Leveling-Theory, Methods, Equipments, Filed procedure and Computation

Dr. Khalil Al-Jumboori
UOB
Department of Civil Engineering and Architecture
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Outline

• Definitions (vertical line, level surface, horizontal line, vertical datum, elevation, mean sea level, Bench mark, control points)
• Leveling equipments (lab illustrated)
• Element of the surveyor level 4.1
• Curvature and refraction errors in leveling 4.8
• Procedure in leveling. HPC methods, Flying leveling, Series leveling
• Inverted staff
• Trigonometric leveling
**Leveling-theory and Methods**

*Leveling is the process by which elevations of points or differences in elevation are determined.***

**Example Applications**

- Design highways, railroads, canals, sewers, water supply systems.
- Establish new vertical control (BM).
- Develop maps showing general ground configuration and provide spot heights or contours on a plan.
- Calculate volumes of earth work and provide data for road cross-sections.
- Provide a level or inclined plane in the setting out of construction works.
- Set grades and elevations for construction projects
  - Investigate drainage.
- To determine the topography of sites for design projects.
A plane perpendicular to the local direction of gravity or local vertical line (In plane surveying)

Line perpendicular to the vertical

curved surface that at every point is perpendicular to the direction of gravity (plumb line), e.g. still lake surface.

A line that follows the local direction of gravity as indicated by a plumb line

A level surface to which elevations are referred (i.e. reference surface such as MSL)
• **Level surface**
  – A surface over which water will not flow
  – The direction of gravity is always normal to a level surface

• **Horizontal surface**
  – A *horizontal* surface will be tangent to a *level* surface
  – Over short distances (<100 m) the horizontal surface and the level surface will coincide
Definition

- **Direction of gravity**
- **Horizontal surface**
- **Level surface**
- **Limit of practical coincidence (~100 m)**
Definitions ....

Mean Sea Level (MSL):
Average elevation of the sea surface based on hourly tide gauge measurements over a period of 19 years

Bench Mark (BM):
A permanent reference point with a known elevation (relative to some datum, usually MSL)

Vertical Control:
A series of bench marks or other points of known elevation established throughout an area.
Categories of Leveling Instruments

- Dumpy levels
- Hand levels
- Tilting levels
- Automatic levels
- Precise levels
- Digital levels
- Electronic laser levels

All leveling instruments create horizontal plane through the telescope (Plane of Collimation).


Leveling Instruments - Old levels

- Early age levels are
  - Dumpy levels.
  - Tilting levels.
1. Leveling Instruments

![Automatic level with micrometer](image)

**Figure 4-14**  Automatic level with micrometer. (Copcon Corp.)

1. Leveling Instruments

![Diagram of leveling instrument with labels for different parts: Circular level bubble, Sight, Objective lens focus, Objective lens, Eyepiece focus, Horizontal motion screw, Capstan screws, Leveling screws.]

**Figure 4–9** Parts of an automatic level. (Courtesy Leica Geosystems.)

Surveying Telescope
Now most commonly used leveling instruments are - Auto level.

Auto level, as name sounds it has a auto level compensator and corrects automatically if instrument goes out of level.

Survey work can be done fast

Less chances of error,

Magnification available is more,

Range is more,
Equipment: Staff/Pole

- Wood, aluminum
- INVAR type for high precision leveling
Equipment: Bubble

- Keep the pole upright
  - Any tilt will disturb your readings
Reading an “E-Face Staff”
Reading a Staff

- Read the [m], [dm] & [cm]
- Estimate the [mm]
- Check yourself for frequent used numbers (2/3) or (7/8)

1422
Reading an “E-Face Staff”

**Example**

1. Make a list of the staff readings ‘a’ to ‘f’ in Fig. 4.5.

**Answer**

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a.</td>
<td>1.960</td>
<td></td>
</tr>
<tr>
<td>b.</td>
<td>2.033</td>
<td></td>
</tr>
<tr>
<td>c.</td>
<td>1.915</td>
<td></td>
</tr>
<tr>
<td>d.</td>
<td>1.978</td>
<td></td>
</tr>
<tr>
<td>e.</td>
<td>2.050</td>
<td></td>
</tr>
<tr>
<td>f.</td>
<td>2.002</td>
<td></td>
</tr>
</tbody>
</table>
• They are not popular instead auto levels are more extensively used.
• The Trimble DiNi Digital Level: Determine accurate height information 60% faster than with automatic leveling
• The surveyor don’t need to read the staff thus Eliminate human errors. And
• There is no need to focus the instrument on the stuff, this is done automatically. (Average of 36 reading)
• Transfer data to the office easily
Digital Level

Figure 4–16  (a) Electronic digital level and (b) associated level rod.
(Courtesy Topcon Corp.)

