Contractor Construction Staking

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2.0 Contractor Construction Staking

2.1 General Items, Equipment & Methods

The goal of construction staking is to produce a structure that is located both vertically and horizontally as directed on the plans when completed. Construction staking is conducted throughout construction at the stages and locations defined in the Specifications. Other surveys that are not required by the specifications may be needed. A standard of care that includes people trained in surveying techniques is required. Work is to be performed under the supervision of a licensed surveyor at a minimum. Errors in alignment and height have occurred previously when these steps were not performed. In some cases they resulted in a substantial loss of time and money.

The contractor is responsible for surveying and construction staking of structures. Staking by the contractor generally is performed by either employees on staff or hired consultants. The construction staking by either of whom must be at a minimum overseen by a licensed surveyor. Even though the construction staking is performed by non-KDOT personnel, at a minimum it is important and beneficial for construction inspectors to possess a working knowledge of surveying techniques .This working knowledge enables the inspector to spot and address questionable practices and busts in a survey. If questions or concerns arise upon inspection of the survey notes consult with the district surveyor. The district surveyor is a good source of information and can offer guidance when the inspector lacks knowledge or experience in construction staking.

An important and often overlooked way of stopping these errors is to include a minimum of two temporary benchmarks in all level loops when establishing the elevation of critical bridge elements. Two temporary benchmarks in a level loop is intended to make sure the accuracy of temporary benchmarks is maintained. When crossing a stream, place enough temporary benchmarks on both sides of the stream so that level loops still include a minimum of two temporary benchmarks. The inclusion of two benchmarks in a level loop is considered good technique and practice among reputable surveyors and KDOT surveying management. The practice of balancing shots should also be implemented when running level loops. The reason for balancing shots is to negate equipment and environmental errors that would not be addressed otherwise.

The stakes, disks, spikes and any other item used to mark and establish a point of interest or benchmark during the construction process will follow the guidelines found in the Standard Specifications Sections 102 & 802 and the Special Provisions associated with these sections. Disk(s) and brass placards should be placed according to plan sheets.

GPS systems and total stations that meet tolerance can be used for horizontal layout and staking of critical bridge members. The checking and setting of elevations for critical bridge members shall be done with an auto-level. All GPS, total stations, and levels should be routinely cleaned and calibrated by a reputable equipment dealer or qualified repair personnel. It is advisable that KDOT personnel be familiar with the process of pegging the level. The familiarity with this process is intended to help maintain the precision of a KDOT level so it is not compromised. The methodology of pegging the level is located in Appendix A of this chapter. The precision of the level is crucial when KDOT personnel are performing elevation checks during construction. If chains or steel tapes are being used for construction staking they should be pulled consistantly to the correct tension during each measurement. The amount of correction due to ambient air temperature should be noted in the surveyor's notes during the time the measurements were taken.

Establishing temporary benchmarks is necessary for achieving the desired elevation on critical bridge elements. The following steps will increase the chances for producing reliable temporary benchmarks.

- The new temporary benchmark should be located in an area that will not hinder or impede the construction process(es) of the contractor.
- The benchmark should be clearly marked with highly visible flagging and staking to indicate its importance and that it should not be disturbed.
- The new temporary benchmark shall be established such that it resists vertical displacements.
  a). Set temporary benchmarks in power poles, the trunk of large healthy trees, and on permanent structures with stable foundations that are sufficiently deep enough to resist heave are preferred.
  b). Consider and address frost heave on larger projects that will take more than one construction season to complete. Place rods that are at least 6 inches longer than the depth required to penetrate past the frost zone. Place benchmarks on large foundations or objects that extend well below the frost zone.
  c). Do not place a temporary benchmark on a recently placed fill as settlement will occur causing an inaccurate benchmark elevation.
  d). Confirm that the temporary benchmarks are robust enough to resist accidental strikes by construction personnel. For example, inadvertently being stepped on, tools being set on, or light loads of material being placed on.
- Establish enough benchmarks that multiple benchmarks are still intact and can be used in the case one or more benchmarks are destroyed during construction.

