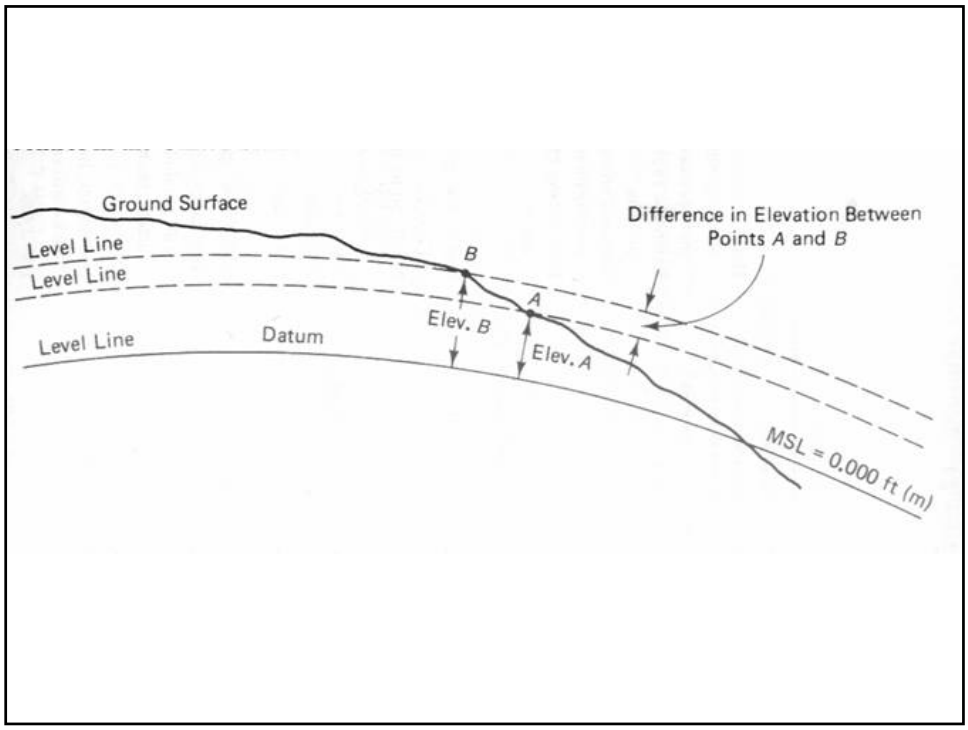
Chapter. 3
Leveling

- **Leveling** is the procedure used to determine differences in elevation between points that are remote from each other.
- **Elevation** is a vertical distance above or below a reference datum.
- (Mean Sea Level) MSL = 0.000 m.
- **Vertical line** is line from surface of the earth to the earth center → ***plumb line*** *or* ***line of gravity.***
- **Level line** is a line in level surface.
- **Level surface** is curved surface parallel to the mean surface of the earth.
- **Horizontal line** is a straight line perpendicular to vertical line.



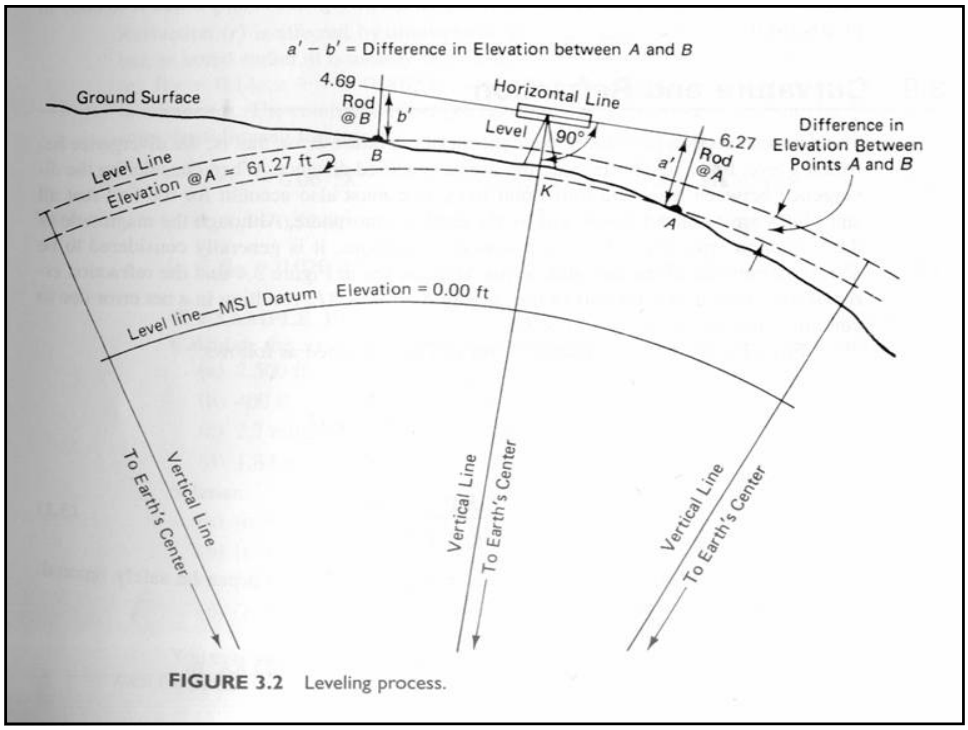


FIGURE 3.2 Leveling process.

3.2 Theory of Differential Leveling

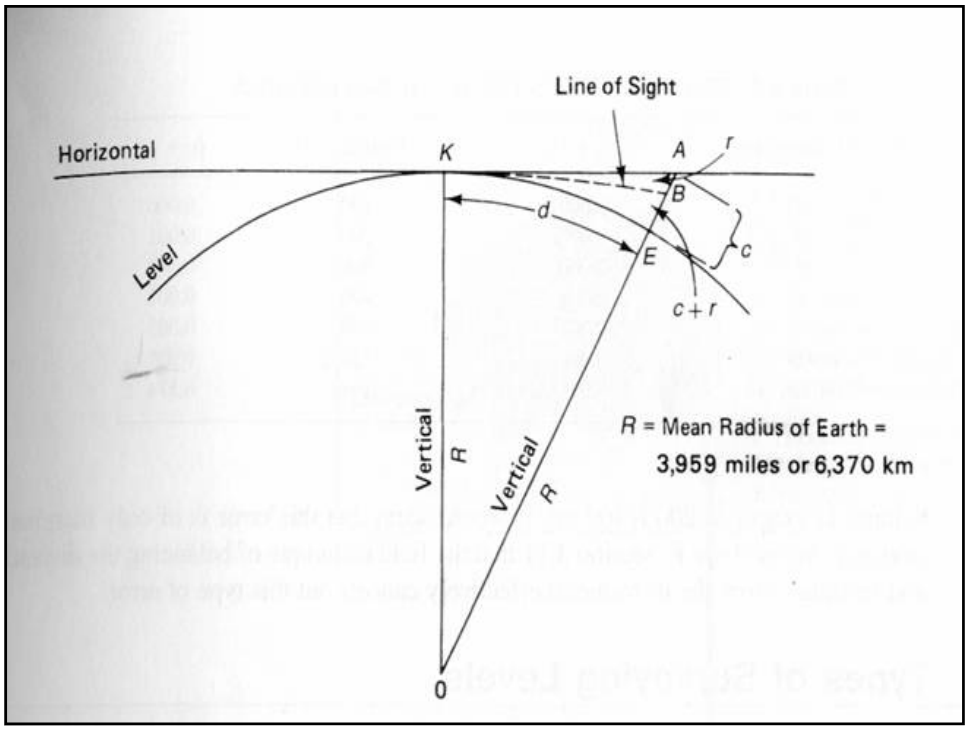
- **Differential leveling** is used to determine the elevation between remote points using surveyor's level with graduated measuring rod
- **Level** is a cross hair equipped telescope

