Chapter 3

Surveying Equipment, Measurements and Errors

Table of Contents

Table of Figures and Forms

Chapter 3
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3.1 EQUIPMENT

The procurement and maintenance of surveying equipment, tools and supplies are important parts of the Department's survey effort. Proper care in the use, storage, transportation and adjustment of the equipment is a major factor in the successful completion of a survey. Lack of good maintenance practices can jeopardize the efficiency and accuracy of the survey. This manual addresses the various types of survey equipment used by the Department's construction/survey personnel, the maintenance and care of the equipment and general procedures for surveys using the equipment. The majority of surveys done by and for the department utilize total stations, Global Positioning System (GPS), engineers levels (optical and digital) and data collectors. Appendix A includes sample notes associated with various field surveys. These sample notes may be beneficial in cases where field notes are taken and/or helpful to determine information that should be recorded in the data collector.

It is the Engineering Project Manager (EPM) and/or the party chief's responsibility to train all crew members in the proper use of surveying equipment and the maintenance of all surveying instruments, tools and supplies. The Photogrammetry & Survey Section or the District land surveyor should be contacted if additional training beyond the instruction provided by the EPM is required.

3.1.1 PERSONAL USE OF STATE ISSUED EQUIPMENT

Refer to current management memos and/or MDT policies regarding the use of state issued equipment for personal use.

3.1.2 GENERAL INSTRUMENT CARE AND SERVICING

Surveying instruments are designed and constructed to provide years of reliable use. Although they are constructed for rugged field conditions, the mechanical components and electronics of precision instruments can be damaged by careless acts or inattention to the procedures for use, care and adjustment of the instruments.

3.1.2.1 Operator's Manual

An operator's manual is furnished with each new instrument. Among other information, the manual contains basic instructions for operation of the instrument and describes recommended servicing and adjusting methods. The manual should be kept with the instrument at all times. Study the manual before using the instrument, particularly before making field adjustments. If the manual is lost, stolen or damaged beyond use, obtain a replacement copy of the manual.

3.1.2.2 Routine Care of Equipment

Before making the first set-up of the day, visually inspect the instrument for damage. Check the machined surfaces and the polished faces of the lenses and mirrors. Try the clamps and motions for smooth operation (absence of binding or gritty sound).

Clean the exterior of the instrument frequently. Any accumulation of dirt and dust can scratch the machined or polished surfaces and cause friction or sticking in the motions. Remove dirt and dust with a clean, soft cloth or with a camel-hair brush. Clean non-optical parts with a soft cloth or clean chamois.

Clean the external surfaces of lenses with a fine lens brush and, if necessary, use a dry lens tissue. Do not use silicone-treated tissues because they can damage coated optics. The lens may be moistened before wiping it, but do not use liquids (oil, benzene, etc.) for cleaning. Do not loosen or attempt to clean the internal surfaces of any lens.

After an instrument has been used in damp or cold situations, use special precautions to prevent condensation of moisture inside the instrument. If the instrument is used in cold weather, leave it in the carrying case in the vehicle during non-working periods rather than take it into a heated room. If you store the instrument in a heated room overnight, remove it from the carrying case. If the instrument is wet or frost-covered, bring it into a warm, dry room, remove it from its case and leave it at room temperature to dry out.

3.1.2.3 Vehicular Transport

Transport and store instruments in positions that are consistent with the carrying case design. For example, total stations should be carried and stored in their correct position. Many instrument cases indicate the position in which they should be transported.

Treat tribrachs, prisms and tripods with care. Carry them in their shipping cases or cushion them with firm polyfoam or excelsior-filled cases to protect them from jolting or vibrating excessively.

3.1.2.4 Casing and Uncasing

Before removing an instrument, study the way it is placed and secured in the case. Place it in the same position when you return it to the case. In removing the instrument from the case, carefully grip it with both hands, but do not grip the vertical circle standard or where pressure will be exerted on tubular or circular level vials.

3.1.2.5 Setups

Whenever possible, the instrument should be used in areas where operation is not dangerous to the instrument operator or the instrument. Select stable ground for the tripod feet. Do not set an instrument in front of or behind a vehicle or equipment that is likely to move.

In cold or hot weather when vehicle climate controls are used, survey instruments should be acclimated to outside conditions for an adequate period of time prior to final setup adjustments.

At the survey mark, firmly set the tripod with its legs spread wide. Push along the legs, not vertically downward. Extra precautions should be taken on smooth surfaces. The total station should **not** be attached to the tripod.

Always have the tripod firmly set before removing the instrument from its carrying case. Immediately secure the instrument to the tripod. If a total station is to be used, remove the instrument from the tribrach. Center and level the instrument over the mark using only the tribrach. Then place the total station in the tribrach for final leveling and verification that the instrument is still centered above the mark.

Never leave an instrument or its tribrach on the tripod without securing either to the tripod. Moderate pressure on the fastener screw is sufficient. Excessive tightening causes undue pressure on the foot screws and on the tribrach spring plate. Make sure the tribrach clamp is in the lock position.

3.1.2.6 Field Adjustments

Frequently check level vials, optical plummets, tripods, etc. for proper adjustment. In the field, make adjustments only when the instrument results are poor or require excessive manipulation.

Instruments should only be checked under favorable conditions. Only the adjustments described in the manual for the instrument should be made in the field or shop. Do not “field strip” (dismantle) instruments.

3.1.2.7 Major Adjustments

When an instrument has been damaged or otherwise requires major adjustments, contact the Construction Bureau. Indicate the type of repairs needed. In the case of total stations, digital levels or optical levels, describe the conditions under which the instrument does not function properly. Indicate if a “loaner” instrument is required.

3.1.3 EQUIPMENT DESCRIPTIONS

Specific surveying equipment is described below, along with its uses and any special precautions for its care.

3.1.3.1 Total Stations

A total station is used for measuring both horizontal and zenith angles as well as slope distances. In addition, they also have features for measurement to points that cannot be directly observed (offset measurement) and basic Coordinate Geometry (COGO). At one time, total stations were classified as either directional or repeating instruments. Most total stations have the ability to make horizontal angular measurements using either the directional method or the repetition method.

Directional Method The horizontal circle remains fixed during a series of observations. The direction of each foresight is measured in relationship to the backsight. The mean horizontal angle is then equal to the average of all the individual angles.

Repetition Method Successive measurements of an angle can be accumulated. The mean angle is then equal to the sum of the total angle divided by the number of observations.

Procedures The directional method will be used exclusively for the control survey, ties to aerial photography control points (targets), property corners, right of way, property controlling corners and secondary control traverses. All horizontal angles will be measured clockwise (angle right) from the backsight regardless of the size of the angle.

Special Care Although total stations are ruggedly built, careless or rough use and unnecessary exposure to the elements can seriously damage the instruments. If they are handled reasonably, the instruments will provide consistently good results with a minimum of down time for repair or adjustment. Some general guidelines for the care of instruments are:

- Transport and store instruments in positions that are consistent with their carrying case design. Protect the instruments from excessive vibrations by carrying them in their shipping cases.
- Instruments should be removed from the case with both hands. Generally, instruments are equipped with a carrying handle; use one hand to grip the handle and the other to support the base. Use one hand to continually support the instrument until the tribrach lock is engaged or the tripod fixing screw is secured.
- In most cases, total stations and other instruments should be removed and re-cased for transportation to a new point. If the instrument has a carrying handle, you can use the handle for walking the instrument between set-ups; however, it is recommended to case the instrument for transportation.
- The instrument should not be placed on the ground since dust or dirt can accumulate on the threads and the base plate.
- As feasible, protect the instrument from moisture.
- Never carry the instrument on the tripod.
- Turn the instrument off prior to removing the battery.
- Remove the battery from the instrument before the instrument is placed in its carrying case.
- Never use a total station for a solar observation unless an approved solar filter is used. This will destroy an element in the EDM, plus damaging the eye of the observer.