2.2 Surveying and Staking Critical Bridge Elements

Arrange to meet with the contractor and/or foreman prior to beginning the staking process to thoroughly explain the importance of staking the abutments and piers for bridges. The explanation of the "double-check" survey of critical bridge elements prior to starting construction of critical bridge elements as defined by KDOT. Critical bridge elements are defined by KDOT Standard Specifications.

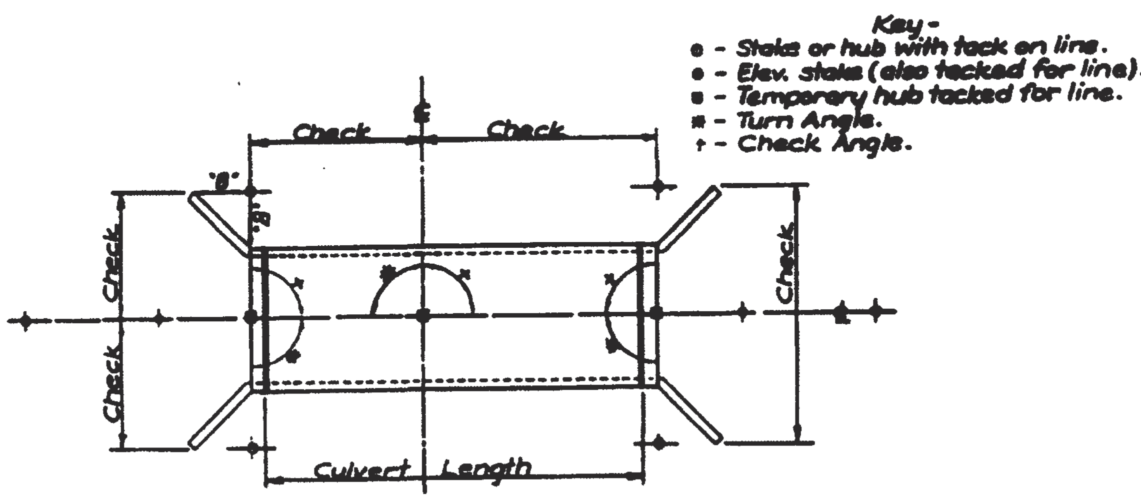
Set all stakes and benchmarks for structures with an offset distance and placement in a manner that attempts to stop their destruction during construction. Consulting the contractor or their staff can aid in the best placement of the structure stakes to provide longevity of stakes for the duration of construction. It is advisable to stake the structure in its entirety prior to beginning construction. It is good practice to set sufficient points so that in the case some points are disturbed a minimum of three valid points are still visible from all setup spots. This becomes important in the reestablishment of a line which should always include a minimum of three points of reference. Establish enough points on both sides of a stream crossing that the reestablishment of a line from a minimum of three valid points is achievable.

Mark construction stakes to denote if they are located on center line of the structural element or center line of traffic. To advoid confusion at a lator time, when setting an offset stake reference center line of either the structural element or traffic. Note that the center line of a structure is not always the center line of traffic. This is due to different shoulder widths, sidewalks, or turning lanes on a bridge for example.

The following common practices and a typical bridge layout(s) are taken from Section 3.23.02 of the "1999 Kansas Department of Transportation Construction Manual". Figures 2.2.1, 2.2.2, and 2.2.3 describe and illustrate those practices.

Hubs should be set on each side of each bridge and culvert at the time the center line is reestablished. These hubs should be set in their true position and tacked for line. One hub shall be set on the center line of the project on each side of each culvert and in the immediate vicinity thereof. At least two hubs shall be set on center line back of each bridge abutment. It is not always possible to see from one side of the stream to the other along the center line during periods of construction due to obstructions such as equipment or materials. For this reason it is desirable to have the center line independently established on each side of the stream. Two stakes on each side should be sufficient for this purpose; but on large bridges, which may be constructed for a year or more, it is good policy to set a third stake 100 feet back from the abutment to insure the preservation of the center line. It should be kept in mind that once the work has started the location must not be altered.

EXAMPLE-CULVERT STAKING



Stakes on the outside of the hubguard preferably should be set on the "B" distance from the side of the culvert, but in all cases should be set to clear the channel excavation.

