector.
    - Native binary format of the above file
    - Coordinate file containing reduced X-Y-Z-attribute data for each observed point
    - Other types of field recorded data may also be downloaded, e.g., pen tablet field sketches and notes, digital photo images, etc.

## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)

- Step 3--Reformatting.
  - If a coordinate file was not directly generated in the field, then the raw data files must be processed in the computer to produce a coordinate file that contains point number, point code, X-Y-Z coordinate values, and a point descriptor.
  - Survey software packages provide review and edit capabilities at this stage of the processing, checking point codes and descriptors before they are imported into the CADD platform.
  - These software packages are also useful in generating standardized feature and attribute codes which can be uploaded to the data collector to ensure consistent observing methods.
- Step 4--Convert data into a graphics design file for use in a CADD program such as MicroStation or AutoCAD.
  - A number of software conversion programs are available to convert raw data collector files into a CADD file.
  - The program CVTPC, available from ERDC, is an example of a program commonly used to convert the ASCII files into 2D or 3D MicroStation design files.
  - Level, label, symbol, and line definitions are assigned to each point based upon a point code.





## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)

- Step 5--CADD specific applications.
  - Once data are contained in the CADD platform, the basic topographic data can be plotted for review and edit.
  - Digital terrain models (DTM) can be generated that can be used to generate contours, quantity take-offs, etc.
  - Final editing and addition of notes are completed, yielding topographic data in a digital format or as a plotted map.
  - Sheet layouts are assigned and the topographic data are ready to be used for their intended engineering, design, planning, or construction function.
  - As stated previously, many of the above steps can be skipped if field data are collected using procedures, software, and coding that is directly compatible with the final CADD platform.
  - Thus, uniform operating procedures are needed when collecting and processing survey data.
  - The use of proper field procedures is also essential to prevent errors or omissions in generating the final site plan or map products.
  - Collection of survey points in a systematic and meaningful pattern aids in this process.
  - If consistent field procedures are employed, then a minimal amount of post-processing or editing on the CADD platform will be required.

## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)

- a. Various software/ hardware packages are available to collect and process survey data.
  - Some data collectors are actually PC-based processors that can log total station data and run various survey adjustment software packages.
  - Field PC-based software can perform post-processing and adjustments, and import the data directly into a CADD workstation.
- b. When procuring components of a data collection and processing system, compatibility between components and a minimum capability must be assured.
  - Survey coordinates with a descriptor or code to indicate the surveyed feature should be input, as a minimum, to the CADD system.
  - ASCII X-Y-Z or latitude-longitude-height data, along with alphanumeric descriptor data, are usually accepted by CADD software and are commonly output by data collectors or survey processing programs.
  - The CADD program should have some flexibility in the order the coordinates are received (X-Y-Z, Z-X-Y, etc.) and the length of the data records.





## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)

- c. More complex and sophisticated information, such as contour lines and symbols, can sometimes be passed from survey to CADD programs through common graphic formats, such as DXF.
  - However, note that a 100% reliable transfer of graphic data is not always possible.
  - For example, contour lines passed to a CADD program in DXF format may have isolated breaks or overlap.
  - Transfer of graphic data using proprietary formats is usually most reliable.
- d. Transferring data to a field or office PC is a fairly straightforward process and is usually detailed in the operating manuals associated with the data collector software or CADD/GIS software.
  - Field data are often transferred directly into a CADD or GIS software program using import features on that program.
  - Optionally, an ASCII file may be created on the PC that is generic to any CADD/GIS program.
  - These CADD programs can usually import data from a variety of survey systems and data collectors, including generic datafiles.

## Field Computers and Software for Viewing and Processing Data

- Many districts perform much of the survey reduction, processing, editing, and adjustment in the field, and are transferring files directly into a CADD package.
- The greatest advantage of this procedure is uncovering a mistake which can be easily corrected if the crew and equipment are on the site.
- Laptop and notebook computers are normally used to download GPS and total station data.
- Once the files are stored in the computer, data processing and plotting in a CADD package can be performed.
- Data can be viewed and edited in the field before it is sent on to a CADD platform.



