8 Differential Leveling Survey Specifications

Survey specifications describe the methods and procedures needed to attain a desired survey standard. Specifications in this section 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 the Department. For details regarding standards, refer to Chapter 5, "Accuracy Classifications and Standards."

The Department's differential leveling survey specifications shall be used for all Caltrans-involved transportation improvement projects, including special-funded projects.

8.1 Differential Leveling Method

These specifications apply to the use of compensator-type engineer's levels and electronic digital/bar code leveling systems. Specifications for trigonometric leveling are covered in Chapter 7, "Total Station Survey System (TSSS) Survey Specifications." Specifications for GPS derived elevations are covered in Chapter 6, "Global Positioning System (GPS) Survey Specifications."

Equipment to be used is specified under "Method" for each order of accuracy in this Chapter.

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 is covered in Chapter 3, "Survey Equipment."

8.2 General Differential Leveling Survey Specif cations

8.2-1 Sight Distances

Sight distances and the balance between foresights and backsights are critical to maintaining accuracy in differential leveling. Sight distances should be reduced when poor environmental conditions are encountered. Under normal conditions the specified sight distances in this Chapter will produce surveys that meet the Department's accuracy standards for second-order, third-order, and general-order surveys. See Section 8.3-3, "Limits of Sight Distances".

8.2-2 Turning Points

Turning points (TP) should be set in stable, protected locations. Spikes or large nails set in pavement; wooden stakes set in firm soil; prominent points such as rock outcroppings or the top of concrete curbs may be used as turning points. Each turning point should have a definite high point or be marked at the exact point of rod contact. If a permanent TP cannot be driven, then a turning plate ("trivet" or "turtle") weighing at least 15lbs. should be used. In situations allowing neither turning pins nor turning plates (sandy or marshy soils), a long wooden stake with double-headed nail should be driven to a firm depth.

Turning points (except turning plates) should not be removed after use, but left 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 benchmark (TBM).

8.2-3 Benchmarks

Establish benchmarks with physical characteristics and quality commensurate with the order of the leveling survey. Benchmarks should be of a stable, permanent nature; e.g., galvanized steel pipe; steel rod driven into a firm soil base; or cast in place concrete. A brass disk epoxied into a drilled hole in rock or concrete is also acceptable.

Benchmarks should be conveniently located and easily accessible. Whenever possible, benchmarks should be located 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 2600 feet apart. Minimum spacing for benchmarks is normally 1000 feet. Prepare a written benchmark/station description for inclusion in the survey notes and in the project final control report.

8.2-4 Differential Leveling Survey Notes

Rod readings for single- or three-wire leveling operations using a compensator-type engineer's level, should be recorded 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. See Chapter 14, "Survey Records." Field notes can be recorded by hand in a bound field book, or on the Department's forms HCS-88 or DH-SP-14.

8.2-5 Adjustment of Differential Leveling Surveys

Second-order and third-order differential leveling surveys, when run as a single loop or section, are adjusted by a straight-line interpolation process. 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 Section 5.4 "Least Squares Adjustment."

8.3 Second-Order Differential Leveling Surveys

8.3-1 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 Specif cations for Geodetic Control Networks* published by the Federal Geodetic Control Committee, September, 1984 and the Federal Geodetic Control Subcommittee document titled, "FGCS Specifications and Procedures to Incorporate Electronic Digital/Bar-Code Leveling Systems".

8.3-2 Equipment

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

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

8.3-3 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 0.003 feet within a 200 foot sight distance is detected, the level should be readjusted. If the instrument is severely jolted or bumped, or suspected as such, it should be immediately checked. Compensator-type instruments should be checked for proper mechanical operation at least every two weeks of use.

Limits of Sight Distances

Sight distances should not exceed 230 feet. When more than two rod readings (see Rod Readings, below) are rejected in every ten setups, reduce the sighting distance. The difference in length between foresights and backsights of a single setup should not exceed 16 feet.

Rod Readings

Rod readings are estimated to the nearest 0.001 yard. For each foresight and backsight reading of a set, the middle wire reading must be within 0.001 yard of the mean of all three-wire readings. If this is not achieved, the misread or misrecorded wire must be identified and corrected before moving to the next setup.

See Table 8-1 for second-order, three-wire differential leveling standards and specifications.

