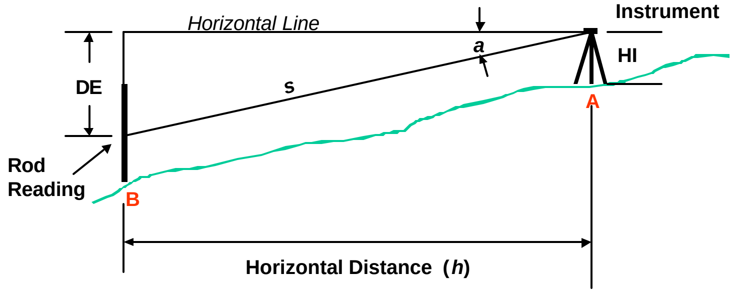
Chapter 6
Vertical Control Survey Techniques

6-1. General

Vertical control is established to provide a basic framework for large mapping projects, to establish new vertical control in remote areas, or to further densify existing vertical control in an area. The purpose of vertical control surveys is to establish elevations at convenient points over the project area. These established points (benchmarks) can then serve as points of departure and closure for leveling operations and as reference benchmarks during subsequent construction work. The NGS, NOS, USGS, other Federal agencies, and many USACE commands have established vertical control throughout the CONUS. Unless otherwise directed, these benchmarks will be used as a basis for all vertical control surveys. Descriptions of benchmark data and their published elevation values can be found in data holdings issued by the agency maintaining the circuit. Information on USACE maintained points can be found at District or Division offices.

a. Differential leveling. With differential leveling, differences in elevation are measured with respect to a horizontal line of sight established by the leveling instrument. Once the instrument is leveled (using either a spirit bubble or automated compensator), its line of sight lies a horizontal plane. Leveling comprises a determination of the difference in height between a known elevation and the instrument and the difference in height from the instrument to an unknown point by measuring the vertical distance with a precise or semi-precise level and leveling rods. Digital (or Bar Code) levels are used to automatically measure, store, and compute heights, and are capable of achieving Second Order or higher accuracies. Manufacturer's procedures should be followed to achieve the point closure standards shown in Table 3-2. When leveling in remote areas where the density of basic vertical control is scarce, the semi-precise rod is generally used. The semi-precise rod should be graduated on the face to centimeters and the back to half-foot intervals. When leveling in urban areas or areas with a high density of vertical control where ties to higher order control are readily available, the standard leveling rods are used--e.g., a Philadelphia rod graduated to hundredths of a foot. Other rods that are graduated to centimeters can be used. Both types of rods are furnished with targets and verniers that will permit reading of the scale to millimeters or thousandths of a foot if required by specifications. This is generally not required on lower order trigonometric level lines. Standard stadia rods may also be used for lower order level lines. The stadia rod is graduated to the nearest 0.05 foot, or two centimeters. These rods are generally equipped with targets or verniers, but if project specifications require, they can be estimated to hundredths of a foot.

b. Trigonometric heighting. This method applies the fundamentals of trigonometry to determine the differences in elevation between two points by observing a horizontal distance and the vertical angles above or below a horizontal plane. Trigonometric leveling is generally used for Second Order or lower order accuracy vertical positioning. Trigonometric leveling is especially effective in establishing control for profile lines, for strip photography, and in areas where the landscape is steep. With trigonometric leveling operations, it is necessary to measure the height of instrument (and target) above the monument, the slope distance, and the vertical angle and the rod intercept. From this data, the vertical difference in elevation can be computed using the sine of the vertical angle and applying the rod difference (Figure 6-1). Refinements to this technique include doubling vertical angles, taking differences from both stations and using the mean values. If the horizontal distance is known between the instrument and the rod, it is not necessary to determine the slope distance. The instrument most commonly used for trigonometric heighting is a directional theodolite or Total Station. Manufacturer specifications and procedures should be followed to achieve the point closure standards in Chapter 3.