3.1.3.2 Global Positioning System Instruments

The Department uses Global Positioning System (GPS) receivers for various types of surveys and data collection. GPS receivers may be classified as hand held, mapping grade and survey grade receivers. Regardless of the type of GPS receiver, all final horizontal positions (latitude and longitude and/or state plane coordinates) of the observed marks will be relative to the North American Datum of 1983 (NAD83) and not the North America Datum of 1927 (NAD27) or the World Geodetic System of 1984 (WGS84).

Hand Held Receivers The less expensive GPS receivers obtain only limited information from the satellites. This type of receiver can be obtained from sporting good stores and other retailers. They are typically small, portable, battery powered and have a built in display. Currently the expected point positioning accuracy with selective availability disabled is approximately 30 ft (10m) horizontal. Typical uses are:

- to search for NGS bench marks
- to search for property corners and/or property controlling corners
- wetland delineations

Mapping Grade Receivers These receivers are generally used to export the collected data to an external databases such as Geographical Information System (GIS). Besides obtaining point positions, they also have an advantage over the hand held receivers since the data collected can be differentially corrected. This technique requires two receivers. One receiver is referred to as the base and is located on a known position. The second receiver is referred to as the roving receiver and it is placed over the point(s) to be positioned. Common satellite data is then stored in the base and the rover receivers. In the office, the satellite data is processed to compensate for position errors at the marks occupied by the rover. Expected horizontal accuracy can be as good as 3 ft (1m) typical uses are:

- marking locations of such things as roadway images (MDT's Photolog System)
- boring/core hole locations
- wetland delineations
- sand pits, stock piles, rest areas, Remote Weather Information Sites (RWIS), etc
- road geometrics

Survey Grade Receivers Are single or dual frequency. Information obtained is generally post processed to arrive at positions of the occupied points. These receivers may also have the ability to perform Real Time Kinematic (RTK) surveys. Only dual frequency receivers will be used to observe base lines in excess of 6.2 miles (10km). Geodetic antennas having a ground plane are required in some cases. Expected horizontal accuracies can be as good as 0.1 ft (0.03m). Typical uses are:

- HARN densification (post processed static/fast static)
- project control (post processed static/fast static)
- cadastral surveys (post processed fast static and/or kinematic and/or RTK)
- project control densification (post processed fast static and/or kinematic and/or RTK)

Precautions Prior to commencing a GPS project insure that the latest versions of all software have been obtained, all tribrachs have been adjusted as outlined below and all cables and connections have been visually checked.

3.1.3.3 Tribrachs

A tribrach is the detachable base of all total stations, and they are also used to attach prisms to a tripod. A Department tribrach is equipped with a bull's-eye bubble (circular level) and optical plummet.

Special Care The tribrach is an integral part of the precision equipment and should be handled accordingly. It should be transported in a separate compartment or other container to prevent damage to the base surfaces, bull's-eye level and optical plummet eyepiece. Over-tightening of the tripod fastener screw can put undue pressure on the leveling plate.

Adjustments An out-of-adjustment tribrach will cause centering errors. Each tribrach should be routinely checked for centering. Using a plumb bob is quick method for checking if the tribrach is out of adjustment. To perform this task, center the instrument over the point using the plumb bob, remove the plumb bob and check the centering using the optical plummet. If the error exceeds 0.01 ft (0.003m) use one of the following methods to correct the centering error.

One field method used to adjust for centering errors is to mark and rotate the tribrach 120 degrees at a time on a tripod. Before adjusting the optical plummet, adjust the bull's-eye bubble by using the instrument plate level bubble. For the first sighting, draw a line with a soft pencil on the tribrach head around the tribrach base. Carefully level the tribrach and mark the sighting point on the ground using the optical plummet. Then rotate the tribrach 120 degrees, carefully set it in the pencil marks, re-level it and mark the new sighting point. Then rotate a third time and repeat the procedure. If the tribrach is out of adjustment, the three rotational marks should form a triangle. Adjust the optical plummet to the center of the triangle using the capstan screws. Repeat the test to verify the adjustment triangle is minimized.

A tribrach-adjusting ring is the preferred method. Place a tribrach on a tripod and the adjusting ring in the tribrach. Place the tribrach to be adjusted upside down on the ring. Look through the optical plummet and pick out a well-defined point on the ceiling. Turn the leveling screw on the bottom tribrach to center the optical plummet on the selected point on the ceiling. Rotate the top tribrach on the ring 180 degrees. If the cross hair stays on the point when rotated, the optical plummet is in adjustment. If not, use the leveling screws on the bottom tribrach to eliminate one half of the error. Eliminate the remaining error with the adjusting screws on the optical plummet. Repeat the procedure until the cross hair rotates on the point. The tribrach does not have to be level to perform the adjustment.

When adjusting the optical plummet, slightly loosen the appropriate capstan screw and equally tighten the opposite capstan screw. Use caution when tightening the capstan screws since they can easily be twisted off. Refer to the instrument user manual for detailed instructions.

3.1.3.4 Electronic Distance Measuring Instruments (Total Stations)

The development of electronic distance measuring instruments (EDM/EDMIs) has had a profound effect on the surveying profession. Linear measurement, in any practical range, can be made speedily and accurately due to the development of these instruments. The Department no longer supports nor recommends the use of EDMs that are independent of a total station.

Most EDMs have approximately the same distance measuring accuracy when operated in accordance with the manufacturer's instructions. Every instrument has an inherent plus or minus error in every measurement plus a small error based on parts per million of the distance measured.

The primary differences among makes and models of EDMs are the distance they can measure with one or multiple reflector prisms and the time required to make a measurement. Total stations incorporate EDMs as well as provisions for angular measurements and basic coordinate geometry (COGO).

Operating and maintenance procedures are covered in the manuals supplied with each instrument.

Advantages Some of the advantages of using an EDM are:

- a reduction in the time and crew size required for most measurements
- the ability to measure across traffic or construction operations without inconvenience to others (motorists or construction crews) or undue hazard to the survey crews
- the ability to measure otherwise inaccessible points, such as across deep canyons or rivers
- the ability to set many points from a relatively sparse control network, which is especially useful in construction staking
- the ability to measure with increased precision and consistency
- the ability to quickly establish better supplemental control for construction staking
- interface with a data collector

Base Line Report In 2002 and 2003, NGS completed new observations of all calibrated base lines in Montana. NGS base line data can be obtained from NGS's web site at http://www.ngs.noaa.gov/products_services.shtml#EDMI. Once a year and prior to commencing a control survey, distance measurements obtained from the total station must be compared against an NGS calibrated base line. All measurements associated with the base line report will be metric units. A comparison consists of obtaining and recording the measurements shown on Form 3-1. A blank base line report form is included in the Appendix. This report can be copied and taken to the base line, completed in the field and then submitted. An alternative method is to obtain the required measurements and then complete the online version of the base line report that is available on the MDT web page at http://www.mdt.mt.gov/publications/forms.shtml#survey. Prior to the observations, check and adjust tribrachs and tighten all tripods and compare the thermometer and barometer against a standard. The barometer should be compared with what is known as station or absolute pressure. Larger airports will have this pressure. The barometer must be taken to the airport and adjusted to the given station pressure. Station pressure is not the pressure that is broadcast during a weather report. At the baseline, record the shaded temperature, the station pressure, instrument heights and prism height and all other required information including the measured distances. It is advisable to complete the reporting form and the analysis of the measurements *before* leaving the baseline.

