CE 371 Surveying

LEVELLING CALCULATIONS

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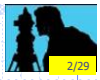
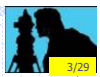


Overview

- Levelling procedures
- Arithmetic check
- Differential Leveling Precision
- Adjustment of a Level Loop
- Adjustment of a Level Line
- Reciprocal Leveling
- Three-Wire Leveling
- Sources of Errors in Leveling
- Types of Errors in Leveling



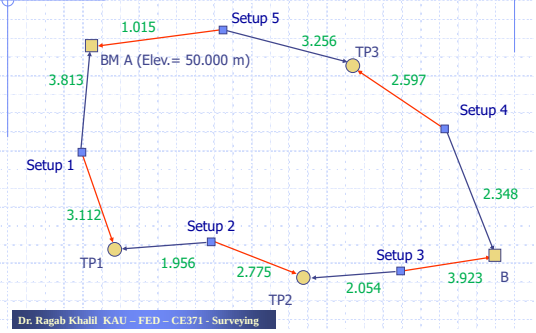
Levelling procedures

- Three stages:
  - Observation procedures
  - Booking procedures
  - Reduction procedures

Differential leveling loop

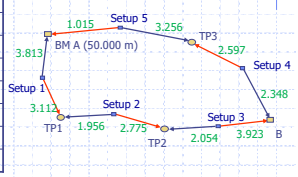
- A **differential leveling loop** is the one in which leveling starts at a benchmark up to the required point then closing back at the same benchmark.
- Different turning points and instrument setups must be used when moving back from the required point to the benchmark.

A sample level loop



Booking the observations

Point	BS	IS	FS
BM A	3.813		
TP1	1.956		3.112
TP2	2.054		2.775
B	2.348		3.923
TP3	3.256		2.597
BM A			1.015



Reducing levels (HI)

Point	BS	HI	FS	Elev.	Adj. Elev.	
BM A	3.813			50.000		
		53.813				
TP1	1.956		3.112	50.701		
		52.657				
TP2	2.054		2.775	49.882		
		51.936				
B	2.348		3.923	48.013		
		50.361				
TP3	3.256		2.597	47.764		
		51.020				
BM A			1.015	50.005		
Σ						
Δ						

Arithmetic check (HI)

Point	BS	HI	FS	Elev.	Adj. Elev.	
BM A	3.813			50.000		
		53.813				
TP1	1.956		3.112	50.701		
		52.657				
TP2	2.054		2.775	49.882		
		51.936				
B	2.348		3.923	48.013		
		50.361				
TP3	3.256		2.597	47.764		
		51.020				
BM A			1.015	50.005		
Σ	13.427		13.422			
Δ			0.005	0.005		ok

$\sum$ B.S - $\sum$F.S = Last R.L – First R.L.

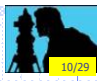
Loop misclosure

Misclosure

- The amount by which the *measured* Elevation (H_{meas}) derived from the computations differs from the *known* Elevation (H_{known}) of the starting and finishing benchmarks

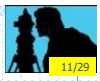
$$\text{Misclosure } (E_c) = H_{meas} - H_{known}$$

An acceptable misclose?



- *Small* misclosures in closed level loops are expected because of the accumulation of errors
- If the misclosure is *small*, it can be adjusted
- If the misclosure is *large*, the loop (or part of it) must be repeated
- Misclosures can also result from errors in published BM levels and from BM instability

Differential Leveling Precision



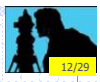
- The amount of misclosure we are prepared to accept depends on the accuracy we are hoping to achieve
- In order for differential leveling results to be acceptable, the computed closure error E_C must be compared with permissible values on the basis of either number of setups **n** or distance covered **K** in kilometers.
- On a simple construction survey: $E_c < 6.1\sqrt{n}$ mm
- Or $E_c < m\sqrt{k}$ (according to American standards)

m= 4 (1st order class I) *m= 5 (1st order class II)*

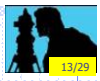
m= 6 (2nd order class I) *m= 8 (2nd order class II)*

m= 12(3rd order)