DE = *s* * Sin (*a*) OR DE = *h* * Tan (*a*)

Elev B = Elev A + HI - DE - Rod Reading

Figure 6-1. Trigonometric heighting

c. Barometric heighting. This method uses the differences in atmospheric pressure as observed with a barometer or altimeter to determine the differences in elevation between points. This method is the least accurate of determining elevations. Because of the lower achievable accuracies, this method should only be used when other methods are not feasible or would involve great expense. Generally, this method is used for elevations when the map scale is to be 1:250,000 or smaller.

d. Reciprocal leveling. Reciprocal leveling is a method of carrying a level circuit across an area over which it is impossible to run regular differential levels with balanced sights (Figure 6-2). Most level operations require a line of sight less than 300 or 400 feet long. However, it may be necessary to shoot 500-1,000 feet, or even further, in order to span across a river, canyon, or other obstacle. Where such spans must be traversed, reciprocal leveling is appropriate. The reciprocal leveling procedure can be described as follows. Assume points "A" and "B" are turns on opposite sides of the obstacle to be spanned (Figure 6-2) where points A and B are intervisible. Two calibrated rods are used, one at point A, and the other at point B. With the instrument near A, read rod at A, then turn to B and have target set as close as possible and determine the difference in elevation. Leaving rods at A and B, move the instrument around to point B, read B, then turn to read A and again determine the difference in elevation. The mean of the two results is the final height difference to be applied to the elevation of A to get an elevation value for point B. If the long sight is difficult to determine, it is suggested that a target be used and the observations repeated several times to determine an average value. For more precise results it will be necessary to take several foresights, depending on the length of the sight. It is typical to take as many as 20 to 30 sightings. When taking this many sightings, it is critical to relevel the instrument and reset the target after each observation. Reciprocal leveling assumes the conditions during the survey do not change significantly for the two positions of the level. Reciprocal leveling with two instruments should never be done unless both instruments are used on both sides of the obstacle and the mean result of both sets used. The use of two instruments is advised if it is a long trip around the obstacle. Reciprocal leveling is effective only if the instruments used will yield measurements of similar precision.

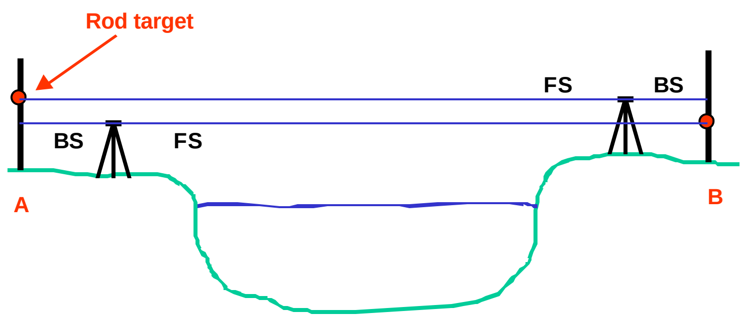


Figure 6-2. Reciprocal leveling for river crossing

e. Three wire leveling. This method can be used for most types of leveling work and will achieve any practical level of accuracy. However, most applications do not require the accuracies possible with three wire leveling; plus, it is labor intensive. Three wire leveling can be applied if the reticule of the level has stadia lines and substadia that are spaced so that the stadia intercept is 0.3 foot at 100 feet, rather than the more typical 1.0 feet at 100 feet. The substadia lines in instruments meant for three wire leveling are short cross lines that cannot be mistaken for the long central line used for ordinary leveling. Although there are many different observing techniques for three wire leveling, in the following example, the rod is read at each of the three lines and the average is used for the final result. Before each reading, the level bubble is centered. The half-stadia intervals are compared to check for blunders. The following values were taken and recorded and calculations made:

Upper Wire:	8.698	2.155 :Upper Interval
Middle Wire:	6.543	
Lower Wire:	4.392	2.151 :Lower Interval
Sum	19.633	
Average	6.544	

The final rod reading would be 6.544 feet. The upper and lower intercepts differ by only 0.004 foot--an acceptable error for this sort of leveling and evidence that no blunder has been made. It is recommended that "Yard Rods" specifically designed for three wire leveling operations be used instead of Philadelphia rods that are designed for ordinary leveling.

f. Two rod leveling. In order to increase the productivity in precise leveling operations, it is advisable to use two rods. When the observations are completed at any instrument setup, the rods and the instruments are moved forward simultaneously. An even number of setups should be used to minimize the possible effects of rod index error. Two rods are recommended when using an automatic level, as this takes full advantage of the productivity possible with this type of instrument.

g. Tidal benchmarks and datums. For guidance on the establishment of tidal benchmarks and datums refer to Appendix D in this manual or EM 1110-2-1003.