Caution An incorrect barometric pressure or temperature will affect the measured distances of the longer lines. The prism offset in the instrument also needs to be set correctly. Department prisms have an offset of minus 30mm (-30mm). The sign of the offset is critical.

An analysis of the measurements consists of a comparison of the differences between the measured mark to mark distance and the NGS reported mark to mark distances. The standard errors of the instrument must be known. The standard errors are given in the operator's manual and consist of a constant error and a part per million error (refer to Form 3-1).

As an example, assume the distance from the 0m to the 150m mark shows a difference of 0.0016m. The standard errors per the instrument are 0.005m + 3 part per million (ppm). Is this difference acceptable? If the difference is less than or equal to 2 times the standard errors, the answer is yes. In this example, twice the standard deviation for this line would be equal to 2[0.005 + (3 x 150/1,000,000)] = 0.0109m. The measured difference (0.0016m) is less than 0.0109m; therefore, the difference is acceptable.

As an additional example, determine whether the difference of 0.0030m is acceptable for the line from the 0m to the 1420m mark. The computation is 2[0.005 + (3 x 1420/1,000,000)] = 0.0185m. The difference of .0030m is less than 0.0185m, so the difference is acceptable. All mean mark-to-mark differences should be acceptable. If not, repeat the test after checking the tripods, optical plummets, barometer, and thermometer. Send all base line reports to the Photogrammetry and Survey Section.

3.1.3.5 Miscellaneous Equipment

The Department uses a wide range of sights in conjunction with total stations. The main purpose of a sight is to provide a reference that is visible to the instrument operator. In this context, sights may be required for line, distance, or a combination of line and distance.

Gammon Reel and Plumb Bob The plumb bob and Gammon reel is the old standard for short-distance sighting, particularly for establishing temporary points. Steadiness of the holder can be enhanced by the use of braces or any type of framework. Various types of inexpensive string-line targets are also available.

Prism Poles Prism poles are the most common sight used by the Department. These poles are made of various materials and in different lengths. The more common prism poles can be extended to allow for changing the height of the prism to avoid obstructions.

Prism Pole/Rod Levels The circular level (bull's-eye) is used to maintain both level rods and prism poles in a vertical position. An out-of-adjustment bubble used on either a level rod or a prism pole can cause errors in both angle and distance measurements. The bubble is easily adjusted by using Hold A Pole™ or a similar device.

Force-Centering Targets/Prisms Tribrach-mounted prisms are required for the control survey. The range poles mentioned above are not to be used for the control survey nor should they be attached to a tribrach to extend the height of the prism.

Prisms Most manufacturers of EDMs supply special prisms and prism holders that are compatible with their equipment. The single lens, tiltable holder with provisions for direct connection on the top of a prism pole or attached to a tribrach is the most common type used in most survey work. The prism assembly is generally equipped with a sighting target mounted above or below the prism to provide parallel sight between the sighting and measuring beams.

The maintenance of parallel sight is more significant in the accuracy of measurements as the distance is decreased. The use of the tiltable prism assembly maintains the parallel sight relationship.

It is important that the proper prism constant is used; otherwise, a systematic error will be introduced into all the measurements made between a particular EDM and prism. The best way to verify that true measurements will be made is to test the EDM and prism on a calibration base line. The Department only uses prisms that have a manufactures specification of -30mm offset; the EDM must be set accordingly.

Compass Hand compasses are used to determine approximate directions. Directions are measured in degrees and may be a bearing or an azimuth. The Department uses a compass for obstruction diagrams associated with GPS surveys, corner search, and rough checks on the direction of a line as determined by a celestial observation. The correct magnetic declination must be used or noted.

Care and Maintenance of Equipment As with any survey equipment, proper care will extend the useful life of sighting equipment.

- Check the prism pole bubble prior to each day's use. A quick check by fixing the rod in a tripod and rotating it 180 degrees will verify the adjustment.
- Check the bull's-eye bubble on the telescoping range pole using the "Hold A Pole".
- Prism assemblies and prisms should be transported in suitable carrying cases.

3.1.3.6 Leveling Instruments

Hand Levels Hand levels are useful in level runs for quick location of turn and instrument points. They are also quite useful for elevation checks during grading operations. As with any other level, the level bubble can become out of adjustment and should be checked periodically.

Clinometers Clinometers can be used in place of a hand level and for measuring approximate angles of slopes. If the clinometer is used as a level, it should be set to zero degrees. If the clinometer is used to measure slopes, the correct scale should be utilized since they generally have two scales. The most common being degrees and percent. The degree reading is generally on the left and percent on the right. Clinometers are also used for obstruction diagrams associated with GPS surveys.

Levels (Optical and Digital) These types of levels are the standard leveling instruments used by the Department. The principle of operation is essentially the same for all types of levels. The line of sight is maintained perpendicular to the direction of gravity through a system of prisms referred to as a compensator.

These levels are fast, accurate and easy to maintain. Proper care and service are required to ensure continuous service and required precision. Do not disassemble instruments in the field. Attempt only those adjustments described in the instrument manual.

Review the previously stated guidelines for care of instruments. These guidelines are generally true for the proper care of levels, although levels may be shouldered and carried; they should be carried as vertical as possible. Additional guidelines are:

- Do not spin or bounce pendulum levels, as such movement can damage the compensator.
- Protect the level from dust. Dust or foreign matter inside the scope can cause the compensator's damping device to hang up.

- Check adjustment of the bull's-eye bubble. Make certain it remains centered when the level is rotated 180 degrees. Proper adjustment reduces the possibility of compensator hang-up.
- To check for compensator hang-up, lightly tap the telescope or lightly press on a tripod leg. If the instrument has a push-button release, use it. If the compensator is malfunctioning, send the instrument to the Construction Bureau for repair.

Care and Adjustment of Leveling Instruments Most of the comments dealing with care of instruments earlier in the chapter apply to all surveying equipment, including levels. Typically, only line of sight and bull's-eye bubble adjustments are needed for the automatic and digital levels used by the Department.

The bull's-eye bubble is adjusted first. Center the bubble and rotate the telescope 180 degrees. The bubble should remain close to the center. If not, adjust the bubble one half of the distance to the center using an adjusting pin. Center the bubble and rotate the telescope 180 degrees. Repeat the procedure until the bubble remains close to the center when the telescope is rotated 180 degrees.

The line of sight is checked next and adjusted using what commonly is known as "pegging the instrument." To adjust the line of sight of an automatic level, drive two hubs approximately 200 ft (60m) apart (hub "A" and hub "B"); drive them at a slight angle so that each has a definite high point. Set up at the midpoint between the two hubs and take readings on both hubs A and B; record the readings as "a" and "b." Then set up about 10 ft (3m) from hub B. Take readings on both hubs A and B again; record the hub B reading as "c" and the hub A reading as "d." The readings are used to determine whether the cross hair in the level needs to be adjusted. Do not move the instrument from the hub B location until you confirm that the line of sight is within tolerance:

- The true difference is a - b
- The false difference is d - c
- If a - b and d - c agree within 0.01 ft (0.003m), no adjustment is needed

If the difference is more than 0.01 ft (0.003m), the cross hair needs adjustment. The correct reading, d', is equal to d + [(a - b) - (d - c)].