Elevation of A + rod reading A - rod reading at B = elevation of B

- All rods reading contain an error C over distance d.
- The divergence between a **leve**l and **horizontal** line is quite small for short distances.
- For distant of 1000 ft: divergence = 0.024 ft

  300 ft = 0.002 ft

  100 m = 0.0008 m



3.3 Curvatures and Refraction Concept of Curvature Error

Divergence between level line & horizontal line over specified distances.
•All sight lines are refracted downward by the earth's atmosphere.
•Magnitude depends on atmospheric condition
Generally considered one-seventh of curvature error.

$(R + C)^2 = R^2 + KA^2$
$R^2 + 2RC + C^2 = R^2 + KA^2$
$C (2R + C) = KA^2$
$C = KA^2 /(2R + C) = KA^2/2R$
Take R = 6,370 km
$C = KA^2$ X 103/2 x 6370 = $0.0785\ KA^2$

Refraction is affected by atmospheric pressure and temperature
Geometric location usually = 1/7 C

If r = 1/7 C
$C + r = 0.0675\ K^2$
K = KA length of sight in km

3.4 Types of Surveying Levels

3.4.1 Automatic level

•Employs gravity referenced prism or mirror compensator to automatically orient the line of sight (line of collimation)
•The instrument is quickly leveled using circular spirit level.
•Compensator maintains horizontal LOS even if telescope is slightly titled
• 3 or 4 screws leveling base.
•2 & 3 Screws can change elevation of line of sight

3.4.2 Digital Level

- Electronic image processing for determining height and distance
- Electronic mode with rod face graduated in bar code (Fig. 3.12)
- Compare image with the whole rod image. - Auto determination of height & dist and recorded

3.4.3Tilting Level

- Equipped with circular spirit level for rough leveling which telescope is pointed to the rod.
- The telescope is precisely leveled by tilting screw which raise or lower eyepiece end of telescope until tube level is leveled.
- Tube level is viewed through separate eyepiece lens or telescopes its self.
- 3 screws leveling base.
- Screws can change elevation of line of sight.

3.5 Leveling Rod

- Wood, metal, fiberglass
- Graduated in ft or meter 0.01 ft 0.001 m with mm estimated
- Optical micrometer can be read more precise values.
- One piece rod → more precise.
- Normal leveling 2-3 piece rods
- Metal plate at bottom (zero mark).
- Wide verity of marks see p. 69
- Surveyor must be familiar with graduation
- Rectangular rod → folding or sliding
- Bench mark leveling → uses folding rods or invar rods with built in handles and rod level.

3.6 Differential Leveling

- **Benchmark** (BM) is a permanent point of known elevation.
- **Temporary benchmark** (TBM) is a semi-permanent point of known elevation.
- **Turning point** (TP) is a point temporarily used to transfer an elevation.
- **Back sight** (BS) is a rod reading taken on a point of known elevation in order to establish the elevation of the instrument line of sight.
- **Height of instrument** (HI) is the elevation of the line of sight through the level (i.e. elevation of BM + BS = HI).
- **Foresight** (FS) is a rod reading taken on a turning point, benchmark, or temporary benchmark in order to determine its elevation (i.e., HI - FS = elevation of TP (BM or TBM).
- **Intermediate foresight** (IS) or (IFS) is a rod reading taken at any other point where the elevation is required.

HI - IS = elevation of the point

3.7 Techniques for Leveling

- Choose convenient location (e.g. hard surface)
- Hard surface & spreading the legs of tripod improve stability
- Soft surface: push legs hard into ground
- On hills one leg uphill, tow leg downhill
- Attach the inst. to tripod head and level it
- Use 2 screws at a time to level the inst
- Revolve the inst. to check leveling
- Focus the eyepiece lenses on the rod (sharp image)
- If both focusing operations are correct the cross hairs are super imposed on leveling Rod.
- If either focusing operation is not correct it will appear that cross hair is moving up and down as observer-head moves slightly up or down.
- If one or both not focus the result and error is known as **parallax**.

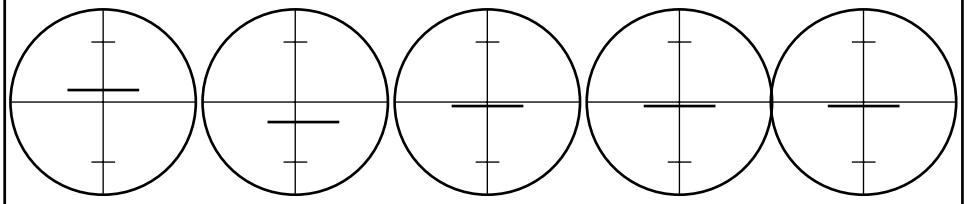
Parallax

When focussing any optical instrument it is vitally important that we eliminate Parallax.

Move the eye up and down (or from left to right) over the eyepiece of the telescope.

If the cross hairs move relative to the object being observed then Parallax exists and the focussing is not satisfactory.

Elimination of Parallax



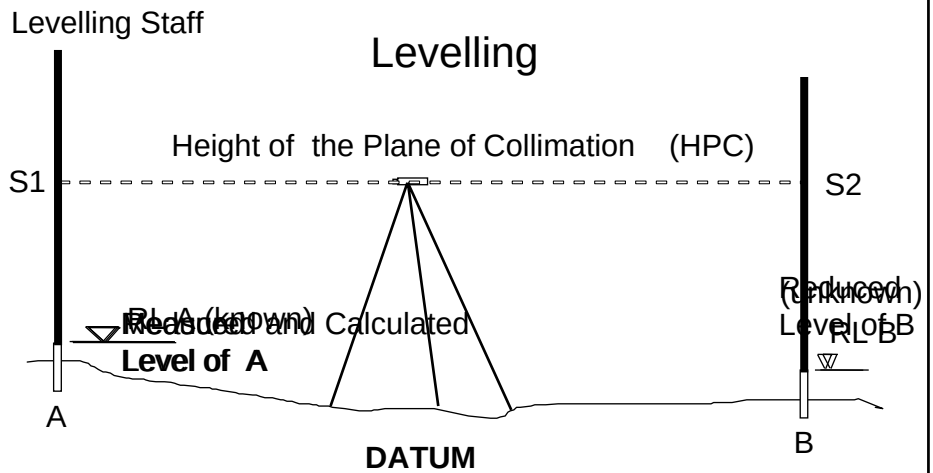
Focus the eyepiece
(using the Focussing screw)

The cross hairs appear to move over the object
Parallax exists and must be removed by better focussing

Focus the object
(using the Focussing screw)

