APPENDIX D

INSTRUMENT CALIBRATION AND TESTING PROCEDURES

D.1. Leveling Instruments

Like all instruments, survey levels need to be periodically tested to ensure that they are properly functioning. There are two critical relationships in the level that can dramatically affect the survey results. These are the level bubble and the line of sight (collimation axis). The level bubble, when leveled properly, must be perpendicular to the vertical axis. Thus, it defines the horizontal axis. The line of sight must also, when the instrument is leveled, be parallel to the horizontal axis. The optical axis is defined by the line from the center of the objective lens to the cross-hairs.

D.1.1. Level Bubble Test

To test if the level bubble is truly level, begin by leveling the bubble in one direction that is parallel to two of the leveling foot screws. Then turn the telescope tube 90° and level the bubble along the remaining foot screw. Turn the telescope tube back to the original position and make sure that the bubble is leveled. Once the bubble remains leveled in both positions, rotate the instrument 180°. If the bubble stays in the middle of the bubble tube then the bubble is level. Otherwise, the bubble needs to be adjusted. This is done by rotating the capstan screw that contains the level bubble. To neutralize the effects of the bubble not being level, during the test, if the bubble is out of level when the instrument is rotated 180°, bring the level bubble half way back towards the center of the bubble tube (Figure D.1). An instrument is leveled when the instrument can be rotated completely about its vertical axis and the bubble stays in the same place.

Figure D.1
Compensating for error in level bubble.

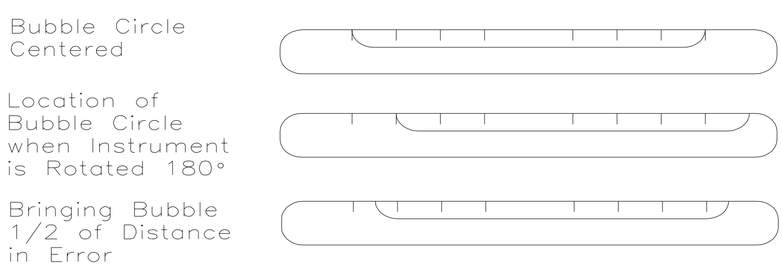
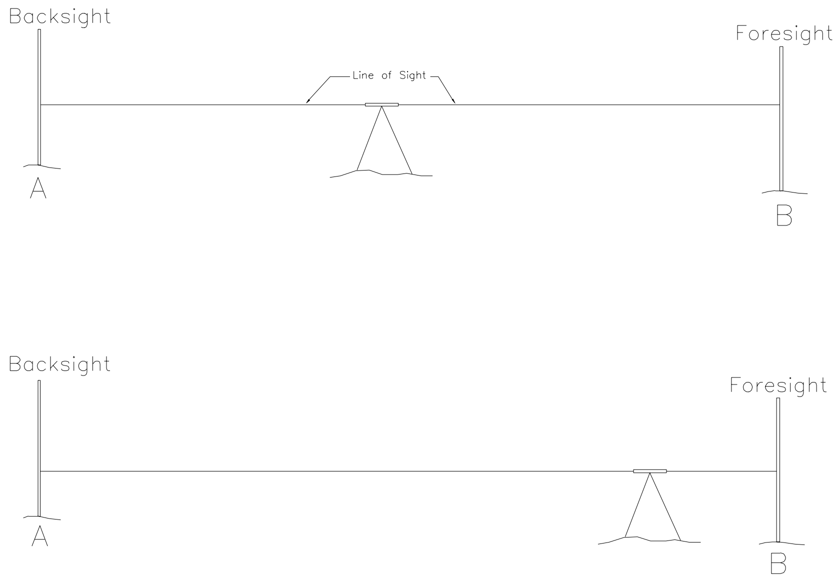


Figure D.2
Sample configuration for performing the peg test.



D.1.2. Collimation Error (Peg Test)

Prior to any accurate leveling project, the level must be checked to ensure that the optical axis is parallel to the horizontal axis when the instrument is level. This is done using the Peg Test (Figure D.2). Set two hubs or mark two points on solid objects approximately 150 feet apart. Set the level up in the middle between the two points and read the level on the two points. The difference in elevation between the two points is a true difference because any inclination in the optical axis is compensated for by setting the instrument up in the middle.

Set the instrument close to one of the level rods. Read the level rod on the short sight and the rod on the long sight. The difference in elevation here is considered a false difference in elevation since the longer sight has more of the effect of collimation error. The amount of error is proportional to the distance of the sight. This can be simply computed using proportions and the "correct" rod reading that the level should read on the long sight is computed. Adjust the cross-hair until the horizontal line coincides with the desired reading.

It is usually better to perform these kinds of adjustments in a controlled environment. Thus, the collimation error can be computed and this correction factor can be applied to the rod readings when the backsight and foresight distances are not equal. In all cases, it is good practice to always keep the backsight and foresight distances as close to equal as possible. Not only will this compensate for the collimation error but it will also reduce the effects of refraction and earth curvature.

D.1.3. Compensator Test

Automatic levels employ a compensator that is designed to keep the instrument line of sight level even if the instrument itself becomes out of level by a small amount. There are two types of tests that should be performed. First, prior to each observation, make sure that the compensator is not stuck in a rigid position. Some levels have a button that can be pushed that will make sure that the compensator is hanging freely in its desired position. For those instruments without the button, a slight tap on the telescope tube by the optical eyepiece will free the compensator up if it becomes stuck in place. This problem is not very significant with today's instruments.