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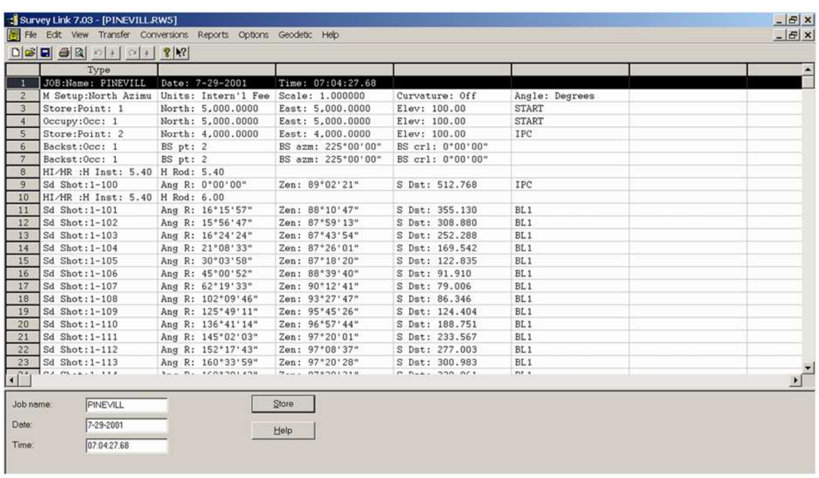


**Figure 39: Editing total station raw data file in TDS Survey Link 7.03.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)



- Listed below are some software considerations to install on field computer systems.
- Some of these features may also be available on the data collector.
  - Interface with field data collector.
  - A system of predefined codes for most common objects and operations in a database.
  - User-defined codes for site-specific requirements in a database.
  - Survey adjustment programs such as:

    *Compass rule adjustment*
    *Transit rule adjustment*
    *Crandall method*
    *Least squares*
    *Angle adjustment*
    *Distance adjustment*

  - Include a program which can assign an alphanumeric descriptor field for each survey point.
  - Include a full-screen editor to examine and edit ASCII data files.





## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)



- Have an interface program to convert files to common graphic interchange formats such as IGES or DXF.
- A program to connect features which were not recorded in order such as fence, curb and gutter, edge of pavement, waterline etc.
- Provide an operating system which will be compatible with post-processing machines with CADD programs such as MicroStation or AutoCAD.
- Custom programs which can use all the features available to the total station or the data collector.
- Select software which provides training if possible.

### Field Quality Control and Quality Assurance Checks

- a. Backups.
  - Upon the completion of the file transfer, make a backup copy of the raw data.
  - Once this transfer is complete, and only after this transfer is complete, then the data in the data collector can be deleted.
- b. Hard copy prints.
  - Print a copy of the formatted data and check it against the field notes.
  - Check the field input of data against the field notes.
  - Specifically, check the instrument locations, azimuths to backsights, and the elevation of benchmarks.
  - Also scan the data for any information that seems to be out of order.
  - Check rod heights.





- c. Edit the data.
  - Eliminate any information that was flagged in the field as being in error.
  - In the system, make a record of any edits, insertions, deletions, who made them, and when they were made.
- d. Process the control data.
  - Produce a short report of the data that were collected in the field.
  - Check the benchmark elevation to be certain that the given elevation is the calculated elevation and that the coordinates of the backsights and foresights are correct.
- e. Data quality.
  - To assure that complete data are being supplied by the field, make certain that the field crew fully understands the automated processes that are being used and that they take care to gather data appropriately.
  - It is much easier and more productive for the field crew to get a few extra shots where they know there will be difficulty in generating a good contour map than it will be for those in the office to determine where certain shots should have been made and add them to the database.
  - The field crew must also make sure they pick up all breaklines necessary to produce the final map.

- f. Terrain contouring.
  - The field crew will need to become educated about the contouring package used by the District Office.
  - As the data are brought in from the first few projects, and periodically thereafter, the crew should observe the product produced by the contouring program.
  - This will help them to understand where and what amount of data may be needed to get the best results.
  - The District Office staff needs to be aware that in some circumstances the field crew may have difficulty in getting some information (terrain restrictions, traffic, etc.).
- g. Field edit.
  - The person responsible for the field work should be involved in the initial phase of editing because he or she will most likely remember what took place.
  - Preferably, the editing should be done the same day the data are gathered, while the field person's memory is still fresh.
  - If it is not possible for someone to walk the site to ensure that the final map matches the actual conditions, then the field person should be the one to review the map.



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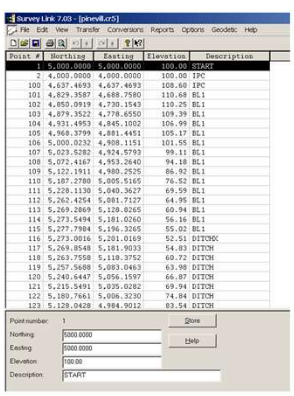
- The figure here shows one example by which processed data can be checked for quality.