Parallax has been removed
Therefore focussing is good

Levelling



HPC = RL A + S1

RL B = HPC - S2

DATUM

DATUM

To determine elevation of selected point with respect to a point of known elevation:

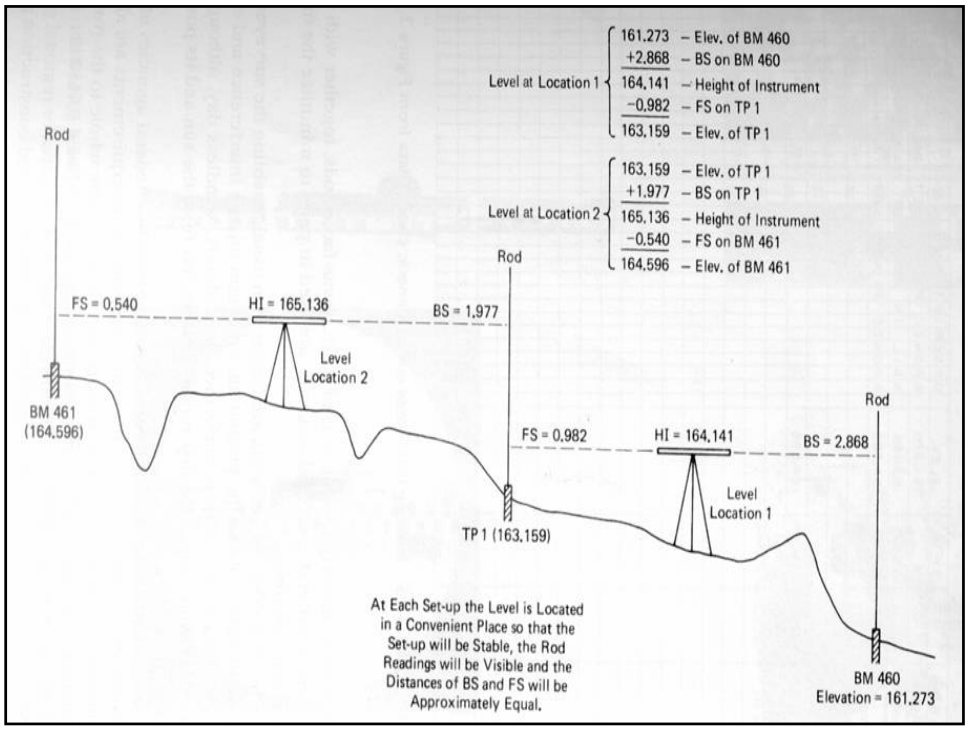
Elevation of A	=	220.15
BSA	=	+1.80
HI	=	221.95
FS B	=	- 2.45
Elevation B	=	219.40 m

The elevation of any point lower than LOS, and the rod is visible from level, can be determined.

For any instrument setup:

Existing elevation + B S = HI
HI -FS = new elevation
Distance of BS should = FS to eliminate or minimize errors due to curvature and refraction

- Numerous setups may be required before reading desired pint.
- Survey must be closed to a point of known elev. (BM) or loop



To determine accuracy and acceptability of survey:

- If closure is not within allowable limit the survey must be repeated.
- To insure rod is plumb use rod level or rod man gently waves the rod toward and a way from inst.
- Avoid sitting the rod on the back edge

Arithmetic check

Original elevation + ΣBS - Σ FS = new elevation

- Verify first BM can be down through leveling to the closest alliance BM.

3.8 Benchmark Leveling (Vertical Control Survey)

- This type is employed when system of benchmarks is to be established or for an extension to existing system
- High level of precision see Table 3.2
- Precision level coincidence tabular bubble sensitive 10" (seconds) per 2 mm
- Micrometer
- Invar rods with base plate & rod level and supports
- Tripod is larger than usual minimize reflection (LOS is higher)
- Identical work closely windless days, protect inst. from sun
- For municipal & regional grid specification are relaxed some what

Differential Leveling

Importance of Leveling

- The determination of elevations is called ***leveling***
- Measuring relative elevations changes is a comparatively simply process
- Precise and accurate control of relative elevations are critical to most construction projects

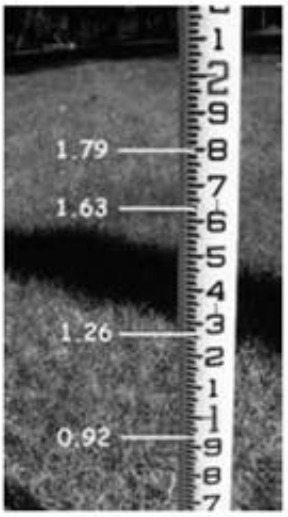
Differential Leveling

The Level

- A ***level*** consist of a high-powered telescope
- The level is attached to a spirit or bubble level that keeps the line of sight of the telescope horizontal