6-2. Second Order Leveling

a. General. The leveling operation consists of holding a rod vertically on a point of known elevation. A level reading is then made through the telescope on the rod, known as a backsight (BS), which gives the vertical distance from the ground elevation to the line of sight. By adding this backsight reading to the known elevation, the line of sight elevation, called "height of instrument" (HI), is determined. Another rod is place on a point of unknown elevation, and a foresight (FS) reading is taken. By subtracting the FS reading from the height of instrument, the elevation of the new point is established. After the foresight is completed, the rod remains on that point and the instrument and back rod are moved to forward positions. The instrument is set up approximately midway between the old and new rod positions. The new sighting on the back rod is a backsight for a new HI, and the sighting on the front rod is a FS for a new elevation. The points on which the rods are held for foresights and backsights are called "turning points." Other foresights made to points not along the main line are known as "sideshots." This procedure is used as many times as necessary to transfer a point of known elevation to another distant point of unknown elevation.

b. Leveling accuracy. Second Order leveling point closure standards for vertical control surveys are shown in Table 3-2. Second Order leveling consists of lines run in only one direction, and between benchmarks previously established by First Order methods. If not checking into another line, the return for Second Order Class I level work should check within the limits of 0.025 times the square root of M feet (where "M" is the length of the level line in miles), while for Second Order Class II work, it should check within the limits of 0.035 times the square root of M feet.

c. Leveling equipment. The type of equipment needed is dependent on the accuracy requirements.

(1) Second Order level. Instruments used in Second Order leveling can be a total station, precise level, or equivalent. Often a graduated parallel plate micrometer is built into the instrument to allow reading to the nearest 0.001 of a unit. The sensitivity of the level vial, telescopic power, focusing distance, and size of the objective lens are factors in determining the precision of the instrument. Instruments are rated and tested according to their ability to maintain the specified order of accuracy. Only those rated as precise geodetic quality instruments may be used for Second Order work.

(2) Precise level rods. Precise level rods are required when running Second Order levels. The rods must be of one piece, invar strip type, with the least graduation on the invar strip of 1 centimeter. The invar strip is 25 millimeters wide and 1 millimeter thick, and is mounted in a shallow groove in a single piece of well-seasoned wood. The front of the rod is graduated in meters, decimeters and centimeters on the invar strip. The back of the rod is graduated in feet and tenths of feet, or yards and tenths of yards. These rods must be standardized by the National Institute of Standards and Technology and their index and length corrections determined. Rods with similar characteristics are paired and marked. The pairings must be maintained throughout a line of levels. The invar strips should be checked periodically against a standard to determine any changes that may affect their accuracy. The precise level rod is a scientific instrument and must be treated as such; not only during use but also during storage and transporting. When not in use they must be stored in their shipping containers to avoid damage. The footpiece should be inspected frequently to make sure it has not been bent or otherwise damaged.

d. Calibrations and adjustments. To maintain the required accuracy, certain tests and adjustments must be made at prescribed intervals to both the levels and rods being used.

(1) Determination of stadia constant. The stadia constant factor of the leveling instrument should be determined by calibration. The stadia factor is required for measurement and computation of distances from the instrument to the leveling rod. This determination is made independently for each level used in the field and is permanently recorded and kept with project files. The determination is made by comparing the measured stadia distance to known distances on a test course. The test course should be laid out on a reasonably level ground and marked with temporary points placed in a straight line at measured distances of 0, 25, 35, 45, 55, 65, and 75 meters. The optical and mechanical centers of the instrument are not necessarily at the same point for a given instrument. Therefore, when determining the stadia constant, this constant should be applied to the measurement before making the test comparison. This constant offset value should be available from the manufacturer's manual. For the test data collection, read the rod at each of the six test points and record the rod intervals. The level bubble should be accurately centered. Each half-wire intervals should be recorded as a check against erroneous readings. The sum of the total intervals for the six readings should be computed. The stadia constant is the sum of these measured distances (300 meters) divided by the sum of the six total wire intervals. As a check against gross errors each separate observation should be computed. The average of the six separate computations serves as a numerical check on the computations.