Wolf/Ghilani, Elementary Surveying: An Introduction to Geomatics, 10e, ©2002, Prentice Hall
Field Procedures and Computations

Carrying and Setting Up a Level

- Always carry it in the container,
- Screw the head snugly on the tripod.
- For bull eye’s bubble, alternately turn one screw and then the other two.
- On side-hill setups, place one leg on the uphill side and other two on the downhill side.
- Use hand level to check for proper height of the setup before precisely leveling the instrument.
SETTIN UP A LEVEL

- Start by placing the tripod over the point with the legs spread and extended about halfway.
- You want to have the plate as level as possible.
SETTIN UP A LEVEL

- Mount the instrument in the center of the plate with the shape of the instrument bottom plate and the tripod plate shape aligned.
- Coarsely level the instrument by adjusting the leg length of the tripod. When looking at the level bubble, the bubble being to that side indicates the high side.
SETTIN UP A LEVEL

• Adjust the instrument by adjusting the leveling screws.
• The bubble is approximately centered by using the thumb and first finger of each hand to simultaneously adjust the opposite screws.
• Rotate the telescope by $90^\circ$ and adjust the remaining leveling screw until it is precisely centered.

A bubble follows the left thumb when turning the screws.
Testing and Adjusting the Line of Sight

\[(R_B - 2\varepsilon) - (r_A - \varepsilon) = (r_B - \varepsilon) - (R_A - 2\varepsilon)\]

Solving for \(\varepsilon\) (colimation error) yields:

\[\varepsilon = \frac{R_B - r_A - r_B + R_A}{2}\]

If \(\varepsilon = 0\), the level is working perfect, if not make sure to balance BS and FS at all time. If not possible make proper correction.
Field Procedures and Computations

Duties of a Rodperson

- For correct reading, the level rod must be held plumb.
- Using rod level, when the bull’s-eye bubble is centered the rod is plumbed in both directions.
- When a rod level is not available waving the rod is one of the procedure.
Definitions

• **Back sight (BS)**
  – The *first* reading from a new instrument stand point (i.e. take the height to the instrument)

• **Fore sight (FS)**
  – The *last* reading from the current instrument station (i.e. give the height to a benchmark)

• **Intermediate sight (IS)**
  – Any sighting that is not a back sight or fore sight
LEVELING FIELD PROCEDURE

After leveling the instrument:
- balance BS and FS
- Make sure rod will be visible when instrument leveled at new position

Rod Person:
- hold rod vertical (plumb)
- move rod back and forth (minimum reading noted)
- select TP’s that are stable
Difference in Elevation

- Horizontal Plane through point B is serving as datum.
- The height of point A and C are required relative to this datum.
- The height in large scale survey maps are measured relative to datum which is the **Mean Sea Level (MSL)**.
Determining Differences in Elevation

- Measuring vertical distances by taping or EDMs
- Differential leveling
  - Differential leveling theory and applications can be expressed by two equations, which are repeated over and over.

\[
\text{HI} = \text{elev} + \text{BS}
\]

and

\[
\text{elev} = \text{HI} - \text{FS}
\]
Differential Leveling

Level set up half way between BM and X - equal BS and FS

\[ \Delta h_{BMX} = BS - FS = 8.42 - 1.20 = 7.22 \]

\[ h_X = 820.00 + \Delta h_{BMX} \]
Leveling methods

Differential Leveling

BM Mil
Elev 2053.18

TP 1
0.22
8.37

HI = 2054.51

TP 2
7.91
0.96

HI = 2046.36

TP 3
11.72
0.46

BM Oak

Mean sea level

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All Levelling surveys must be checked (i.e. closed), otherwise there is no confidence in the results.

