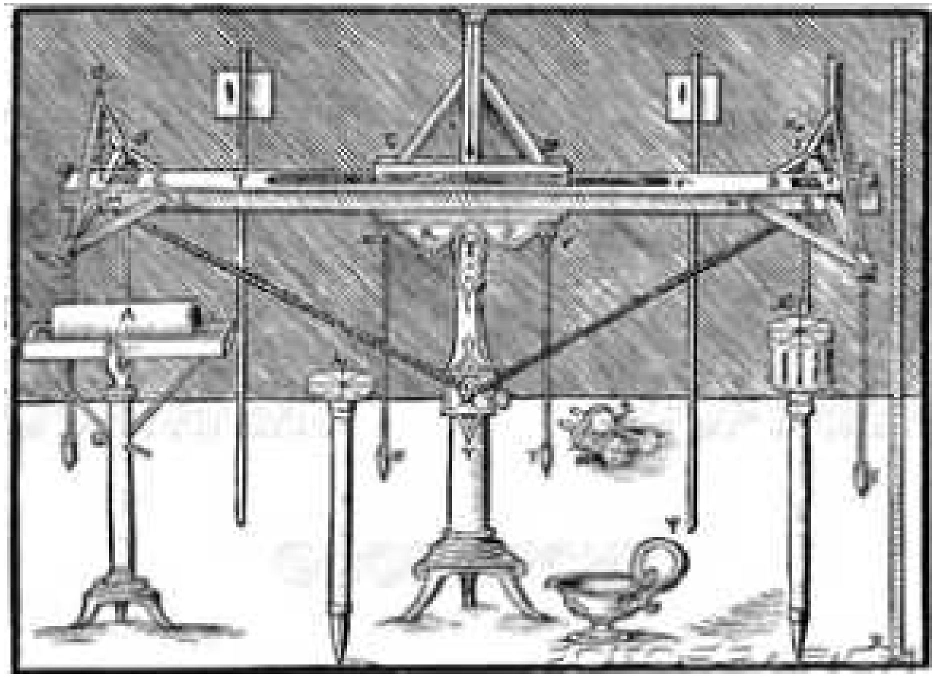
Surveying & Measurement

Levelling

Levelling

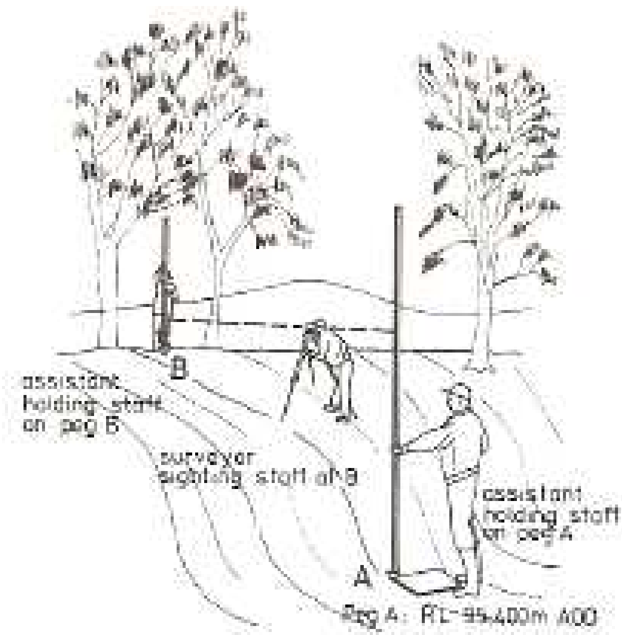
- The general term applied to any of the various processes by which elevations of points or differences in elevation are determined.

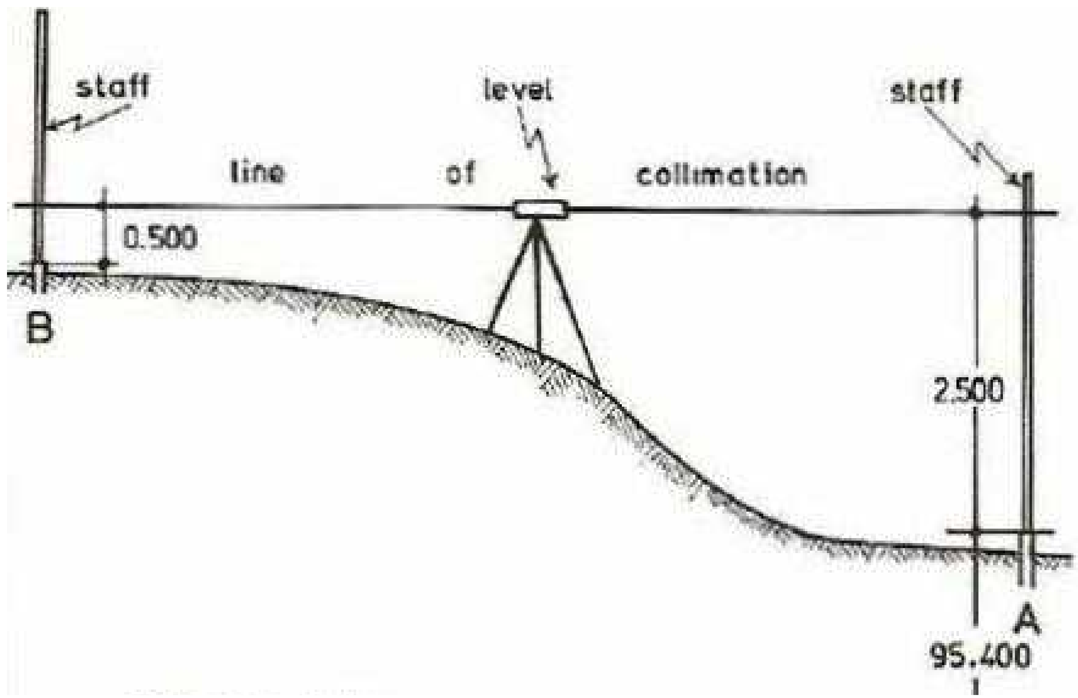


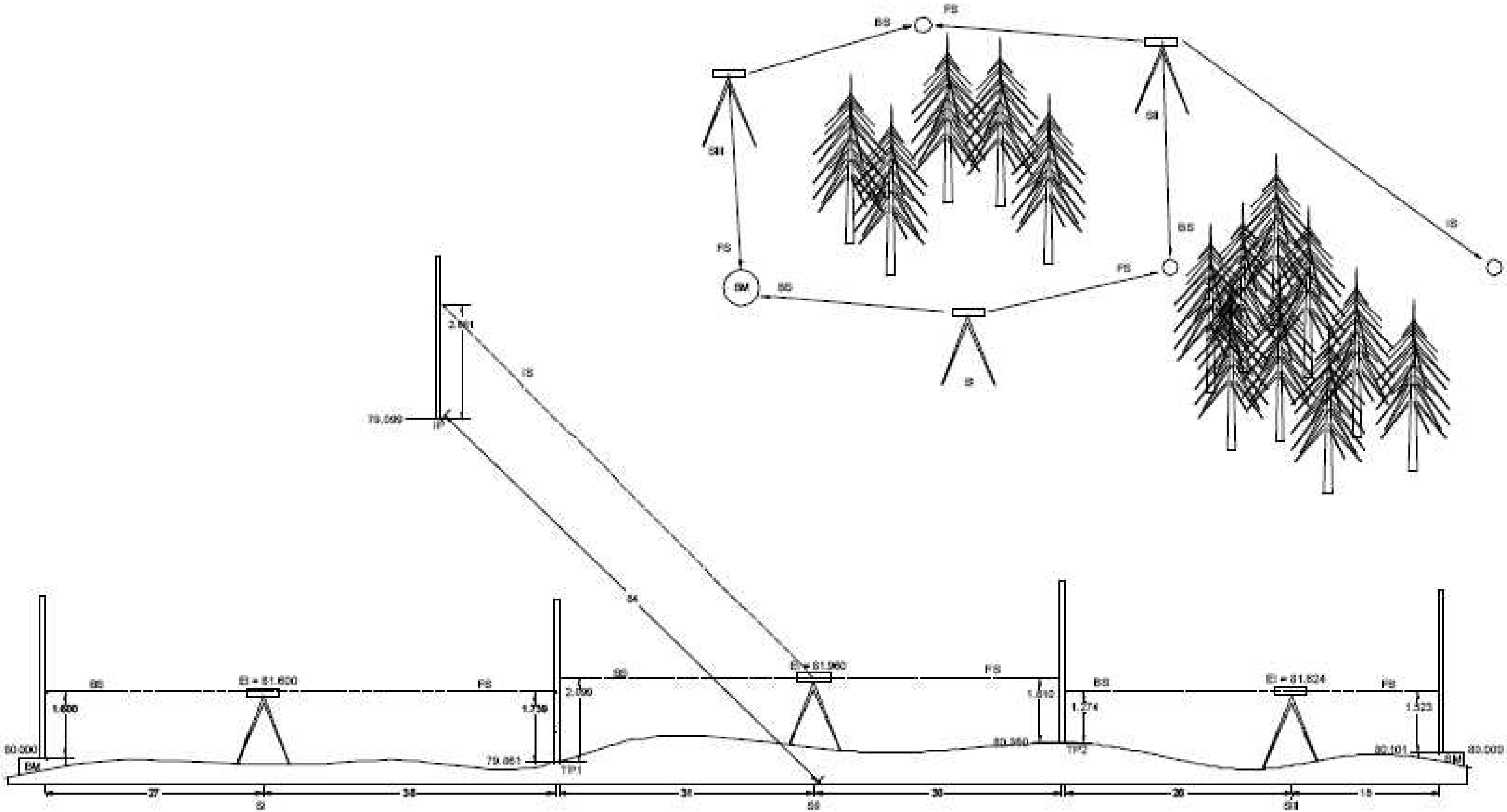
Levelling

- To measure the difference in height (ΔH) between two points A and B, vertical rods are set up at each of these two points and a level somewhere between them.
- The height difference between A and B is the difference between the rod (staff) readings.

- Once the elevation of a point is determined, that point can be used for determining the elevations of other points.







BS
FS
SII
FS
BM
BS
FS
BS
SIII
IS
SI
2.861
IS
79.099
IP
BS
EI = 81.600
FS
1.600
1.739
80.000
BM
79.861
TP1
BS
2.099
EI = 81.960
FS
1.610
80.350
TP2
BS
1.274
EI = 81.624
FS
1.523
80.101
BM
80.000
27
38
31
30
28
15
SI
SII
SIII

Some Definitions (1)

- **Levelling** · A surveying operation carried out to determine the elevation of points or to find the difference in elevation of points
- **Spirit Level/Engineer's Level** · A surveying instrument used to carry out levelling
- **Backshot (BS)** · A sighting with a level back to a point of known elevation
- **Foreshot (FS)** · A sighting with a level to determine the elevation of a point
- **Turning Point** · A point at which you have established an elevation with FS and on which you will subsequently take a BS
- **Intermediate Shot** · A foreshot to a point at which you want to know the elevation but which will not be used as a turning point

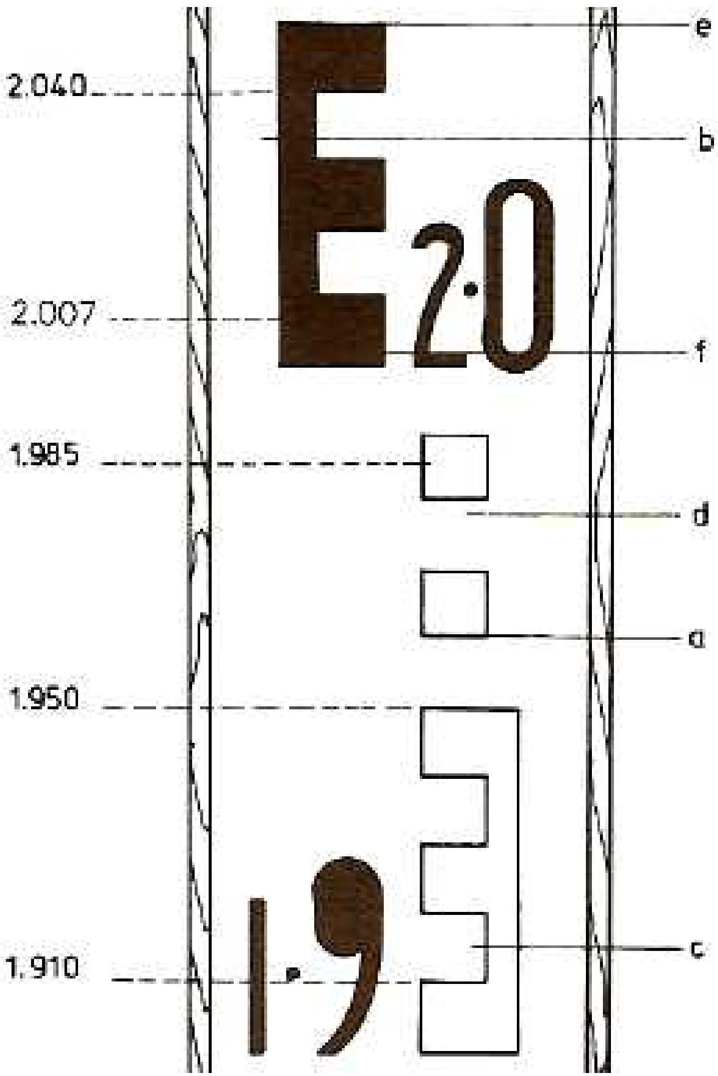
Some Definitions (2)

- **Peg Test** · Surveying operation carried out to determine if the levelling bubble and telescope line-of-sight are parallel
- **Elevation of Instrument (EI)** · Elevation of the telescope cross-hairs
- **Balancing shots** · Attempt when doing a levelling survey to keep the lengths of FS and BS at any given instrument setup as close as possible.
- **Closure Error** · Difference in elevation determined from the levelling survey and the known elevation of a benchmark.