It is important to test to make sure that the compensator is operating properly. First, set the level up and level the instrument. Sight on a target about 100 feet away. Tap one of the tripod legs slightly while looking through the telescope at the target. The operator should see the cross-hairs move off the target and then move back to its original position. As a further test, move one of the leveling screws slightly in the direction of the target. Since the optical axis is now tilted, the cross-hairs will move off the target. If the compensator is operating properly, the cross-hairs should then return to the original position.

D.2 Theodolites (Stand Alone or Incorporated into Total Stations)

Theodolites are used to measure horizontal and vertical angles at a point. This means that critical relationships must exist for these instruments to work properly. First, the horizontal circle must lie in a plane parallel to the horizontal axis. Recall that this will be defined by the axes of the level bubble tubes. Next, the optical axis must be perpendicular to the vertical axis and the trunnion support axis that holds the optical axis in place must be a horizontal line. A number of checks are available to test the validity of these relationships.

D.2.1. Optical Plummet Check

The optical plummet is used to set the instrument directly over the point on the ground. If the axis of the optical plummet is not truly vertical, the instrument will not be exactly over the point and an error in the measured angle and distance can occur. The easiest way to check the optical plummet is to use a plumb bob to set the instrument over the point. Remove the plumb bob and look through the optical plummet. If the cross-hairs on the optical plummet are not directly over the point, it must be adjusted.

For instruments with the optical plummet located in the tribrach, the optical plummet can be tested by using two tribrachs together. First, one tribrach is set onto a tripod and leveled. Next, a flat cylindrical jig is placed on the tribrach, making sure that it sets on the pads the hold the instrument when it is attached to the tribrach. The second tribrach is placed upside-down over the cylindrical jig so that the optical axis is pointing towards the ceiling. Simply rotate the tribrach around. If the cross-hairs remain in the same position, the optical plummet is in adjustment.

If the optical plummet is attached to the instrument itself, the best approach is to mark the cross-hair position on the ground. Then rotate the instrument around the vertical axis. The optical plummet is in adjustment if the cross-hair remains on the initial point.

D.2.2. Theodolite Plate Level Check

The effect of the plate level not being in a horizontal plane will result in an angle that is not truly a horizontal angle. To check the theodolite plate level bubble, use the same procedure to test for the level bubble on a level.

D.2.3. Circular Bubble of Tribrach

The circular bubble of the tribrach is tested in the same fashion as the plate level bubble.

D.2.4. Horizontal Collimation Check

The effect of horizontal collimation error is that when the telescope is rotated about the trunnion support axis that it defines a conical surface instead of a true circle. To test for this error, set the theodolite over a point and sight on a point about 450 feet away with the theodolite in the direct position. Invert the telescope and set a point on the other side of the theodolite at about the same distance. With the instrument now in the reverse position, sight on the backsight station again. Invert the telescope and mark where the line of sight is sighted on the other side of the instrument. If there was no line of sight problems, the two points will coincide. If not, there is an error. Mark the correct point halfway between the two sightings. Move the instrument back one-fourth the difference between the two pointings. Then, adjust the cross-hair until it coincides with the halfway mark that was just established.

D.2.5. Vertical Collimation Check

To test for the vertical collimation of a theodolite, sight on an object about 360 feet away from the leveled instrument. Record the zenith angle to the point. Invert the telescope and again record the zenith angle to that same point with the telescope in the reverse position. The sums of these two angles should be 360º. If not, the instrument is out of adjustment. It is best to take a number of observations and compute the mean value. If the mean value exceeds the least count of the vertical circle then the instrument needs to be adjusted.

D.3. Electronic Distance Measuring Check

The advantage of EDM observations is that distances can be measured very accurately in very little time. Many surveyors understand that taping is fraught with potential sources of errors. Yet, many fail to understand that the electronics that make up the EDM can also change over time with use and possible abuse. Thus, it is important that the EDM be routinely checked and compared to known values at an EDM Comparison Range.

At a minimum, the surveyor needs to visit a comparison range and check the measurement with the EDM to one of the distances recorded between points on the range. This may indicate if major problems exist with the instrument. This minimum check will not identify any of the cyclic types of error that may exist in the measurement. A comparison range consists of four different monuments placed at 0-m, 150-m, 430-m, and 1,400-m stations (Figure D.3). This yields 12 different measurements if each station is occupied and distances measured to all other stations are taken. A least squares adjustment is used to determine the performance of the EDM.

D.3.1. Determining Prism Constant

The measurement of a distance electronically is dependent upon the uncertainty that exists at the EDM instrument as well as the prism (reflector). The prism constant cannot be determined precisely except in a laboratory. A relative prism constant can be determined by measuring a series of distances with two different prisms. The average differences will yield the relative prism constant. This is usually done by designating one of the prisms as the reference reflector.

D.4. Checking and Adjusting Survey Rod Leveling Devices

The easiest method of checking the leveling devices of rod levels is to set the level rod in a vertical direction as accurately as possible. This can be done by using two theodolites/transits set 90º apart from each other. Note that one instrument could also be used but this will take more time because of the multiple instrument set-ups that would be required. Using the cross-hairs in the theodolite, adjust the level until it is truly vertical in both directions. Then, the level rod bubble should be in the center of the bulls-eye circle if it is in complete adjustment.

Figure D.3
EDM range configuration.