For an example of pegging the instrument, assume:

- a = 4.97
- c = 5.83

- b = 5.72
- d = 5.02

Then, a - b = -0.75 and d - c = -0.81. The difference between a - b and d - c is greater than 0.01 ft, so the cross hair needs adjustment. The correct reading is d' = 5.02 + [(-0.75) - (-0.81)] = 5.08 ft. With the level still near hub B, raise the cross hair from 5.02 ft to 5.08 ft. Refer to the operator's manual for the correct procedure for adjustment of the cross hair. After making the adjustment, check it by repeating the peg method described above. The four readings may be estimated to the nearest 0.002 ft (0.001m) to keep random errors to a minimum.

The line of sight in a digital level should be adjusted using methods specific to the particular digital level being used. The operator should refer to the manual supplied with the level.

Digital Levels Differential levels associated with the control survey should use a digital level and the corresponding digital rod. It is recommended that digital levels be used for all surveys that require elevations such as additional control marks established after the control survey has been completed and photo control marks.

The digital level may be used as an optical instrument. In this case the instrument's line of sight should be verified and if required, adjusted using the "pegging method" as discussed in this section.

The Department provides their survey crews with the DiNi™ digital levels; however, equivalent digital levels are acceptable. The following outlines the suggested settings associated with the DiNi™ digital level. The instrument parameters, step VI e, must be verified and set **before** other settings are made. Additional information in a PowerPoint presentation is available on the intranet at http://www.mdt.mt.gov/publications/manuals.shtml#survey

I. RPT (Keypad #1)
   a. Number of measurements - 3 to 5
   b. Standard deviation – 0.01 ft (0.003m)

II. INV (Keypad #2)
   a. Inverted rod - NO

III. PNr (Keypad #4)
   a. Input individual point number (iPNo) or toggles to input current point number (cPNo)

b. Upper or lower case alpha and/or special characters **(if alpha selected-always use UPPER case)**

IV. REM (Keypad #5)
a. Input point code - upper or lower case alpha and/or special characters

V. EDIT (Keypad #6) **DO NOT ATTEMPT TO EDIT OBSERVATIONS IN THE INSTRUMENT**

VI. MENU (Keypad #7)
- a. INPUT
  - i. Maximum distance – 200 ft (60m)
  - ii. Minimum sight – 0.5 ft (0.15m)
  - iii. Maximum difference – 0.005 ft (0.0015m)
  - iv. Refraction coefficient – 0.140
  - v. Vertical offset – 0.00 ft (0.000m)
- b. ADJUSTMENT
  - i. Select Japanese method
    1. Curvature correction - ON
    2. Refraction correction - ON
- c. DATA TRANSFER
  - i. Interface 1
    1. DiNi™ - Periphery (Transfers data via HyperTerminal™)
    2. Periphery-DiNi™
    3. Set parameters
       - a. Format - REC E
       - b. Protocol - XON-XOFF
       - c. Baud rate - 9600
       - d. Parity - NONE
       - e. Stop bits - 1
       - f. Time out - 10 seconds
       - g. Line feed - yes
       - h. Name - COMP1
  - ii. Interface 2 - Same as above (generally not required)
  - iii. PC-demo - OFF
  - iv. Update/Service – IGNORE THIS OPTION
- d. SET RECORD PARAMETERS
  - i. Recording of data
    1. Remote control - OFF
    2. Record - IMEM

            3. Rod reading - R-M
            4. PNo Increment - 1
        ii. Parameter setting
            1. Format - REC E
            2. Protocol - XON-XOFF
            3. Baud rate - 9600
            4. Parity - NONE
            5. Stop bits - 1
            6. Time out - 10 seconds
            7. Line feed – YES
    e. SET INSTRUMENT PARAMETERS
        i. Height unit – FEET (METERS)
        ii. Input unit – FEET (METERS)
        iii. Display R – 0.001 ft (0.0001m)
        iv. Shut off - 10 minutes
        v. Sound – ON
        vi. Language - E 300

3.1.3.7 Tripods

Tripods provide a fixed base for all types of surveying instruments and sighting equipment. Instrument manufactures have standardized surveying tripods. The typical tripod has a 5/8-inch diameter x 11 threads per inch instrument fastener that secures the instrument or the tribrach to the tripod head. The centering range is approximately 1-1/2 inches.

Care of Tripods A stable tripod is required for precision in measuring angles. A tripod should not have any loose joints or parts that might cause instability. Some suggestions for proper tripod care are:

- Maintain firm snugness in all metal fittings, but never tighten them to the point where they will unduly compress or injure the wood, strip threads, or twist off bolts or screws.
- Tighten leg hinges only enough for each leg to just sustain its own weight when legs are spread out in their normal working position.
- Keep metal tripod shoes tight.
- Keep wooden parts of tripods well painted or varnished to reduce moisture absorption and swelling or drying out and shrinking.
- Replace the top caps on tripods when they are not in use or store the tripods such that the tops are not damaged.

- The most damage occurs to tripods when being placed into or taken out of survey vehicles. The life and usefulness of tripods can be significantly extended if compartments are constructed such that the tripod is not riding on or against other equipment.
- Wet tripods should not be stored with the leg extensions clamped.

3.1.3.8 Level Rods

Philadelphia Rod At one time the Philadelphia rod was the most widely used rod. This type of rod is made in two sliding sections held in contact by two brass sleeves. For readings seven feet or less, the back section is clamped in its normal clamped position. For greater readings, the rod is extended to its full length such that graduations on the front face of the back section are a continuation of those on the lower front strip. When extended, the rod is called a “high” rod.

Fiberglass Rod Twenty-five-foot and five-meter fiberglass rods have generally replaced the Philadelphia rod. These level rods are widely used by the Department for slope staking, bench levels and the determination of miscellaneous elevations. The added height reduces turns and its relatively short sections make it easy to transport. Although they are made of strong, resilient fiberglass, they require specific care to remain serviceable and accurate. Use the following guidelines:

- Grit and sand can freeze the locking system of the slip joints. The close fit of these joints will not tolerate foreign matter. Do not lay a fiberglass rod in sand, dust, or loose granular material.
- Lower the sections as the rod is being collapsed. Do not let them drop. Dowels through the bottom of a section keep the section above from falling inside that section. Dropping sections during collapsing will loosen the dowels and jam the telescoping. It can also shatter the fiberglass around the dowel holes.
- When the slip joint goes bad, remove the rod from service.

Fiberglass rods are *not* to be used for differential levels associated with the determination of project control marks.

Foldable Rod These rods have advantages over the fiberglass rod since there are fewer moving parts. This type of rod is recommended for differential levels associated with control marks and bench levels in lieu of the fiberglass rod.

Checking Accuracy of Level Rods An approximate check to determine if a level rod has excessive error is to extend the rod and check foot (meter) marks throughout the length of the rod with an accurate tape or chain. Do this at the beginning of control level surveys. If the rod indicates a tendency to be off, it should be checked each time it is extended. A rod that is off by 0.01 ft (0.003m) will accumulate error but can show a perfect closure when the level circuit is closed on itself.

