Survey – Baseline Calibrations

Overview

Equipment must be properly maintained, regularly checked, and calibrated for accuracy at the beginning of any survey project to ensure that the equipment is operating properly. Errors due to poorly maintained or malfunctioning equipment will not be tolerated. These errors will need to be verified and eliminated prior to performing any survey. Ideally, for surveys lasting longer than six months, the checking, and calibration of equipment shall be repeated once every six months to show that the equipment is staying within acceptable tolerances. In the event of an accident, i.e. dropped, run over, etc. the equipment should be calibrated and checked immediately thereafter to make sure it is working and functioning properly. At the minimum, the checking and calibration of the equipment shall be performed once a year, per, WAC 332-130-100 and is stated as follows;

WAC 332-130-100 - Equipment and Procedures. (1) All land boundary surveys filed or recorded shall contain a statement indentifying the type of equipment used, such as 10-second theodolite and calibrated chain or 10-second theodolite and electronic distance measuring unit and procedures used, such as field traverse, photogrammetric survey, global positioning system survey or a combination thereof to accomplish the survey shown;

(2) All measuring instruments and equipment shall be maintained in adjustment according to manufacturers specifications and all distance measuring instruments shall be, at a minimum, compared and adjusted annually to a National Geodetic Survey calibrated baseline.

Equipment Definition

Equipment is defined as any and all types of survey and or office survey equipment used to perform the functions of field surveying. The specifications and procedures as stated in this page are guidelines and shall apply to any and all makes and models of equipment. However, please refer to your instruments' owners/operating manual for the specific maintenance, adjustment, care, use and repair information of your particular instrument.

All electronic survey instruments shall be repaired, adjusted, or calibrated only by an authorized equipment vendor or manufacturers service department.

Federal Published Calibration Baseline Check

The National Geodetic Survey (NGS) conducts a cooperative program that provides surveyors with a means for checking and calibration of errors in electronic distances meters (EDM). Publications are available for the procedures for checking of EDM against a Federal Calibrated Baselines from NGS. The unadjusted baseline length accuracy tolerances shall meet or exceed the manufacturers ratings for the equipment used when checked against a calibrated baseline length for both horizontal and vertical. The checking and calibration of an EDM involves the determination or verification of instrument constants and the assurance that the measured distances meet required accuracy specifications. Although it is not necessary to utilize a measured distance to determine or verify instrument constants, the verification effort is reduced when an accurately measured distance can be used. However, to assure that the measuring capabilities of an instrument have not significantly deteriorated, a known distance of high accuracy or, preferably, a sequence of distances forming a calibration range or base line is required. Experience shows that a base line consisting of four on-line monuments spaced at intervals of 150 m, 400 to 430 m, and 1000 to 1400 m will meet the needs of users for the checking and calibration of EDM.

NGS/NOAA

The following link provides information and downloads of Federal Published Calibrated Baselines in Washington state

http://www.ngs.noaa.gov/CBLINES/BASELINES/wa

Practical Use and Application of a Calibrated Baseline

The primary purpose for comparing a total station's EDM over a calibrated base line is to make sure it is performing within the manufacturer's stated accuracy. Secondly, it is to determine the instrument constants. The constants should be applied to measured distances only after a sufficient history of baseline comparisons have been made. This assumes the optical plummets and plate levels of the equipment are in good adjustment.

Equipment

1. The optical plummet in the alidade or tribrach needs to be checked before going out to the baseline. An adapter is available for adjusting tribrachs in the office, but a plumb bob can be used to check a tribrach in the field to look for gross errors. This is a very important adjustment and care should be used in doing this adjustment by following the instructions in the manual or with the adapter. Check the tribrach for missing screws or for looseness from wear. Clean the tribrach optics so you can better see the point the instrument is supposed to be over.
2. The weather equipment should be in good condition and adjusted. The barometer should be set for uncorrected pressure, not corrected to sea level as given on the radio. The thermometer should also be checked. There should be no air bubbles where the mercury is in the thermometer. The local weather station can check the barometer and thermometer in five or ten minutes for free. If only a dry bulb thermometer is at hand, just record that information.
3. Remember to record the height of instrument and prism to the center of the instrument and the prism and measure this carefully. This is the least accurate part of this operation, but if done with care the highest level of

accuracy can be achieved. While on the Base Line a Meter tape is to be used, because all differences in elevation Mark to Mark are in Meters. Conversion can be made after you finish by the factor derived from: one meter = 3937/1200 Feet. Also all distances should be taken in Meters and Feet to check the internal workings of the Total Station Instrument. Most baselines have supports for the feet of the tripod to insure that the instrument or any of the reflectors won't settle off the mark causing erroneous readings. If there are not supports provided, stakes should be driven into the ground and the legs of the tripods set on these. This is also recommended in the field especially while doing control work. The saying "A building is no better than the foundation it set upon," is especially true in precision surveying.