Survey Link 7.03 - [pinevill.cr5]
File Edit View Transfer Conversions Reports Options Geodetic Help

| Point # | Northing | Easting | Elevation | Description |
|---|---|---|---|---|
| 1 | 5,000.0000 | 5,000.0000 | 100.00 | START |
| 2 | 4,000.0000 | 4,000.0000 | 100.00 | IPC |
| 100 | 4,637.4693 | 4,637.4693 | 108.60 | IPC |
| 101 | 4,829.3587 | 4,688.7580 | 110.68 | BL1 |
| 102 | 4,850.0919 | 4,730.1543 | 110.25 | BL1 |
| 103 | 4,879.3522 | 4,778.6550 | 109.39 | BL1 |
| 104 | 4,931.4953 | 4,845.1002 | 106.99 | BL1 |
| 105 | 4,968.3799 | 4,881.4451 | 105.17 | BL1 |
| 106 | 5,000.0232 | 4,908.1151 | 101.55 | BL1 |
| 107 | 5,023.5282 | 4,924.5793 | 99.11 | BL1 |
| 108 | 5,072.4167 | 4,953.2640 | 94.18 | BL1 |
| 109 | 5,122.1911 | 4,980.2525 | 86.92 | BL1 |
| 110 | 5,187.2780 | 5,005.5165 | 76.52 | BL1 |
| 111 | 5,228.1130 | 5,040.3627 | 69.59 | BL1 |
| 112 | 5,262.4254 | 5,081.7127 | 64.95 | BL1 |
| 113 | 5,269.2869 | 5,128.8265 | 60.94 | BL1 |
| 114 | 5,273.5494 | 5,181.0260 | 56.16 | BL1 |
| 115 | 5,277.7984 | 5,196.3265 | 55.02 | BL1 |
| 116 | 5,273.0016 | 5,201.0169 | 52.51 | DITCHX |
| 117 | 5,269.8548 | 5,181.9033 | 54.83 | DITCH |
| 118 | 5,263.7558 | 5,118.3752 | 60.72 | DITCH |
| 119 | 5,257.5688 | 5,083.0463 | 63.98 | DITCH |
| 120 | 5,240.6447 | 5,056.1597 | 66.87 | DITCH |
| 121 | 5,215.5491 | 5,035.0282 | 69.94 | DITCH |
| 122 | 5,180.7661 | 5,006.3230 | 74.84 | DITCH |
| 123 | 5,128.0428 | 4,984.9012 | 83.54 | DITCH |

Point number: 1
Northing: 5000.0000
Easting: 5000.0000
Elevation: 100.00
Description: START
Store
Help

**Figure 40: Reviewing final X-Y-Z coordinate files.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- The figure here depicts feature and attribute assignments on one of the objects ("FH" -- fire hydrant) that were imported into a Trimble Geomatics Office (TGO) software display.

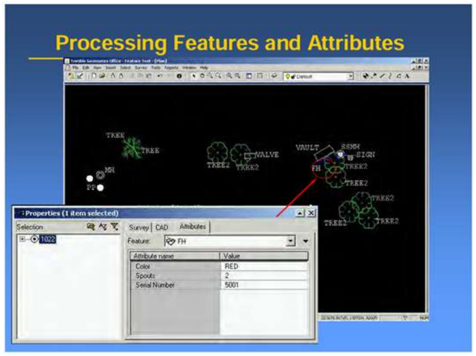



**Figure 41: Feature and attribute coding--Trimble Geomatics Office.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





## Cell Libraries Containing Corps of Engineers Standardized Symbology

- A "cell" in MicroStation and a "block" in AutoCAD are groups of graphical elements that can be manipulated as a single entity.
- Examples of cells/blocks are hydrants, poles, benchmarks, etc.
- The use of such symbology enhances CADD productivity and provides an excellent opportunity for CADD standardization.
- MicroStation cells are contained in cell libraries (.cel) and custom line styles contained in resource files (.rsc).
- AutoCAD blocks are in an individual drawing (.dwg) file, patterns in a pattern library file (.pat), multilines in a multiline library file (.mln), and custom line styles in a line type library file (.lin).

- a. Graphical presentations of the entire symbology library are shown in Appendix D of the A/E/C CADD Standard.
  - The symbology library contains four types of elements: Lines, Patterns, Symbols, and Objects.
  - Lines are defined as a graphical representation of linear drawing features (e.g., utility lines, fence lines, contours).
  - Patterns are defined as repeated drawing elements (e.g., lines, dots, circles) within a defined area.
  - Symbols are defined as MicroStation cells or AutoCAD blocks that are representative of objects (e.g., electrical outlets, smoke detectors).
  - Objects are defined as MicroStation cells or AutoCAD blocks that retain their actual size no matter the scale of the drawing.





- b. The figure here depicts a portion of the surveying and mapping symbols published in the CADD/GIS Technology Center "A/E/C CADD Standard"--ERDC/ITL TR-01-6.