There are two methods of checking levelling survey:

i. The levelling begins and finishes on the same point, via the same or different route, in which case the difference in level should be zero.

ii. The levelling begins in one point of known level and finishes on another, in which case the observed differences in level should equal the known differences.
Observation Procedures

(a) Procedure with Automatic Levels

Side View

Top View

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Observation Procedures

(a) Procedure with Automatic Levels

- Determine the **Reduced level** of points B,C,D,E,F, and G **relative** to point (A). which is the **bench mark**.
- The Levelling is to be closed on the second bench Mark (H).
- The instrument has to be set up twice in particular cases
- Every time the instrument set:
  - The First Sight Taken from that position is called **BACK** sight (BS).
  - The Last Sight Taken from that position is called **FORE** sight (FS).
  - Any Other sight observed between backsight and foresights is called **INTERMEDIATE** sight (IS).

- Point G, Inverted Stuff Reading
- Point E, where a foresight followed by backsight is taken is called, change point.
- Each point is given a **separate** line in the field book, either BS, FS or IS.

*What about Point E?*

- At each point, the Staff holder hold the staff on the mark and ensure that it is held **vertically**. **Focus and Multiple Reading**
a) Levelling between two points.

HPC = reduced level A + staff reading
= 205.500 + 2.400
= 207.900 m

reduced level B = HPC – staff reading
= 207.900 – 1.800
= 206.100 m

Table 4.12

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Distance</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 1</td>
<td>2.400</td>
<td></td>
<td>207.900</td>
<td>205.500</td>
<td></td>
<td>A. Ground level</td>
</tr>
<tr>
<td>Line 2</td>
<td></td>
<td>1.800</td>
<td></td>
<td>206.100</td>
<td></td>
<td>B. Ground level</td>
</tr>
</tbody>
</table>
b) Series Levelling.

Points Observed from single Instrument
(HPC) Method

- One setup,
- One line of collimation,
- All points refers to the same HPC

### Table 4.13

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Distance</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.510</td>
<td>3.720</td>
<td>108.030</td>
<td>107.520</td>
<td></td>
<td></td>
<td>A. (TBM)</td>
</tr>
<tr>
<td>0.920</td>
<td>0.920</td>
<td>108.030</td>
<td>107.110</td>
<td></td>
<td></td>
<td>B. Foundation level 1</td>
</tr>
<tr>
<td>2.560</td>
<td>2.220</td>
<td>108.030</td>
<td>105.470</td>
<td></td>
<td></td>
<td>C. Foundation level 2</td>
</tr>
<tr>
<td>-2.220</td>
<td>-1.710</td>
<td>2.220</td>
<td>105.810</td>
<td>107.520</td>
<td></td>
<td>D. Foundation level 2</td>
</tr>
<tr>
<td>-1.710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>E. Foundation level 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F. Foundation level 4</td>
</tr>
</tbody>
</table>

**Remarks**

- A. (TBM)
- B. Foundation level 1
- C. Foundation level 2
- D. Foundation level 2
- E. Foundation level 3
- F. Foundation level 4

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### Misclosure Check

**Table 4.13**

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Distance</th>
<th>Remarks</th>
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<td></td>
<td></td>
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</tr>
<tr>
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<td>107.110</td>
<td></td>
<td></td>
<td>B. Foundation level 1</td>
</tr>
<tr>
<td>2.560</td>
<td></td>
<td>108.030</td>
<td>105.470</td>
<td></td>
<td></td>
<td>C. Foundation level 2</td>
</tr>
<tr>
<td></td>
<td>2.220</td>
<td>108.030</td>
<td>105.810</td>
<td></td>
<td></td>
<td>D. Foundation level 2</td>
</tr>
<tr>
<td></td>
<td>0.510</td>
<td>2.220</td>
<td>105.810</td>
<td></td>
<td></td>
<td>E. Foundation level 3</td>
</tr>
<tr>
<td></td>
<td>-2.220</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>F. Foundation level 4</td>
</tr>
<tr>
<td></td>
<td>-1.710</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Check</td>
</tr>
</tbody>
</table>

