

LEVELING

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Introduction

"Leveling" is a general term used in land surveying that applies to vertical measurements. Vertical measurements are made and referenced to datums, as elevations. The reference datum might be an arbitrary elevation chosen for convenience or a very precise value determined after lengthy studies. The standard reference datum used throughout California is mean sea level, based on the National Geodetic Vertical Datum (NGVD 1929).

Three methods used to measure differences in elevation are direct vertical measurement, trigonometric leveling, and differential leveling. It is important to understand the procedure, equipment and note keeping format used for each method.

Performance Expected on the Exams

Define the terms "curvature" and "refraction," be able to calculate their combined effects and explain the procedure used to limit their effects.

Explain how to peg a level and calculate the collimation correction of a properly adjusted level.

Given field measurements, calculate the difference in elevation between two stations using trigonometric leveling method.

Explain, interpret, reduce and adjust differential leveling notes.

Explain, interpret, reduce and adjust three-wire leveling notes.

Obtain the difference in elevation between two stations by reciprocal leveling.

Plan and analyze the results of a leveling project with regard to NGS standards and specifications.

Key Terms

Altimetry	Lenker rod
Automatic pendulum level	Mean sea level
Backsight (+shot)	National Geodetic Vertical datum
Bench mark	(NGVD 1929)
Curvature	North American Vertical Datum (NAVD 1988)
Datum	Pegging a level
Direct leveling	Philadelphia rod
Differential leveling	Plumb line
Elevation	Profile leveling
Foresight (-shot)	Reciprocal leveling
H.I.	Refraction
Horizontal line	Three-wire leveling
Horizontal plane	C C
Intermediate foresight (side shot)	Trigonometric leveling
Leveling	Turning point (TP)
Level surface	Vertical difference
Level line	Vertical line

Video Presentation Outline

Basic Concepts

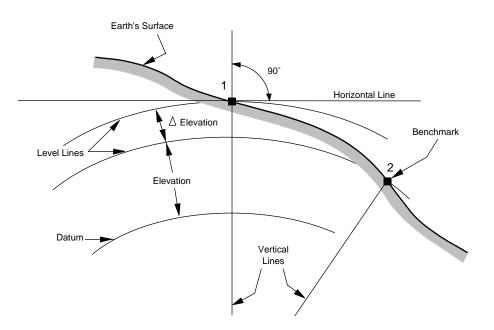


Figure 6-1. Leveling concepts.

- Level line
- Horizontal line
- Vertical line
- Datum

Curvature and Refraction

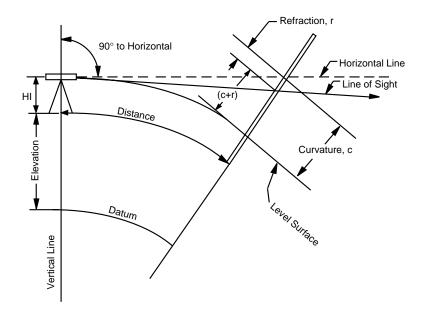


Figure 6-2. Curvature and refraction.

- Curvature
- Refraction
- The formula for computing the combined effect of curvature and refraction is:
 - $C + R = 0.021K^2$
 - C = correction for curvature
 - R = correction for refraction
 - K = sighting distance in thousands of feet
- Corrections for various distances

Distance	Correction
100'	0.00021'
200'	0.00082'
500'	0.0052'
700'	0.01'
1 mile	0.574'

Three Methods of Vertical Measurement Leveling

Direct Vertical Measurement Leveling

- Altimetry
- Direct elevation rods
- Lasers
- G.P.S.

Trigonometric Leveling

- Equipment
- Method
- Calculation

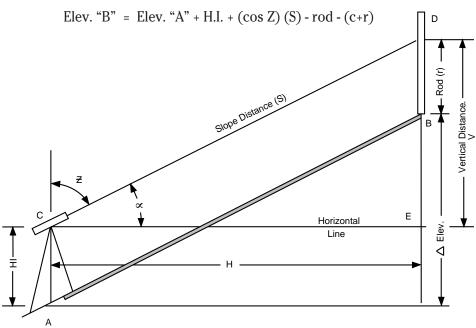
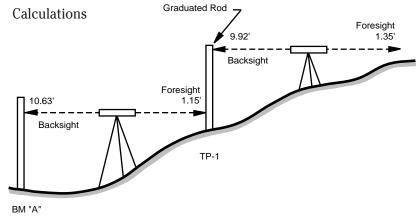


Figure 6-3. Trigonometric leveling.