Continuing the example

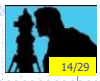


- The misclosure E_c = 50.005 - 50.000 =+ 0.005 m
- E_c = +5 mm
- Suppose that was a simple construction survey
- Number of setups = 5
- The allowable closure error
- $E_A = 6.1\sqrt{5} = 13.6\ mm$
- $E_c < E_A$ ok.. This leveling job is accepted
- The error can be adjusted



Adjusting the misclose

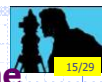
- Adjustment is carried out to ensure that the measured and known elevation of the closing benchmark agree
- The misclosure is linearly distributed according to the number of *set-ups in opposite sign*
- The adjustment per set-up for the previous example is (-0.005/5) =-0.001 (cumulatively)



Adjusting the misclose

Point	BS	HI	FS	Elev.	Adj. Elev.	
BM A	3.813			50.000	50.000	
		53.813				-0.001
TP1	1.956		3.112	50.701	50.700	
		52.657				-0.002
TP2	2.054		2.775	49.882	49.880	
		51.936				-0.003
B	2.348		3.923	48.013	48.010	
		50.361				-0.004
TP3	3.256		2.597	47.764	47.760	
		51.020				-0.005
BM A			1.015	50.005	50.000	
Σ	13.427		13.422			
Δ			0.005	0.005		ok

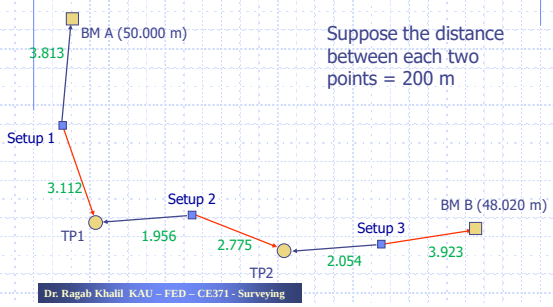
=1*(-0.001)
=2*(-0.001)
=3*(-0.001)
=4*(-0.001)
=5*(-0.001)



Adjustment of Leveling Line

- A **differential leveling line** is the one in which leveling starts at a benchmark, then progresses to the points whose elevations are required, and finally closing at another benchmark.
- The same procedure as closed loop is followed

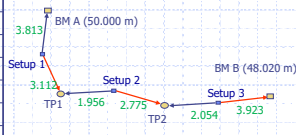
A sample leveling line



Suppose the distance between each two points = 200 m

Booking the observations

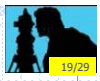
Point	BS	IS	FS
BM A	3.813		
TP1	1.956		3.112
TP2	2.054		2.775
BM B			3.923



Reducing levels (Rise & Fall)

Point	BS	IS	FS	Rise	Fall	Elev.	Adj. Elev.	
BM A	3.813					50.000		
TP1	1.956		3.112	0.701		50.701		
TP2	2.054		2.775		-0.819	49.882		
BM B			3.923		-1.869	48.013		
Σ								
Δ								

Arithmetic check (R&F)



Point	BS	IS	FS	Rise	Fall	Elev.	Adj. Elev.	
BM A	3.813					50.000		
							∑ B.S - ∑F.S = ∑ Rise - ∑Fall = Last R.L – First R.L.	
TP1	1.956		3.112	0.701		50.701		
TP2	2.054		2.775		-0.819	49.882		
BM B			3.923		-1.869	48.013		
Σ	7.823		9.810	0.701	2.688	-1.987		
Δ			-1.987		-1.987			ok

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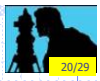
Continuing the example



- The misclosure E_c = 48.013 - 48.020 =- 0.007 m
- E_c = - 7 mm
- The distance between BMs = k= 600 m = 0.60 km
- $m_c = E_c/\sqrt{k}$ = $7/\sqrt{0.6}$ = 9 (8 < m_c < 12)
- This job meets **third-order** class
- If the needed precision is higher than the 3rd order, the job should be repeated, otherwise the leveling job is accepted and the error can be adjusted