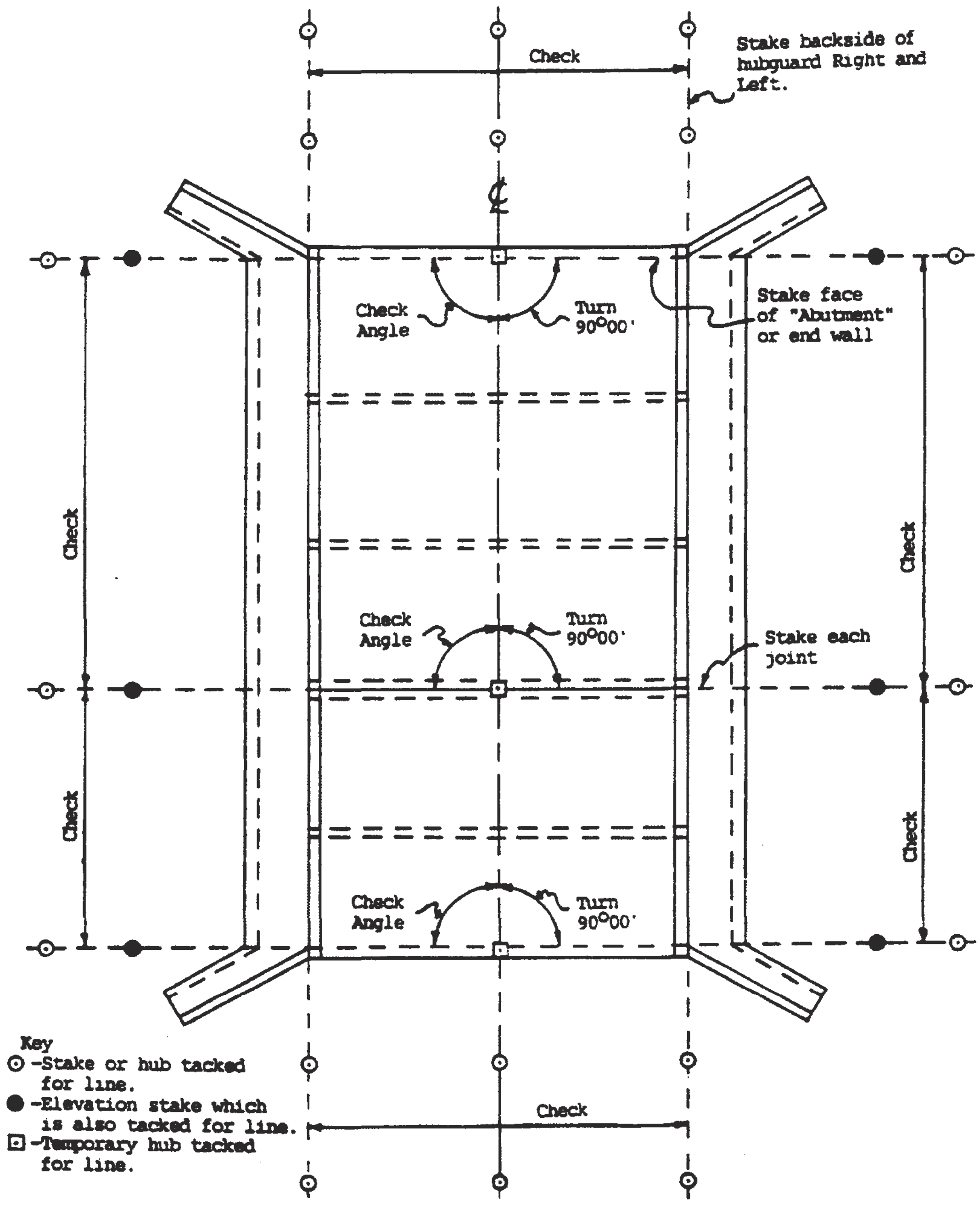
Note: The vernier shall be set at 0°0' to check angle.

Elevation stakes shall indicate the cut to F.L. elevation on the end of the culvert on which the stakes are set.

Stakes on the centerline of the culvert are optional and in some locations their removal is necessary.