Differential Leveling

- Equipment
- Method

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Elevation 100.00'

Figure 6-4. Differential leveling.

Notekeeping for Differential Leveling

• Standard notekeeping

	+	$\overline{\Lambda}$	_	Elev.
				(412.011)
B.M. #2			5.090	412.005
	7.330	417.095		
T.P.			4.765	409.765
	6.995	414.530		
B.M. #1				407.535

Figure 6-5. Profile leveling noteform.

Three-Wire Leveling Method

Foot Rod

Diffe	rential	eveling	(3-wire)	with Foo	t Rod
	Half-			Half -	
BS(+)	Interval	Mear(+)	FS(-)	Interval	Mean(-)
(1) BA			TA		
8.266					
			3.491	171	
8.105	165	8.1037	3.320	168	3.3210
7.940	326		3.152	339	
(Z) TE	1		_	2	
6.574	216		4.623	204	
6.358	217	6.3577	4.419	200	4.4203
6.141	759	14.4614	4.219	743	7.7413
(<u>3)</u> TP	2		8~	30	
6.203	182		2.819	188	
6.021	178	6.0223	2.631	185	2.6320
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3.843	1119	+ <i>20.483</i> 7 - <i>10</i> 3733	2.446	1116	<u>-10.3733</u>
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		- <i>10.3733</i> + <i>10.1104</i>	ff.(D.E.)		
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Figure 6-6. Level notes for foot rod from noteforms for surveying measurements. (Reproduced with permission from Landmark Enterprises.)

Meter Rod

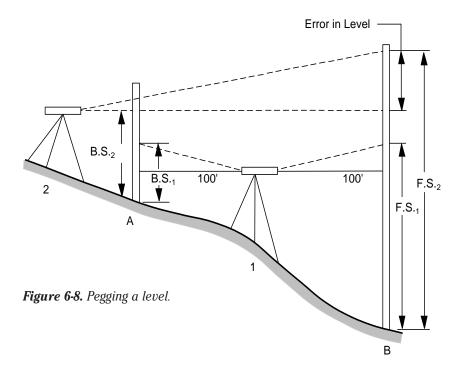
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Figure 6-7. Level notes for meter rod from noteforms. (Reproduced with permission from Landmark Enterprises.)

Special Leveling Procedures



Sample Peg Test

Station	Backsight (+)	H.I.	Foresight	Elevation
A	5.10	105.10		100.00'
(assumed	d)			
В			4.96	100.14'
А	5.51	105.51		100.00'
В			5.35	100.16'

Adjustment = elevation of B from setup 1 - elevation of B from setup 2.

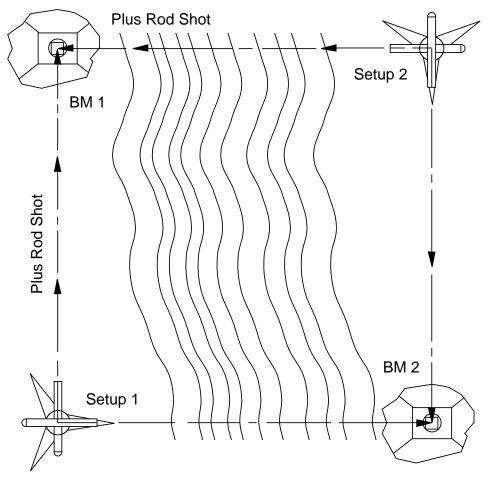


Figure 6-9. Reciprocal leveling.