The Use of Levelling

- To design highways, railroads, canals, sewers, water supply systems etc, having grade lines that best conform the existing topography,
- To lay out construction projects according to planned elevations,
- To calculate volume of earthworks and other materials,
- To investigate drainage characteristics of an area, etc.

The Equipments : Rod (Staff) (1)



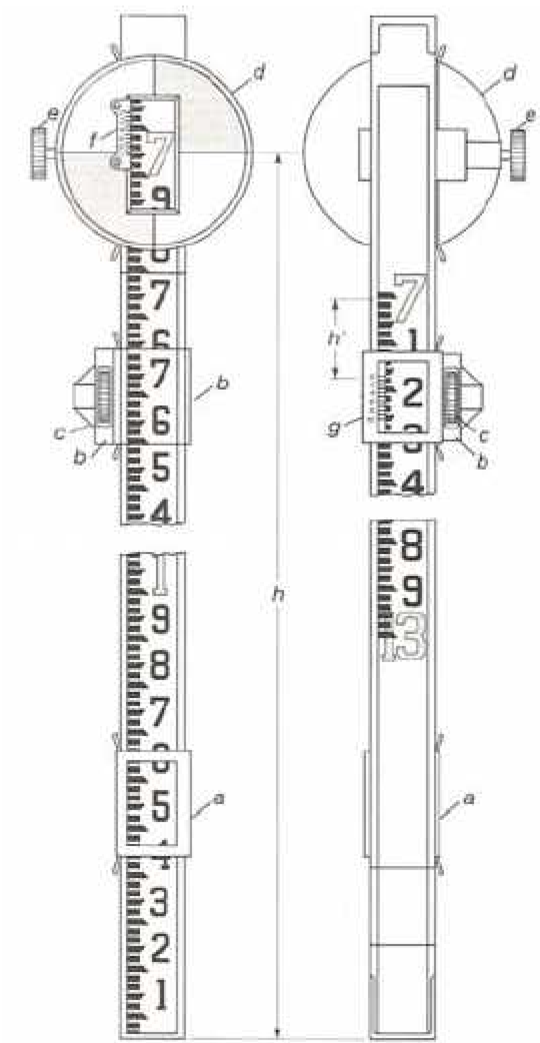
Example

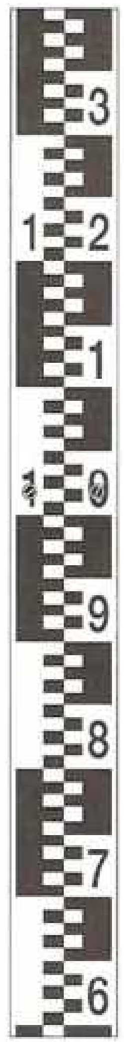
2 Make a list of the staff readings 'a' to 'f' in Fig. 4.14 and reading 'g' in Fig. 4.15.

Solution

a, 1.960 m	b, 2.033 m	c, 1.915 m
d, 1.978 m	e, 2050 m	f, 2.002 m
g, 1.156 m		

The Equipments : Rod (Staff) (2)



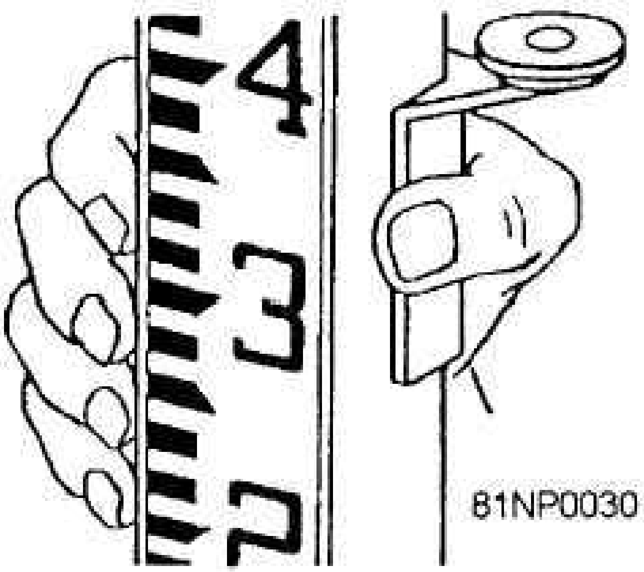


Philadelphia Rod (front)

Philadelphia Rod (rear)

Double faced levelling rod

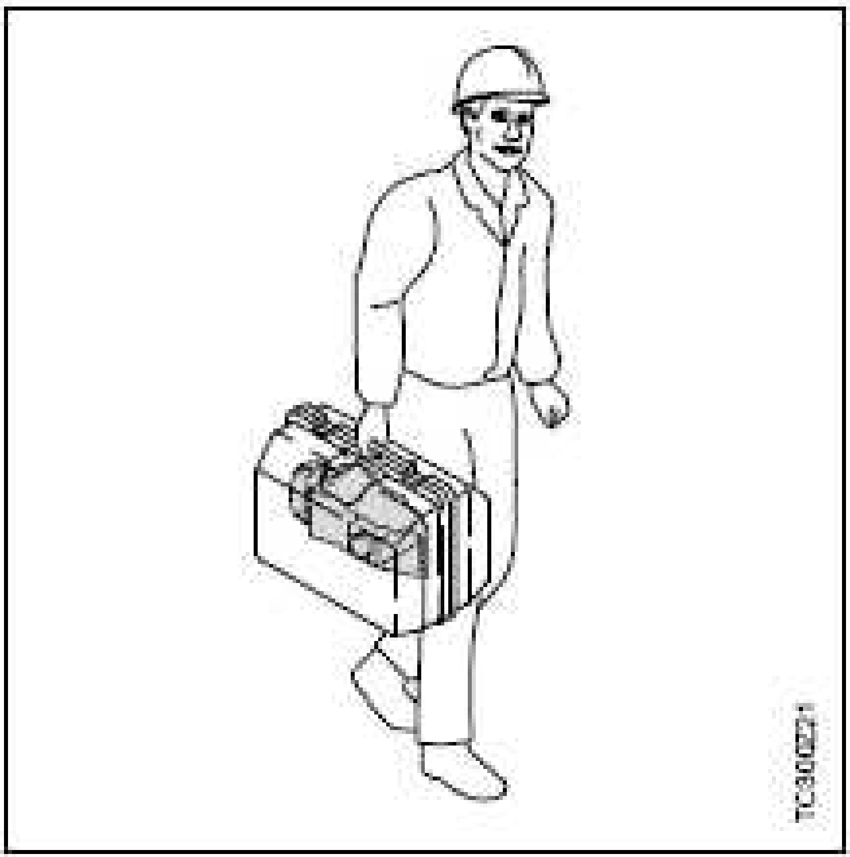
The Equipments : Rod Level and Tripod

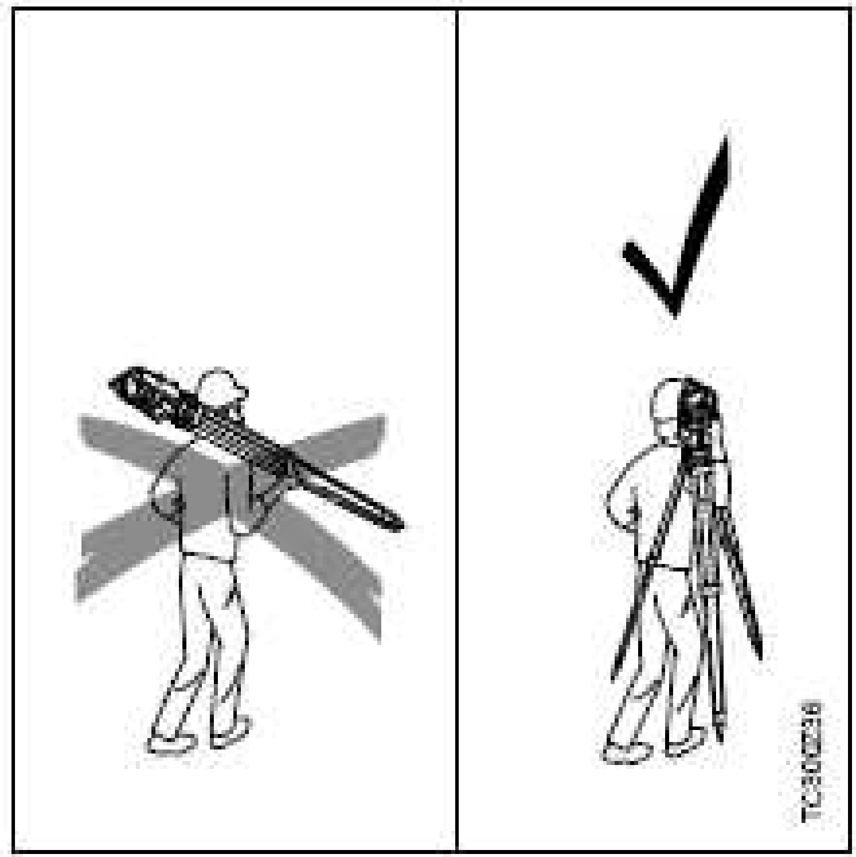


Carrying and Setting Up a Level

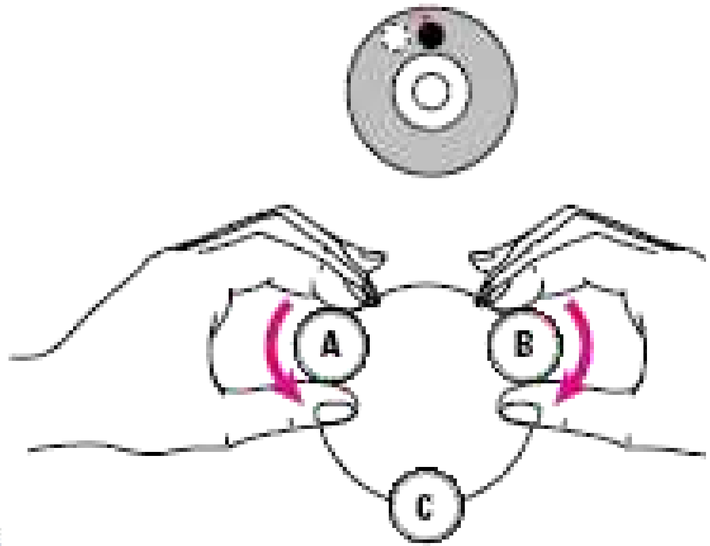
- Always carry it in the container.
- Screw the head snugly on the tripod.
- For bull eye's bubble, alternately turn one screw and then the other two.
- On side-hill setups, place one leg on the uphill side and other two on the down hill side.
- Use hand level to check for proper height of the setup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