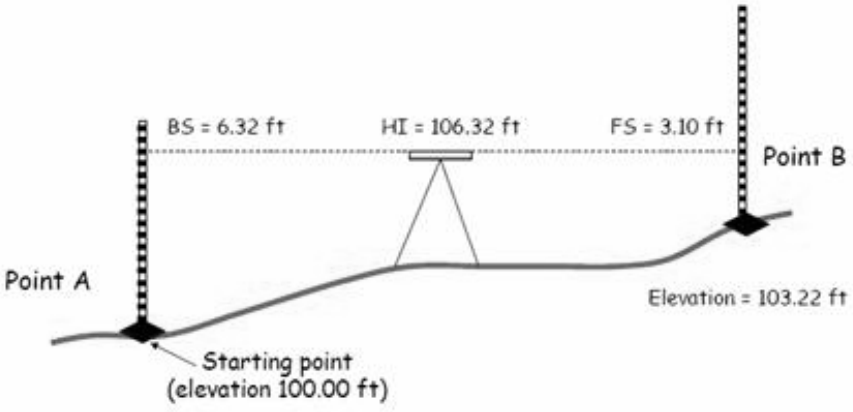
Differential Leveling

Level Instrument



Differential Leveling

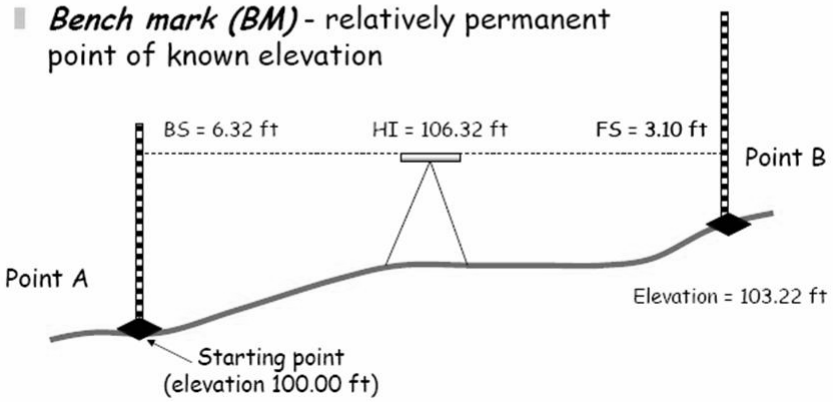
Definitions



Differential Leveling

Definitions

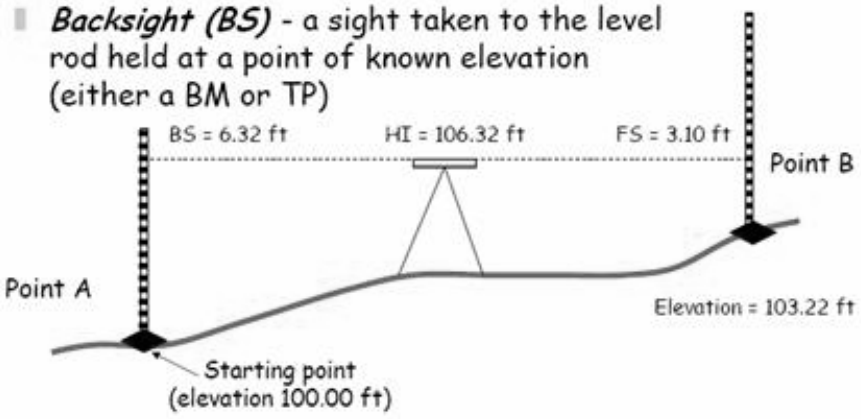
- ***Bench mark (BM)*** - relatively permanent point of known elevation



Differential Leveling

Definitions

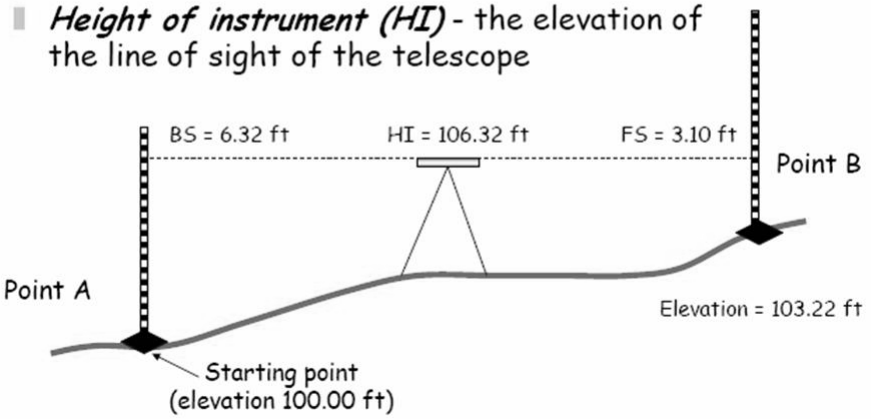
- ***Backsight (BS)*** - a sight taken to the level rod held at a point of known elevation (either a BM or TP)



Differential Leveling

Definitions

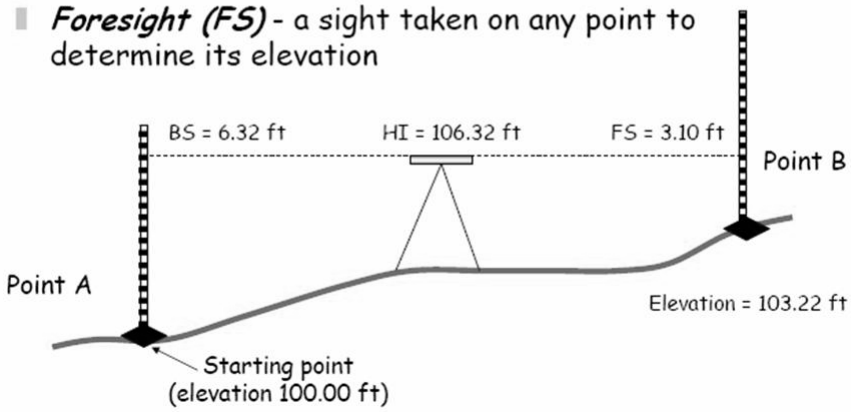
- ***Height of instrument (HI)*** - the elevation of the line of sight of the telescope



Differential Leveling

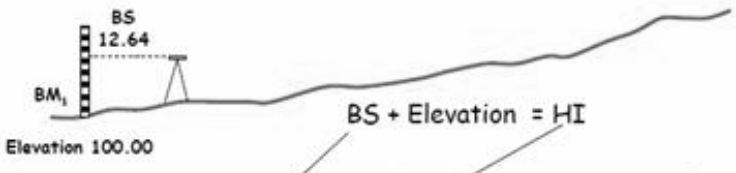
Definitions

- ***Foresight (FS)*** - a sight taken on any point to determine its elevation



Differential Leveling

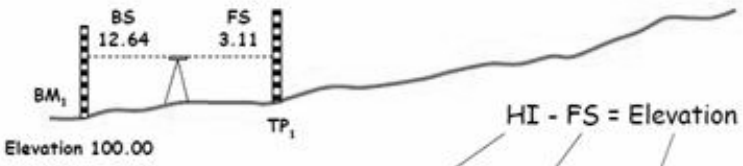
Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00

Differential Leveling

Computation of Elevations

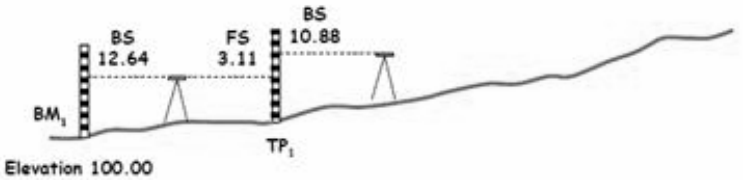


HI - FS = Elevation

Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1			3.11	109.53

Differential Leveling

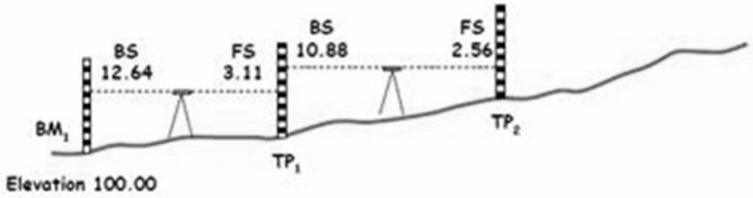
Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53

Differential Leveling

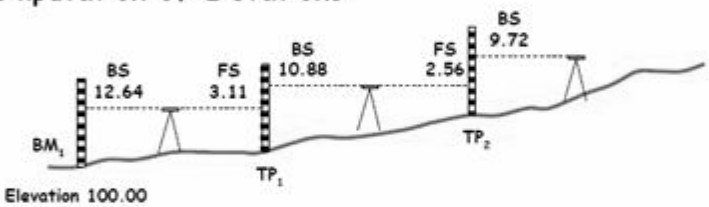
Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53
TP_2			2.56	117.85

Differential Leveling

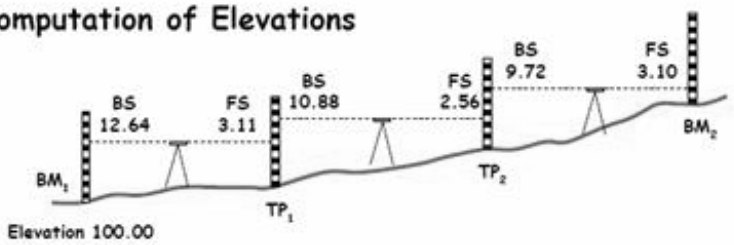
Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53
TP_2	9.72	127.57	2.56	117.85

