Chapter 10 Differential Leveling Survey Specifications

10-01 General

Survey specifications describe the methods and procedures needed to attain a desired survey standard. Specifications in this chapter are based on Federal Geodetic Control Subcommittee (FGCS) standards and specifications. Except where noted, they have been modified to give results that will meet the requirements for various types of differential leveling surveys typically performed by WSDOT. For details regarding standards, refer to Chapter 7, "Accuracy Classifications and Standards."

WSDOT differential leveling survey specifications are to be used for all WSDOT-involved transportation improvement projects, including special-funded projects.

10-02 Differential Leveling Method

These specifications apply to the use of compensator-type engineer's levels and electronic digital/bar code leveling systems. Equipment to be used is specified under "Method" for each order of accuracy in this chapter.

- Specifications for trigonometric leveling are covered in Chapter 9, "Total Station System (TSS) Survey Specifications."
- Specifications for GPS derived elevations are covered in Chapter 8, "Global Positioning System (GPS) Survey Specifications."

All differential leveling equipment must be properly maintained and regularly checked for accuracy. Systematic errors due to poorly maintained equipment must be eliminated to ensure valid survey adjustments. Equipment acquisition, repair, adjustment, and maintenance are covered in Chapter 3, "Survey Equipment."

10-03 General Differential Leveling Survey Specifications

10-03.1 Sight Distances

Sight distances and the balance between foresights and backsights are critical to maintaining accuracy in differential leveling. When poor environmental conditions are encountered reduce the sight distances. Under normal conditions the sight distances specified in this chapter will produce surveys that meet WSDOT accuracy standards for second-, third-, and general-order surveys. (See "Limits of Sight Distances," page 10-4.)

10-03.2 Turning Points

Set turning points (TP) in stable, protected locations. Spikes or large nails set in pavement; wooden stakes set in firm soil; and prominent points such as rock outcroppings or the top of concrete curbs may be used as turning points. If a turning point does not have a definite high point, provide a mark at the exact point of rod contact.

Do not remove turning points after use, but leave them in place to provide a check in the event of blunders or excessive misclosures. A solid, well defined turning point may be used as a temporary bench mark (TBM).

10-03.3 Benchmarks

Benchmarks are a series of permanent points of known elevation located within the limits of the project. Benchmarks are very important, since the gradeline, earthwork, structure work and drainage are all referenced to benchmarks for elevation.

Establish benchmarks with physical characteristics and quality commensurate with the order of the leveling survey. Use benchmarks of a stable, permanent nature; e.g., galvanized steel pipe; steel rod driven into a firm soil base; or poured in place concrete. A brass WSDOT disk epoxied into a drill hole in rock or concrete is also acceptable. Stamp benchmarks with identifying information; date, point designation at a minimum.

Locate benchmarks where they will be conveniently and easily accessible. Whenever possible, locate benchmarks outside of construction areas, clear of traffic, and within a public right of way or easement. Allow for future changes in landscaping and overgrowth of trees and foliage.

Space benchmarks as required by project conditions and convenience of operation, generally not to exceed 3000 ft (1 km) apart. Minimum spacing for benchmarks is normally 1000 ft (300 m). In hilly terrain, place a benchmark where there is a 50 ft (15 m) difference in elevation. Place benchmarks within 200 ft (60 m) and on both sides of structure sites. Prepare a written benchmark/station description for inclusion in the survey notes and in the benchmark summary report.

Benchmarks should be shown on the Monumentation Map or the Record of Surveys as a method of recording.

10-03.4 Differential Leveling Survey Notes

Record rod readings, for single- or three-wire leveling operations using a compensator-type engineer's level, in digital form on a hand-held programmable calculator, computer, or data collector. Such calculators must produce a hard copy of all readings, reductions, and adjustments. Hard copies of data collection, reduction, and adjustment calculations will be incorporated into, and become a permanent part of, the survey field notes. Field notes can be recorded by hand, but must be scanned to obtain electronic images of the notes.

Raw field data generated by an electronic digital/bar code leveling system will be translated into field book format by use of conversion software such as "DIGILEV Translation Program" or "STARPLUS Data Conversion Utility."

10-03.5 Adjustment of Differential Leveling Surveys

A straight-line interpolation process adjusts second- and third-order differential leveling surveys, when run as a single loop or section. Corrections for the closing error will be prorated to each benchmark and TP between the two controlling benchmarks.