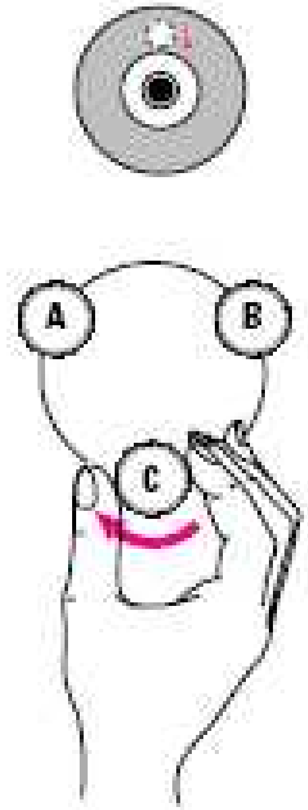
Carrying and Setting Up a Level

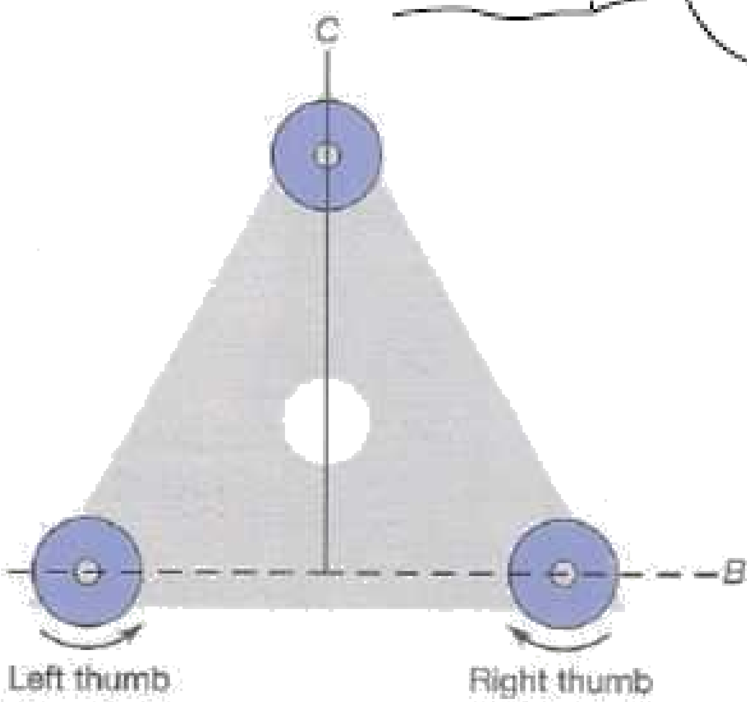




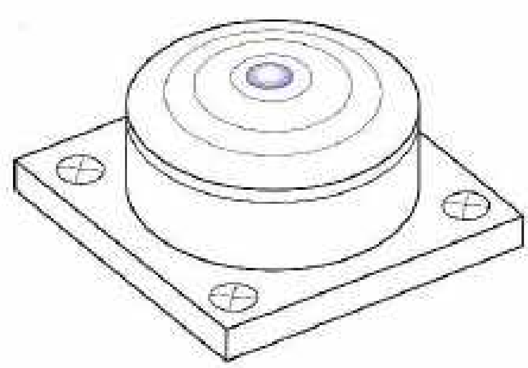
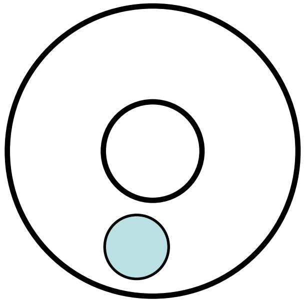
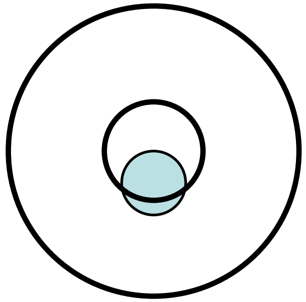
Carrying and Setting Up a Level







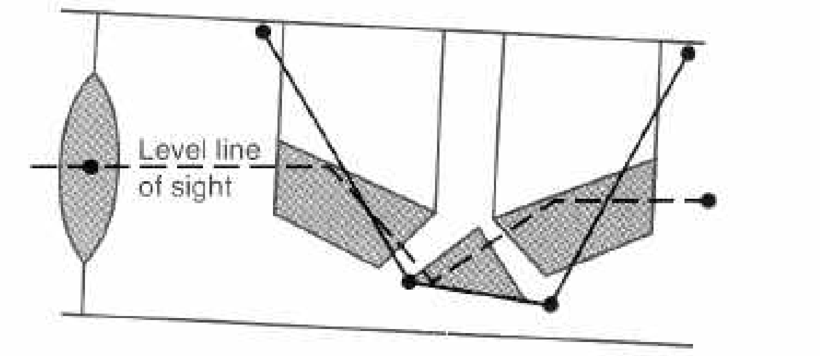
Pond Bubble

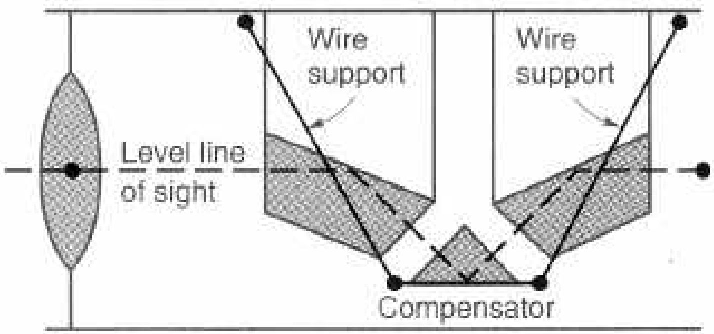
- When pond bubble is centred the instrument’s standing axis is approximately vertical.
- The compensators in the instrument take over and adjust the optical Line of Collimation so that it is horizontal.
- When the instrument is rotated the compensators ensure that a **horizontal plane of collimation** is swept out.

Automatic Levels

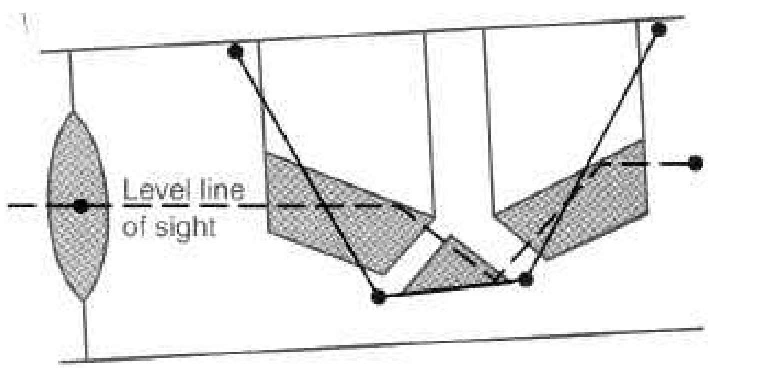
After the pond bubble is manually centered, an automatic compensator levels the line of sight, and keeps it level.



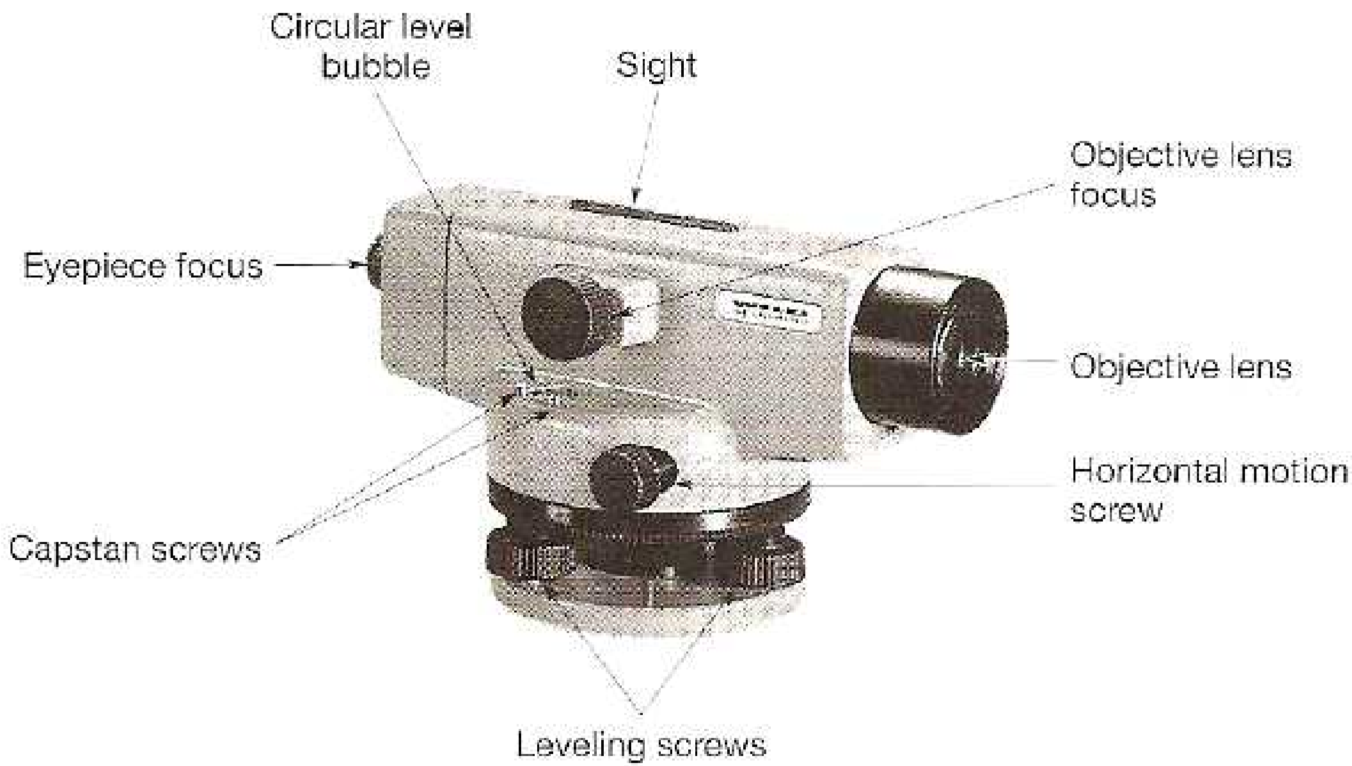
When telescope tilts up, compensator swings backward.