Care and Maintenance of Level Rods Level rods should be maintained and checked as any other precision equipment. Accurate leveling is as dependent on the condition of the rods as on the condition of the levels. Reserve an old rod for rough work, such as measuring sewer inverts, water depths, etc. The care requirements common to all types of rods are:

- Protect rods from moisture, dirt, dust and abrasion.
- Clean graduated faces with a damp cloth and wipe dry. Touch graduated faces only when necessary and avoid laying the rod where the graduated face can come into contact with other tools, objects, matter or materials or may become soiled.
- Do not abuse a rod by placing it where it might fall; do not throw, drop or drag a rod, or use it as a vaulting pole.
- Keep the metal shoe clean and avoid using it to scrape foreign matter off a bench mark or other survey points.
- If possible, leave a wet rod uncovered, unenclosed and extended until it is thoroughly dry.
- Store rods either vertically (not leaning) or horizontally with at least 3-point support, in a dry place and in their protective cases.
- Periodically check all screws and hardware for snugness and operation.

3.2 MEASUREMENTS

3.2.1 ANGULAR MEASUREMENTS

Horizontal angular measurements are made between survey lines to determine relative directions of the lines. When horizontal distance measurements are applied to the derived direction, the relative position of a point is established. Horizontal angles are measured on a plane perpendicular to the vertical axis (plumb line) and always clockwise in relationship to the initial backsight. The directional method will be used exclusively for surveys associated with control traverses, ties to photo control points, cadastral surveys (right-of-way, property corners and property controlling corners) and secondary control traverses.

Zenith angular measurements are measured to determine the slope of survey lines from the horizontal plane (level line). Zenith angles are used to determine horizontal distance and vertical distances. A zero degree zenith angle is directly above the instruments

In the United States, the sexagesimal system of angular measurement is used. There are 360 degrees in the circumference of a circle. A degree is divided into 60 minutes (60'), and a minute is divided into 60 seconds (60") and decimals of a second.

3.2.1.1 Terms

The following terms are defined specifically for angular measurement as used in this manual. Their meanings may differ slightly in other contexts.

- Pointing — A pointing consists of a single sighting and reading on a single object.
- Observation — An observation is a single, unadjusted determination of the size of an angle.
- Mean — The mean (average) is the final determination of the magnitude of an angle before adjustment. At least two observations are required before a mean can be determined.
- Backsight (BS) — A backsight is a survey point that is used as an initial sight for orientation when measuring horizontal angles and directions.
- Direction — A direction is the value of a clockwise angle between a backsight and any other survey point. The readings of each backsight are reduced to zero

degrees, and the directions to the other survey points are computed from this survey point.

- Setting the Circle — Setting the circle is the act of setting a specified horizontal reading while the telescope is pointed toward a backsight. Generally zero degrees, or the calculated “back azimuth,” or a predetermined setting is used.
- Direct and Reverse Readings — A direct reading is taken with the telescope in the upright position with the vertical circle on the left (left face). A reverse reading is with the telescope inverted and the vertical circle (zenith circle) on the right (right face).
- Position — A position consists of two direct and two reverse horizontal readings (two observations). For a directional instrument, the horizontal circle remains stationary for a given position but is reset for each new position. Notes for angles turned using the directional method are grouped by position. More than one position may be required.
- Set of Repetitions — A set of repetition angles is a series of observations of the same angle. Each observation is accumulated on the horizontal circle of the instrument. Half a set is measured in the direct mode and the other half in the reverse mode.

3.2.1.2 Importance

Determination of the direction of a line, azimuth or bearing is a fundamental requirement for establishing the horizontal position of one point and its relationship with any other point in the survey.

Distance and angular measurements are of equal importance in establishing point positions. Angular errors are by far the most difficult and expensive to isolate and correct. Analysis of a traverse closure error can sometimes reveal the types of errors and aid in their elimination.

3.2.2 COORDINATE MEASUREMENTS

Most total stations have the capability to locate or stake out points using coordinates. This method may be used to stake miscellaneous items such as signs and signals. Caution should be used when using this function for various reasons, such as, it produces no written record, some total stations do not allow for consideration of a scale factor and there is a possibility of inputting incorrect coordinate values and HI’s.

3.2.3 VERTICAL MEASUREMENT

A survey may require vertical measurement in addition to linear and angular measurement. Vertical measurements establish the differences in elevation between survey points.

3.2.3.1 Importance

The determination of accurate elevations is an extremely important part of the information required for the design of highway projects. Grade lines, drainage structures and other highway features are designed in relation to existing and final elevations. Volumetric quantities are determined by preliminary (before) and final (as-constructed) cross sections or by a digital terrain model (DTM).

Due to its importance in all other phases of the project, vertical measurements to establish primary vertical control are made at an early stage in the survey. Differential levels are used to establish elevations for all project control monuments. These control monuments are then used to extend the vertical control through the project area. Subsequent level loops between the control monuments, again by differential leveling, are used to establish vertical control for photogrammetric, preliminary, construction, or additional control monuments.

3.2.3.2 Planning

By the time a project is completed from preliminary through the construction phase, each bench mark will have been used many times to provide the base for vertical measurement. Proper planning in anticipation of the future uses of vertical control points (bench marks) is as essential as that required for the horizontal control. Some considerations for the placement of horizontal and vertical points are:

- location of the primary control (project control monuments)
- permanence (outside of anticipated construction limits — do not set in fence lines, next to trees or buildings)
- accessibility (on the right of way or other accessible lands)
- type of monument set — concreted monuments (permanent), rebars (semi-permanent) and wooden hubs (temporary)

- bench mark spacing is generally at 1,000 ft (250m). Keep in mind that the horizontal control points can be used as bench marks — in other words, projects may not require the traditional bench marks if all control points have elevations
- estimated final design grade
- visibility

3.2.3.3 Methods

Vertical measurements are made directly or indirectly. The choice of the method and its procedures depends on present and future accuracy requirements and the relative cost. Consider these items in selecting the method and procedures:

- the precision of the survey should be compatible with the accuracy of the controlling monuments
- the type of equipment available
- the future survey needs

Direct Vertical Measurement This method refers to the direct reading of elevations or vertical distances. Direct elevations can be determined using altimeters, differential levels and profile levels.

Indirect Vertical Measurement Indirect vertical measurements require the use of calculations to determine elevations or vertical distances. Trigonometric levels are one example.

Prior to the development of total stations, almost all vertical measurements on highway projects were made by differential leveling. Trigonometric measurements using total stations can be a cost effective method of making vertical measurements, but some precautions need to be taken.

3.2.3.4 Differential Leveling

Equipment The standard instruments for all differential leveling are the optical or the digital levels.

The Department primarily uses fiberglass or foldable leveling rods. Each type of rod has its particular advantage under certain field conditions. Any rod used should be clean, "tight," and have properly indexed scales. Check slip-joint rods for index periodically.

Instrument Setups The following guidelines pertain to instrument setups:

- Do not waste time by deeply embedding tripod feet. Settlement is usually insignificant. Avoid setups on hot pavement or in spongy or muddy soil.
- Set turning points so that the backsights and foresights for each setup are approximately equal. This compensates for curvature and refraction and for systematic errors in the instrument.
- Use sight distances that best fit the terrain and are the most comfortable for the instrument operator. Sight distances should not exceed 200 ft (60m).
- In steep terrain, place "turns" and instrument setups so they follow parallel paths (not along the same line).
- Take an extra turn rather than try to read the bottom or top of the rod.
- Periodically test the level to be certain the pendulum compensator is working. Point on a "natural" sight with the telescope over a foot screw and turn the screw back and forth or lightly tap the instrument. If the cross hair dips and returns to its original position, the compensator is working properly.