Classification of Accuracy Standards and Adjustments

General Specifications for Vertical Control Field Procedures

Order Class	First I	First II	Second I	Second II	Third
Minimal Observation Method	Micrometer	Micrometer	Micrometer or Three-Wire	Three-Wire	Center Wire
Section Running	DR, DS, or MDS	DR, DS, or MDS	DR	DR	DR
Difference of forward and backward sight lengths never to exceed:					
per setup (m)	2	5	5	10	10
per section (m)	4	10	10	10	10
Maximum sight length (m)	50	60	60	70	90
Minumum ground clearance of line of sight (m)	0.5	0.5	0.5	0.5	0.5
Even no. of setups when not using leveling rods with detailed calibratic	on yes	yes	yes	yes	
Determine temp. gradient for vert. range of line of sight for each setup		ves	yes		
Maximum section misclosure (mm)	3√D	4√D	6√D	8√D	12√D
Maximum loop misclosure (mm)	4√E	5√E	6√E	8√E	12√E
Single-Run Methods					
Reverse direction of single runs every half day	yes	ves	yes		
Non-reversible compensator leveling instruments)))		
Off-level/relevel instrument bet. observing the high and low rod scales	yes	yes	yes		
Three-Wire Method	,	,	,		
Reading check (difference between top and bottom intervals)					
for one setup not to exceed (tenths of rod units)			2	2	3
Read rod first in alternate setup method			yes	yes	yes
Double Scale Rods)	j	j
Low-high scale elevation difference for one setup not to exceed (mm)					
With reversible compensator	0.40	1.00	1.00	2.00	2.00
Other instrument types:					
Half-centimeter rods	0.25	0.30	0.60	0.70	1.30
Full-centimeter rods	0.30	0.30	0.60	0.70	1.30
DS-Double Simultaneous procedure					
DR-Double-Run					
MDS-Modified Double Simultaneous					
D-shortest length of section (one-way) in km.					
E-perimeter of loop in km.					
# Must double-run when using three-wire method					
* May single-run if line length between network control points is less th	han 25 km and ma	ay single-run if line	length between	network contro	ol points is
less then 10 km.			U U		
NOTE: See Geometric Geodetic Accuracy Standards and Specification Control Committee for latest specifications.	ns for Using GPS R	elative Positioning	Techniques, Fede	eral Geodetic	

Figure 6-10. "General Specifications for Vertical Control," National Geodetic Survey.

Adjustments to Level Runs

- Length of lines methods
- Number of turning points method
- Least squares method

Sample Test Questions

- 1. When pegging a level the surveyor reads 5.25 on the backsight rod and 5.38 on the foresight rod. After moving the level adjacent to the backsight rod, a reading of 5.18 is taken on the near rod. What should be on the far rod?
- 2. When pegging a level, how far apart should the rod readings be taken?
- 3. The effects eliminated by keeping backsights and foresights equal are ______ and ______.
- 4. Does an instrument in perfect adjustment sight a level line to a distant object? Explain.

Station	B.S. (+)	H.I.	F.S. (-)	Elevation
3.M. A				256.18
Г.Р. 1	4.05	<u>a.</u>	6.48 10.26	253.75 <u>b.</u>
	5.26	259.01	B F A	(top Pipe)
Г.Р. 2	2.56	254.01	7.56	<u> </u>
Г.Р. З	<u> </u>	250.45	<u> </u>	245.56
B.M. B			7.08	<u>f.</u> (243.39)

5. Fill in the missing data in the sample differential level run below.

- 6. What is the misclosure in the sample differential level run in problem 5? What is the adjusted elevation of T.P. 2?
- 7. To meet Class II, Second Order accuracies, what would be the maximum misclosure of a level run of two kilometers?
- 8. What is the recommended leveling method for meeting the Class II Second Order Standard?
- 9. Is it necessary to balance the foresights and backsights to achieve the necessary accuracies in question 7? If yes, what is the maximum difference allowed per setup? What is the maximum length allowed per sight?
- 10. A theodolite is set up over Point 123 with an H.I. of 5.59 feet. The elevation of Point 123 is 2105.67 feet. The measured zenith angle to a target with an H.I. of 4.77 at Point 124, is 94° 35' 46". The slope distance measured from the theodolite to the target is 2145.89 feet. What is the difference in elevation between Point 123 and Point 124? What field procedure could you use that would allow you to discount the effects of curvature and refraction on the results?
- 11. Problem D-6, 1978 LS

Problem Statement: A collection of rod readings is shown below. These readings were taken over a section of line of three-wire levels run in both directions using a precision self-leveling level and invar-faced-rods graduated in centimeters with readings estimated to the nearest millimetre. The C-factor of the instrument is -0.150, the stadia constant is 0.335 and the average rod temperature is 30° C.