**Table 4.14**

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Distance</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.240</td>
<td>3.450</td>
<td>107.760</td>
<td>107.520</td>
<td></td>
<td></td>
<td>A. (TBM)</td>
</tr>
<tr>
<td></td>
<td>0.655</td>
<td>107.760</td>
<td>107.105</td>
<td></td>
<td></td>
<td>B. Foundation level 1</td>
</tr>
<tr>
<td></td>
<td>0.650</td>
<td>107.760</td>
<td>107.110</td>
<td></td>
<td></td>
<td>C. Foundation level 2</td>
</tr>
<tr>
<td></td>
<td>2.290</td>
<td>107.760</td>
<td>105.470</td>
<td></td>
<td></td>
<td>D. Foundation level 2</td>
</tr>
<tr>
<td></td>
<td>1.955</td>
<td>107.760</td>
<td>105.805</td>
<td></td>
<td></td>
<td>E. Foundation level 3</td>
</tr>
<tr>
<td></td>
<td>0.240</td>
<td>1.955</td>
<td>105.805</td>
<td></td>
<td></td>
<td>F. Foundation level 4</td>
</tr>
<tr>
<td></td>
<td>-1.955</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>-1.715</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
If \( B \) is calculated wrongly to be \( 104.9 \), the above check would not detect the Error.
(HPC) Method

Arithmetic Check

\[
\text{Sum of reduced levels (except first)} = \sum \text{ (each height of collimation \times number of IS and FS observed from each)} - \sum \text{ (IS column + FS column)}
\]

- Sum of reduced Levels Except first = 
  \[104.31 + 107.11 + 107.11 + 105.47 + 105.81 = 529.81\]
- Sum of Each HPC \times number of IS and FS = 
  \[108.03 \times 5 = 540.15\]
- Sum ( IS Column + FS column) = 
  \[(8.12 + 2.22) = 10.34\]
- Therefore : 
  \[529.81 = 540.15 - 10.34\]
b) Series Levelling.

Multiple Instrument Settings
### Table 4.15

<table>
<thead>
<tr>
<th>Line</th>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.56</td>
<td></td>
<td></td>
<td>36.83</td>
<td>35.27</td>
<td>BM</td>
</tr>
<tr>
<td>2</td>
<td>1.43</td>
<td></td>
<td></td>
<td>35.40</td>
<td></td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>0.59</td>
<td></td>
<td></td>
<td>36.24</td>
<td></td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>1.07</td>
<td></td>
<td></td>
<td>35.76</td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>2.35</td>
<td>1.09</td>
<td></td>
<td>38.09</td>
<td>35.74</td>
<td>D</td>
</tr>
<tr>
<td>6</td>
<td>2.48</td>
<td></td>
<td></td>
<td>35.61</td>
<td></td>
<td>E</td>
</tr>
<tr>
<td>7</td>
<td>1.98</td>
<td></td>
<td></td>
<td>36.11</td>
<td></td>
<td>F</td>
</tr>
<tr>
<td>8</td>
<td>0.95</td>
<td>1.76</td>
<td></td>
<td>37.28</td>
<td>36.33</td>
<td>G</td>
</tr>
<tr>
<td>9</td>
<td>1.50</td>
<td>0.74</td>
<td></td>
<td>38.04</td>
<td>36.54</td>
<td>H</td>
</tr>
<tr>
<td>10</td>
<td>1.35</td>
<td></td>
<td></td>
<td>36.69</td>
<td></td>
<td>I</td>
</tr>
<tr>
<td>11</td>
<td>1.50</td>
<td></td>
<td></td>
<td>36.54</td>
<td></td>
<td>J</td>
</tr>
<tr>
<td>12</td>
<td>1.63</td>
<td></td>
<td></td>
<td>36.41</td>
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<td>K</td>
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<td>13</td>
<td></td>
<td>2.76</td>
<td></td>
<td>35.28</td>
<td></td>
<td>BM</td>
</tr>
<tr>
<td>14</td>
<td>6.36</td>
<td>12.03</td>
<td>6.35</td>
<td></td>
<td>35.28</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>-6.35</td>
<td></td>
<td></td>
<td></td>
<td>-35.27</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>0.01</td>
<td></td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>
Misclosure Check

\[ E = (\pm 5\sqrt{n}) \text{ mm} = \pm 10 \text{ mm} \]

Arithmetic Check

Last Reduced level - First Reduced level = \text{Sum (BS) - Sum (FS)}

Sum of RLs except first = 432.65 m
Sum of HPC \times \text{number of IS and FS}
\[ = 36.83 \times 4 = 147.32 \]
\[ + 38.09 \times 3 = +114.27 \]
\[ + 37.28 \times 1 = +37.28 \]
\[ + 38.04 \times 4 = +152.16 \]
\[ \frac{451.03}{18.38} \]
\[ (451.03 - 18.38) = 432.65 \text{ m} \]
c) Series Levelling