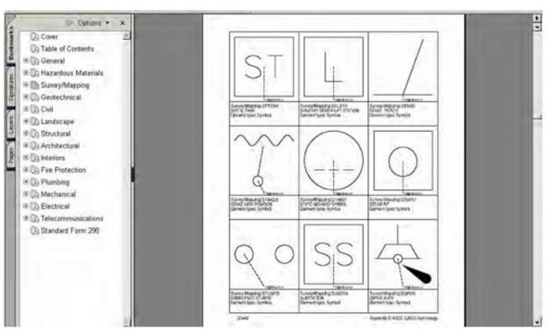



**Figure 42: Portion of A/E/C CADD Standard surveying and mapping symbology listing.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Sheet and Model Files

- A model file contains the physical components of a building (e.g., columns, walls, windows, ductwork, piping, etc.).
- Model files are drawn at full scale and typically represent plans, elevations, sections, etc.
- A sheet file is synonymous with a plotted CADD drawing file.
- A sheet file is a selected view or portion of the model file(s) within a border sheet.
- A sheet file is a view or portion of an assembly of referenced model files plus additional sheet-specific information (e.g., north arrows, scales, section cuts, title block information).
- A sheet file is the final project sheet, which is a “ready-to-plot” CADD file within a border sheet and is usually plotted at a particular scale, since the border sheet is scaled up to fit around the full-scale model files.





## Reference Files

- Reference files (external references or XREFs) enable designers to share drawing information electronically, eliminating the need to exchange hard copy drawings between the design disciplines.
- With the use of reference files, the structural engineer need not wait for the architect to complete the architectural floor plans before beginning the structural framing plan model file.
- Nor does the engineer have to redraw the architect's structural walls on the structural framing plan model file.
- Referencing electronic drawing information makes any future changes made by the architect apparent to the structural designer.
- This real-time access to the work of others ensures accuracy and consistency within a set of drawings and helps promote concurrent design efforts.
- No longer does one discipline have to wait until another discipline is nearly finished before they begin their drawings.
- The use of reference files is a key component in the successful use of the level/layer assignments.
- To create either a model file or a final sheet file, multiple referenced model files may be required.

Check the next slide to explore an interactive GIF about the classification of survey features

## FINAL SITE PLAN OR MAP PRODUCTION (CONT'D)



### FEATURE TYPE SORTER

Sort the survey features into the correct CADD/GIS categories.

Fire Hydrant

| Point Features | Line Features | Area Features |
|---|---|---|

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## SURVEY DOCUMENTATION AND SUBMITTALS

### General

- This chapter provides guidance on survey documentation, such as field notes, deliverables, metadata, and final submittal reports generated for a topographic survey project, such as a site survey, control survey, hydrographic survey, or construction measurement and payment survey.
- Generally, a project report is prepared for every major surveying project; in particular, those projects involving new work.
- Less formal letter reports will usually suffice for routine or repetitive construction surveys.
- Contract survey specifications will indicate when a formal report is required.
- This narrative report should describe all salient events and procedures involved in the project.
- The report will outline all submittals or deliverables attached with the report, to include: raw data files (GPS, data collector), coordinate files, design files (*.dgn), ESRI shape files, sheet index files, hard-copy drawings, quantity take-off computations, etc. In addition, any QC and/or QA procedures should be described.
- If real property surveys are involved requiring filing in local jurisdictions, then appropriate licensing certifications must be made on the submitted drawings.
- FEMA or FAA certifications will require survey reports to be submitted in that agency's format.

## Final Survey Report Format--Civil Works

- A standardized report format should be used for all major survey projects--especially those for planned design and construction.
- A project report submitted in a consistent format provides essential background information to the design engineer.
- The following outline may be used for guidance in preparing a survey report on a topographic survey.



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## Outline for Survey Report Submittals

- Section 1: General Project Description
  - Overview of the project including location, purpose, and parties involved.
- Section 2: Background
  - Reason for project (more detailed description) and more specific location description including a map.
  - Accuracy and deliverables should be discussed in this section.
  - Attach or include a copy of the original Scope of Work prepared by the originator.
  - Add funding information if applicable.
- Section 3: Project Planning
  - How the project was planned including but not limited to: reconnaissance results; control establishment; datums; DGPS method(s) selected; topographic survey techniques; feature and attribute standards selected.
- Section 4: Data Collection
  - Overview of how data was collected including but not limited to: Equipment used (make and model); data collection method(s) and/or techniques used; control points used; amount of data collected; number of crews and personnel per crew; how long the data collection took; data processing/error checking performed in field.