Figure 2.2.1 Culvert Staking

EXAMPLE-MULTIPLE BOX BRIDGE STAKING



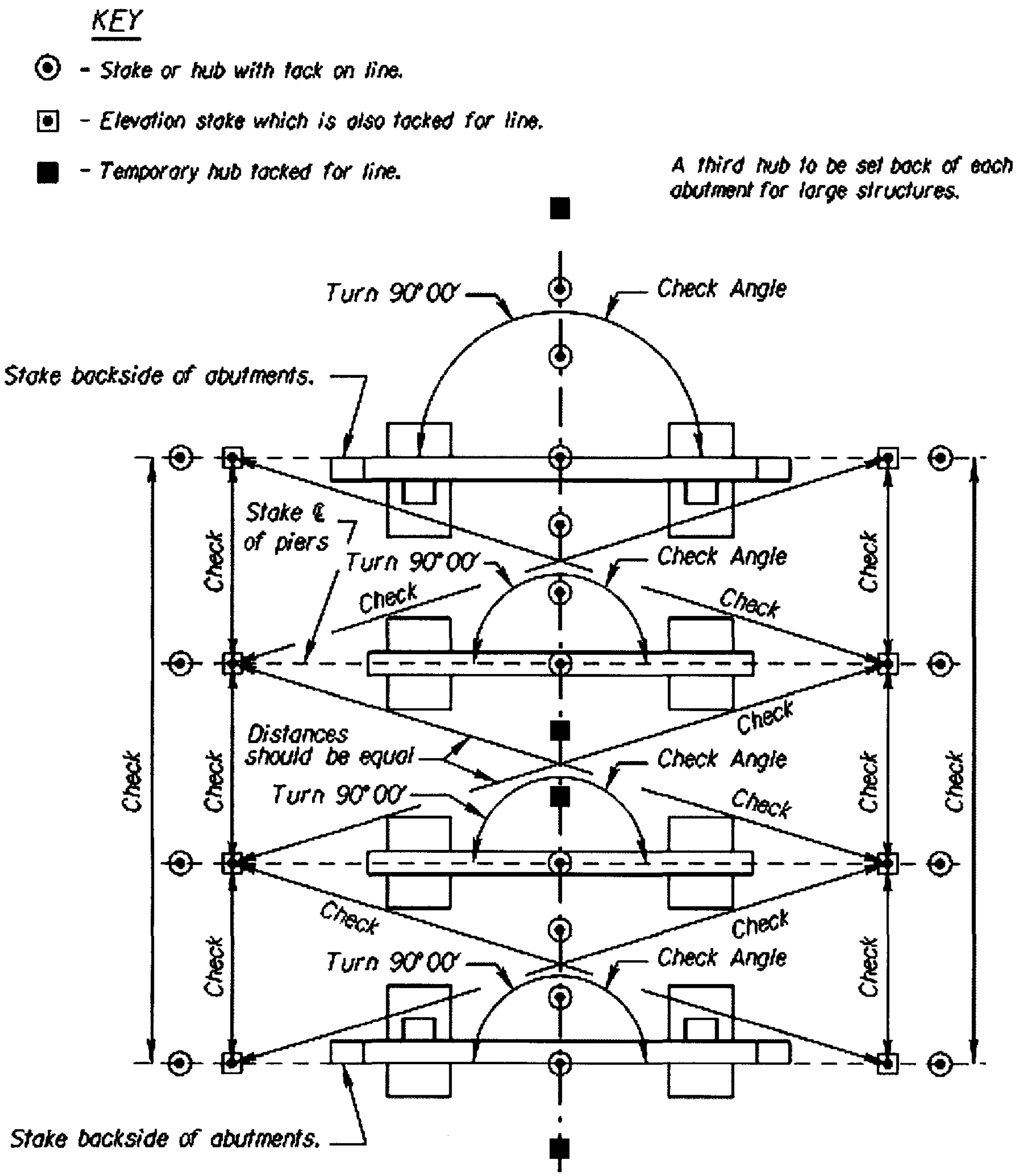
Note: Linear and angular check measurements as indicated must be taken in all cases. All distances shall be checked at least once in addition to check measurements indicated.

The vernier shall be set at 0°00' to check angles.

Elevation stakes shall indicate the cut to flow line elevation on the side on which the stakes are set.