Calculate the reduced level of the stations and determine which, if any, stations have been wrongly observed.
PRECISION

FGCC Accuracy Standard.......................... \( C = m \sqrt{K} \)

where: \( m = \text{constant} \); \( K = \text{total length of line in Kms} \); \( C = \text{allowable error in mm} \)

**FGCC STANDARDS (Federal Geodetic Control Committee)**

1st Order: \( m = 4 \)  
2nd Order, Class II: \( m = 8 \)
1st Order, Class II: \( m = 5 \)  
3rd Order: \( m = 12 \)
2nd Order, Class I: \( m = 6 \)

Other Standards ........ \( C = 0.02 \sqrt{n} \)

where \( C = \text{allowable error and } n = \text{number of setups} \)

In example \( C = 0.02 \sqrt{7} = 0.05 \Rightarrow \text{meets the standard} \)

These standards are used for expressing the QUALITY of the measurements

**For Construction projects  \( m=6 \) is acceptable**
# Inverted Staff Reading

**Example 1**

![Diagram](image)

### Table 4.18

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>Rise</th>
<th>Fall</th>
<th>Reduced level</th>
<th>Distance</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.750</td>
<td>-3.100</td>
<td>4.850</td>
<td>4.590</td>
<td>72.300</td>
<td>77.150</td>
<td>72.560</td>
<td>Bench mark (72.300)</td>
</tr>
<tr>
<td></td>
<td>1.490</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>A Frame (lift shaft)</td>
</tr>
<tr>
<td>-4.210</td>
<td>-2.560</td>
<td>4.050</td>
<td>8.410</td>
<td>76.610</td>
<td>68.200</td>
<td></td>
<td>B Floor level</td>
</tr>
<tr>
<td></td>
<td>4.200</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>C Canopy</td>
</tr>
<tr>
<td>-2.460</td>
<td>+1.640</td>
<td>8.900</td>
<td>13.000</td>
<td>68.200</td>
<td></td>
<td></td>
<td>D Bench mark (68.195m)</td>
</tr>
<tr>
<td>-1.640</td>
<td>-13.000</td>
<td>-72.300</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>-4.100</td>
<td>-4.100</td>
<td>-4.100</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Inverted Staff Reading

Example 2

Check:
Sum of RLs except first = 294.52
= (74.050 \times 3) + 72.400 - (-1.61 + 1.64)
= 222.15 + 72.40 - 0.03
= 294.52

Table 4.19

<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>Reduced level</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.750</td>
<td>-3.100</td>
<td>74.050</td>
<td>72.300</td>
<td></td>
<td>Bench mark (72.300)</td>
</tr>
<tr>
<td></td>
<td>1.490</td>
<td></td>
<td>77.150</td>
<td></td>
<td>A Frame (lift shaft)</td>
</tr>
<tr>
<td>-4.210</td>
<td>-2.560</td>
<td>72.400</td>
<td>76.610</td>
<td></td>
<td>B Floor level</td>
</tr>
<tr>
<td></td>
<td>4.200</td>
<td></td>
<td>68.200</td>
<td></td>
<td>C Canopy</td>
</tr>
<tr>
<td>-2.460</td>
<td>-1.610</td>
<td>1.640</td>
<td>68.200</td>
<td></td>
<td>D Bench mark (68.195m)</td>
</tr>
<tr>
<td>-1.640</td>
<td></td>
<td></td>
<td>-72.300</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-4.100</td>
<td></td>
<td>-4.100</td>
<td></td>
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</tr>
</tbody>
</table>

3/21/2014

Dr. Khalil Al-Juboori
Leveling loop
<table>
<thead>
<tr>
<th>BS</th>
<th>IS</th>
<th>FS</th>
<th>HPC</th>
<th>RL</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.596</td>
<td></td>
<td></td>
<td></td>
<td>10.000</td>
<td>A</td>
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<tr>
<td>1.384</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Simple Loop Adjustment based on Distances

Error of closure is +0.24 ft
d is computed
difference in elevation
Profile Leveling
Profile Leveling

Grade - 0.15%

Profile
Hwy. 169 to Elm St.