Turning Points and Bench Marks

- Set bench marks in stable, protected locations. Do not set spikes in utility poles because they may be hazardous to utility workers. Wooden stakes and hubs should be used only as temporary bench marks. The project control monuments should be used as the primary bench marks.
- Make each turn stable and with a definite high point. If a TP does not have a prominent point, mark the exact point with keel or paint.
- All bench marks should be described as to type (aluminum cap, red plastic cap, Morasse™ cap and rebar, etc) and include its location.

Rod Reading

- Eliminate parallax before any readings are made.
- Do not deliberate over readings. Read and call them out in a moderate rhythm.
- Whenever possible, plumb the rod with a rod bubble. In the absence of a rod bubble, slowly rock the rod toward and away from the instrument. The observer reads and records the lowest reading. The rod must be set on a sharp or

rounded projection; otherwise, the rod will rise as it is rocked and will result in a false reading.

- Avoid low, ground-skimming shots where refraction might become pronounced. Also, avoid sighting close to obstructions that might diffract the line of sight — if possible, no closer than 1 ft from an obstruction.
- Read and record to the nearest 0.01 ft (0.002m).
- Record exact splits always high or low.

3.2.3.5 Single-Wire Levels

Single-wire leveling is the most common and widely used method of vertical measurement. With proper attention to procedures, third-order accuracy may be achieved with single-wire leveling. Some of the methods will be described in general terms only. Detailed procedures may be found in publications such as those listed in Appendix B. Sample notes showing a level loop associated with a control traverse is shown in Appendix A.

Normally, single-wire notes are reduced to height of instrument (HIs) and elevations as the survey progresses. To check the elevations of bench marks (BMs) that are turned through, differences in elevations are calculated. In the case of a level loop, the algebraic sum of the backsight and foresight should equal the ending elevation of a BM minus the starting elevation of a BM. See the sample notes in Appendix A for examples. Side shots will not be used to establish any temporary bench marks (TBMs), BMs, elevations for photo control, or project control monuments.

Differential levels can be used to establish new elevations between previously established vertical control points. If the vertical error is within tolerances then a return is not required. Caution is necessary if differential levels are used to establish new elevations and the return is made to the starting vertical control point.

3.2.3.6 Double-Turn Point Leveling

This technique uses two parallel, independent foresight and backsight turn points (TPs) for each HI. Each pair of TPs is set, if possible, at an appreciable difference in elevation (preferably one-half foot or more). They are also set a few feet apart so the level will have to be rotated slightly between the two rod readings.

From each set-up, single-wire plus shots are read on both backsight TPs; minus shots are read on both foresight TPs. Notes are kept separately for each line of levels. The adjusted elevations from the two lines of TPs are averaged.

The system has some advantages in that the HI is determined from each of the two lines and misreading or misleveling blunders can be isolated immediately. However, the system is time-consuming and both lines are run in the same direction, which may not cancel systematic errors. There is also a danger in misreading the initial backsight and the final foresight. Therefore, this method should only be utilized in unique situations.

3.2.3.7 Three-Wire Leveling

With this leveling technique, the cross hair and both stadia hairs are recorded. Stadia intercepts of plus and minus shots are accumulated. The running totals are constantly monitored so balance can be maintained between totals of foresight and backsight distances. The backsights and foresights should be balanced within 32 ft (10m). Sample notes are included in Appendix A.

This technique is generally preferred over previously described methods when elevations that are more accurate are required. With the advent of digital levels, there are few reasons for the Department to use three-wire leveling. Its special requirements are below.

Instruments The Department uses levels with either a stadia ratio of 0.3 to 100 or 1.0 to 100. For precise levels, the 0.3 to 100 ratio is preferred because the stadia hairs are nearer the optical center. It also permits a greater elevation difference between the level and the TP while keeping all three cross hairs on the rod.

Most of the Department's instruments are equipped with the 1.0 to 100 stadia ratio and their use is acceptable. Spacing of the setups and TPs will need to be adjusted for the instrument used.

Rods The Department does not have invar rods suitable for three-wire levels. It is recommended that the best rod available be used on these surveys. Even new rods should be checked upon delivery, as some rods have been found to be off.

Instrument and Rod Checks Before starting each day's run, test the level for collimation error (pegging the instrument). Test at or near the first setup of the day and record the process in the field notes. If the error exceeds 0.01 ft in 200 ft (0.003m in 60m), the instrument should be adjusted. Any time the instrument has a severe jolt or bump, the instrument should be pegged.

Check the rod in the raised position to ensure there is no index difference above and below the slip joint. Recheck the rod each time it is extended.

Setups Keep all sights within 200 ft (60m). When rejected readings average more than two in every ten, shorten the sighting distance.

Turning Points and Bench Marks Railroad spikes, boat spikes, wooden stakes or hubs may be used for TPs. Permanent BMs should be numbered so they can be identified when recovered.

Bench marks can be set prior to or during leveling. Check all found monuments that are to be incorporated in the level line for stability.

Rod Readings Plumb the rod with an accurate rod level. Do not use the wave method for three-wire levels. Start the rod reading with the top stadia wire, and progress to the bottom wire. Estimate readings to the nearest 0.003 foot (0.001m). Read at moderate speed, without deliberations. Do not turn or pick up the instrument until the note keeper has verified the spread. If the spread between top and center wire and bottom and center wire exceeds 0.005 ft (0.002m), re-read all three wires. The original readings should be crossed out and new readings entered on the next line. In some cases, it may not be necessary to provide all checks as shown in the sample notes.

Level Line (Loop) The highest order of accuracy required can normally be met by a single run of three-wire levels using an optical level or a single run using a digital level between existing NGS benchmarks or project control marks. If the levels fail to close within the tolerance specified, one of several problems may exist, including but not limited to the following:

- There may be a discrepancy between the elevations of the beginning and closing bench marks. Be sure that the data sheet is the most current for the two bench marks. (There is a possibility that one or both of the benchmark elevations have been readjusted.) If the latest information was used, carry the survey to the next NGS benchmark.
- The benchmarks may be on different lines.
- You are mixing NGS and USGS bench marks (NGVD29 and NAVD88).
- You made a reading or calculation error.
- One of the two bench marks have been disturbed.

If the possibilities above do not account for the discrepancy, the run should be re-leveled in the opposite direction.

3.2.3.8 Trigonometric Vertical Measurement

Trigonometric vertical measurement is a procedure in which vertical differences in elevation are computed from slope distance and zenith angle measurements. HIs and height of sights (HSs) are required.

The development and continuing refinement of total stations are making rapid changes in the use of trigonometric vertical measurements. These instruments are of varied vertical angle accuracy and certain procedural restrictions must be applied.