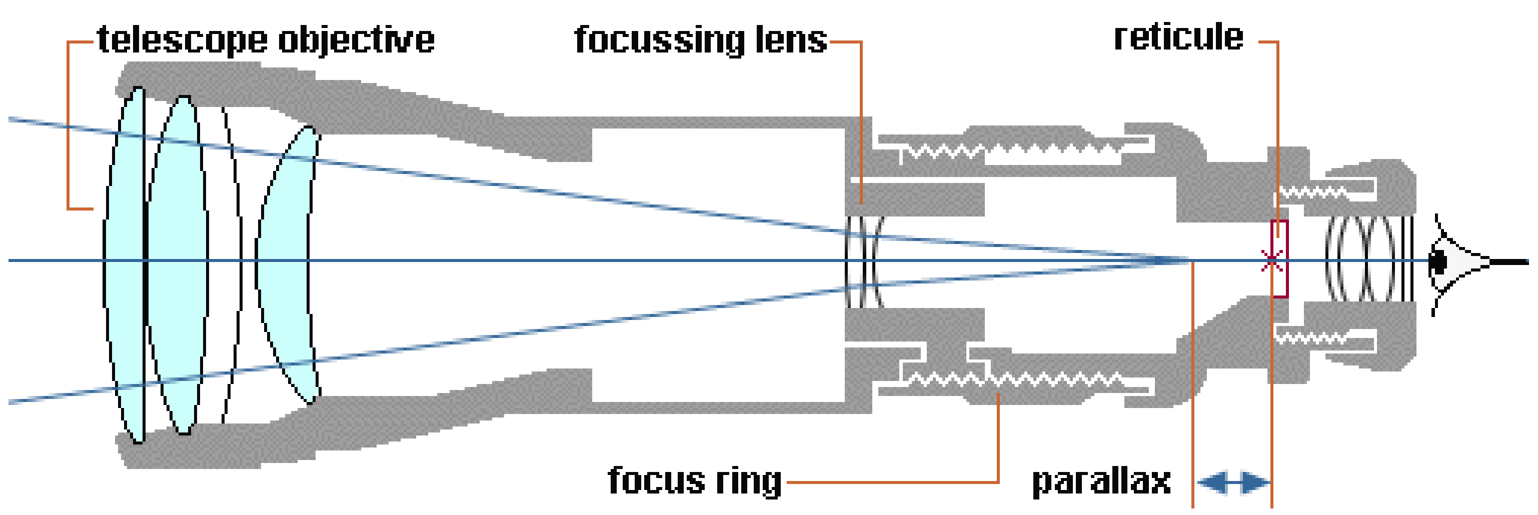


Telescope horizontal

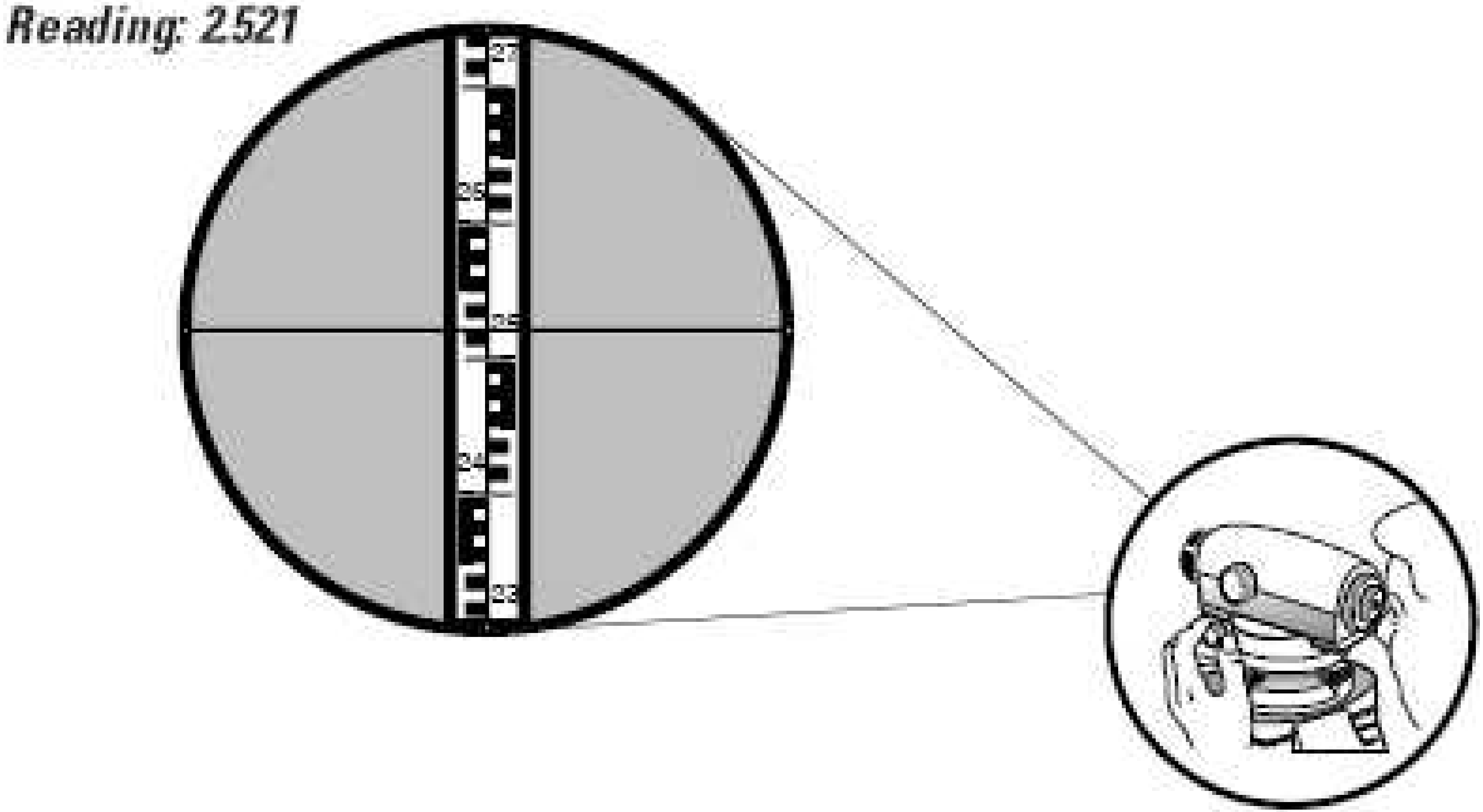


When telescope tilts down, compensator swings forward.

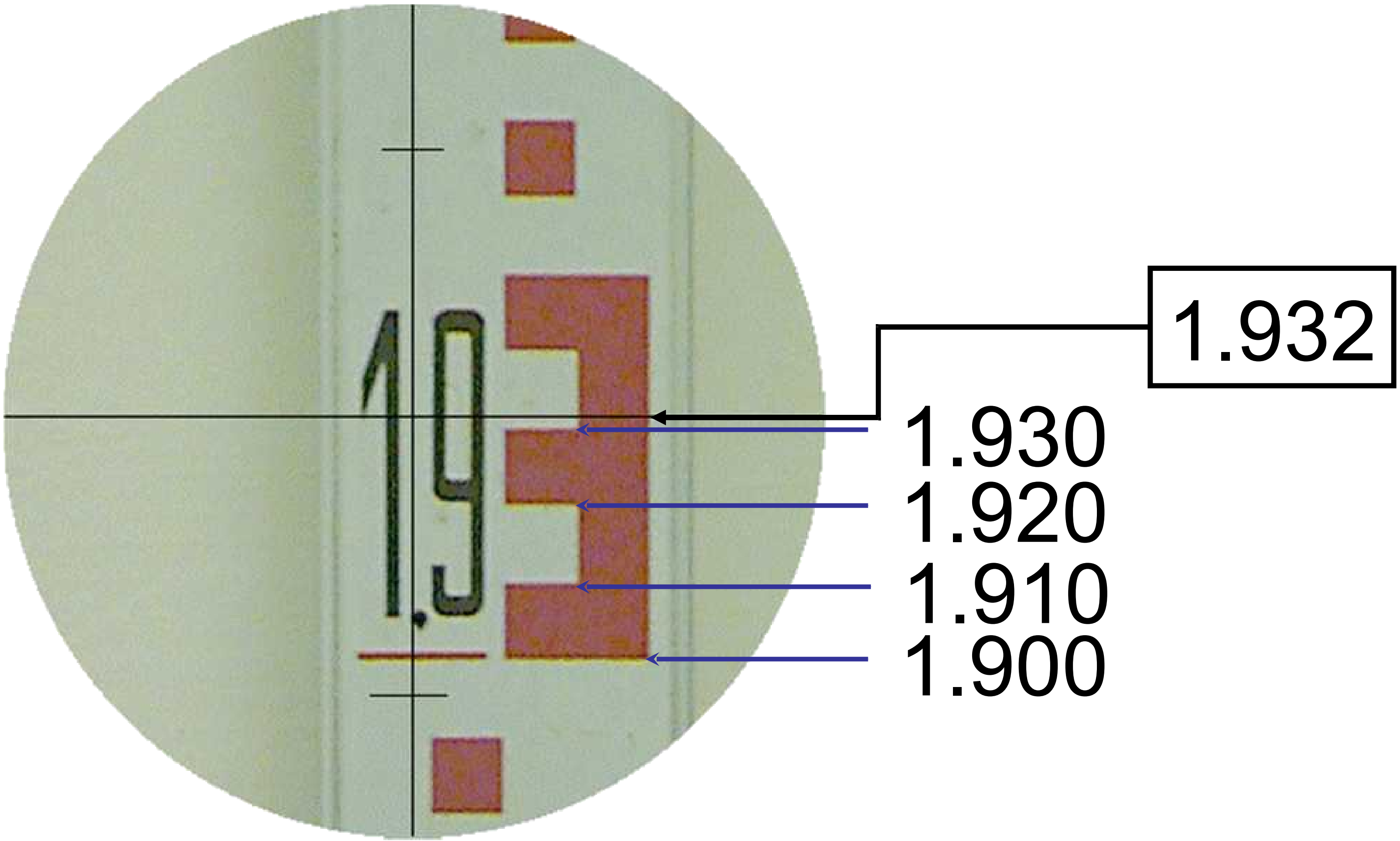

Circular level bubble
Sight
Objective lens focus
Eyepiece focus
Objective lens
Horizontal motion screw
Capstan screws
Leveling screws


telescope objective
focussing lens
reticule
focus ring
parallax

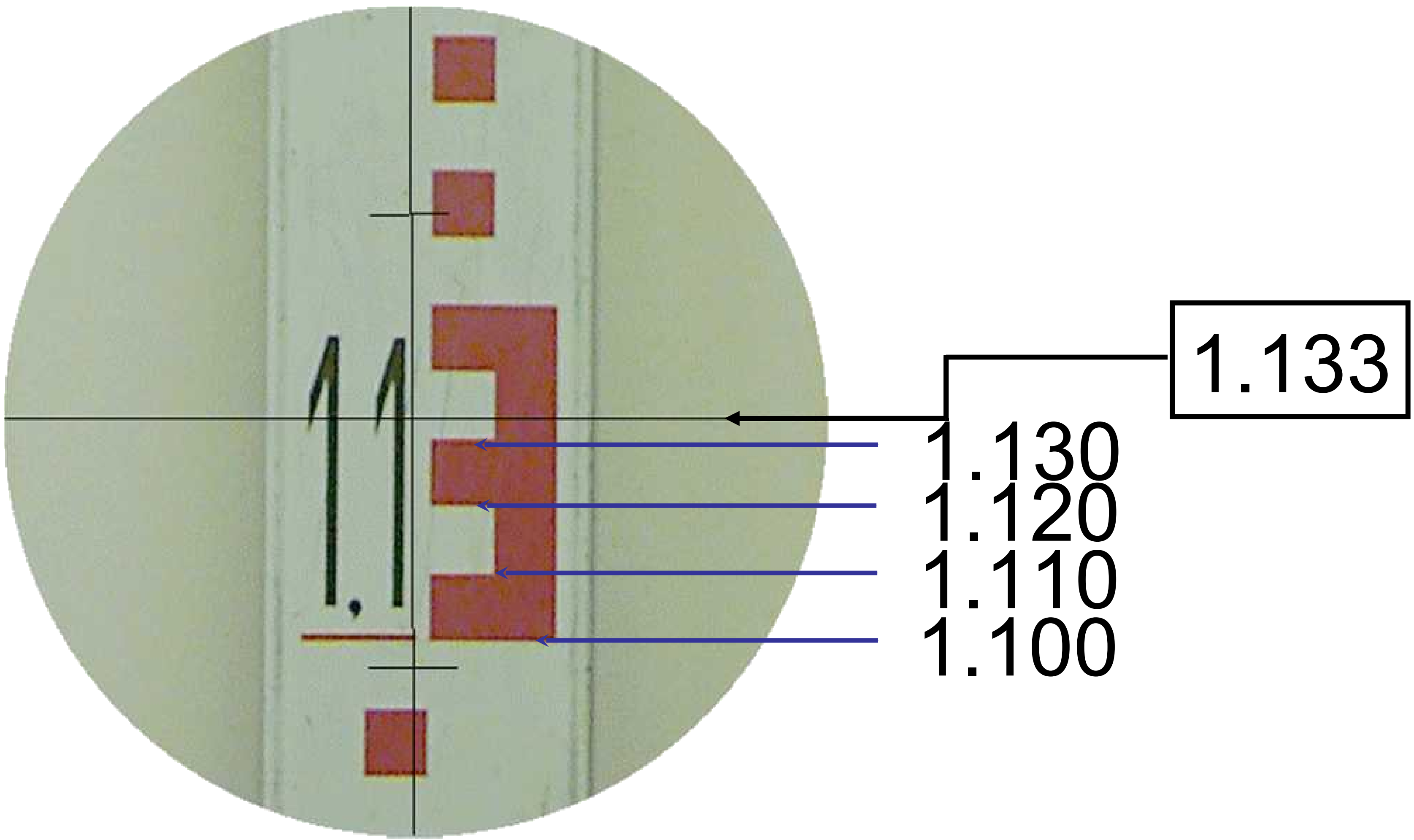
E-type Levelling Staff (1)



E-type Levelling Staff (2)



E-type Levelling Staff (3)



Common Error Sources

- Level rod not vertical
- Levelling rod not fully extended or incorrect length
- Level instrument not level
- Instrument out of adjustment
- Environment - wind and heat

Suggestions for Good Levelling

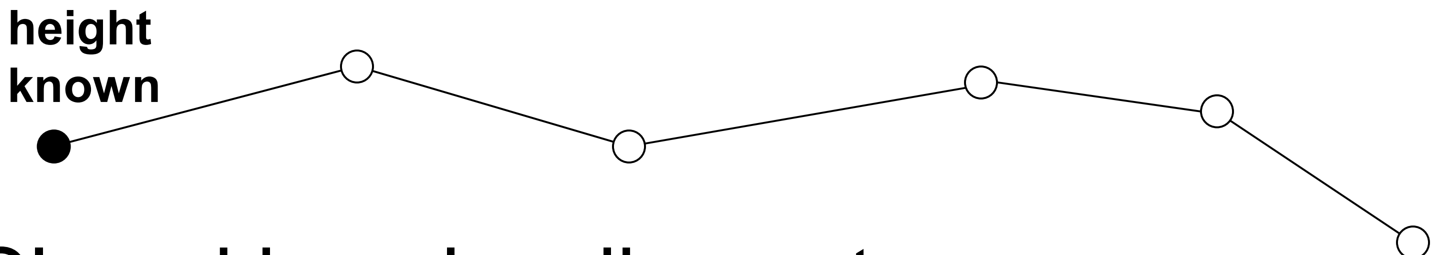
- Anchor tripod legs firmly
- Check the bubble level before and after each reading
- Take as little time as possible between BS and FS
- Try to keep the distance to the BS and the FS equal
- Provide the rod person with a level for the rod

Elimination of Parallax

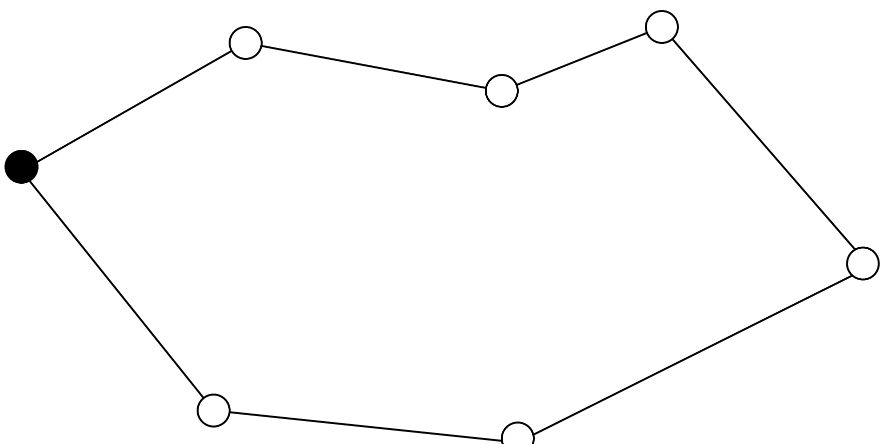
- Parallax is the apparent movement of the image produced by movement of the observer's eye at the eyepiece.
- It is eliminated by focusing the telescope on infinity and then adjusting the eyepiece until the cross-hairs appear in sharp focus. The setting will remain constant for a particular observer's eye.