Differential Leveling

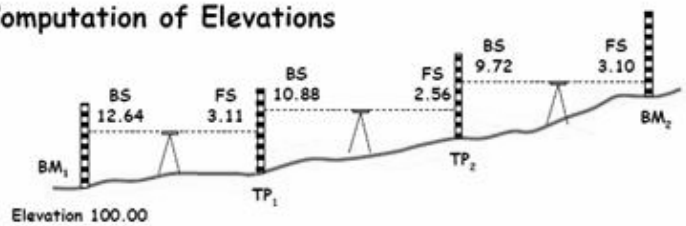
Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53
TP_2	9.72	127.57	2.56	117.85
BM_2			3.10	124.47

Differential Leveling

Computation of Elevations



Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53
TP_2	9.72	127.57	2.56	117.85
BM_2			3.10	124.47

Differential Leveling

Computation of Elevations

- Check the summation of the backsight and the foresight with the change in elevation

Point	BS	HI	FS	Elevation
BM_1	12.64	112.64		100.00
TP_1	10.88	120.41	3.11	109.53
TP_2	9.72	127.57	2.56	117.85
BM_2			3.10	124.47
	+33.24		-8.77	

Change in elevation = **33.24 -8.77 =24.47**

Differential Leveling

- The initial ***backsight (BS)*** is taken to a point of known elevation
- The backsight reading is added to the elevation of the known point to compute the ***height of the instrument (HI)***
- The level may be moved to a temporary point called a ***turning point (TP)***
- The elevation of a point is the ***height of the instrument (HI)*** minus the ***foresight (FS)***

Differential Leveling

Common Mistakes

- Misreading the rod - *reading 3.54 instead of 4.54*
- Moving the turning point - *use a well-defined TP*
- Field note mistakes - *work within your group to check you records*
- Mistakes with extended rod - *make sure the leveling rod is fully extended*

Differential Leveling

Common Mistakes

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

Differential Leveling

Suggestions for Good Leveling

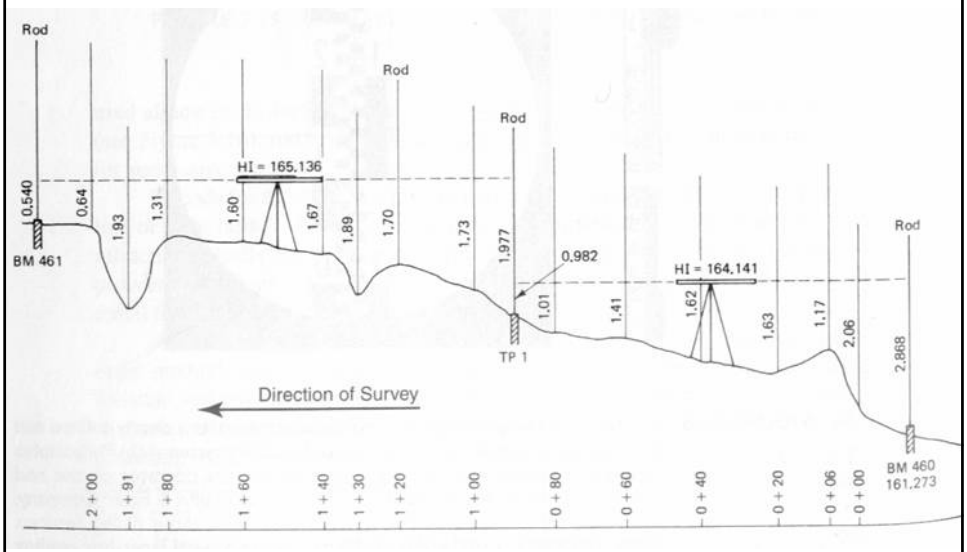
- Anchor tripod legs firmly
- Check the bubble level before and after each reading
- Take as little time as possible between BS and FS
- Try to keep the distance to the BS and the FS equal
- Provide the rodperson with a level for the rod

3.9 Profiles and Cross Section

For route survey:

-**Plan view =** top view
-**Profile =** side view along CL define xyz coordinates
-**Cross section =** side view at right angle of CL
(Fig. 3.17, 3.19 and Fig. 3.20)
- Profile taken on ***Centerline*** (proposed ***Centerline*** staked out at even interval 50 - 100 ft (20-30 m)
- Choose level setup in convenient location so that BM and as many as intermediate points can be measured
Rod reading at each significant change of slope.
- Call for turning point TP

-Turning point TP on wood stake, corner of concrete monument (hard surface or stakes driven), Should be easy to describe and found later.
-BM to BM or loop back
-Field note BS, IS, FS on separate columns
-Rod reading on soft ground closest 0.1 Ft or 0.01 m on hard surface 0.01 ft, 0.003 m
-Cross section are taken at each even station with rod pending taken at each significant change in slope
-Uniform slope : reading at each station
-Cross section note (municipal format) (Fig. 3.21)
-Cross section note (highway format) (Fig. 3.22)
-Borrow pits (gravel pits) determine the volume of material (costing)
-Reference base lines away from stripping and stockpiling
-Grid elevation of original surface and excavated surface (Fig. 3.23)



SMITH–NOTES
BROWN–$\bar{x}$
JONES–ROD

PROFILE OF PROPOSED ROAD 0 + 00 to 2 + 00 [metric]

Job 21 °C – SUNNY LEVEL L–14

Date AUG 3 2005 Page 72

STA.	B.S.	H.I.	I.S	F.S.	ELEV.	DESCRIPTION
BM 460	2.868	164.141			161.273	BRONZE PLATE SET IN --- ETC.
0 + 00			2.06		162.08	℄
0 + 06			1.17		162.97	℄ – TOP OF BERM
0 + 20			1.63		162.51	℄
0 + 40			1.62		162.52	℄
0 + 60			1.41		162.73	℄
0 + 80			1.01		163.13	℄
T.P. 1	1.977	165.136		0.982	163.159	NAIL IN ROOT OF MAPLE --- ETC.
1 + 00			1.73		163.41	℄
1 + 20			1.70		163.44	℄
1 + 30			1.89		163.25	℄ BOTTOM OF GULLY
1 + 40			1.67		163.47	℄
1 + 60			1.60		163.54	℄
1 + 80			1.31		163.83	℄
1 + 91			1.93		163.21	℄ BOTTOM OF GULLY
2 + 00			0.64		164.50	℄
BM 461				0.540	164.596	BRONZE PLATE SET IN --- ETC.
						164.591 – PUBLISHED ELEV.
	Σ=4.845			Σ=1.522		E = 164.596
ARITHMETIC CHECK: 161.273 + 4.845 – 1.522						164.591
					= 164.596	0.005
						ALLOWABLE ERROR (3RD ORDER)
						= 12 mm $\sqrt{K}$, = .012$\sqrt{.2}$ = .0054 m.
						ABOVE ERROR (.005) SATISFIES 3RD ORDER.