## SURVEY DOCUMENTATION AND SUBMITTALS (CONT'D)



- Section 5: Primary Control Data Processing
  - How the control data processing was performed including but not limited to process followed.
    - Subsection 5-1: Total station Traversing--adjustment software, results, closures, final adjustment results and coordinate listings.
    - Subsection 5.2: GPS Control Surveys & Baseline Processing--Software used; baseline processing results (summary); reprocessed baselines and reason for; parameters for baseline processing (elevation mask, type of ephemeris used); summary results or loop closures (if applicable).
    - Subsection 5.3: Combined GPS, Total Station, Differential Leveling Network Adjustments---Software used; results of unconstrained adjustment, minimal constrained adjustment, and fully constrained adjustment; summary of weights used, general statistics.



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- Section 6: Project Summary and Conclusion
  - This section shall include overall results of the processing, products produced, listing of deliverables being submitted, list of metadata files submitted, overall accuracy of the data collection (based on results from data processing section), problems encountered during data collection and data processing, recommendations for future data collection efforts of this type or in this area (lessons learned).
- Section 7: Output and Reports from Software
  - This section shall include the detailed reports and output from software packages used during the data processing. This section might have multiple subsections--e.g., one for each step in the processing that has output that is critical in evaluating results.

## Final Survey Report Format--Military

- FM 3-34.331 recommends the following format be utilized for final project reports involving military facilities.
- The guidance and report outline is excerpted from FM 3-34.331.
  - An end-of-project report is used to inform the commander and the customer that the project has been completed.
  - The results of the project will generally be listed on DA Form 1962. Copies of DA Form 1959, map overlays, and other graphics may be included.
  - The report should be broken down into readily identifiable numbered and titled paragraphs, as follows:
    - Paragraph 1. References.
      - A complete listing of all orders, letters, project directives, and memorandums for record (MFRs) concerning the project.
      - Normally, the other reports will not be listed as references.





- Paragraph 2. Personnel.
  - The name and rank of all personnel participating in the project.
  - The inclusive dates of their involvement should also be listed.
  - This paragraph can be further broken down as follows:
    - ✓ Field-crew personnel from the parent unit.
    - ✓ Visiting or inspecting personnel (the unit or office should also be included).
    - ✓ Local officials directly involved in the project
- Paragraph 3. Objective.
  - The specific mission statement.
- Paragraph 4. Discussion.
  - A detailed discussion of exactly what transpired during the conduct of the project.
  - Specific dates and details should be included.
  - The milestone objectives outlined in the recon report should be discussed.
  - Indicate whether the project was kept on schedule, or fully explain the reasons for falling behind schedule.

- Paragraph 5. Problem Areas.
  - Specific problem areas and the solutions to the problems.
  - This information becomes a historical record to be used for future planning purposes.
  - Technical information will be included in the narrative and graphic sections of the recon report.
- Paragraph 6. Funding.
  - All fund citations and a total of all funds expended.
  - The ISVT and recon reports are the sources for this information.
  - Copies of all travel vouchers and other expenses should be included.
- Paragraph 7. Work Hours.
  - The total number of expended work hours (broken down by rank).
  - A composite of all progress reports should be included.
- Paragraph 8. Conclusions and Recommendations.
  - Cite specific conclusions and recommendations.





- Examples of final survey reports submitted by an AE contractor and Corps in-house staff are included in the application projects in some of the appendices to this manual.
- Although these reports do not conform to the above formats, they do include the same general information.

## Field Note Keeping Procedures and Formats

- Field notes will supplement digital data records.
- Typically all field notes will be recorded in a standard, bound, hardcover surveyor's field book as the measurements are made in the field.
- a. Entries.
  - All field note entries shall be made with a black lead pencil or ink.
  - Notations made by other than the original surveyor shall be made with a colored pencil so a clear distinction exists between the field observations and subsequent corrections, adjustments, comments or supplemental data.
- b. Index.
  - The first two (or more) pages of each field book shall be reserved for the index and shall be annotated with Roman numerals.
  - An index entry shall be made for each day.
  - The index should contain the date and description of the survey, Project or Contract number, the type of survey, and the page numbers containing the survey data.
  - The remainder of the field book shall contain the actual field data and shall be numbered beginning at page one.



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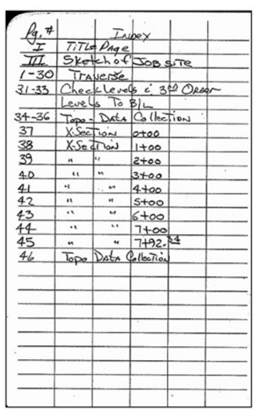
- A sample field book index is shown in the figure here.



| Pg. # | Index | |
|---|---|---|
| I | Title Page | |
| III | Sketch of Job site | |
| 1-30 | Traverse | |
| 31-33 | Check levels c 3rd Order Levels To B/L | |
| 34-36 | Topo - Data Collection | |
| 37 | X-Section | 0+00 |
| 38 | X-Section | 1+00 |
| 39 | " " | 2+00 |
| 40 | " " | 3+00 |
| 41 | " " | 4+00 |
| 42 | " " | 5+00 |
| 43 | " " | 6+00 |
| 44 | " " | 7+00 |
| 45 | " " | 7+92.34 |
| 46 | Topo Data Collection | |

**Figure 43: Sample index page in a field survey book.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- c. Title page.
  - A separate Title Page shall be prepared for each day's work, or partial days work if applicable.
  - The Title Page shall be referenced in the field book Index.
  - The Title Page shall contain all pertinent information about the survey--project, contract number, personnel, weather, instruments used, etc.