(2) Determination of "C" Factor. Each day, just before the leveling is begun, or just after the beginning of the day's observations, and immediately following any instance in which the level is subjected to unusual shock, the error of the level, or "C" factor, must be determined. This determination can be made during the regular course of leveling or over a special test course; in either case the recording of the observations must be done on a separate page of the recording notes with all computations shown. If the determination is made during the first setup of the regular course of levels, the following procedure is used (Figure 6-3). After the regular observations at the instrument station "A" are completed, transcribe the last FS reading "a" as part of the error determination; call up the backsight rodman and have the rod placed about 10 meters from the instrument; read the rod "b", over the instrument to a position "B" about 10 meters behind the front rod; read the front rod "c" and then the back rod "d". The two instrument stations must be between the rod points. The readings must be made with the level bubble carefully centered and then all three wires are read for each rod reading. The required "C" factor determined is the ratio of the required rod reading correction to the corresponding subtended interval, or:

$$C = (R1 - R2) / (R3 - R4)$$

where

R1 = Sum near rod readings
R2 = Sum distant rod readings
R3 = Sum distant rod readings
R4 = Sum near rod readings

The total correction for curvature and refraction must be applied to each distant rod reading before using them in the above formula. It must be remembered that the sum of the rod intervals must be multiplied by the stadia constant in order to obtain the actual distance before correction. The maximum permissible "C" factor varies with the stadia constant of the instrument. The instruments must be adjusted if the "C" factor is:

C	>	0.004	for a stadia constant of 1/100
C	>	0.007	for a stadia constant of 1/200
C	>	0.010	for a stadia constant of 1/333.

The determination of the "C" factor should be made under the expected conditions of the survey as to length of sight, character of ground, and elevation of line of sight above the ground. The date and time must be recorded for each "C" factor determination, since this information is needed to compute leveling corrections.

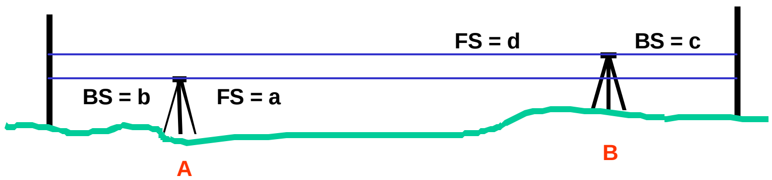


Figure 6-3. C-factor Calibration Procedure

(3) Adjustment of level. The type of instrument being used will dictate the method and procedure used to adjust the instrument if the "C" factor exceeds the allowable limits. The manufacturer's procedures should be followed when adjusting a level.

(4) Test of rod levels. Precise rod levels must be tested once each week during regular use or whenever they receive a severe shock. This test is made with the level rod bubble held at its center, and the deviation of the face and edge of the rod from the vertical are determined. If the deviation from the vertical exceeds 0.01 meter on a 3-meter length of rod, the rod level must be adjusted. The rod level is adjusted in the same manner as any other circular bubble. A statement must be inserted in the records showing the manner in which the test was made, the error that was found, if any, and whether an adjustment was made. When using other than precise leveling rods, this test is not required.

e. Leveling monumentation. All benchmarks used to monument Second Order level lines will conform to criteria published in EM 1110-1-1002. Benchmarks used to monument Second Order level lines shall be standard USACE brass caps set in concrete. The concrete should be places in holes deep enough to avoid local disturbance. If the brass cap is not attached to an iron pipe, use some type of metal to reinforce the concrete prior to embedding the brass cap. Concrete should be placed in a protected position. If possible, benchmarks should be set close to a fence line, yet far enough away to permit plumbing of level rod. Do not set monuments closer than four feet to a fence post, as the benchmark likely will be disturbed if the post is replaced. Each brass cap must be stamped to identify it by the methods detailed in EM 1110-1-1002. In addition to stamping a local number or name on the cap, it is optional to stamp the elevation on the brass cap after final elevation adjustment has been made. The benchmarks must be set no less than 24 hours in advance of the level crew if the survey is to be made immediately after monument construction.

f. Leveling notes. Notes for Second Order levels will be kept in a manner approved by the survey supervisor. A set style cannot be developed due to different types of equipment that may be employed. Elevations will not be carried in the field as they will be adjusted by the field office and closures approved prior to assigning a final adjusted elevation.