3.10 Reciprocal Leveling

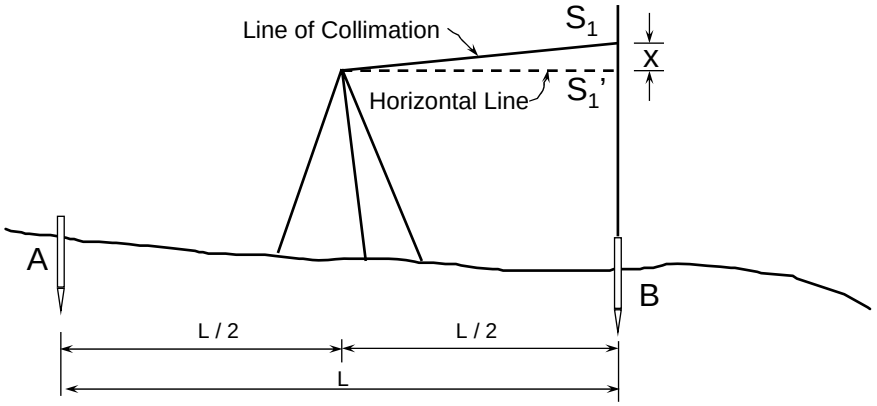
-BS and FS with equal distances from level setup

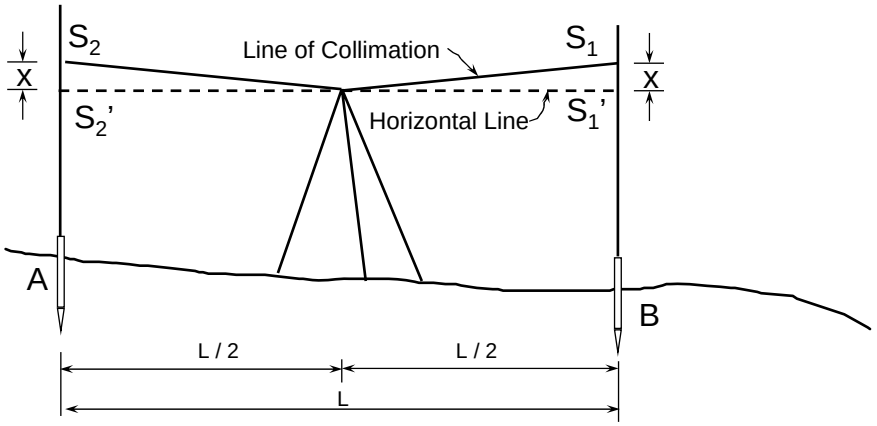
-Obstacle river, change level position and obtain 2 differences in elevation take average (Fig. 3.24)

3.11 Peg Test

Test to check that L.O.S through level is horizontal
Fig. 3.26) Ex. 3.2
True difference and apparent difference
Error in 60 m → error in m/m
Collimation correction (C factor)
Equal distance → eliminate collimation error
In ordinary work → negligible.

Two - Peg Test for a Level

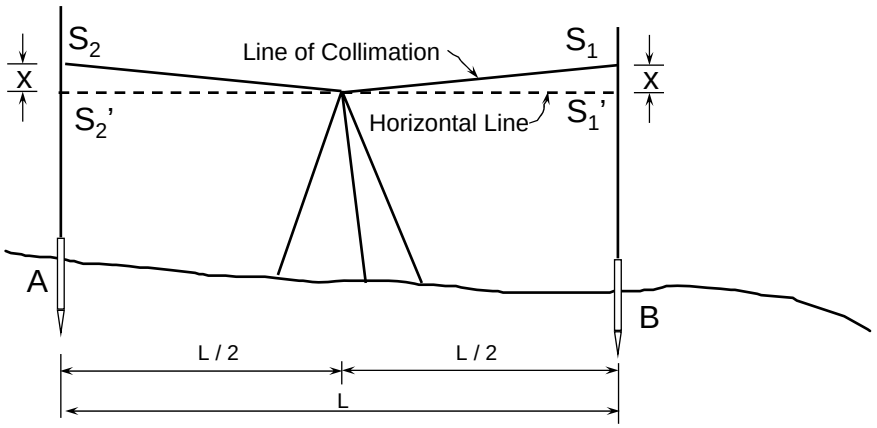




The TRUE height difference $\delta h_T = S_1' - S_2'$

The APPARENT height difference $\delta h_A = S_1 - S_2$

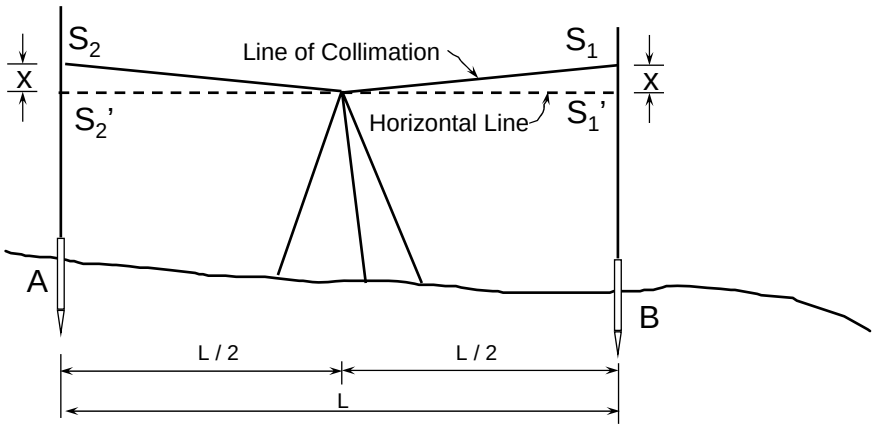
$S_1 = S_1' + x$ and $S_2 = S_2' + x$



The TRUE height difference $\delta h_T = S_1' - S_2'$

The APPARENT height difference $\delta h_A = S_1 - S_2$

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



The TRUE height difference $\delta h_T = S_1' - S_2'$

The APPARENT height difference $\delta h_A = S_1 - S_2$

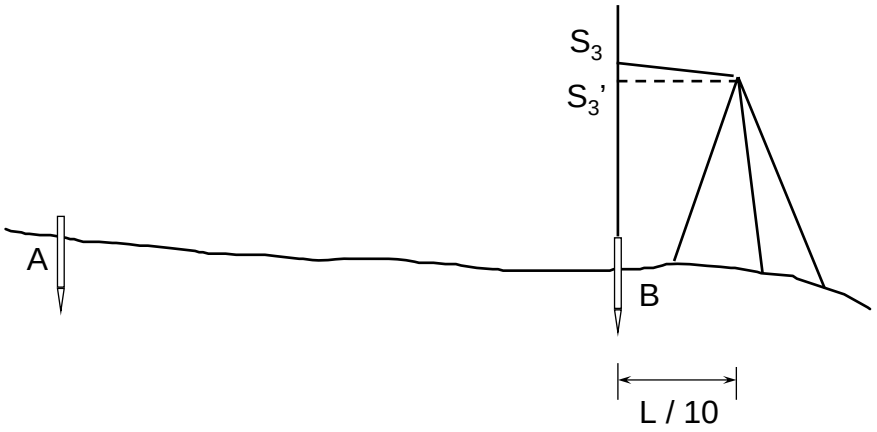
$S_1 = S_1' + x$ and $S_2 = S_2' + x$ $\delta h_A = S_1' - S_2' = \delta h_T$