Types of Levelling Nets

- Open leveling nets

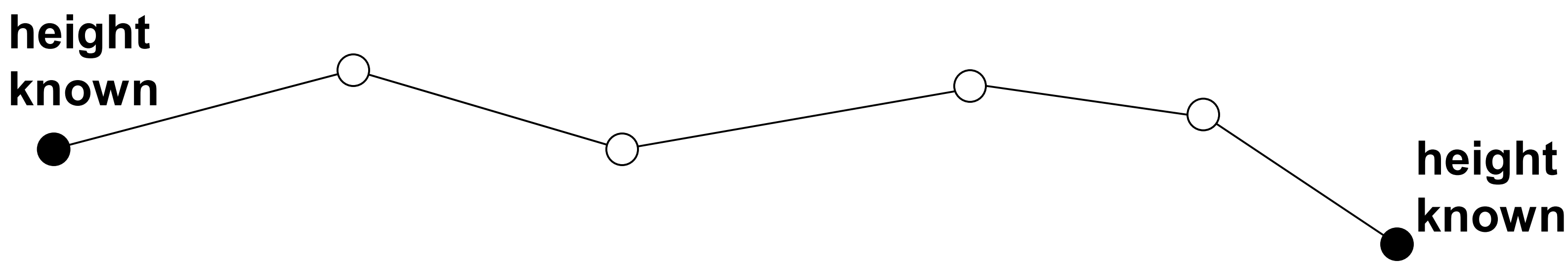


- Closed loop leveling nets



Types of Levelıng Nets

- Closed link or closed connecting leveling nets



- Leveling between two points is performed in two steps: forward (ΔHAB) and backward (ΔHBA). The height differences, ΔHAB and ΔHBA should be theoretically equal.

$\forall$ $\Delta HAB - \Delta HBA \leq d$

HPC Method

Height of the Plane of Collimation Method

- It consists in finding the elevation of the plane of collimation for every set up of the instrument and then obtaining the reduced levels (RL) of point with reference to the respective plane of collimation.
- The HPC method is generally used in profile levelling and in setting out levels for constructional work.

HPC Method

Height of the Plane of Collimation Method

- Same staff position as last reading therefore the same row
- New staff position therefore a new row

HPC = Reduced Level (RL) + BS

RL = HPC - FS

RL = HPC - IS

CLOSED-LOOP LEVELING COMPUTATION
Collimation Method

Bench Marks	Distance (m)	Rod Readings (m)			Collimation Height	Heights	Corrected Heights (m)
		BS	IS	FS			
1		2.147			128.621	126.474	**126.474**
	40						
2		1.613		0.491	129.743	128.130^{-1}	128.129
	80						
3		1.079		2.312	128.510	127.431^{-2}	127.429
	70						
4		3.452		0.286	131.676	128.224^{-3}	128.221
	50						
5		0.314		0.179	131.811	131.497^{-4}	131.493
	60						
6		0.271		3.598	128.484	128.213^{-5}	128.208
	70						
7		2.745		1.052	130.177	127.432^{-6}	127.426
	84						
8		0.682		1.423	129.436	128.754^{-8}	128.746
	42						
1				2.953		126.483^{-9}	**126.474**

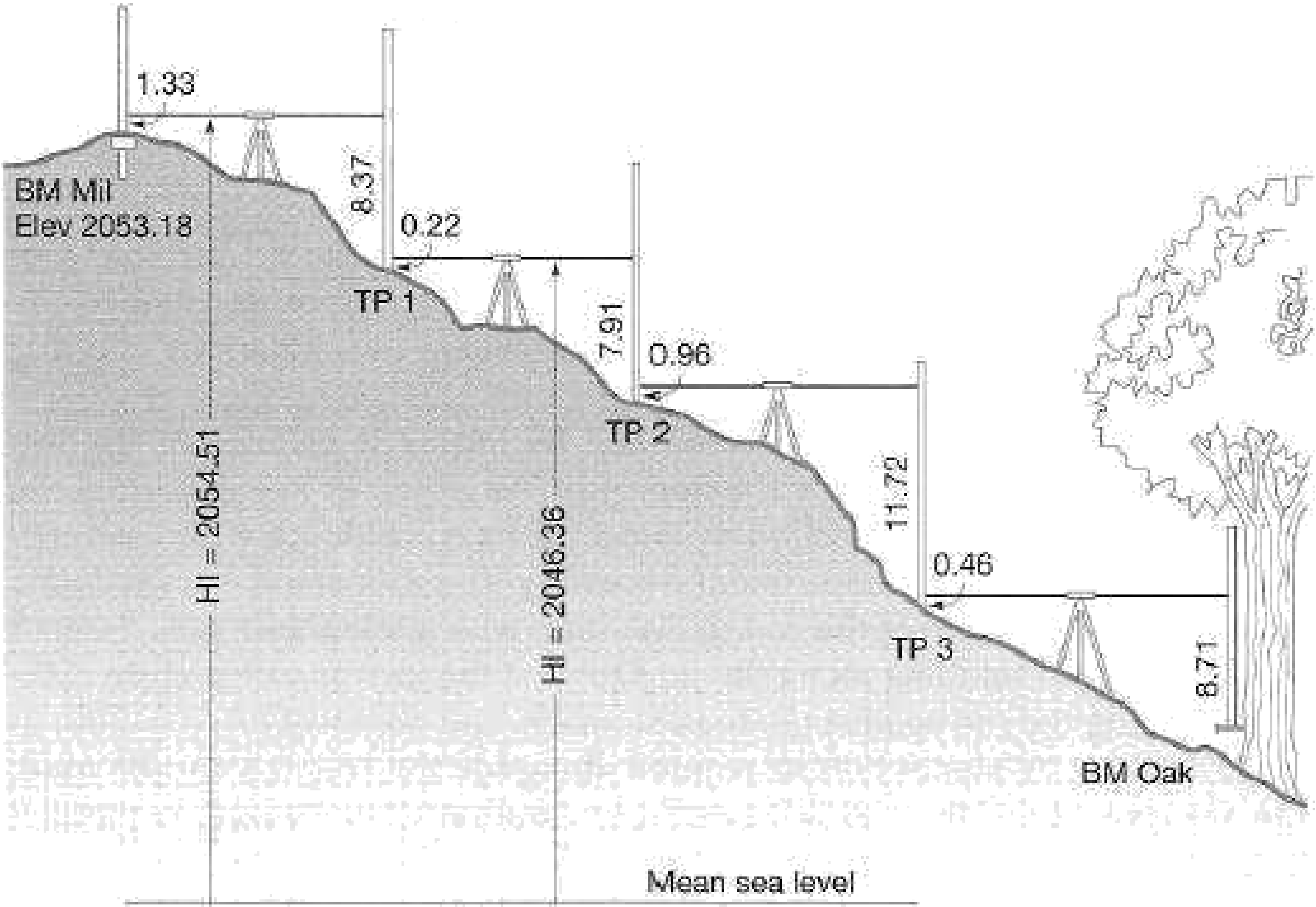
Σ L = 496 m Σ_{BS}=12.303 126.483 – 126.474 = 0.009 m

Check : Σ_{BS} - Σ_{FS} =12.303 – 12.294 = 0. = 0.009m

HPC Method

Height of the Plane of Collimation Method

BS	*IS*	*FS*	*HPC*	*RL*	*Remarks*	
1.5			62.0	60.5	TBM (60.5)	1*A*
	2.5			59.5		2*A*
	4.0			58.0		3*A*
3.0		2.0	63.0	60.0	Change pt	4*A* (1*B*)
	5.5			57.5		2*B*
6.0		1.0	68.0	62.0	Change pt	3*B* (1*C*)
		3.0		65.0	TBM (65.1)	2*C*
10.5	12.0	6.0		65.0	Checks	
6.0				60.5	Misclosure	0.1
4.5				4.5	*Correct*	


1.33
BM Mil
Elev 2053.18
8.37
0.22
TP 1
HI = 2054.51
7.91
0.96
TP 2
HI = 2046.36
11.72
0.46
TP 3
8.71
BM Oak
Mean sea level

DIFFERENTIAL LEVELS

Sta.	+ B.S.	H.I.	− F.S.	Elev.	Adj. Elev.
BM Mil.	1.33			2053.18	2053.18
		2054.51			
TP1	0.22		8.37	2046.14	2046.14
		2046.36			
TP2	0.96		7.91 ~~8.91~~	2038.45	2038.44
		2039.41			
TP3	0.46		11.72	2027.69	2027.68
		2028.15			
BM Oak	11.95		8.71	2019.44	2019.42
		2031.39			
TP4	12.55		2.61	2028.78	2028.76
		2041.33			
TP5	12.77		0.68	2040.65	2040.62
		2053.42			
BM Mil.			0.21	2053.21	2053.18
Σ =	+40.24	Σ =	−40.21		

Page Check:

2053.18
+ 40.24
2093.42
− 40.21
2053.21 Check

GRAND LAKES UNIV. CAMPUS

BM Mil. to BM Oak

BM Mil. on GLU Campus	29 Sept. 2000
SW of Engineering Bldg.	Clear, Warm 70° F
9.4 ft. north of sidewalk	T.E. Henderson N
to instrument room and	J.F. King ϕ
1.6 ft. from Bldg. Bronze	D.R. Moore ⊼
disk in concrete flush	Lietz Level #6
with ground, stamped "Mil"	

BM Oak is a temporary project bench mark located at corner of Cherry and Pine Sts., 14 ft. West of computer laboratory. Twenty penny spike in 18″ Oak tree, 1 ft. above ground.

Loop Misclosure = 2053.21 − 2053.18 = 0.03

Permissible Misclosure = $0.02\sqrt{n} = 0.02\sqrt{7}$
= 0.05 ft.

Adjustment = $\frac{0.03}{7}$ = 0.004′ per H.I.

T.E. Henderson

Calculation checks

Simple check

$\sum FS - \sum BS = 1st\ RL - Last\ RL$

Full check

$\sum IS + \sum FS + \sum (RLs\ except\ first)$
$= \sum (each\ HPC \times number\ of\ applications)$

Check Misclosure

Allowable Misclosure = $\pm 5\sqrt{N}$ mm. ("Rule of Thumb")
When calculations are checked and
if the misclosure is allowable
Distribute the misclosure.

Rise and Fall Method

- It consist in determining the difference of level between consecutive points by comparing each point after the first with that immediately preceding it.
- The difference between their staff reading indicates a rise or a fall according as the staff reading at the point is smaller or greater than that preceding point.
- The RL of each point is then found by adding rise or subtracting fall to or from the RL.
- The RF method provides complete check on IS.
- It is commonly used for differential levelling.