When multiple leveling survey loops interconnect to form a network, such as in corridor or project control, points common to two or more loops will be adjusted by application of least-squares adjustment. See "Least Squares Adjustment" in Chapter 7, "Accuracy Classifications and Standards."

10-04 Second-Order Differential Leveling Surveys

10-04.1 Application

Second-order leveling surveys are generally confined to extending vertical control data over long distances, and establishing and maintaining corridor vertical control.

For second-order differential leveling specifications acceptable to the National Geodetic Survey, see *Standards and Specifications for Geodetic Control Networks* published by the Federal Geodetic Control Committee, September 1984.

10-04.2 Equipment

Differential leveling survey methods/equipment to achieve second-order standards are:

- Compensator-type (automatic) engineer's level (three-wire observations) with an invar-tape yard rod or a suitable metric graduated invar-tape rod.
- Electronic digital/bar-code leveling system with one-piece invar rod.
- If matched rods are used they must be alternated (leapfrogged) between setups.

10-04.3 Second-Order Three-Wire Differential Leveling Surveys

Instrument Check

At the beginning and end of each day's operation, check the instrument for collimation error (two-peg test), recording the tests into the survey notes. Description of the two-peg test can be found in any standard surveying text. If an error in excess of 0.007 ft (2 mm) within a 200 ft (60 m) sight distance is detected, readjust the level. Immediately check the instrument if it is severely jolted, bumped, or suspected as such. Check compensator-type instruments for proper mechanical operation at least every two weeks of use. See Section 3-03 Adjustment of Equipment for specific instructions on performing the two-peg test.

Limits of Sight Distances

Do not exceed sight distances of 230 ft (70 m). When more than two rod readings (see Rod Readings, below) are rejected in ten setups, reduce the sighting distance. Do not exceed 15 ft (5 m) for the difference in length between foresights and backsights of a single setup.

Rod Readings

Rod readings are estimated to the nearest 0.005 ft (1 mm). For each foresight and backsight reading of a set, the middle wire reading must be within 0.005 ft (1 mm) of the mean of all three wire readings. If this is not achieved, the misread or mis-recorded wire must be identified and corrected before moving to the next setup.

See Figure 10-1 for second-order, three-wire differential leveling standards and specifications.

10-04.5 Second Order, Electronic Digital/Bar Code Rod Leveling System

Manufacturers specifications recommend that the electronic digital leveling instrument not be exposed to direct sunlight. Use umbrellas in bright sunlight. When using electronic digital leveling instruments, the absolute collimation error will be recorded along with the leveling data.

See Figure 10-1 for second order electronic digital/bar code differential leveling standards and specifications.

Operation/Specification	Compensator-Level Three-Wire Observation	Electronic/Digital Bar Code Level
Difference in length between fore and back sights, not to exceed per setup	16 ft (5 m)	16 ft (5 m)
Cumulative difference in length between fore and back sights, not to exceed per loop or section	33 ft (10 m)	33 ft (10 m)
Maximum sight lengths	230 ft (70 m)	230 ft (70 m) *see Note 1*
Minimum ground clearance of sight line	1.5 ft (0.5 m)	1.5 ft (0.5 m)
Maximum section misclosure	0.035 ft $\sqrt{Dm}$ *(*8 mm $\sqrt{Dk}$*)* *see Note 2*	0.035 ft $\sqrt{Dm}$ *(*8 mm $\sqrt{Dk}$*)* *see Note 2*
Maximum loop misclosure	0.035 ft $\sqrt{Dm}$ *(*8 mm $\sqrt{Dk}$*)* *see Note 3*	0.035 ft $\sqrt{Dm}$ *(*8 mm $\sqrt{Dk}$*)* *see Note 3*
Difference between top and bottom interval not to exceed:	0.20 of rod unit	N/A
Collimation (Two-Peg) Test	Daily - not to exceed 0.007 ft (2 mm) *see Note 4*	Daily
Minimum number of readings. (Use repeat measure option for each observation.)	N/A	3 *see Note 5*

Notes;

1. Leveling staff in backlit condition may decrease maximum sight distance.

2. *D* = Shortest one-way length of section in miles *(Dm)* or kilometers *(Dk)* (section is defined as an unbroken series of setups betweentwo permanent control points).

3. *E* = Length of loop in km (loop is defined as a series of setups closing on the starting point).