8.3-5 Second Order, Electronic Digital/Bar Code Rod Leveling System

Manufacturers specifications recommend that the electronic digital leveling instrument should not be exposed to direct sunlight. Umbrellas should be used in bright sunlight. When using electronic digital leveling instruments, the absolute collimation error will be recorded along with the leveling data. See Table 8-1 for second order, electronic digital/bar code differential leveling standards and specifications.

Table 8-1 Second Order Differential Leveling Specifications

Operation/Specification	Compensator-Level Three- Wire Observation	Electronic/Digital Bar Code Level
Difference in length between fore and back sites, not to exceed per setup	16 feet	16 feet
Cumulative difference in length between fore and back sights, not to exceed per loop or section	33 feet	33 feet
Maximum sight lengths	230 feet	230 feet
Minimum ground clearance of sight line	1.6 feet	1.6 feet
Maximum section misclosure	0.04 feet *x* (√D) *(See Note 2)*	0.04 feet *x* (√D) *(See Note 2)*
Maximum loop misclosure	0.04 feet *x* (√E) *(See Note 3)*	0.04 feet *x* (√E) *(See Note 3)*
Difference between top and bottom interval not to exceed:	.20 of rod unit	N/A
Collimation (Two-Peg) Test	Daily (not to exceed 0.003 feet) *(See Note 4)*	Daily
Minimum number of readings. (Use repeat measure option for each observation)	N/A	3

Notes:

1. Leveling staff in backlit condition may decrease maximum sight distance
2. *D* = Shortest one-way length of section in miles (section is defined as a series of setups between two permanent control points).
3. *E* = Length of loop in miles (loop is defined as a series of setups closing on the starting point).
4. Readjust level if 0.003 feet in 200 feet is exceeded.
5. If the standard error of the mean exceeds 0.0003 feet, continue repeat measurements until the standard error of the mean is less than 0.0003 feet.

8.4 Third-Order Differential Leveling Surveys

8.4-1 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

8.4-2 Specif cations

Methods:

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

See Table 8-2 for third-order differential leveling methods and specifications.

Table 8-2 Third Order Differential Leveling Specifications

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 feet	33 feet	33 feet
Cumulative difference in length between fore and back sights, not to exceed per loop or section	33 feet	33 feet	33 feet
Maximum sight lengths	300 feet	300 feet	300 feet
Minimum ground clearance of sight line	1.6 feet	1.6 feet	1.6 feet
Maximum section misclosure	0.06 feet *x* (√D) *(See Note 2)*	0.06 feet *x* (√D) *(See Note 2)*	0.04 feet *x* (√D) *(See Note 2)*
Maximum loop misclosure	0.06 feet *x* (√E) *(See Note 3)*	0.06 feet *x* (√E) *(See Note 3)*	0.04 feet *x* (√E) *(See Note 3)*
Difference between top and bottom interval not to exceed:	.30 of rod unit	N/A	N/A
Collimation (Two-Peg) Test	Daily (not to exceed 0.007 feet) *(See Note 4)*	Daily	Daily
Minimum number of readings. (Use repeat measure option for each observation)	N/A	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 (section is defined as a series of setups between two permanent control points).
3. *E* = Length of loop in miles (loop is defined as a series of setups closing on the starting point).
4. Readjust level if 0.007 feet in 200 feet is exceeded.
5. If the standard error of the mean exceeds 0.0003 feet, continue repeat measurements until the standard error of the mean is less than 0.0003 feet.

8.5 This section intentionally left blank

8.6 General Order Differential Leveling Surveys

Appropriate procedures for Order G (General) differential leveling are determined by the survey party chief based on the particular needs of the survey task being performed. Considerations in determination of procedures should include: objective of task, specific needs of the project and most efficient use of time.

See Chapter 11, "Engineering Surveys" and Chapter 12, "Construction Surveys" for tolerances and accuracy standards for specific types of surveys.

8.6-1 Applications

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

- Supplemental Design Surveys
- Construction Layout
- Environmental Surveys
- GIS Data Surveys
- Topographic Survey Data Capture

8.6-2 Specif cations

Methods:

- Compensator-type engineer's level (single-wire method) Philadelphia-style rod
- Compensator-type engineer's level (single-wire method) direct elevation reading (adjustable endless tape) rod
- Compensator-type engineer's level (single-wire method) 25 foot extendible fiberglass rod