Required:

- A. Arrange these notes in the workbook paper as would be done in a field book, showing all data normally shown in field notes for precise leveling.
- B. Reduce and analyze the notes, showing all intermediate steps and checks. Note any deviations from acceptable practice and/or limits, and proceed to a determination of the mean difference in elevation for the section and assumptions you make. Compute and apply all applicable corrections for systematic errors. Express the difference in elevation in meters.
- C. Determine and state the highest order of leveling for which this run would qualify. Use the latest published standards for vertical control surveys.

D. Discuss the concept of orthometric corrections: What it is, what it does, when it is used, and the kind of work to which it is normally applied. Would it be likely to be applied to the data in this problem? Why?

Rod Re	Rod Readings		Wire Levels
Forwar	rd Run	Backy	ward Run
+	-	+	-
234	2392	1831	721
198	2359	1802	693
162	2327	1775	666
1455	1629	3077	171
1384	1557	3057	151
1313	1484	3037	131
158	3250	3332	298
155	3227	3310	227
112	3203	3288	257
126	3125	1854	1811
117	3106	1784	1742
088	3087	1714	1672
808	1832	2603	240
777	1795	2563	202
747	1779	2542	164

Answer Key

- 1. 5.31 ft
- 2. 200 ft
- 3. Curvature, refraction
- 4. No, the line of sight is a curved line due to atmospheric refraction.
- 5. A. 260.23
 - B. 249.97
 - C. 251.45
 - D. 8.45
 - E. 4.89
 - F. 243.37
- 6. Misclosure = -.02 ft., t.p.#2 = 251.46
- 7. 11.31 mm
- 8. Three-wire, double-run or single-run double simultaneous procedure
- 9. Yes, 10 m, maximum sight length is 70 m
- 10. Change in

Elevation = H.I. PT. 123 - H.I. PT 124 + ((cos Z) (slope dist.) - (c+r)) = $5.59 - 4.77 + (cos 94^{\circ} 35' 46'' x 2145.89) - (.021 x 2.14589^{2})$ = -171.23 ft

The effect of curvature and refraction will be canceled if measurements are made from each end of the line, and the mean of the results of the two sets of measurements is used.

- 11. A. Refer to Figure 6-7 for field noteform for three-wire level notes using a meter rod.
 - B. Assume K = 100

Forward run		
distance leveled	=	B.S. Intervals + F.S. Intervals + 10
		(Stadia Constant)
	=	359 + 367 + 10 (.335)
	=	729.4M
	=	.7294 km
Corrected elev.	=	F.S. + B.S.
	=	2.6013 + (-12.0440)
	=	-9.4427 m
Correction for		
interval imbalance	=	Difference between F.S. and B.S. Intervals x - 0.15
	=	8 x -0.15 mm
	=	-1.2 mm
Elev.	=	-9.44270012 = -9.4439
Backward run		
distance leveled	=	712 M + 10 (.335) = .7154 km
Corrected elev.	=	<u>9.4510 - 10X.15</u> 1000
	=	9.4495 m

There are two bad rod readings in the notes, both in the forward run.

- 1. The foresight middle wire reading at STA. 4 should be 107 rather than 117.
- 2. The backsight low wire reading at STA. 5 should be 1759 rather than 1779.

C.	Average length of section		Mean of forward and backward runs .7224 km
	Average difference in elevation	=	9.4467
	Difference in elevation between forward and		
	backward runs	=	9.4439 - 9.4495
		=	.0056 m
		=	5.6 mm

Difference in forward and backward sight lengths < 10 m and maximum section misclosures from Figure 6-10 show this run meets Second Order, Class II requirements.

D. Reference: *The Surveying Handbook*, Brinker and Minnick and *Caltrans Surveys Manual*.

Level surfaces are perpendicular to the direction of gravity. Gravity is affected by the variation of centrifugal force which increases with altitude and decreasing latitude. In geodetic leveling, this variation in gravity accounts for nonparallel level surfaces. Orthometric correction is applied to account for convergence of level surfaces for long level runs in north-south directions or runs at high elevations.

Orthometric correction would not be applied to the data in this problem because required information for application of orthometric correction such as latitude and elevation are not given, and short level runs of this order and class would be unaffected by orthometric correction.

References

- _____, *Surveys Manual*, California Department of Transportation, Chapters 2, 4, and 5.
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