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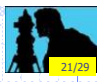
Adjusting the misclose



- Adjustment is carried out to ensure that the measured and known elevation of the closing benchmark agree
- The misclosure is linearly distributed according to the number of *set-ups*
- Number of setups = 3
- The adjustment per set-up for the previous example is (+0.007/3) =+0.0023 (cumulatively)

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Arithmetic check (R&F)

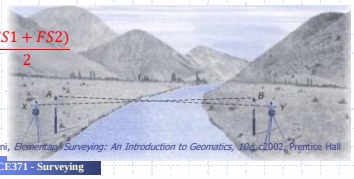
Point	BS	IS	FS	Rise	Fall	Elev.	Adj. Elev.	
BM A	3.813					50.000	50.000	
							=1*(0.0023)	0.002
TP1	1.956		3.112	0.701		50.701	50.703	
							=2*(0.0023)	0.005
TP2	2.054		2.775		-0.819	49.882	49.887	
							=3*(0.0023)	0.007
BM B			3.923		-1.869	48.013	48.020	
Σ	7.823		9.810	0.701	2.688	-1.987		
Δ			-1.987		-1.987			ok

Reciprocal Leveling

Balancing BS and FS distances may not be possible all times, for example, when crossing rivers, lakes, or canyons. In such cases do the following:

1. At setup 1, take a BS_1 at A, then a FS_1 at B.
2. At setup 2, take a BS_2 at A, then a FS_2 at B.
3. Elev. Difference between A and B =

$$\Delta H = \frac{(BS1 + BS2)}{2} - \frac{(FS1 + FS2)}{2}$$

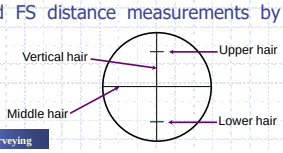


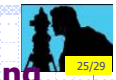
Wolf/Ghilani, *Elementary Surveying: An Introduction to Geomatics*, 10th c2002, Prentice Hall

Three-Wire Leveling

It is a leveling method in which level rod readings at upper, lower, and middle hairs are taken, then the average of the three readings is used. Advantages over regular method are:

1. Providing checks against rod reading blunders.
2. Producing greater accuracy because average of 3 readings is available.
3. Providing for BS and FS distance measurements by Stadia method.





Sources of Errors in Leveling

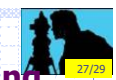
Natural Errors

1. **Earth curvature:** Increases rod readings. Can be eliminated by balancing distances of BS and FS readings.
2. **Refraction:** Decreases rod readings. Can be eliminated by balancing distances of BS and FS readings.
3. **Temperature:** Heat waves near ground surface make the rod appear to wave and prevent accurate sighting. Can be eliminated by raising the line of sight by high tripod setup along with choosing short sights.
4. **Settlement of the instrument:** If the tripod legs are not pushed firmly into the ground, the HI when taking a BS and a FS may not be the same.

Sources of Errors in Leveling

Instrumental Errors

1. **Line of sight not horizontal**, even after leveling the instrument which indicates manufacturing defect. May be eliminated by calibrating the instrument or by running a two-peg test.
2. **Horizontal hair not exactly horizontal**: Can be eliminated by reading the rod near the center of the horizontal cross hair.
3. **Incorrect length of level rod**, and graduation errors: Can be eliminated by comparing with standardized tape.



Sources of Errors in Leveling

Human Errors

1. **Bubble not centered**: Check the bubble before and after each reading.
2. **Parallax**: Improper focusing of objective and/or eyepiece lenses.
3. **Faulty rod reading and recording**: Check before and after recording.
4. **Level rod not vertical**: It increases rod readings. Can be eliminated by carefully leveling the rod circular bubble, and by waving the rod.

Types of Errors in Leveling

Three types of error

1. **Systematic errors**: such as earth curvature, refraction, incorrect length.
2. **Random errors**: Due to temperature, wind, and settlement of instrument.
3. **Mistakes**: such as misreading or misrecording measurements, not properly leveling the instrument, and not holding the rod vertical.

Summery

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