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  - An example of a comprehensively detailed title page is shown in the figure here.


**Figure 44: Sample Title Page in a field survey book.**
*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## SURVEY DOCUMENTATION AND SUBMITTALS (CONT'D)

- d. Page setup.
  - The first page of each entry should contain (at the top left side of the page) the name of the installation or project location, a specific project title, and the type of work being done.
  - At the top of the right side of the right half of the page, record the actual date of the survey, weather conditions, type and serial number of instruments used, members of the crew and their assignment, map or field book references, and other remarks as necessary for a complete understanding of the survey.
  - Pages are numbered on the right-hand page only.





## SURVEY DOCUMENTATION AND SUBMITTALS (CONT'D)

- e. Corrections.
  - No erasures should be made in the field book.
  - If errors are made, they will be crossed through and the corrections will be entered ensuring that the original data remains legible.
  - No figure should be written over the top of another-- nor should any figure be erased.
  - If a whole page is in error, the complete page will be lined or crossed through and the word "VOID" will be written in large letters diagonally across the page.
  - An explanation of the error, and a cross-reference will be entered on the voided page showing the book and page number where the correct information may be found.
  - At the end of each day of work, the field notes shall be signed and dated by the individual responsible for the work.

- f. Data collector.
  - If a data collector is used, the basic setup information (station description, HI, sketch, etc.) needs to be recorded in the field book.
  - This information is used to document the sequence of the survey.
  - Sketches are added in the field book as needed to supplement the data collector and aid the CADD technician with the planimetric features.
  - On some critical projects (e.g., boundary location, construction payment surveys, etc.) it may be prudent to duplicate digitally recorded data in the field book as it is observed.
  - The requirement for such duplicative recording will depend on the nature of the project, including factors such as potential contract disputes and claims, boundary encroachments, etc.





- g. References.
  - When it is necessary to copy information from another field book or other source, a note will be made which clearly states that the information was copied and the source from which it came.
  - If the notes are a continuation from another field book, a description will be written in the field book to the effect "NOTES CONTINUED FROM BK XXXX PAGE XX."
  - A similar description (e.g., CONTINUED IN BOOK XXXX FROM PAGE XX) will be written on the last page of each section of notes if those notes are to be continued either in another book or on another page that is not adjacent to the current page.
- h. Sketches.
  - Sketches are absolutely essential on many site plan surveys, especially if complex utility details are involved.
  - The sketch should show all the details, dimensions, and explanatory notes required.
  - The sketch should be written on a whole page whenever possible.
  - If necessary, multiple pages with the sketch divided equally among the pages should be used if the sketch has too many details to be shown on one page.

- i. Digital photos.
  - Sketches and other data may be supplemented by digital photos taken in the field.
  - Photos are often useful of permanent control monuments occupied, utility access covers/boxes, utility identification signs, sample vegetation and tree cover, culverts, bridges, towers, etc.
  - References to digital photos should be made in the field book or data collector.
- j. Descriptive project data.
  - Field book records must contain sufficient descriptive notes so that the survey can be easily reconstructed by different personnel or at any later point in time.
  - Thus, it is important to describe the starting horizontal and vertical control points and their coordinate values.
  - Problems or control discrepancies should be clearly noted in the field book.
  - Sketches of traverse or level routes should be drawn in the field book.
  - Instruments used should be identified.
  - All the forgoing applies whether or not a data collector system is used.



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- The figure here depicts a portion of a field book that describes the initial base station set up parameters for a RTK survey.
- Such basic information is critical in the event the subsequent RTK survey data is questioned.

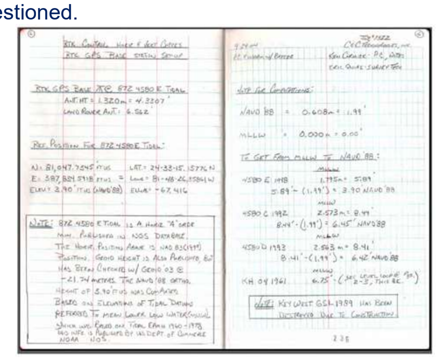

**Figure 45: RTK reference notes in a field survey book.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

- k. Project archives.
  - In general, a separate field book should be initiated for each design or construction project.
  - Field books should be copied or scanned as soon as possible after the field work is completed.
  - The original book should be submitted with the deliverables for permanent retention by the District office.