4. The bull's-eye bubble that comes on tribrachs is at best a good way to get close to the point, for precision a vial bubble that attaches to the tribrach should be used. This gives the tribrachs the same accuracy as the total station that has a vial bubble to level with. This should also be used on all control surveys to achieve the desired accuracy. For a total station the instruments EDM should be checked not only directly to the calibrated baseline itself, but also in conjunction with the methods that will be used to perform the survey such as with a data collector and downloading the data into a survey processing surveying program. The primary purpose for comparing a total station's EDM over a calibrated base line is to make sure it is performing within the manufacturer's stated accuracy. Secondly, it is to determine the instrument constants. The constants should be applied to measured distances only after a sufficient history of baseline comparisons have been made. This assumes the optical plummets and plate levels of the equipment are in good adjustment.

Weather

1. A comparison can only be achieved if the "operator" induced errors are minimized. These include: Leveling instruments and reflectors. Centering or plumbing instruments and reflectors. Applying meteorological (weather) observations. Leveling instruments and reflectors - on the surface this would appear inconsequential, but accumulatively, it is not. Assume the instrument plate bubble is 20" of arc per division. Also assume the target level used for setting up the reflector is 60" of arc per division. If the instrument and reflector are at a height of 1.5 meters (4.92 ft.) over the marks and one division out of level, then the equipment can be off the point by 0.14 mm (0.0005 ft.) and 0.43 mm (0.0014 ft) respectively, or a total of 0.57 mm (0.0019 ft.).

2. Centering or plumbing the instrument should be done with care. In calm conditions, the instrument can be plumbed over the mark to within 0.02 mm (0.00007 ft.) using a plumb bob. Most equipment today utilizes optical plummets, which should be good to within 0.500 mm (0.0016 ft.). Optical

plummets should be checked regularly to ensure they are in adjustment, otherwise considerable error can be introduced.

3. If not taken with care, meteorological observations can induce a significant error in distance measurements. A good rule of thumb is that an error of 1 degree Celsius (1.8 deg. f.) will induce a 1 PPM or 1 mm per 1000 m (0.0033 ft.) error in the measured distance. For microwave instruments the error is even greater. Therefore, to ensure good results, the thermometers should be of a quality to give at least 1 deg. accuracy. Equally critical are the barometric pressure observations. An error in pressure of 0.1 in. of mercury will result in the same 1 PPM error in the measured distance.
4. Each of the above errors is small when considered individually, but assuming the following situation and combining them indicates the necessity to do all operations as accurately as possible.

   Leveling error of instrument (1 div.) 0.140 mm = 0.0005 ft.

   Level error of reflector (1 div.) 0.430 mm = 0.0014 ft.

   Optical plummet (adjusted) 0.500 mm = 0.0016 ft.

   Temp. error 1 deg. C. (1000 m line) 1.000 mm = 0.0033 ft.

   Pres. error 0.1 in Hg. (1000 m line) 1.000 mm = 0.0033 ft.
5. (Nearly half of the single measurement rejection limit of ± 0.02 ft. on any individually measured distance.)

The basic observation procedures are outlined as follows:

Raw observations are collected on either a Calibrated Baseline Worksheet (See Appendix Calibrated Baseline Worksheet) or in a hardbound fieldbook labeled Total Station Log Book along with the instrument's serial number. For a hardbound fieldbook, the normal baseline uses 12 pages for each complete test. If you allow 20 pages for each test, there will be room for analysis, recommendations, and where, when and why the instrument was sent to the manufacturer or a service center for cleaning, adjustment and or repair.

1. Setup the instrument and reflectors over all the marks using care to minimize centering and leveling errors. This allows you to apply the method of forced centering in your calibration. This method allows you to move the total station throughout the course without resetting any tripods. This will enable you to distinguish operator problems from equipment problems.
2. Measure and record instrument and reflector heights above the marks.
3. Let the instrument acclimatize in accordance with manufacturer's instructions prior to making any measurements.
4. Observe and record meteorological observations. Since ambient meteorological conditions have a direct bearing on the results of distance observations and the near topography atmosphere is the most turbulent,

all precautions should be taken to secure accurate data. When making temperature observations, the thermometer should be kept in the shade. Leaving it in the sun will cause significant error. Likewise pressure observations are raw pressure altitude data, not corrected to sea level. Ideally, meteorological observations are made along the entire line, but this is not feasible so the second most desirable method is to make simultaneous observations on each end of longer lines, so the data as observed at the instrument site, and reflector can be averaged.