Use Trigonometric levels may be used in certain cases to establish elevations in rolling to steep terrain. They are also useful for other types of surveys. Some of these are:

- check levels for long differential lines
- establishing low order bench marks by precise vertical traversing (when accuracy is difficult to attain at reasonable expense by differential leveling)
- slope staking
- cross sectioning
- topographic surveys in conjunction with total stations and data collectors
- in certain situations, photogrammetry control marks
- observations (reciprocal) to check GPS derived elevations

Accuracy Attainable The accuracy that can be obtained from trigonometric levels depends on the individual accuracies of the following:

- error in the measurement of the HI and HS
- amount of curvature and refraction in the distance measured
- error in the slope distance (minimal source of error)

Differential Versus Trigonometric Levels Differential leveling is the preferred method for obtaining elevations. Differential levels are used exclusively for the establishment of bench marks and elevations of project control marks (conventional control surveys). In some cases, trigonometric levels may be used to obtain elevations of photo control points. Trigonometric levels are generally used to obtain elevations of miscellaneous points that will be used only for the collection of topography.

3.2.4 LINEAR MEASUREMENT WITH TAPES

Surveyor's tapes are available in various lengths, of different materials and with many methods of graduations. Although the use of total stations has replaced tapes for long measurements, every crew should have a metallic and non-metallic tape available.

3.2.4.1 Taping

Use the following guidelines when taping:

- Do not become careless when plumbing over a point.
- Keep the correct tension on the tape. Tapes of 100 ft or less require 10 pounds of tension when supported along their entire lengths. Light steel tapes stretch 0.01 to 0.02 ft in 100 ft if the tension is increased to 20 pounds.
- Avoid sag by applying the proper tension to the tape.
- Apply the appropriate temperature correction factors for the taped measurements. Tapes are calibrated at 68° F. They expand or contract 0.0000065 ft per ft for each degree of change above or below 68 degrees.
- Ensure that the tape is the correct length.

3.2.4.2 Care and Maintenance of Tapes

Tape reels for metallic or fiberglass tapes save time and help prevent damage to the tape, particularly if used in construction or heavy traffic areas.

Routine care extends tape life. The following are basic guidelines for care of metallic tapes:

- After the day's work, clean and dry tapes that are soiled. In wet weather, lightly oil and then dry tapes before storing. Avoid storing in damp places.

- Clean rusty tapes with fine steel wool and cleaning solvent or kerosene. Use soap and water when tapes are dirty or muddy. To prevent rust after cleaning, oil lightly and then dry the tapes.
- Use chaining clamps to avoid kinking the tape.
- Do not place a tape where it can be stepped on or run over, unless the tape is flat, taut and fully supported on a smooth surface.
- Leave the tape on the reel unless you are making a series of pulls that are full-tape lengths. Do not wind tapes excessively tight on their reels, as it can cause unwanted stresses.
- Keep the tape straight when in use. When dragging a tape between points, watch carefully for loops forming. When pulling a slack tape, a loop can develop into a kink and easily break the tape, especially when going down hill.

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3.3 ERRORS, CORRECTIONS AND PRECAUTIONS

Factors that might influence the occurrence of errors can be roughly divided into five classes: instrument, personal, natural, random and systematic. The first three types of errors are covered below. Random and systematic errors are addressed in Chapter 4.

3.3.1 INSTRUMENT ERRORS

Make adjustments at regular intervals and particularly before starting work on a control survey. Make the adjustments under the most ideal conditions available, normally in the highway yard or shop on an overcast day. Instruments requiring major adjustments should be serviced at an authorized repair shop.

3.3.1.1 Collimation

Collimation errors associated with total stations may be determined by following the procedure outlined in the user’s manual. If either horizontal or vertical collimation errors are found to be excessive, these errors should be eliminated by following proper procedures or request the Construction Bureau arrange for adjustment at an authorized repair center. Horizontal collimation errors are compensated for if a position is turned (two direct and two reverse observations on the back sight and the corresponding foresight). Vertical collimation errors are important if only single face observations are utilized, as is the case for most topographic surveys using the total station and data collector. Excessive vertical error will affect elevations of all observed topographic points.

3.3.1.2 Plate Bubbles, Bull’s Eye Bubble and Optical Plummet

Normal measuring procedures do not compensate for maladjustment of either the plate bubble(s) or the optical plummet. These components must be checked more frequently than others.

Check the optical plummets prior to commencing a control survey. Check the plate bubbles routinely on each setup. If you detect error, adjust the bubbles for the mean of the error. The bull’s eye bubble should be adjusted after the plate bubble. Refer to the manual supplied with the instrument.

3.3.1.3 Parallax

Parallax occurs when the focal point of the eyepiece does not coincide with the plane of the cross hairs. The condition varies for each observer because the focal length depends in part on the shape of the observer's eyeball. Parallax is also a major concern in the optical plummet.

Check for parallax every time you begin to operate a new instrument or one that has been operated by someone else. Check the optical plummet on every setup, particularly if the HI is significantly different from the last setup.

To check for parallax in the telescope, focus the telescope on some well-defined distant object. Slowly move the head back and forth, about an inch from the eyepiece, while watching the relationship of the object to the cross hairs. If the object appears to move, parallax exists.

Parallax associated with the optical plummet can be checked in a similar manner to that of the telescope.

To eliminate parallax, rotate the knurled eyepiece ring until the cross hairs are the thickest and blackest, refocus and check for parallax as described earlier. If parallax still exists, repeat the procedure.

3.3.2 PERSONAL ERRORS

3.3.2.1 Error in the Measurement of the HI and HS.

It is important that these errors do not occur. If either the HI or the HS is measured incorrectly, this error may not be detected. Error in the measurement of the HI of a total station will result in an incorrect elevation of all observed points from that setup. Measuring and recording of the HI in both feet and meters is advisable. An error in the HS of an individual foresight point will affect the elevation of only that point.

3.3.2.2 Setting Up the Instrument

Use the guidelines below for setting up an instrument:

- Be sure the tripod is in good condition and all hardware is snugly fitted.

- Push the tripod shoes firmly into the ground. Do not stamp on the tripod feet. Pressure should be parallel to each leg.
- Place the legs in positions that will require a minimum of walking around the setup. In windy conditions, additional stability can be achieved if one leg is set downwind.
- On hillsides, it is advisable to set one leg uphill and the other two legs downhill.
- If the ground is soft or muddy, drive hubs into the ground to support the tripod legs.
- Be sure the instrument is set properly over the point.
- Check the optical plummet after the instrument is set up and just before moving to another point. If the instrument has moved, check the angle just measured.
- Recheck the instrument level. The bubble should remain within one graduation when the instrument is smoothly turned through one circle (if the instrument is shaded).

3.3.2.3 Setting Sights

When tribrach-mounted prisms are used, take the same precautions as when setting up an instrument. With this equipment, “forced centering” between the prisms and the total station (and vice versa) greatly decreases the effects of plumbing errors in traverse closures. Forced centering is especially beneficial in short-course traverses. Forced centering is the traverse procedure whereby backsight, instrument point and foresight are “leap-frogged.”

Once a tribrach is set over a point, it stays mounted on the tripod over that point for all uses. The instrument and sights are transferred from point to point without disturbing the tribrach setup. This is standard procedure for the control traverse.

Use these guidelines for setting sights:

- Always check a sight before picking up to see that it has not moved.
- When setting a pole sight, plumb it with a precision equal to that required for the total survey. A twenty-second error results from a sight that is one-tenth out-of-plumb and 1,000 ft away.
- If a sight is set near ground level, check the line of sight for obstructions or for excessive heat waves. On very warm days, ground-level sights are not advisable.

3.3.2.4 Pointing

Tangent Screw Use When moving onto a target, always make the last turn of the tangent screw clockwise. Clockwise movement increases the tension on the loading springs. A final turn counter-clockwise releases tension and the spring can hang up, causing a “backlash” error.