### Sample Topographic Survey Field Book Notes

- There is no set format for topographic field notes.
- The amount of detail required in the field book will depend on the nature of the project.
- When a data collector is used with a total station or RTK, then only minimal file referencing data is needed in the field book.

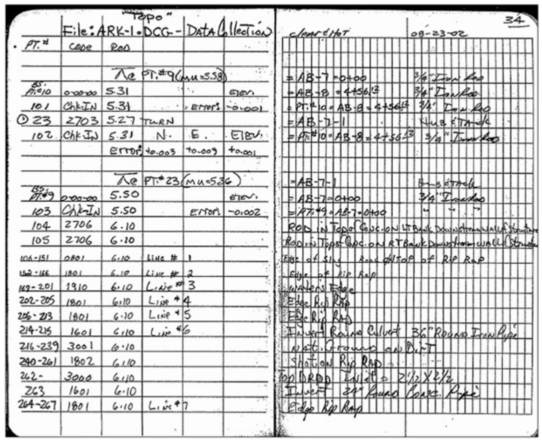


**Figure 46: Topographic survey notes referencing data collector shots.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





- When topographic observations are manually recorded, a variety of field book formats may be used.
- The particular format selected will depend on the note keeper's preferences, the type of project, densification method (radial, cross-sections, or linear profiles), type of instrument, and amount of descriptor data required for individual shots.
- Some representative examples of topographic field notes are shown on the following figures.

℄ Profile — Road A 10/20/85

(27)

| Sta. | + | HI | − | Elev. | Adj. Elev. | |
|---|---|---|---|---|---|---|
| TBM#3 | 11.80 | 183.68 | | | 171.88 | TBM#3 is nail in root of 24" Water oak, |
| 13+00 | | | 9.40 | | | set in June 1975 - Book 42-12 |
| 13+89 | | | 4.96 | | | |
| 13+96 | | | 4.60 | | | |
| 14+00 | | | 4.40 | | | X-SEC. # 3B |
| 14+49 | | | 2.11 | | | |
| TP | | | 1.03 | 182.65 | +.01 182.66 | |
| | | | | | | |
| | 9.94 | 192.59 .60 | | | | |
| 15+00 | | | 8.61 | | | X-SEC. # 4 |
| 15+19 | | | 7.66 | | | |
| 16+00 | | | 3.38 | | | X-SEC. # 5 |
| 16+47 | | | 0.88 | | | |
| TBM#4 | | | 0.81 | 191.78 | 191.80 | TBM#4 is RR spike set in ℄ pavement. |
| | | | | | | Set June 1975 - Book 42-12 |
| | 11.45 | 203.25 | | | | |
| 17+00 | | | 8.87 | | | SAMPLE NOTES - PROFILE |
| 18+00 | | | 3.80 | | | ON EXISTING PAVEMENT |

**Figure 47: Sample notes from a road profile survey--setting elevations on intermediate stations.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*



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X-SECTION STA 0+00 L-8 10

13 SEPT 87

| RANGE | + | HI | − | ROD | ELEV | |
|---|---|---|---|---|---|---|
| | | | | | 10.00 | "FCSJ-2120" (PUBLISHED NGVD 1929) |
| | 4.00 | 14.00 | | | | |
| 200 | | | | 3.9 | | B/L AND TOP OF LEVEE |
| 25 | | | | 6.0 | | SLOPE |
| 30 | | | | 8.0 | | BREAK |
| 34 | | | | 9.9 | | SLOPE |
| 50 | | | | 10.0 | | SLOPE |
| 75 | | | | 12.5 | | SLOPE |
| 300 | | | | 14.5 | | SLOPE |
| | | | 13.55 | | 0.45 | T.P. (2x2 HUB) |
| | 3.55 | 4.00 | | | | |
| 175 | | | | 3.6 | | TOE of LEVEE |
| 150 | | | | 3.6 | | MARSH (GRASS + Water) |
| 125 | | | | 3.6 | | MARSH (GRASS + Water) |
| | | | 2.25 | | 1.75 | "FCSJ-2119" (Published ELEV 1.74) |