Elevation (feet)

Horizontal scale: 1 in. = 200 ft
Vertical scale: 1 in. = 20 ft
Three wire Leveling

- Reading on upper, middle and lower wire
- More precise leveling
- Provide a check on rod reading mistake
- It can be used for determine horizontal distance needed for balancing BS and FS.
# Three wire Leveling

<table>
<thead>
<tr>
<th>Sta.</th>
<th>BS</th>
<th>Stadia</th>
<th>FS</th>
<th>Stadia</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM A</td>
<td>0.718</td>
<td>1.131</td>
<td></td>
<td></td>
<td>103.8432</td>
</tr>
<tr>
<td></td>
<td>0.633</td>
<td>8.5</td>
<td>1.051</td>
<td>8.0</td>
<td>+0.6337</td>
</tr>
<tr>
<td></td>
<td>0.550</td>
<td>8.3</td>
<td>0.972</td>
<td>7.9</td>
<td>104.4769</td>
</tr>
<tr>
<td>Σ1.901/3</td>
<td>16.8</td>
<td>Σ3.154/3</td>
<td>15.9</td>
<td>-1.0513</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.6337</td>
<td></td>
<td>-1.0513</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP1</td>
<td>1.151</td>
<td>1.041</td>
<td></td>
<td></td>
<td>103.4256</td>
</tr>
<tr>
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<td>1.082</td>
<td>6.9</td>
<td>0.969</td>
<td>7.2</td>
<td>1.0820</td>
</tr>
<tr>
<td></td>
<td>1.013</td>
<td>6.9</td>
<td>0.897</td>
<td>7.2</td>
<td>104.5076</td>
</tr>
<tr>
<td>Σ3.246</td>
<td>13.8</td>
<td>Σ2.907</td>
<td>14.4</td>
<td>-0.9690</td>
<td></td>
</tr>
<tr>
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<td>1.0820</td>
<td></td>
<td>-0.9690</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>103.5386</td>
</tr>
</tbody>
</table>

3/21/2014

Dr. Khalil Al-Juboori
# Three wire Leveling

<table>
<thead>
<tr>
<th>Sta.</th>
<th>BS</th>
<th>Stadia</th>
<th>FS</th>
<th>Stadia</th>
<th>RL</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP2</td>
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<td></td>
<td></td>
<td></td>
<td>103.5386</td>
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<td>1.774</td>
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<td>1.123</td>
<td></td>
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</tr>
<tr>
<td>Σ</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BM B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ</td>
<td></td>
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<td>Page check</td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Sources of Errors in Leveling

Instrumental Errors
- Line of sight
- Cross-hear not exactly horizontal
- Rod not correct length
- Tripod legs loose

Natural Errors
- Curvature of the earth
- Refraction
- Temperature variations
- Wind
- Settlement of the instrument
- Settlement of a turning point
Sources of Errors in Leveling

Personal Errors

Bubble not centered
Parallax
Faulty rod reading
Rod handling
Target setting
Sources of Errors in Leveling

Mistakes

- Improper use of a long rod,
- Holding a rod in different places for the plus and minus sights on a turning point.
- Reading a foot too high.
- Waving a flat bottom rod while holding it on a flat surface.
- Recording notes.
- Touching tripod or instrument during reading process.
Sources of Errors in Leveling

Reducing Errors and Eliminating Mistakes by

- Carefully adjusting and manipulating both instrument and rod.
- Establishing standard filed methods and routines.
- The following routines prevent most large errors or quickly disclose mistakes:
  - Checking the bubble before and after each reading.
  - Using a rod level.
  - Keeping the horizontal lengths of plus and minus sights equal.
  - Making the usual field-book arithmetic checks
Curvature and Refraction

In the triangle $L$ is the length of sight in kilometres and $R$ is the mean radius of the Earth (6370 km). By Pythagoras’s theorem:

$$(R + c)^2 = R^2 + L^2$$

i.e.

$$R^2 + c^2 + 2Rc = R^2 + L^2$$

Therefore

$$c(c + 2R) = L^2$$

$$c = L^2/(c + 2R)$$

Since $c$ is so small compared with $R$, it can be ignored. Therefore,

$$c = (L^2/2R) \text{ kilometres}$$

i.e.

$$c = \left( \frac{L^2}{12740} \right) \text{ km}$$

However, $c$ is required in metres while $L$ remains in kilometres:

$$c = \left( \frac{L^2 \times 1000}{12740} \right) \text{ metres}$$

$$c = 0.0785L^2 \text{ metres (where } L \text{ is in kilometres)}$$

Combined correction = \( \frac{1}{7} \times 0.0785L^2 \)

= \( \frac{6}{7} \times 0.0785L^2 \)

= 0.0673L^2 \text{ metres} 

(where $L$ is in kilometres).
8 Calculate the corrected staff reading for a sight of 1500 metres if the observed reading is 3.250.