6-3. Third Order Leveling

a. General. Leveling run for traverse profiles, temporary benchmarks, control of cross-sections, slope stakes, soundings, topographic mapping, structure layout, miscellaneous construction layout, and construction staking shall be Third- or Fourth-Order leveling, as detailed in Table 3-2, unless otherwise directed. All levels will originate from and tie into existing control. No level line shall be left unconnected to control unless by specific instructions of the survey supervisor or written directive.

b. Leveling accuracy. All accuracy requirements for USACE vertical control surveys will conform to the point closure standards shown in Table 3-2. The required accuracy for Third Order levels is 0.050 M feet where "M" is the length of the level line in miles, while Construction Layout level work will conform to 0.100 times the square root of M feet. The length of the line may be determined from quad sheets or larger scale map if a direct measure between points is not available.

c. Leveling equipment. The type of equipment needed is dependent upon the accuracy requirements.

(1) Third Order level. A semi-precise level can be used for Third Order leveling, such as the tilting Dumpy type, three-wire reticule, or equivalent.

(2) Leveling rods. The rods should be graduated in feet, tenths and hundreds of feet. The Philadelphia rod or its equivalent is acceptable. However, the project specifications will sometimes require that semi-precise rods be used that are graduated on the front in centimeters and on the back in half foot intervals. The Zeiss stadia rod, fold type, or its equivalent should be used when the specifications require semi-precise rods.

(3) Lower order. The type of spirit level instrument used should ensure accuracy in keeping with required control point accuracy. Precision levels are not required on lower order leveling work. Fennel tilting level, dumpy level, Wye level, or their equivalent are examples of levels that can be used. A stadia rod with least readings of five-hundredths of a foot or 1 centimeter will be satisfactory. The use of turning pins and/or plates will depend upon the type of terrain or if rods may be placed on firm stones or roadways.

d. Leveling monumentation. The level line shall be tied to all existing benchmarks along or adjacent to the line section being run. In the event there are no existing benchmarks near the survey, new ones should be set, not more than 0.5 mile apart. Steep landscape in the area of survey may require monuments to be set at closer spacings.

(1) Benchmarks should be set on permanent structures, such as, head walls, bridge abutments, pipes, etc. Large spikes driven into the base of trees, telephone poles, and fence posts are acceptable for this level of work. All temporary benchmarks must have a full description including location. Unless they are on a turn, they are not considered to be temporary benchmarks. No closures shown by an intermediate shot will be accepted. All temporary benchmarks must have a name or number for future identification.

(2) Turning pins. Turning pins should be driven into in the ground until rigid with no possibility of movement. Turning points or temporary benchmarks will have a definite high point so that any person not familiar with the point will automatically hold the rod on the highest point, and so that it can spin free. If solid rocks are being used for turns they must be marked with crayon or paint prior to taking readings.

(3) Rod targets. It is not mandatory to use targets on the rod when the reading is clearly visible. However, they are required in dense brush, when using grade rods, or when unusually long shots are necessary.

e. Leveling notes. Complete notations or sketches will be made to identify level lines and side shots. All Third Order or lower level notes will be completely reduced in the field as the levels are run, with the error of closure noted at all tie in points. In practice, the circuit will be corrected to true at each tie in point unless instructed to do otherwise by the survey supervisor or written directive. Any change in rod reading shall be initialed and dated so there is no doubt as to when a correction was made. Cross out erroneous readings--never erase them. The instrument man shall take care to keep peg notes on all turns in the standard field book. The notes will be dated and noted as to what line is being run, station occupied, identification of turns, etc.

6-4. Mandatory Requirements

Level C-factor (or peg tests) described in this chapter are mandatory for all vertical control surveys.