4. Readjust level if 0.007 ft in 200 ft (2 mm in 60 m) is exceeded.

5. If standard error exceeds 0.003 ft (0.1 mm), continue repeat measurements until standard error is less than 0.003 ft (0.1 mm),

Second-Order Differential Leveling Specifications
Figure 10-1

Although the above Figure 10-1 provides maximum specifications it is recommended that the following guidelines be used during normal working conditions:

- Keep sights to 60 meters or less (200 feet).
- Keep imbalances to around 2 meters or less (6.5 feet).

- Always use the same rod used to come off the control mark to establish elevations on new marks.
- Try not to use the very bottom or top of the rod.
- Keep the rod plumb. If a truck wind hits either the instrument or the rod during a shot repeat the shot. Try to take shots between "large" truck traffic.
- Make sure that the claws for the instrument legs are kicked well into the ground.
- If using turtles (turning plates) to aid in leveling, make sure turtle is well into the ground.

10-05 Third-Order Differential Leveling Surveys

10-05.1 Applications

Third-order leveling surveys are used to establish vertical control and maintain benchmarks for:

- Project Control
- Supplemental Control
- Photo Control
- Construction Survey Control
- Topographic Survey Control
- Major Structure Points

10-05.2 Specifications

Methods:

- Compensator-type engineer's level (three-wire method) and yard rod or metric graduated Philadelphia-style rod
- Compensator-type engineer's level (single-wire method) and metric graduated
- Philadelphia-style rod
- Electronic/digital level and bar-code rod (wood or noninvar metal)

See Figure 10-2 for third-order differential leveling methods and specifications.

10-06 Order G (General) Differential Leveling Surveys

The survey party chief determines appropriate procedures for Order G (General) differential leveling, based on the particular needs of the survey task being performed. When developing procedures consider the following: objective of task, specific needs of the project and most efficient use of time.

See Chapter 14, "Location Survey Procedures," and Chapter 15, "Construction Survey Procedures," for tolerances and accuracy standards for specific types of surveys.

10-6.1 Applications

Order G leveling surveys are generally used to provide elevations for:

- Supplemental Design Surveys
- Construction Layout
- Environmental Surveys

- GIS Data Surveys
- Topographic Survey Data Capture

10-6.2 Specifications

Compensator-type engineer's level (single-wire method) methods:

- Philadelphia-style rod
- Lenker-style rod
- 25 foot extendible fiberglass rod

Operation/Specification	Compensator-Level Three-Wire Observation	Compensator-Level Single-Wire Observation	Electronic/Digital Bar Code Level
Difference in length between fore and back sights, not to exceed per setup	33 ft (10 m)	33 ft (10 m)	33 ft (10 m)
Cumulative difference in length between fore and backsights, not to exceed per loop or section	33 ft (10 m)	33 ft (10 m)	33 ft (10 m)
Maximum sight lengths	300 ft (90 m)	300 ft (90 m)	300 ft (90 m) *see Note 1*
Minimum ground clearance of sight line	1.5 ft (0.5 m)	1.5 ft (0.5 m)	1.5 ft (0.5 m)
Maximum section misclosure	0.05 ft √ *Dm* (12 mm √ *Dk)* *see Note 2*	0.05 ft √ *Dm* (12 mm √ *Dk)* *see Note 2*	0.035 ft √ *Dm* (12 mm √ *Dk)* *see Note 2*
Maximum loop misclosure	0.05 ft √ *Dm* (12 mm √ *Dk)* *see Note 3*	0.05 ft √ *Dm* (12 mm √ *Dk)* *see Note 3*	0.035 ft √ *Dm* (12 mm √ *Dk)* *see Note 3*
Difference between top and bottom interval not to exceed	0.30 of rod unit	N/A	N/A
Collimation (Two-Peg) Test	Daily - not to exceed 0.007 ft (2 mm) *see Note 4*	Daily	Daily
Minimum number of readings (Use repeat measure option for each observation)	N/A	N/A	3 s*ee Note 5*

Notes:

1. Leveling staff in backlit condition may decrease maximum sight distance.
2. D = Shortest one-way length of section in miles (Dm) or kilometers (Dk) (section is defined as an unbroken series of setups between two permanent control points).
3. E = Length of loop in km (loop is defined as a series of setups closing on the starting point). Em = miles, Ek = kilometers
4. Readjust level if 0.007 ft in 200 ft (2 mm in 60 m) is exceeded.
5. If standard error exceeds 0.003 ft (0.1 mm), continue repeat measurements until standard error is less than 0.003 ft (0.1 mm).

Third-Order Differential Leveling Specifications

Figure 10-2