CLOSED-LOOP LEVELING COMPUTATION

Rise & Fall Method

Bench Marks	Distance (m)	Rod Readings (m)			DH (m)		Heights (m)
		BS	IS	FS	Rise (+)	Fall (-)	
1		2.147					**126.474**
	40				1.656^{-1}		
2		1.613		0.491			128.129
	80					0.699^{-1}	
3		1.079		2.312			127.429
	70				0.793^{-1}		
4		3.452		0.286			128.221
	50				3.273^{-1}		
5		0.314		0.179			131.493
	60					3.284^{-1}	
6		0.271		3.598			128.208
	70					0.781^{-1}	
7		2.745		1.052			127.426
	84				1.322^{-2}		
8		0.682		1.423			128.746
	42					2.271^{-1}	
1				2.953			**126.474**
Σ L = 496 m		Σ_{BS}=12.303		Σ_{FS}=12.294	Σ = 7.044	Σ = 7.035	

Check : $\Sigma_{BS} - \Sigma_{FS}$ =12.303 – 12.294 = 0.009 $\Sigma_{RISE} - \Sigma_{FALL}$ = 7.044 - 7.035 = 0.009

Rise and Fall Method

BS	*IS*	*FS*	*Rise*	*Fall*	*RL*	*Distance*	*Remarks*	
1.5					60.5	0	TBM (60.5)	1*A*
	2.5			1.0	59.5	30		2*A*
	4.0			1.5	58.0	50		3*A*
3.0		2.0	2.0		60.0	70	CP	4*A* (1*B*)
	5.5			2.5	57.5	95		2*B*
6.0		1.0	4.5		62.0	120	CP	3*B* (1*C*)
		3.0	3.0		65.0	160	TBM (65.1)	2*C*
10.5		6.0	9.5	5.0	65.0		Checks	
6.0			5.0		60.5		Misclosure	0.1
4.5			4.5		4.5		*Correct*	

Rise and Fall Method

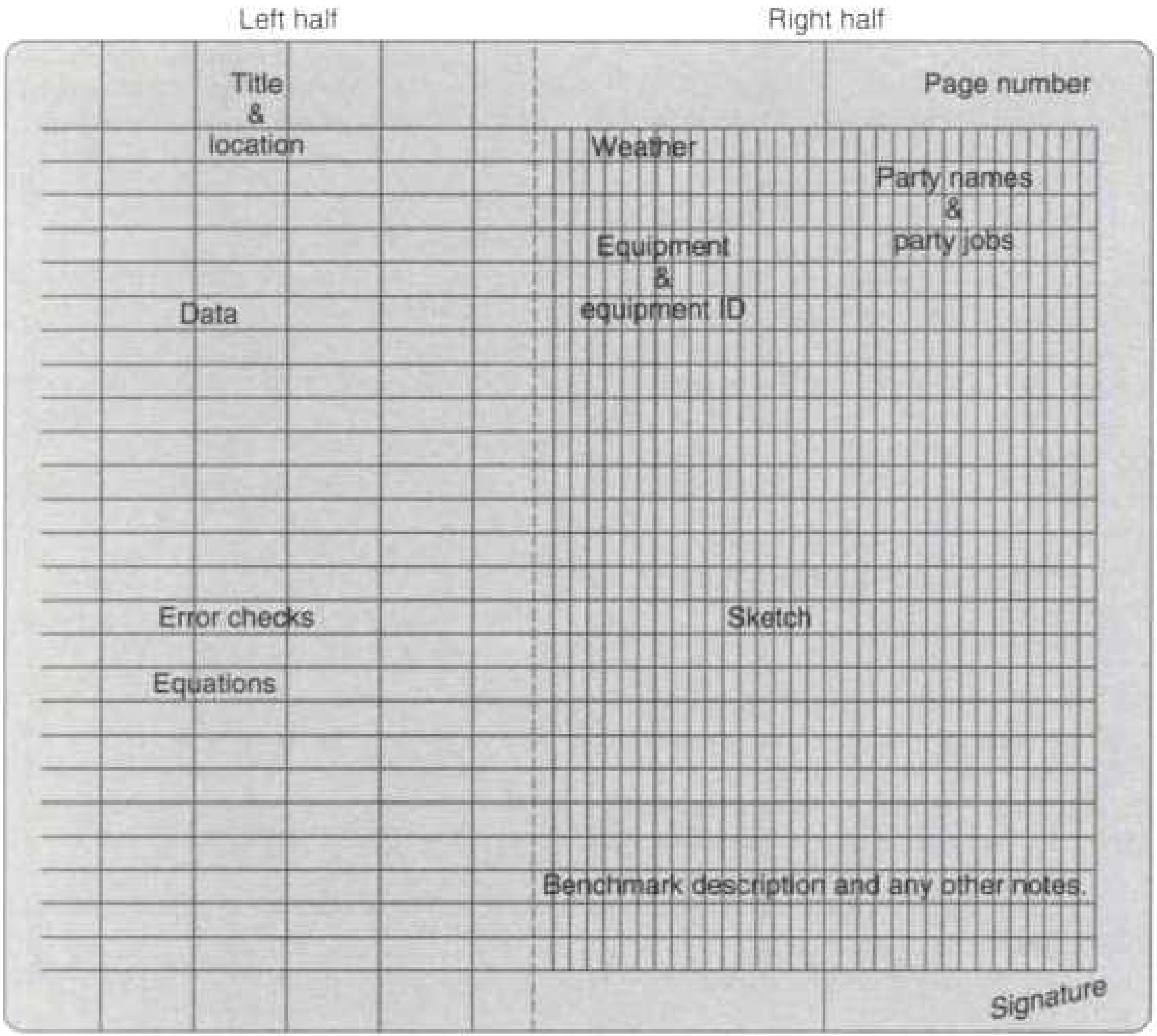
Fall = FS - BS

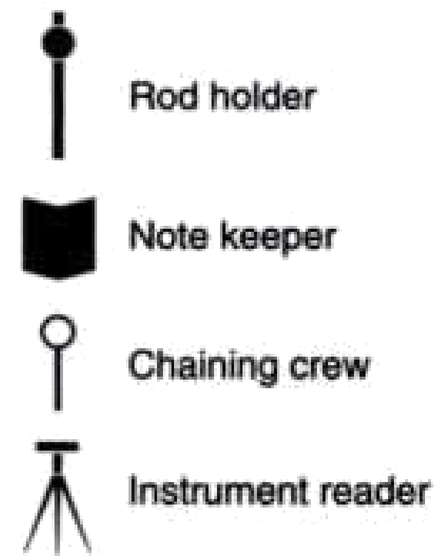
Fall = IS - BS

Rise = BS - FS

RL = Previous RL + Rise

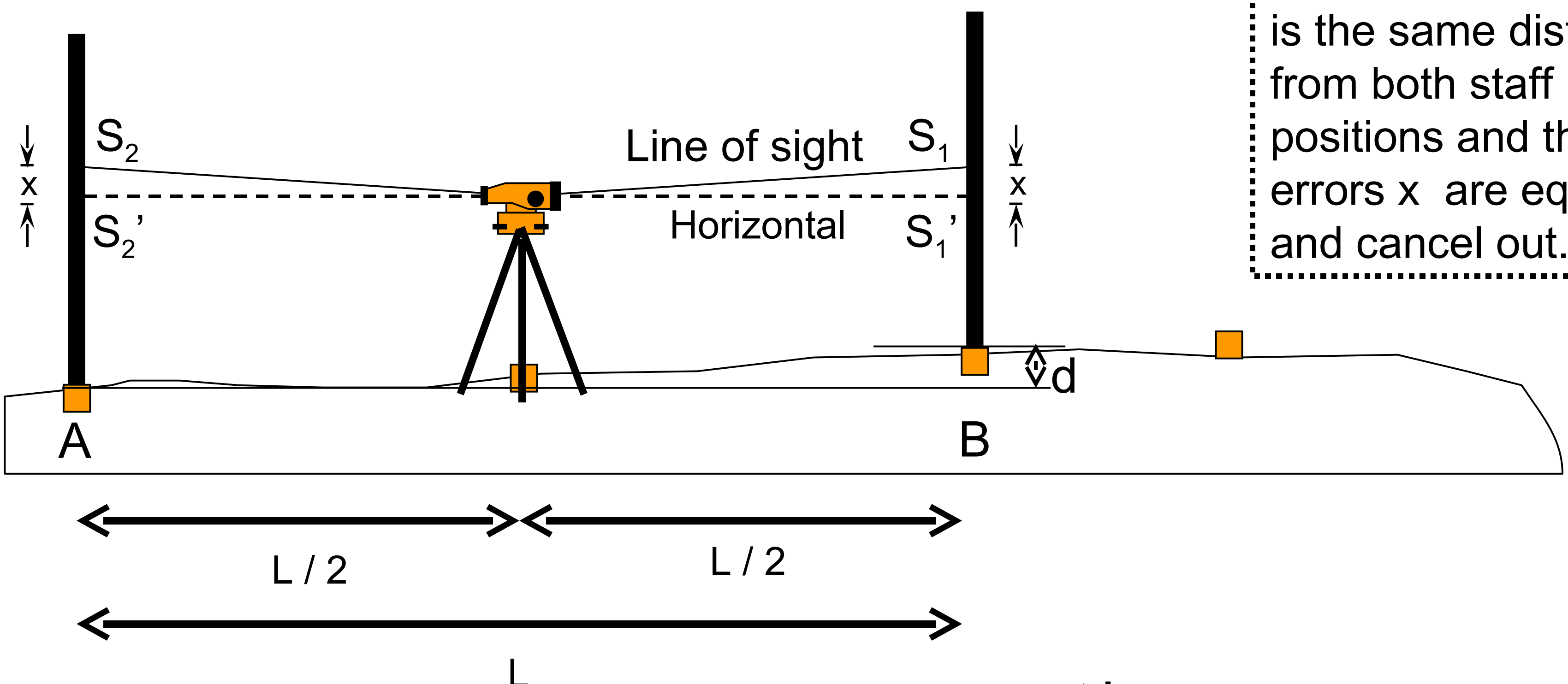
RL = Previous RL - Fall


Left half
Right half
Title
&
location
Page number
Weather
Party names
&
party jobs
Equipment
&
equipment ID
Data
Error checks
Sketch
Equations
Benchmark description and any other notes.
Signature


Rod holder
Note keeper
Chaining crew
Instrument reader

Collimation Error

Two Peg Test



Since the instrument is the same distance from both staff positions and the errors x are equal and cancel out.