Cross Hair Use Sight each object with the same part of the cross hair, preferably near the center of the field of view. This practice minimizes small residual adjustment errors.

The human eye can estimate the center of a wide object more accurately than it can line up two objects. For this reason, different pointing techniques should be used depending on the type and apparent size of the sight in the telescope.

When pointing on narrow sights, such as the center of a red and white target or distant range pole, straddle the sight with the double cross hairs. When pointing on wide sights, such as a lath or range pole at close range, split the sight with the single cross hair.

False Sights Reflective surfaces, such as vehicle headlights, mirrors, windowpanes, etc., can cause false readings, as well as multiple prisms along the line of sight. Always recheck measurements that could be reflected from such reflector surfaces.

3.3.2.5 Measuring Angles

Measure angles as rapidly as comfortably possible with a uniform rhythm. Take the first reading at an object, rather than fidgeting with the tangent screw trying to improve the pointing. Too much pointing time increases the probability of error through instrument settlement or atmospheric changes. Speed; however, should not be cultivated at the expense of good results. Accuracy is more important than speed.

3.3.2.6 Readings

If field notes are being taken, carefully read and call out each reading to the recorder. Call out the entire reading each time so any large blunders are caught. Have the recorder repeat the reading to the instrument operator after it is recorded.

3.3.2.7 Analyzing Field Notes

Many recording errors and inconsistencies can be caught by carefully analyzing the observations. These items should be checked in the field by the recorder and then rechecked in the office. Examples are:

- Spreads between the seconds of direct and reverse readings should be consistent and in the same direction throughout the set.
- The sums of the direct and reverse zenith angles should be consistent.
- When the direct and reverse observations of a position are in different minutes, be sure the average second value is coupled with the correct minutes value.

3.3.3 NATURAL ERRORS

3.3.3.1 Differential Temperatures

Bright sunlight striking certain parts of the instrument may cause differential expansion of the metal components of the instrument, resulting in small errors.

3.3.3.2 Heat Waves

On a hot day, heat waves can cause distortion of lines of sight near a reflecting surface. Control traverses should be halted if excessive heat waves are present.

3.3.3.3 Phase

If a sight is not evenly lighted on both sides, the instrument operator tends to point toward one side. This phenomenon, called “phase,” can be reduced by using a target with a flat surface pointed directly toward the instrument. The targets attached to the prism are useful in reducing phase.

3.3.3.4 Refraction

When light waves pass from a medium of one density into a medium of a different density, the rays change in direction (bend). The change in direction is called refraction. Because sight lines are light rays, they are refracted, or bent, by changes in the atmosphere, causing small errors in angular measurement.

Normally, the lateral refraction is insignificant in most surveys, but its effects can be further minimized by understanding and avoiding situations producing the largest refraction of line of sight. Some of these situations are:

- When the sun shines on a barren, dark surface, the surface warms relatively quickly. This warms the air, and if calm, it produces a column of warm, light air rising from the surface. Examples are:
- dark, freshly plowed fields lying between lighter colored areas of growing crops
- clear areas between heavy forests
- large bodies of warm water between land areas
- Open valleys bordered by bluffs on either side can result in refraction. If a line must pass over a valley, set the observation points as far back from the edges of the valley as possible.
- Air tends to layer parallel to the slopes of embankments or the base of foothills.

When refraction is probable in angles to be measured, or is suspected in angles that have been measured, recon the survey area and plan station locations to avoid the problem conditions listed above.

3.3.3.5 Curvature and Refraction

Curvature corrections deal with the curved surface of the earth. Generally, curvature and refraction are grouped together. In most cases, it is assumed that refraction offsets curvature by 14 percent.

The combined effect of curvature and refraction can be eliminated only by reciprocal zenith angles. Reciprocal zenith angles consist of observations at each end of the line. Reciprocal zenith angles must be used for all photo control points if the observation is from a single control point. Curvature and refraction may be compensated by:

- enabling curvature and refraction in the total station (approximate)
- performing mathematical calculations (approximate)

Total stations should have curvature and refraction enabled to correctly calculate the vertical and horizontal distances. If a data collector or surveying software is used to generate 3D coordinates from raw data, curvature and refraction should also be enabled to correctly generate 3D coordinates. Generally, curvature and refraction has more of an effect on the vertical distance than the horizontal distance.

The amount of curvature and refraction is a function of distance and atmospheric conditions. The effect is not proportional. For example, the curvature and refraction associated with a distance of 1,000 ft is 0.026 ft, but at a distance of 3,000 ft it is 0.185 ft.

The sample notes in Appendix A (Figure A-7) indicates the required information necessary to determine the elevation of a photo control point using trigonometric levels. It is important that all the information shown in the samples be included in your field notes.

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BASE LINE USER REPORT

BASE LINE DESIGNATION:	**HELENA CBL**		
INSTRUMENT OWNER:	MDT		
CREW:	COBARRUBIAS/BAUER		
COUNTY:	LEWIS & CLARK		
DATE:	01/15/03		
WEATHER:	OVERCAST, COOL		
INSTRUMENT:			
MAKE:	SOKKIA		
MODEL:	SET 2110		
SERIAL NUMBER:	D21817		
	mm	ppm	
STANDARD DEVIATION:	2	2	
REFLECTOR:			
MAKE:	SOKKIA		
MODEL:			
CONSTANT:	-30mm		

MARK TO MARK

Instrument Station	0 M	0 M	0 M	150 M	150 M	430 M
Reflector Station	150 M	430 M	1070 M	430 M	1070 M	1070 M
Temperature	5c	5c	5c	5c	5c	5c
Pressure	892mbars	892mbars	892mbars	892mbars	892mbars	892mbars
PPM	25ppm	25ppm	25ppm	25ppm	25ppm	25ppm
Height of Instrument (1)	1.443	1.443	1.443	1.350	1.350	1.420
Height of Reflector (1)	1.386	1.365	1.326	1.365	1.326	1.326
DH=HI-HS	0.0570	0.0780	0.1170	-0.0150	0.0240	0.0940
Measured Distance (Five Readings)						
1	150.0060	430.0010	1070.0210	279.9990	920.0090	640.0200
2	150.0050	430.0010	1070.0170	280.0010	920.0080	640.0190
3	150.0050	430.0010	1070.0150	280.0020	920.0100	640.0190
4	150.0050	430.0020	1070.0160	279.9980	920.0100	640.0200
5	150.0030	430.0000	1070.0160	280.0020	920.0090	640.0190
Average Measured Distance	150.0048	430.0010	1070.0170	280.0004	920.0092	640.0194
Measured Distance in Feet (2)	492.142	1410.764	3510.567	918.632	3018.400	2099.803
Observed Mark to Mark Distance	150.0048	430.0010	1070.0170	280.0004	920.0092	640.0194
NGS Mark to Mark Distance (3)	150.0069	429.9974	1070.0118	279.9908	920.0050	640.0144
Difference	0.0021	0.0036	0.0052	0.0096	0.0042	0.0050
2 x Standard Deviation	0.0046	0.0057	0.0083	0.0051	0.0077	0.0066

NOTES:

(1) Make all measurements including HI and HS in meters except for one slope distance in feet.

(2) This distance is for a check only and should not be used to reduce the measured distance from mark to mark.

(3) NGS Measured 2002

Return copy to: Montana Department of Transportation, 2701 Prospect, Helena, MT 59620
Attn: Photogrammetry and Survey Section

Form 3-1
Base Line User Report

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