**Figure 48: Sample notes from a levee cross-section survey.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

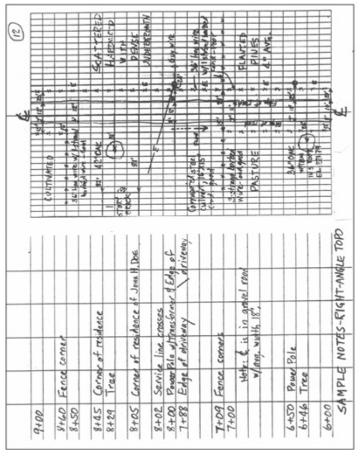


**Figure 49: Notes from a right-angle topographic survey along a road centerline.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*





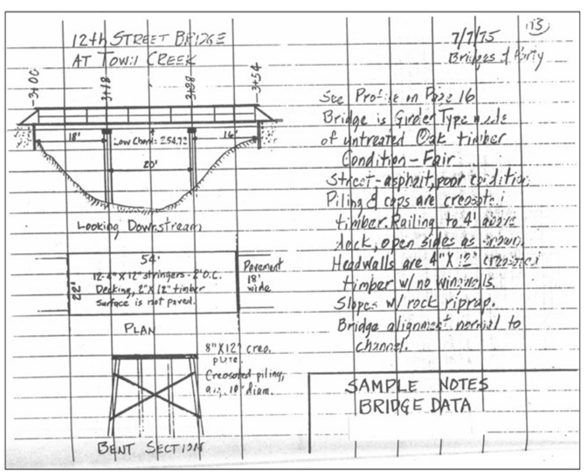


**Figure 50: Sample notes from a bridge survey.**

*(Source: US Army Corps of Engineers, "Control and Topographic Surveying," 1 January 2007, EM 1110-1-1005)*

## Monument Descriptions

- A description of the point occupied shall be made in the field notes.
- This description shall include the type of monument, its general location, and the type of material the point is set in.
- A sketch of the location of the point relative to existing physical features and reference ties shall be made and included in the notes.
- If a horizontal control line is used, a sketch of it shall be made and included in the notes.
- This sketch does not need to drawn to scale, but it should include the relative position of one point to the next and the basic control used.
- Alternatively, DA Form 1959 (Description and Recovery of Horizontal Control Station) may be used to record descriptions of permanent control monuments.
- Optionally, a digital photo or "rubbing" of a monument may be obtained and submitted.





## Deliverable QA Checklist

- The following list may be used for verifying receipt of deliverables and as a QA check on submitted data.
  - GPS network sketch
  - Control diagram
  - GPS raw data along with field observation log sheets filled out in field with all information and sketches
  - Traverse sketches
  - Level line sketches
  - Raw data and computation files with horizontal and vertical abstracts
  - GPS baseline reduction reports
  - Traverse adjustments
  - Level line adjustments
  - Free and constrained adjustment reports (combined observations)
  - Field survey books (original) containing daily record of survey observations
  - Scanned field survey books (in Adobe Acrobat PDF format, one field book per file)
  - Detail sketches of utilities and other planimetric features
  - ASCII file containing all reduced coordinate data in X-Y-Z format
  - DGN, DTM, and ESRI files
  - Advance hard-copy plots (2 sets)
  - Metadata files (*.gen and *.met files)
  - Final Survey Report

Check the next slide to explore an interactive GIF, which is a mind map.

## SURVEY DOCUMENTATION AND SUBMITTALS (CONT'D)










# THANK YOU FOR LISTENING!

*This concludes our presentation, and we hope that you enjoyed it.*

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## REFERENCES

This interactive presentation was adapted from Chapters 8 to 12 of the document by the US Army Corps of Engineers, Control and Topographic Surveying, January 2007, EM 1110-1-1005.





## COURSE PROVIDER BIOGRAPHY

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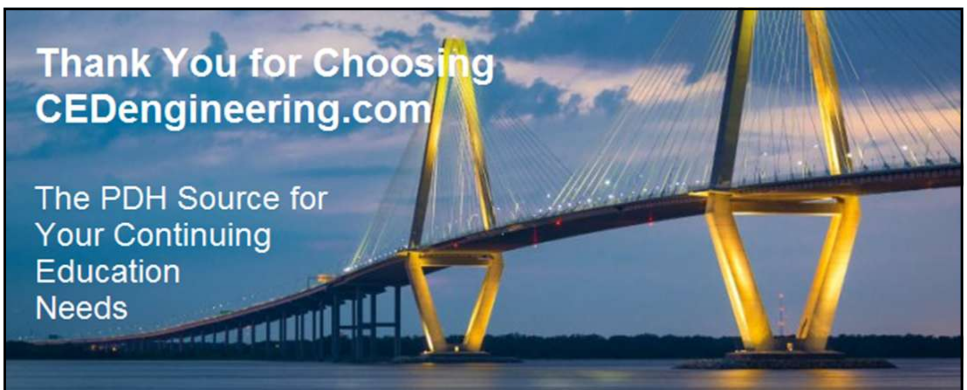


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