The **true** height difference, Δh_T

The **visible** height difference, ΔhA

$S_1 = S_1' + x$ and $S_2 = S_2' + x$

$$\Delta h_T = S_1' - S_2'$$

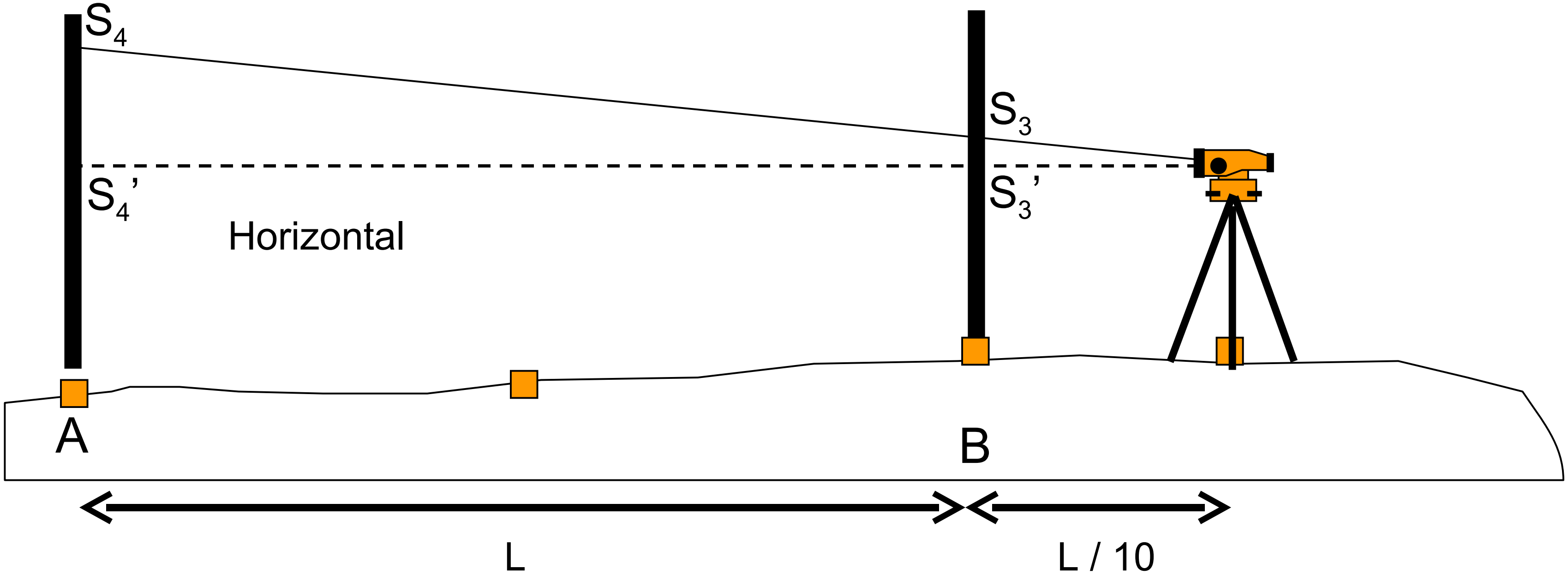
$$\Delta h_A = S_1 - S_2$$

$$\Delta h_A = (S_1' + x) - (S_2' + x)$$

$$\Delta h_A = S_1' - S_2' = \Delta h_T$$

Collimation Error

Two Peg Test



The **visible** height difference $\Delta h_A = S3 - S4$

But the **true** height difference $\Delta h_T = S1 - S2$

If $\Delta h_A = \Delta h_T$ then the instrument is OK

If NOT then the error is $\varepsilon = (S_1 - S_2) - (S_3 - S_4) / L$ mm / m

Collimation Error

Two Peg Test

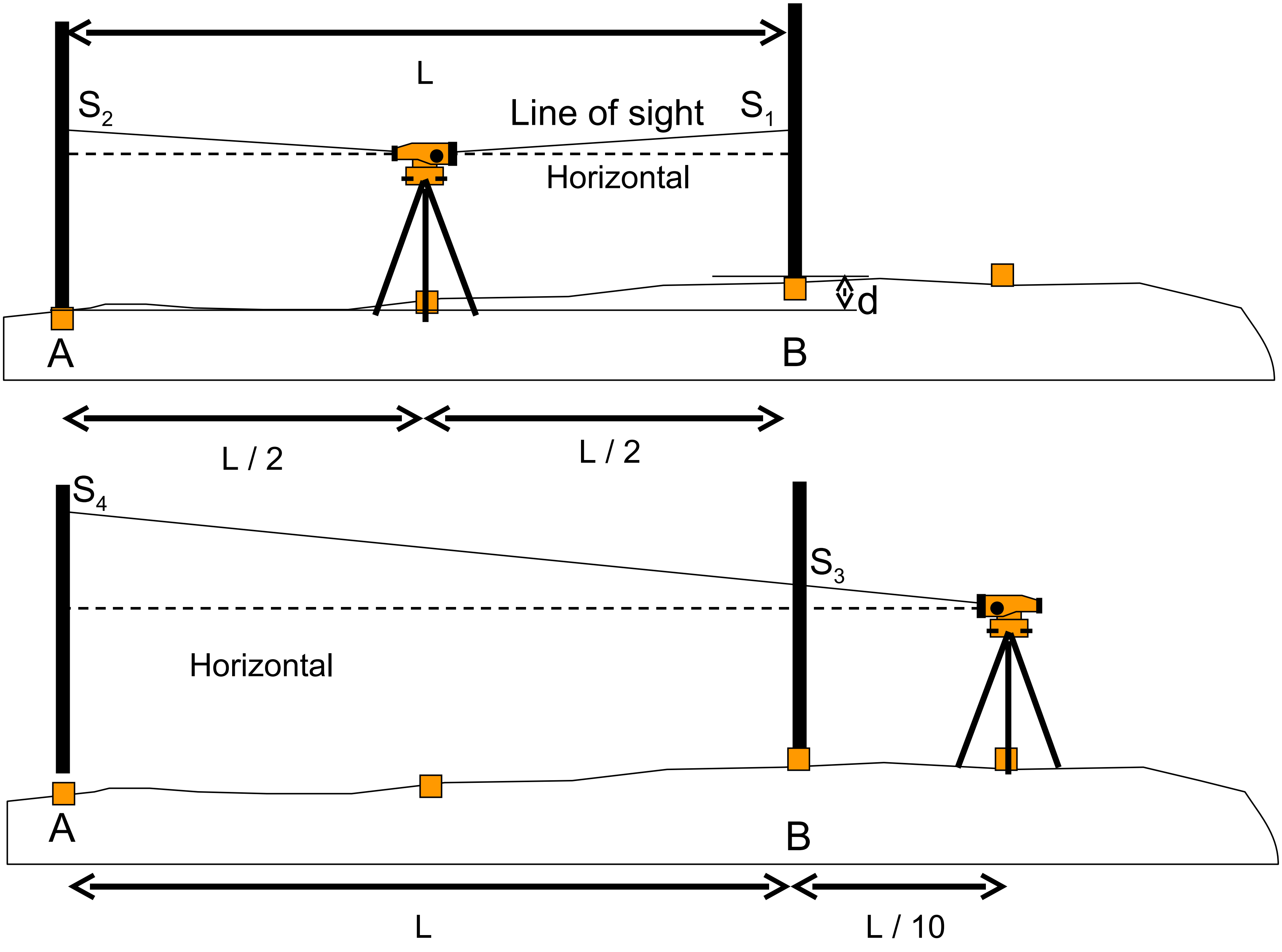
- Place two pegs about L = 30m (to 40m) apart.
- Set up level midway between the two pegs.
- Read staff on each peg, and calculate <u>true</u> height difference .
- Move level about L / 10 = 3m (or 4m) beyond one of the pegs.
- Read staff on each peg again, and calculate height difference.

Collimation Error, ε = difference in the differences and is expressed as a number of mm per L m

Collimation Error

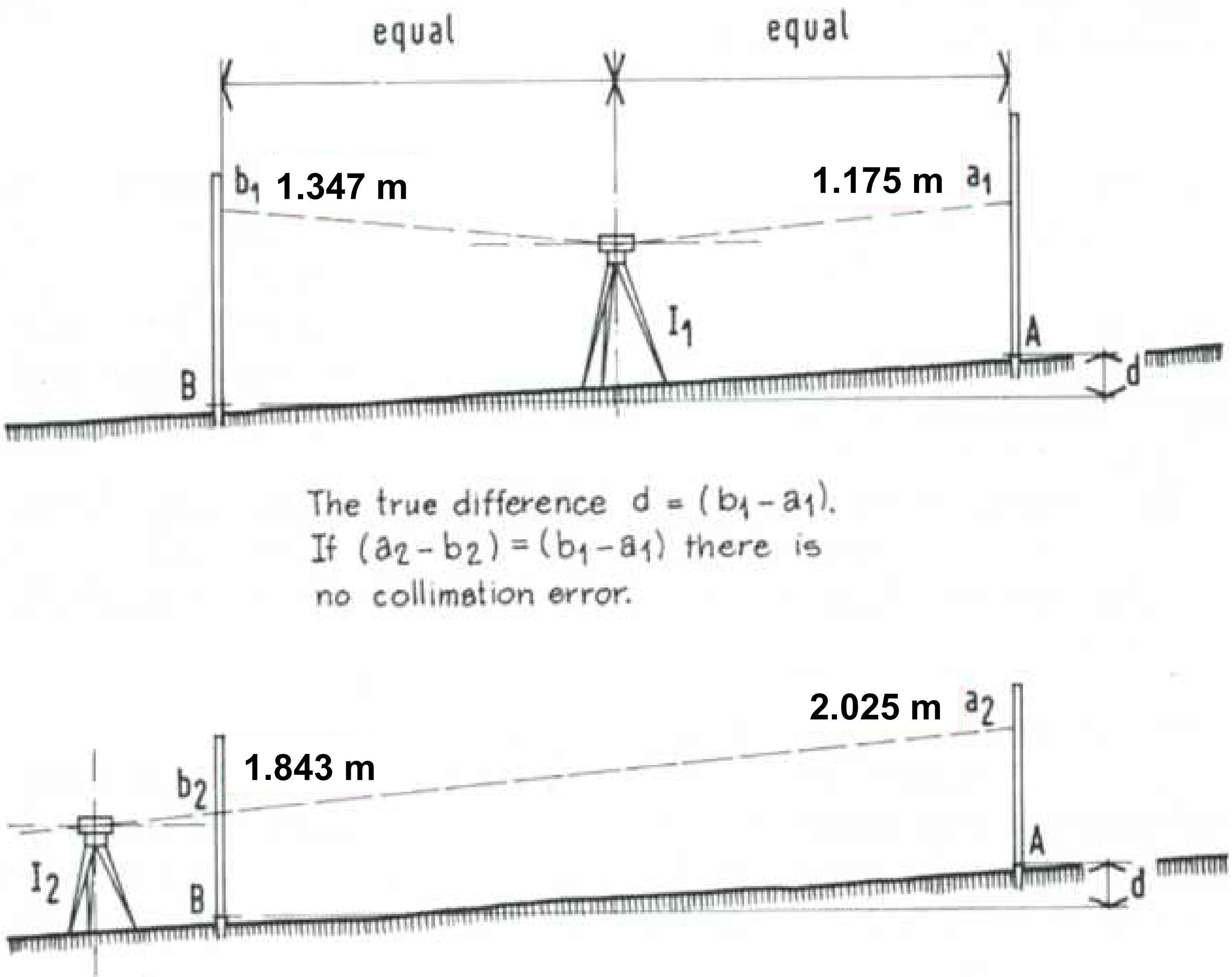
Two Peg Test

- Acceptable errors
  - Uren and Price 1mm per 20m
  - Wimpey 4mm per 50m
- Test should be carried out regularly.



Collimation error, $\varepsilon = (S_1 - S_2) - (S_3 - S_4) / L$, mm/m

A two peg test gave the following results:



True difference between points A & B:

$\Delta h_T = b_1 - a_1$

$\Delta h_T = 1347 - 1175$

$\Delta h_T = 172$ mm

Apparent difference between points A & B:

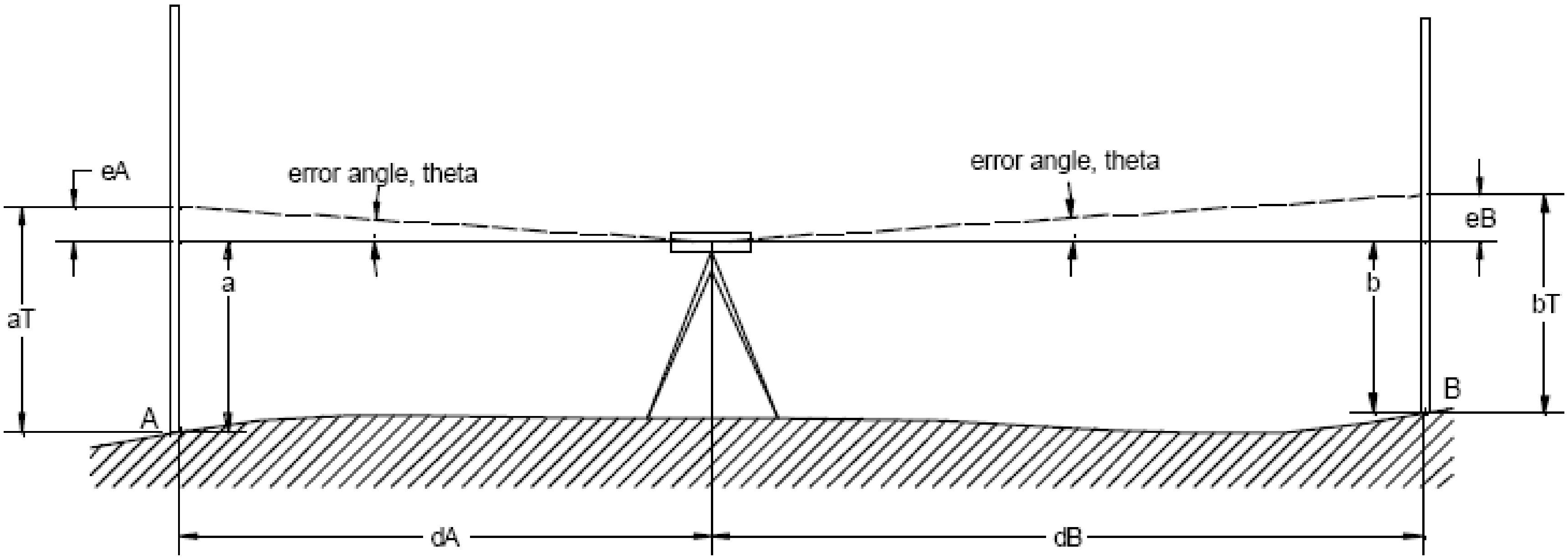
$\Delta h_A = a_2 - b_2$

$\Delta h_A = 2025 - 1843$

$\Delta h_A = 182$ mm

If the distance between the two pegs is 30 m and
the error is 10 mm (182-172) then
the **collimation error**, ε is 10 mm per 30 m
the collimation correction is $0.01 \div 30 = 0.00033$ m/m

