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**

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

<table>
<thead>
<tr>
<th>Distance</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>100'</td>
<td>0.00021'</td>
</tr>
<tr>
<td>200'</td>
<td>0.00082'</td>
</tr>
<tr>
<td>500'</td>
<td>0.0052'</td>
</tr>
<tr>
<td>700'</td>
<td>0.01'</td>
</tr>
<tr>
<td>1 mile</td>
<td>0.574'</td>
</tr>
</tbody>
</table>
Three Methods of Vertical Measurement Leveling

Direct Vertical Measurement Leveling

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

Trigonometric Leveling

- Equipment
- Method
- Calculation

\[
\text{Elev. "B"} = \text{Elev. "A"} + \text{H.I.} + (\cos Z) \cdot (S) - \text{rod - (c+r)}
\]

Figure 6-3. Trigonometric leveling.
Differential Leveling

- Equipment
- Method
- Calculations

Figure 6-4. Differential leveling.

Notekeeping for Differential Leveling

- Standard notekeeping

<table>
<thead>
<tr>
<th></th>
<th>+</th>
<th>(\Delta)</th>
<th>-</th>
<th>Elev.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(412.011)</td>
</tr>
<tr>
<td>B.M. #2</td>
<td></td>
<td>5.090</td>
<td>412.005</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.330</td>
<td>417.095</td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.P.</td>
<td></td>
<td>4.765</td>
<td>409.765</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6.995</td>
<td>414.530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B.M. #1</td>
<td></td>
<td></td>
<td></td>
<td>407.535</td>
</tr>
</tbody>
</table>

Figure 6-5. Profile leveling noteform.
Three-Wire Leveling Method

Foot Rod

Figure 6-6. Level notes for foot rod from noteforms for surveying measurements.
(Reproduced with permission from Landmark Enterprises.)
## Meter Rod

![Image of level notes for meter rod from noteforms.](Image)

*Figure 6-7. Level notes for meter rod from noteforms.*

(Reproduced with permission from Landmark Enterprises.)
### Special Leveling Procedures

![Diagram of Pegging a level](image)

#### Sample Peg Test

<table>
<thead>
<tr>
<th>Station</th>
<th>Backsight (+)</th>
<th>H.I.</th>
<th>Foresight</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>5.10</td>
<td>105.10</td>
<td>100.00'</td>
<td>100.00'</td>
</tr>
<tr>
<td>(assumed)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>4.96</td>
<td>100.14'</td>
<td></td>
<td>100.14'</td>
</tr>
<tr>
<td>A</td>
<td>5.51</td>
<td>105.51</td>
<td>100.00'</td>
<td>100.00'</td>
</tr>
<tr>
<td>B</td>
<td>5.35</td>
<td>100.16'</td>
<td></td>
<td>100.16'</td>
</tr>
</tbody>
</table>

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**

<table>
<thead>
<tr>
<th>Order Class</th>
<th>First I</th>
<th>First II</th>
<th>Second I</th>
<th>Second II</th>
<th>Third</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal Observation Method</td>
<td>Micrometer DR, DS, or MDS</td>
<td>Micrometer DR, DS, or MDS</td>
<td>Micrometer or Three-Wire DR</td>
<td>Three-Wire DR</td>
<td>Center Wire DR</td>
</tr>
</tbody>
</table>

- **Section Running**
  - Difference of forward and backward sight lengths never to exceed:
    - per setup (m)
      - First I: 2
      - First II: 5
      - Second I: 5
      - Second II: 10
      - Third: 10
    - per section (m)
      - First I: 4
      - First II: 10
      - Second I: 10
      - Second II: 10
      - Third: 10
    - Maximum sight length (m)
      - First I: 50
      - First II: 60
      - Second I: 60
      - Second II: 70
      - Third: 90
    - Minimum ground clearance of line of sight (m)
      - First I: 0.5
      - First II: 0.5
      - Second I: 0.5
      - Second II: 0.5
      - Third: 0.5
    - Even no. of setups when not using leveling rods with detailed calibration
      - yes
      - yes
      - yes
      - yes
      - ——
    - Determine temp. gradient for vert. range of line of sight for each setup
      - yes
      - yes
      - 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
    - yes
    - yes
    - ——
    - ——
  - Non-reversible compensator leveling instruments
    - yes
    - yes
    - yes
    - ——
    - ——
  - 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**
  - 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

- **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.

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

<table>
<thead>
<tr>
<th>Station</th>
<th>B.S. (+)</th>
<th>H.I.</th>
<th>F.S. (–)</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B.M. A</td>
<td>4.05</td>
<td>a.</td>
<td></td>
<td>256.18</td>
</tr>
<tr>
<td>T.P. 1</td>
<td>6.48</td>
<td>b.</td>
<td>10.26</td>
<td>253.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(top Pipe)</td>
</tr>
<tr>
<td>T.P. 2</td>
<td>5.26</td>
<td>259.01</td>
<td>7.56</td>
<td>c.</td>
</tr>
<tr>
<td>T.P. 3</td>
<td>2.56</td>
<td>254.01</td>
<td>d.</td>
<td>245.56</td>
</tr>
<tr>
<td>B.M. B</td>
<td>250.45</td>
<td>e.</td>
<td>7.08</td>
<td>f.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(243.39)</td>
</tr>
</tbody>
</table>
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?

<table>
<thead>
<tr>
<th>Rod Readings</th>
<th>Three Wire Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward Run</strong></td>
<td><strong>Backward Run</strong></td>
</tr>
<tr>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>234</td>
<td>2392</td>
</tr>
<tr>
<td>198</td>
<td>2359</td>
</tr>
<tr>
<td>162</td>
<td>2327</td>
</tr>
<tr>
<td>1455</td>
<td>1629</td>
</tr>
<tr>
<td>1384</td>
<td>1557</td>
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<tr>
<td>1313</td>
<td>1484</td>
</tr>
<tr>
<td>158</td>
<td>3250</td>
</tr>
<tr>
<td>155</td>
<td>3227</td>
</tr>
<tr>
<td>112</td>
<td>3203</td>
</tr>
<tr>
<td>126</td>
<td>3125</td>
</tr>
<tr>
<td>117</td>
<td>3106</td>
</tr>
<tr>
<td>088</td>
<td>3087</td>
</tr>
<tr>
<td>808</td>
<td>1832</td>
</tr>
<tr>
<td>777</td>
<td>1795</td>
</tr>
<tr>
<td>747</td>
<td>1779</td>
</tr>
</tbody>
</table>
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° 35' 46" x 2145.89) - (.021 x 2.14589²)
    = -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 = $B.S. \text{ Intervals} + F.S. \text{ Intervals} + 10$

(Stadia Constant)

$= 359 + 367 + 10 (.335)$

$= 729.4M$

$= .7294 \text{ km}$

Corrected elev. = $F.S. + B.S.$

$= 2.6013 + (-12.0440)$

$= -9.4427 \text{ m}$

Correction for interval imbalance = Difference between F.S. and B.S. Intervals x - 0.15

$= 8 \times -0.15 \text{ mm}$

$= -1.2 \text{ mm}$


Backward run

distance leveled = $712 M + 10 (.335) = .7154 \text{ km}$

Corrected elev. = $\frac{9.4510 - 10 \times 0.15}{1000}$

$= 9.4495 \text{ m}$

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.


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.

_______, *Definitions of Surveying and Associated Terms*, A.C.S.M., Bethesda, Maryland, 1978.