Figure 2.2.2 Multi-Cell Culvert Staking

BRIDGE CONSTRUCTION STAKING DIAGRAM



Note: Linear and angular check measurements as indicated must be taken in all cases, when practical. All distances shall be checked at least once in addition to check measurements indicated.

The vernier shall be set at at 0°00' to check angles.

The Contractor's attention should be called to the fact that stakes are set for the back side of abutments, but for the CL of piers

Figure 2.2.3 Bridge Staking

“Prior to construction, provide an independent survey performed under the supervision of a different Licensed Professional Land Surveyor to check the accuracy of the original survey of project control points and locations of the Critical Bridge Elements features”. The intent of this phrase is to result in a “double-check” scenario where a second independent and distinct survey is performed. The two independent surveys resulting in physically separate and unique field notes that use seperate points in the survey. If the second survey does not accomplish these tasks then the accuracy of the first survey has not been verified. The two surveys required by specifications are both to be performed at a minimum under the supervision of a licensed surveyor. Refer to Kansas Standard Specifications.

The tolerance for staking critical bridge members is ± 0.02 feet in the horizontal direction and ± 0.01 feet in the vertical direction. It is necessary to track and record atmospheric changes periodically while collecting measurements. Recording of atmospheric changes is also required when changes become noticeable to the operator’s senses. This will allow the operator to enter the correct atmospheric pressure and temperature when using an electronic measuring device or a total station while performing measurements to obtain the correct measurements. The use of a chain or steel tape also needs to be corrected for temperature when making measurements to set points and stakes for construction. Measure each individual angle a minimum of 2 times with the instrument in the direct position and an equal number of times with the instrument in the reverse position when performing triangulation work. Average the results of the measured values for an angle that was measured. No single measurement in the averaged set can differ more than 30 seconds from the average value. The reason for taking and recording diagonal measurements in field is to confirm that the structure or the layout of the structure is squared up.

The critical bridge elements found in the standard specifications that require a dual survey prior to building and once upon completion of construction are in the table below in Figure 2.2.4: Table 802-1a of KDOT Specifications. In addition to the structural elements in Figure 2.2.4: Table 802-1a of KDOT Specifications all handrail posts including forms for cast-in-place post shall be aligned and elevations set by using the proper surveying equipment prior to placing concrete. Special attention should be given to the alignment and spacing of piers and abutments as these elements are fundamental elements and are the corner stones of construction essential in achieving the proper location, elevations, and physical aspects of the bridge. If the piers or abutments are misaligned, prefabricated beams delivered to the project site will not fit. The solution to the misfitting beam issue is foundations will have to be modified if deemed safe and appropriate by bridge design or the foundations may require a complete replacement. The cost associated with having to execute either of these options are at the contractor’s expense.

CRITICAL BRIDGE ELEMENTS	
Critical Element	**Critical Component(s)**
Spread Footing	Location & Elevation of CL
Pile Cap Footing	Location & Elevation of CL
Drilled Shaft	Location & Elevation of Center
Drilled Shaft Cap	Location & Elevation of CL
Column	Location & Elevation of Center
Pile Bent with Web Wall	Location & Elevation of CL
Abutment Beam/Bearing Seat	Location & Elevation of CL
Pier Beam/Bearing Seat	Location & Elevation of CL
Bearing Devices	Location & Elevation of CL, Temp. Offset
Bearing Stiffener	Location & Elevation of CL, Temperature Offset
Girder/Beam	Location of CL
Anchor Bolts/Preformed Holes	Location of CL
Expansion Device	Gap (Corrected for Temp) and Alignment
Fillets (Tenth Points)	Elevation
Surface of Forms (Slab Bridge Tenth Points)	Elevation
Post-tensioning Duct	Location & Elevation
Bolted Field Splice	Elevation

Figure 2.2.4: Table 802-1a of KDOT Specifications

Appendix A

"The Level" http://whistleralley.com/surveying/level/ April 30, 2012

The Level

The objective of any leveling instrument is to direct the line of sight in a horizontal direction. The various models have different means of approaching this objective. Most levels are capable of turning only on a vertical axis. If that axis is plumb, and the line of sight is perpendicular to the axis, then the locus of the line of sight is a horizontal plane.