**Answer**

Length of sight = 1.5 km

Correction for curvature = $(0.0673 \times 1.5^2)$ m

and refraction = $(0.0673 \times 2.25)$ m

= 0.151 m

Observed staff reading = 3.250

Correction = −0.151

Correct staff reading = 3.099 m
TRIGONOMETRIC LEVELING

\[ \Delta Z_{CD} = V = S \sin \alpha = S \cos z = H \cot z \]

OR

\[ V = H \tan \alpha \]

\[ \Delta Z_{AB} = hi + V - r \quad \text{OR} \quad Z_B = Z_A + hi + S \sin \alpha - r \]

\[ = Z_A + hi + H \cot z - r \]

For long line more than 120 m, combine earth curvature and refraction must be considered.
\[ \Delta ZCD = V = S \sin \alpha = S \cos z \text{ or} \]
\[ \Delta ZCD = V = H \cot z \]
OR \( V = H \tan \alpha \)

Correction for combine earth curvature and refractions

\[ \Delta ZAB = h + V - r + 0.0673 H^2 \]
OR \( ZB = ZA + h + S \sin \alpha - r + 0.0673 S^2 \)
\( ZB = ZA + h + H \cot z - r + 0.0673 H^2 \)
Example

The slope distance and zenith angle between points A and B were observed with a total station instrument as 9585.26 m and 81°42’ 20” respectively. The hi and rod reading r were equal. If the elevation of A is 1238.42 m, compute the elevation of B.

\[ V = S \cos z = 9585.26 \cos(81°42’ 20”) = 1382.772 \]
\[ H = s \cos \alpha = 9585.26 \cos (90° - 81°42’ 20”) = 9504.0 \]

Combine earth and refraction correction = 0.0673(9504/1000)²

\[ C-R = 6.078 \text{ m} \]
\[ V = 1382.772 + 6.078 = 1388.85 \]

\[ Z_B = Z_A + h_i + S \sin \alpha - r + 0.0673 S^2 \]
\[ Z_B = 1238.42 + 1388.85 = 2727.27 \text{ m} \]
Reciprocal Leveling

\[ A_1B = h_1 + c - r - s_1 \]

\[ B_1A = s_2 + r - c - h_2 \]

\[ = \frac{1}{2} (h_1 + c - r - s_1 + s_2 + r - c - h_2) \]

\[ = \frac{1}{2} (h_1 - h_2 + s_2 - s_1) \]
10 Observations were made between points X and Y on opposite sides of a wide water-filled quarry as follows:

Level at X  Instrument height = 1.350
            Staff reading Y = 1.725
Level at Y  Instrument height = 1.410
            Staff reading X = 1.055

Calculate the true difference in level between the stations and the reduced level of Y if X is 352.710 AOD.

**Solution**

$$\text{True difference in level} = \frac{1}{2} \left( h_1 - h_2 + s_2 - s_1 \right)$$

$$= \frac{1}{2} \left( 1.350 - 1.725 + 1.055 - 1.410 \right) \text{ m}$$

$$= \frac{1}{2} \left( 2.405 - 3.135 \right) \text{ m}$$

$$= \frac{1}{2} \left( -0.730 \right) \text{ m}$$

$$= -0.365 \text{ m}$$

**Fall**

$$Y = X - 0.365 = 352.71 - 0.365 = 352.345 \text{ m}$$
Grid, Cross-Section or Borrow-pit Leveling

Grid leveling is a method for locating contours. Rectangular blocks, say 50 by 100 ft or 20 by 30 m, that have the longer sides roughly parallel with the direction of most contour lines may be preferable on steep slopes. The grid size chosen depends on the project extent, ground roughness, and accuracy required.
Homework

1) Book the leveling data shown in the Table below using HPC method.

2) Determine the elevations of points (A, B, C, D, E, and F), perform all the necessary checks.

3) Determine the height difference between A and F?

4) Determine the gradient between A and F?
Leveling methods

Determining Differences in Elevation

- Barometric Leveling

For example:
A change of approximately 1000 ft in elevation corresponds to a change of 1 in. of mercury in atmospheric pressure.