Peg Test [2]



d_A = length of shot to A

d_B = length of shot to B

a = actual reading at A

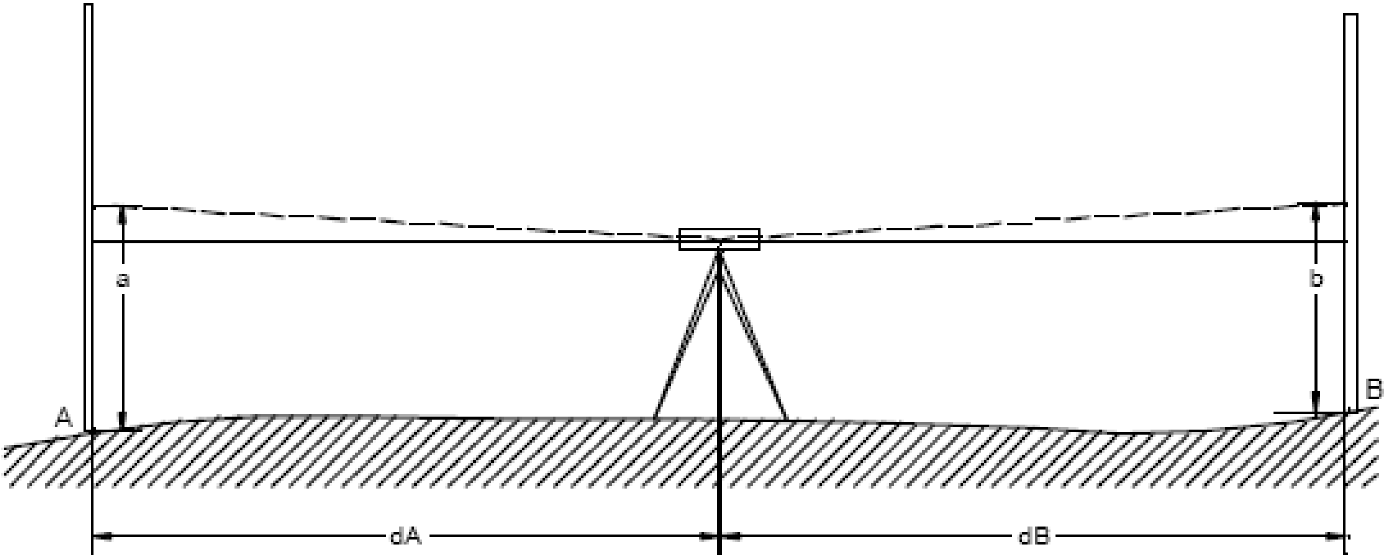
b = actual reading at B

e_A = error component at A due to telescope misalignment

e_B = error component at B due to telescope misalignment

a_T = reading at A seen through telescope

b_T = reading at B seen through telescope



$a = a_T - e_a$ and $b = b_T - e_b$

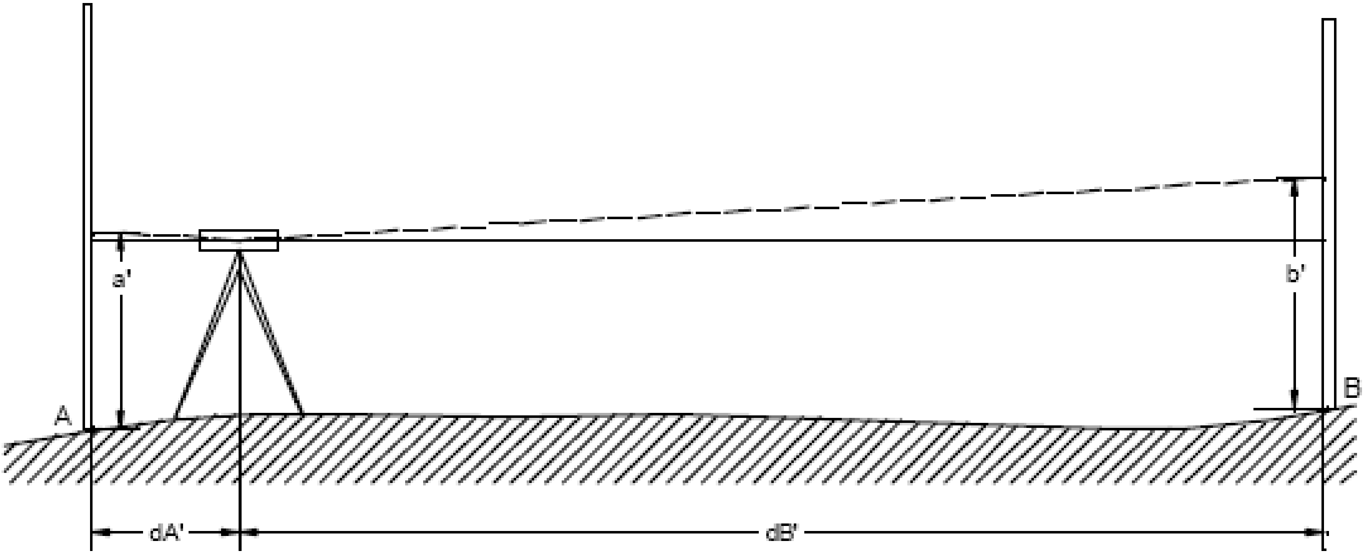
$e_a = d_A \tan\theta$ and $e_b = d_B \tan\theta$

$$a - b = [a_T - d_A \tan\theta] - [b_T - d_B \tan\theta]$$

$$a - b = (a_T - b_T) + (d_B - d_A)\tan\theta$$

therefore :

$a - b = a_T - b_T$ only if $[\tan\theta = 0]$ and/or $[d_B - d_A] = 0$



$$a - b = (a' - b') + (d_{B'} - d_{A'})\tan\theta$$

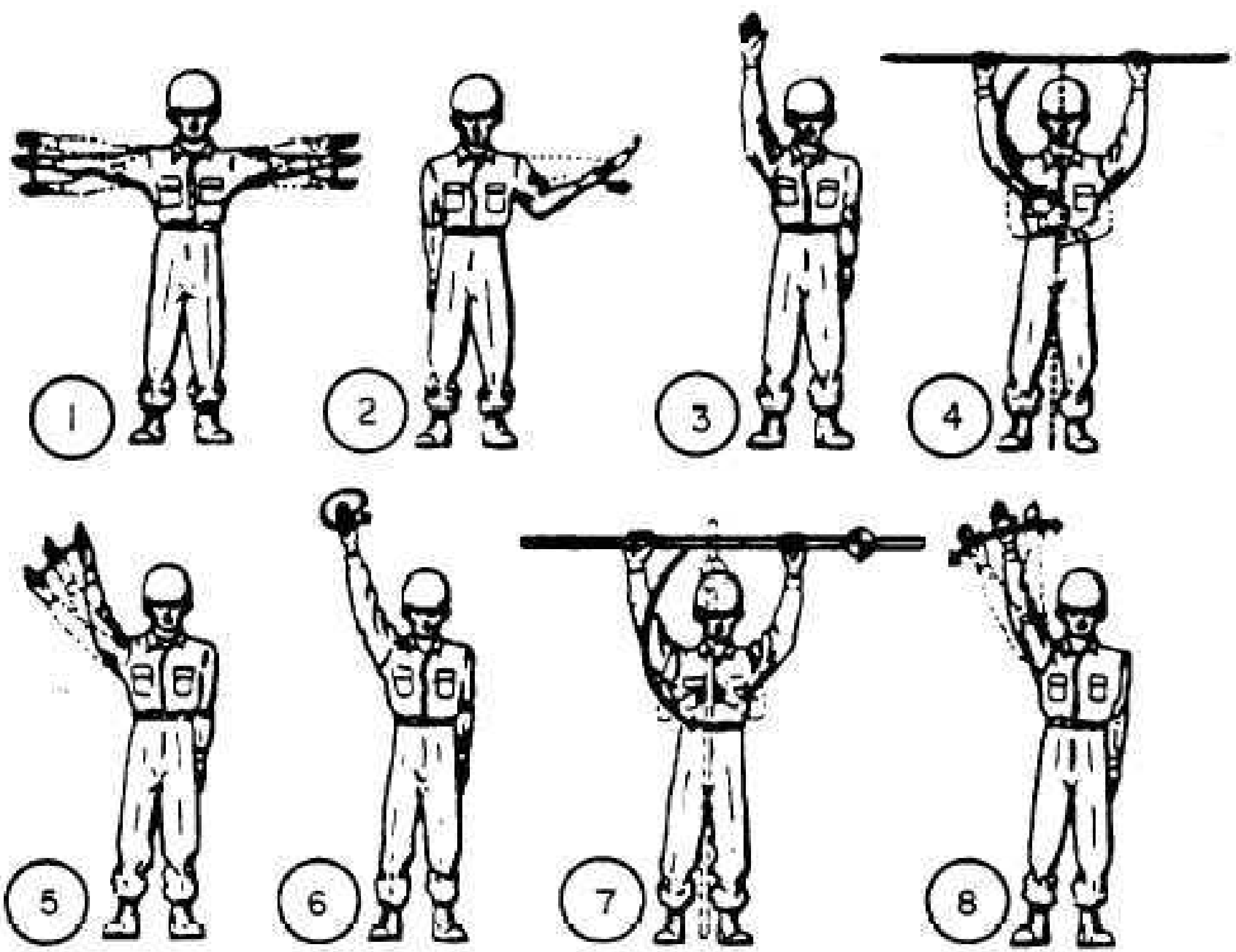
$$\tan\theta = \frac{(a-b)-(a'-b')}{(d_{B'} - d_{A'})}$$

$$\theta = \tan^{-1}\left[\frac{(a-b)-(a'-b')}{(d_{B'} - d_{A'})}\right]$$

Peg Test results are reported in degrees and as slopes. A useful way to express peg test results is in the
units of

"__ mm (high/low) per m length of shot".

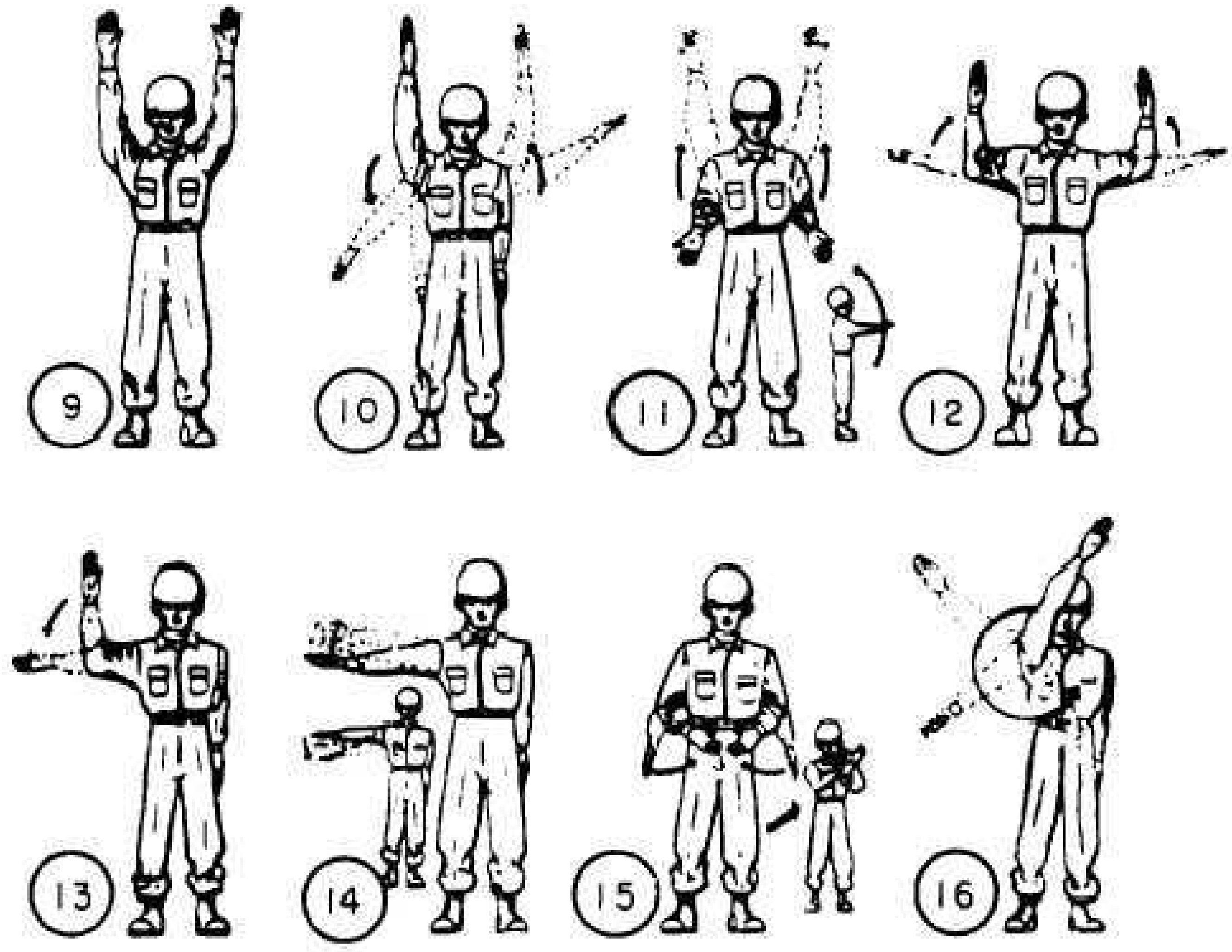
Surveyor's Hand Signals (1)



Surveyor’s Hand Signals (2)

1. All right.
2. Move right or left.
3. Give me a back sight.
4. Give me a line or this is a hub.
5. Plumb the rod.
6. Establish a turning point.
7. This is a turning point.
8. Wave the rod.

Surveyor’s Hand Signals (3)



Surveyor's Hand Signals (4)

1. Face the rod.
2. Reverse the rod.
3. Boost the rod.
4. Move forward.
5. Move back.
6. Up or down.
7. Pick up the instrument.
8. Come in.