5. Record the instrument model number, serial number and manufactures specifications, and the reflector model and offset constant, also any instrument constants.
6. Record general weather conditions (i.e. clear, overcast, partly cloudy, rain, etc).
7. Record any unusual or problematic conditions (i.e. frozen ground, muddy, dusty, loud traffic noise, etc.)
8. Observe and record two (2) sets of forward and reverse measurements to and from all stations, so that a mean and standard deviation can be derived for all measurements, including slope distance, horizontal distance, and vertical difference.
9. The zenith angle is to be recorded for both face 1 and face 2 observations to determine that the culmination is correct. The forward and reverse readings totaled should equal 360 Degrees. For a complete calibration test, the recommended procedure is to perform both forward and backward observations over each section of the base line on separate days. This is a recommendation of NOAA and is not a requirement but might be done prior to setting or resetting NOAA markers.

Comparison Set

After all observations are completed and the data is recorded it may be worthwhile to make a comparison set on a long and near distance with a zero weather setting or zero PPM correction dialed in and calculate the corrected slope distance and convert to horizontal distance or mark to mark distance utilizing the instrument and reflector heights and the station elevations as compared with those taken in the calibration test.

Compare the Results with Published distances

The first step in analyzing the results is to compute the differences between the published and observed distances. These differences should then be compared to the manufacturers accuracy statistic, which is given in terms of standard error, or one- sigma, this value is used to test whether your instrument is in true adjustment. The results should also be compared to three-sigma, or three times the manufacturers accuracy specifications.

Prior to continuing, a little background is in order to understand what we are doing. One-sigma means that statistically 68.3% of the differences between a "true value" and the observed value should fall within these limits. However, this is only true for large samples and for known standard errors. Rarely are both of these criteria satisfied. By using the value of one-sigma as a limit for rejecting observations, it is possible that a valid observation may be rejected. To reduce this possibility, a limit of three-sigma is selected to decide if an observation is acceptable or not. Theoretically, 99.7% of the differences should fall within this limit. Most equipment accuracy is stated something like ± (5mm + 5ppm). What the latter term refers to is an additional error dependent upon the distance measured; or in this case the slope error is an additional 5 mm + 5/1,000,000 x the length measured. Getting back to analyzing the observational results, once the difference, one-sigma, and three-sigma are plotted, it is a matter of simple computations. If 68.3% of the differences fall within the manufacturer's stated accuracy, one-sigma, and 99.7% fall within three-sigma, the instrument can be accepted as working accurately and reliably. If this is not the case then the baseline should be run again, using care to minimize the errors, and the results computed and analyzed. If the results are similar to the first time, then there are two options available. Preferably return the instrument to the manufacturer, (a service center), or through a least square analysis compute the new instrument corrections.

Conclusions

The conclusions that can be drawn from the foregoing are:

In order to get a valid base line comparison, the human induced errors have to be minimized.

If the results meet the sigma and three-sigma tests, then the instrument is working accurately and reliably.

If the results do not meet the sigma and three-sigma tests then before doing anything with the instrument, re-run the base line. If the results are similar, then the first thing is to check with other users to see if there is a problem in the base line. If not, it is recommended to return the instrument to the manufacturer or a service center. This is also assuming that all the tribrachs used on the base line are in adjustment. This can be tested by switching the tribrachs to different stations during the second run of the base line.

The above develops a history for the instrument as well as the base line. This is necessary before computing any new constants through least squares analysis.

Other Factors

Procedures on the calibration base lines are more complex than just taking a total station, setting it up, and taking the distances the machine gives out. Several problems may exist with the equipment the total station sits upon. The tripod is an important part of observations at any time, yet is so often abused and out of adjustment that it is amazing any survey works out. The critical areas of the tripod are the head, the dowels (legs), the hinges/clamps, and the shoes. The head of the tripod should be flat, so an instrument set on it does not rock back and forth. The wooden legs should not be broken and should bear the weight of the instrument without moving. The hinges and clamps should be tight and doing the job of moving yet holding the tripod together. The shoes should be holding the legs and the instrument in the ground without any movement. A test of the tripod will give some indication of any problems it might have. First set up and level the instrument, then point to a well defined point over 500 feet away. Second, twist the tripod head both ways and sight, if the horizontal angle changes after pointing, the tripod needs adjusting, repairing, or replacing.

For questions or comments on this tech note, contact your regional CAE Support Coordinator