Axis Error

Having a plumb axis is more important for certain instruments than for others. The automatic level is the most prevalent type in use these days. It has an internal pendulum compensator, which adjusts the line of sight each time the instrument is moved. This mechanism fixes the line of sight to a constant angle with relation to the gravity vector, not with relation to the vertical axis. Because of this, the axis needs only to be close enough to the vertical to allow the pendulum to swing freely.

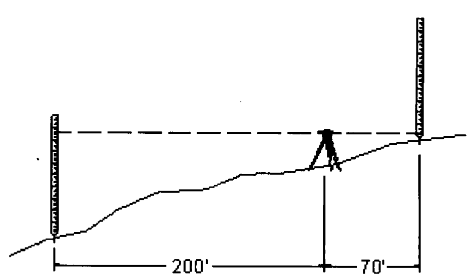
The tilting level, although less common, shares this same advantage. Each time the instrument is moved, the line of sight is manually leveled with a tube vial. The axis needs only to be roughly plumb.

There are other level models (e.g., dumpy) that have the line of sight set at a right angle to the vertical axis. For these models, properly adjusted level vials and strict attention to instrument leveling procedures are crucial.

Crosshair Alignment and Balance

The horizontal position of the crosshair is not important in a level, but if it is out of alignment vertically, it will cause the line of sight to dip or rise. In either case, the locus of the line of sight will become a cone rather than a plane. Assuming a flat Earth, the error on any given sight is in direct variation with the sight distance.

All instruments are in error, so turn the error against itself by balancing shots. In a level circuit with no inverted rod shots, backsight readings are added and foresights are subtracted. Therefore, if the backsight and foresight distances are equal, each backsight error will be canceled by the following foresight error. A rodman should pace the distance as he walks forward to the instrument, then pace the same distance forward to the next turning point. If it is not possible to set a turning point there, he should keep track of the balance. For example, if a foresight is 30 feet heavy, then the next foresight should be 30 feet light.



On steep ground, things can get out of hand in a hurry, especially if the instrument operator is not cooperating. Going uphill, and looking at a long rod, the gunner may be able to walk 200 feet ahead of the rodman before climbing above the top of the rod. When the rodman moves ahead, he may have to stop at only 70 feet because the ground is rising above the instrument. Now the foresight is 130 feet light on a single setup, and since they are still moving uphill, it will only get worse on the next turn. The gunner needs to shorten the backsights. The rodman might otherwise keep track of the balance and compensate on another part of the circuit, when they are moving on level ground or downhill.

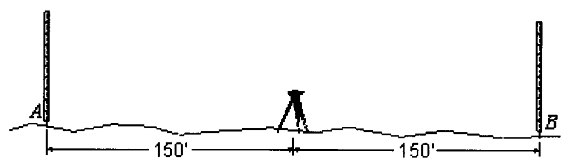
The Peg Check

The peg check is a procedure for finding the vertical error in the alignment of the crosshair. Two variations are presented here. It is assumed that the line of sight is at a fixed angle to the gravity vector. With an automatic level or tilting level, this is a fair assumption. Otherwise, first do what is necessary to plumb the vertical axis.

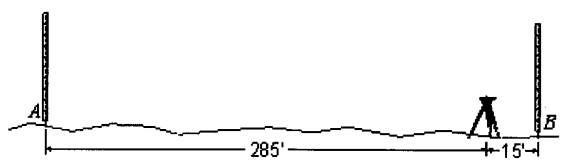
There are certain measures that should be taken no matter what version of the peg check is used. The party member running the instrument should be the one with the best eyesight. Usually that will not be the most senior member, so set pride aside. This is best done in fair weather, preferably on a cloudy day. Do it on level ground, and use the best rod available. If the rod is in sections, arrange for all of the readings to be taken from the same section, negating any error from loose joints or an improperly fitted face. If a parallel plate micrometer is available, use it. If the rod is graduated in hundredths of feet, estimate the thousandths. Paced distances are good enough for all but the highest order work, but have one person do all of the pacing. Stadia distances might also be used.

Center-End Method

The center-end peg check seems to be the most prevalent, perhaps because it is the easiest to learn and understand. It begins with two pegs (*A* and *B*) set about 300 feet apart, and the instrument dead center between them. Give peg *A* an arbitrary elevation. Backsight *A* and foresight *B*. Since the shots are in balance, this should give the correct difference in elevation, even if the instrument is in error.