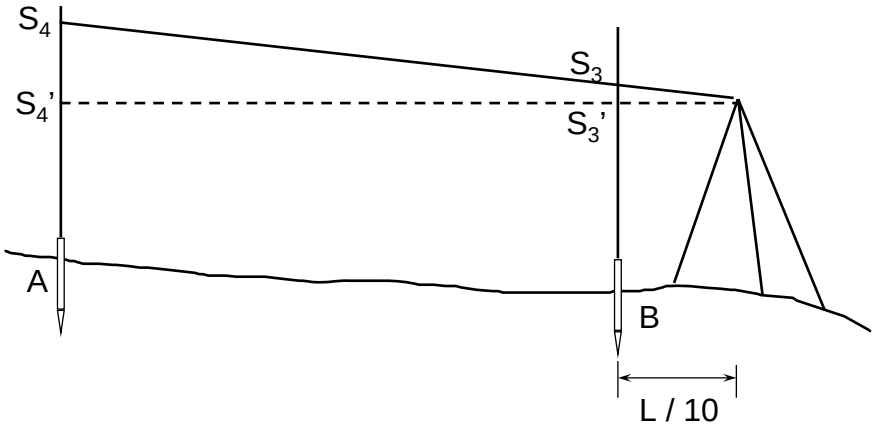
Therefore :

$$\delta h_A = \delta h_T$$

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

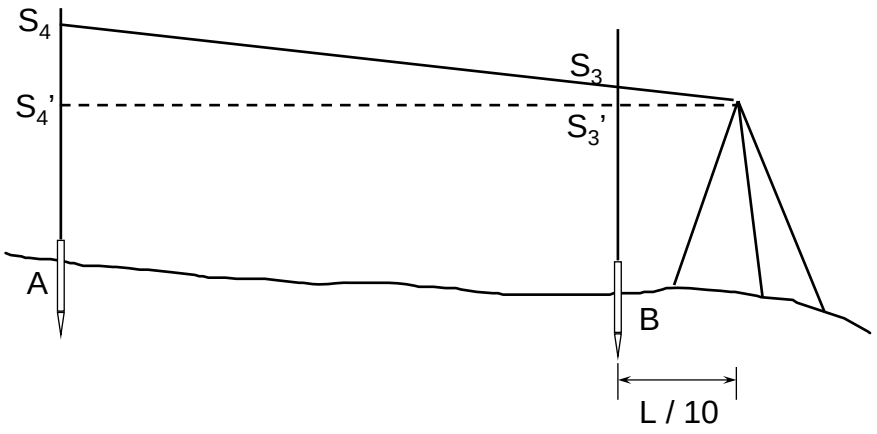
Now move the instrument outside the “odd numbered” peg





The APPARENT height difference $\delta h_A = S_3 - S_4$

But the TRUE height difference δh_T We already know is



The APPARENT height difference $\delta h_A = S_3 - S_4$

But the TRUE height difference $\delta h_T = S_1 - S_2$

Therefore if $\delta h_A = \delta h_T$ then the instrument is OK

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

Summary : 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 true height difference.

Move level about L / 10 = 3m (or 4m) beyond one of the pegs.

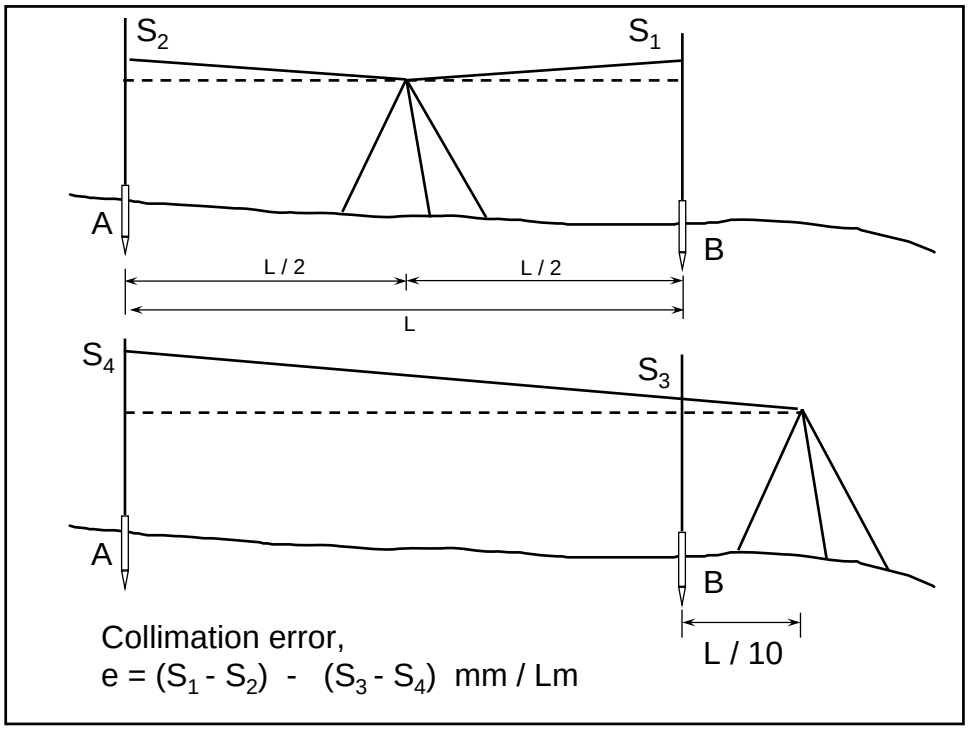
Read staff on each peg again, and calculate height difference.

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

Acceptable errors

Uren and Price	1mm per 20m
Wimpey	4mm per 50m

Test should be carried out regularly say once per week or two.