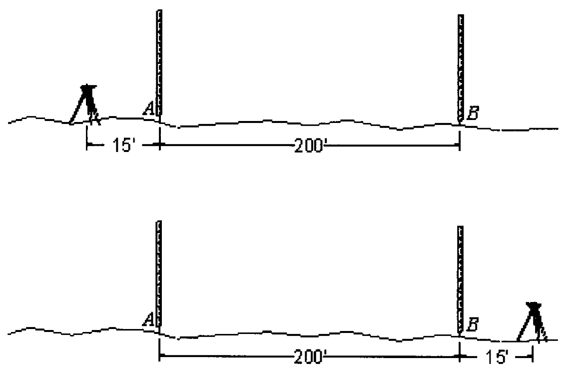
The instrument is then carried toward peg *B* and set up very close to it, just outside the minimum focus distance. Backsight *B* and close the loop back on *A*. The loop is now heavy on the foresight. If the measured elevation of *A* is too low, then the line of sight is rising. If it is too high, then the line of sight is dipping. All of the error is on the back run.



If the error is out of tolerance, leave the instrument in the same position and make the adjustment with the long foresight. At this point, many instrument operators simply adjust the crosshair up or down by the amount of the closure error. That is close, but geometrically incorrect. The error is spread over the distance of the imbalance, but the foresight distance is somewhat longer than that. multiply the closure error by the ratio of the forsight distance to the imbalance. In the example used here, the loop is 270 feet heavy on the foresight and the final foresight is 285 feet. The correct adjustment is the closure error times 285/270.

$$\text{correction} = (\text{closure error}) \cdot \frac{(\text{foresight distance})}{(\text{imbalance distance})}$$

End-End Method



With the end-end peg check, both setups are out of balance. This way it is possible to create a greater imbalance while using shorter sights. Set the pegs about 200 feet apart, and place the instrument very close to peg *A* and outside of the course. Take a short backsight on *A* and a long foresight on *B*. Move the instrument to a spot very close to *B* and outside the course. Backsight *B* and foresight *A*.

The correction adjustment for the end-end peg check has the same formula. Remember that the imbalance is twice the distance between the pegs. In the example above, the adjustment would be the closure error times 215/400.

Back to The Geometry of Surveying

Last update: January 26, 2012 ... Paul Kunkel *whistling@whistleralley.com*
For email to reach me, the word *geometry* must appear in the body of the message.

Appendix B: Glossary

BenchMark: a point of known elevation from which other point(s) elevation may be determined.

Bust: term used to denote that measurements taken disagree on the location or elevation of a point of interest.

Critical Bridge Elements: components of the bridge that must be located correctly during construction in order to achieve proper alignment and elevations of the bridge upon completion.

GPS: acronym for Global Positioning System. System which uses electronic measuring devices which send and receive signals to orbiting satellites in order to triangulate the devices position and make measurements.

Hub: typically a wooden two inch by two inch pointed stake that is driven into the ground and used as a reference point in a survey. Can have a nail driven into the top of it to provide a precise point for future reference.

Level Loop: a series of measurements where backsights and foresights are taken between turn points. The turn points should include at least 2 benchmarks in order to establish the elevation of an unknown point.

Pegging the Level: method to find, determine, and correct the amount of error in the inclination of the reticle in the optics of an auto-level.

Stake: a long slender usually wooden element driven into the ground to produce a reference point which may have offset, centerline station, elevation, and cut or fill depth written on it.

Tacked for line: to drive a tack (nail) into a point on the hubs which creates a perfect line when the tacks are aligned.

Total Station: an electronic/optical instrument which measures angles in both the horizontal and vertical axes and is capable of measuring distances by use of an electronic distance meter.

Balancing Shots: attempting to keep the length of foreshots (FS) and backshots (BS) equivalent at each equipment setup in order to cancel out any equipment and atmospheric errors caused by unequal length of shots.

Heavy: longer shot taken in either the FS or BS when compared to the counter shot

Light: shorter shot taken in either the FS or BS when compared to the counter shot

Gunner: person operating the equipment that takes the desired measurements

Squared up: angles on the corners of the bridge are identical.