Collimation error,
$e = (S_1 - S_2) - (S_3 - S_4)$ mm / Lm

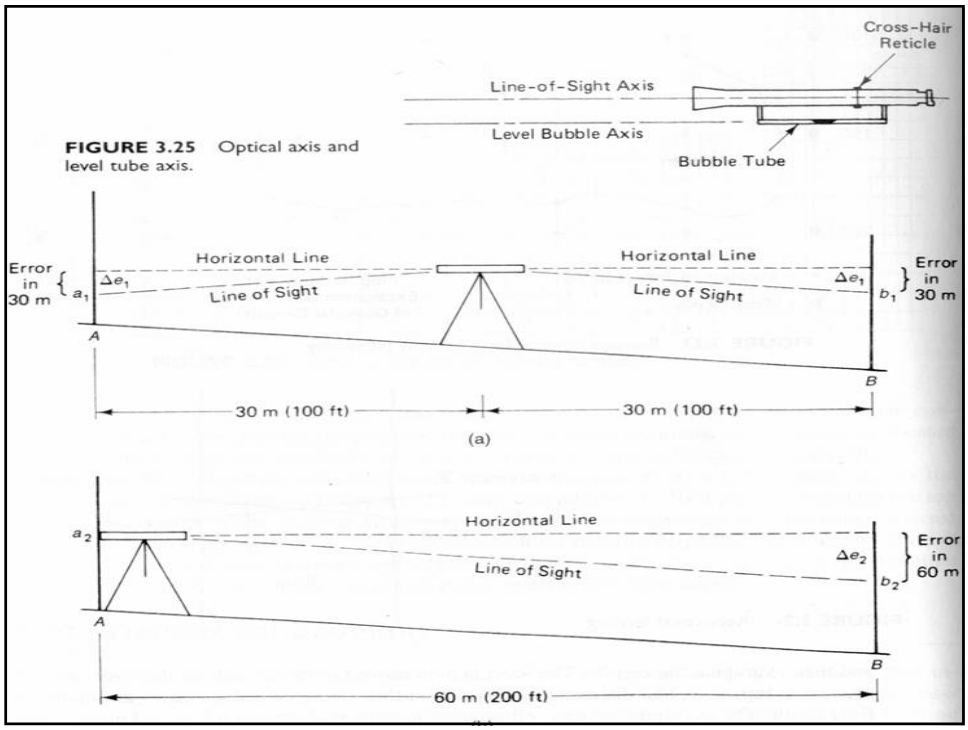


FIGURE 3.25 Optical axis and level tube axis.

3.12 Three-Wire Leveling

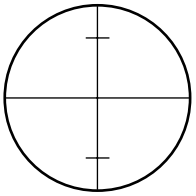
(Calibrated or invar rod)

Stadia cross hairs

Each BS and FS is recorded As three figures and average, then Correction for collimation (determined once a day for precise work)

Correction in Sum of FS

Fig. 3.28



3.13 Trigonometric Leveling

$V = S \sin \theta$

Elev. At A + hi $\pm$ V – RR = elev. At B

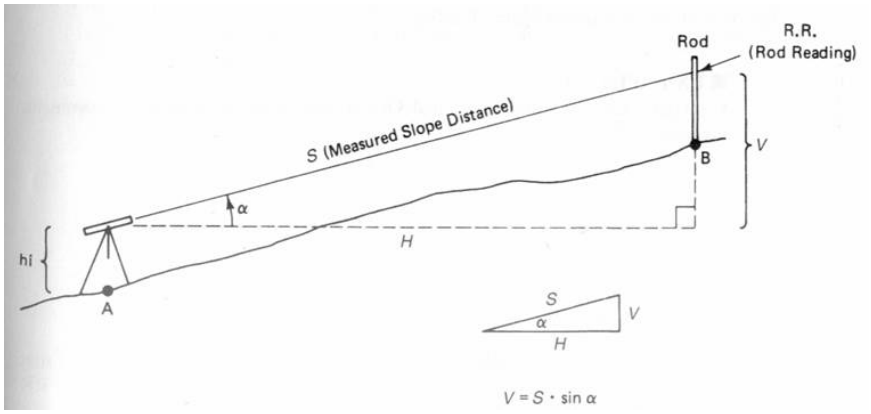
hi = height of instrument from ground to center of telescope

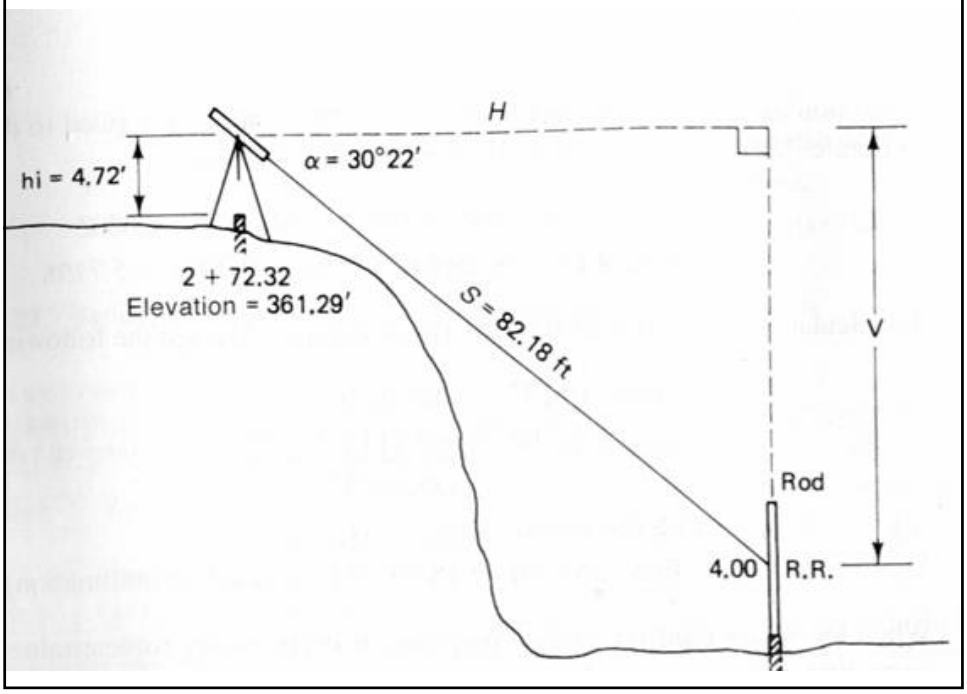
-Used if there is steep cliff on CL of road, pipe, …… etc.

-Slope is measured by tape, EDM or stadia

-Angle measured by theodolite or clinometer for low order survey Fig. 3.30, Ex. 3.3

- If hi can be seen on the road → facilitate computation


Rod
R.R.
(Rod Reading)
S (Measured Slope Distance)
V
B
α
H
hi
A
S
α
V
H
V = S · sin α


H
hi = 4.72′
α = 30°22′
2 + 72.32
Elevation = 361.29′
S = 82.18 ft
V
Rod
4.00
R.R.

3.14 Level Loop Adjustment

-If the error is within allowable tolerances then adjust for it. If not, repeat
-Do adjustment according to distance or number of setup.
-Ex. 3.4, Fig. 3.31
Error E = Initial BM reading – Calculated BM Reading
Correction = (-) Cumulative dist./Total dist. * E

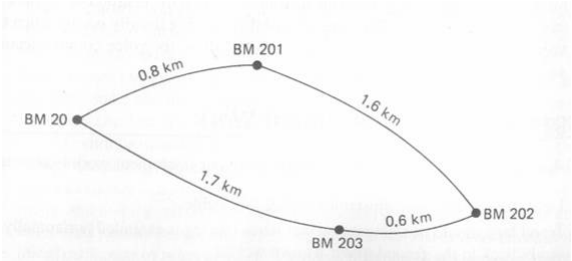


Table 3.4 LEVEL LOOP ADJUSTMENTS

BM	Loop Distance: Cumulative (km)	Field Elevation	Correction: $\frac{\text{cumulative distance}}{\text{total distance}} \times E^*$	Adjusted Elevation
20		186.273 (fixed)		186.273
201	0.8	184.242	$+0.8/4.7 \times 0.015 = +0.003$ =	184.245
202	2.4	182.297	$+2.4/4.7 \times 0.015 = +0.008$ =	182.305
203	3.0	184.227	$+3.0/4.7 \times 0.015 = +0.010$ =	184.237
20	4.7	186.258	$+4.7/4.7 \times 0.015 = +0.015$ =	186.273

*$E = 186.273 - 186.258 = -0.015$ m.