

# Definition

- ❖ The process of finding the elevation at a specified location relative to another known elevation
- ❖ Levelling is the determination of the elevation of a point or difference between points referenced to some datum
- ❖ The general term applied to any of the various processes by which elevations of points or differences in elevation are determined

# Levelling

Levelling is the general term applied to any of the various processes by which elevation are determined. It is a vital operation in producing necessary data for mapping, engineering design, and construction. Levelling results are used to:

- (1) design highways, railroads, canals, sewers, water supply systems, and other facilities having grade line that best conform to existing topography
- (2) lay out construction projects according to planned elevations
- (3) calculate volumes of earthwork and other materials
- (4) investigate drainage characteristics of an area
- (5) develop maps showing general ground configurations
- (6) study earth subsidence and crustal motion

# Levelling

- ❖ To measure the difference in height ( $\Delta H$ ) 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

# Levelling

Most often Mean Sea Level is used

- MSL varies along the coasts

U.S. System: National Geodetic Vertical Datum of 1929

- Has been used as reference for extensive network of BM's
- BM's are periodically adjusted as to elevation
  - Best to check with USGS or NGS for current elevation of a BM and also best to check between two known BM's to verify elevation difference

# Levelling

- ❖ Levelling is a general term used in land surveying that applies to vertical measurements
- ❖ Vertical measurements are made and referenced to datum, 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
- ❖ Three methods used to measure differences in elevation are direct vertical measurement, trigonometric levelling, and differential levelling
- ❖ It is important to understand the procedure, equipment and note keeping format used for each method
- ❖ Levelling is the determination of the elevation of a point or difference between points referenced to some datum
- ❖ A surveying operation carried out to determine the elevation of points or to find the difference in elevation of points

# Uses of Levelling

- ❖ **Referencing of Tide Gauges:**
  - To determine and check the vertical stability of the tide gauge bench mark (TGBM) with respect to reference points (benchmarks) in its immediate vicinity. In order to isolate any local movements, there should be at least three such benchmarks, and the levelling should be repeated on an annual or semi-annual basis
  
- ❖ **Connection to GPS Reference Points:**
  - To determine its regional stability and to separate sea level rise from vertical crustal motion, the TGBM should be connected via GPS to reference stations fixed in a global co-ordinate system. Generally speaking, the GPS antenna cannot be directly placed on the TGBM and a GPS reference point must be established a short distance away. This must be connected to the TGBM by levelling
  
- ❖ **Connection to National Levelling Network:**
  - Mean sea level is used to define vertical datum for national surveying and mapping - hence the TGBM must be connected to the national levelling network. Connection to the network will also allow all tide gauges to be connected to each other, providing information on spatial variations in mean sea level

# Important Definition in Levelling

In order to calculate the heights of points a datum is required, i.e. a reference level. This is usually the mean sea level. For this purpose, the use of Bench Marks is necessary and these are classified as follow:

## **Bench Mark (BM)**

- A permanent object that has a known height above mean sea level (or other reference datum) that are provided by the Department of Survey and Mapping

## **Temporary Bench Mark (TBM)**

- A moveable object that has a known height above a pre-defined level. This level is not absolute and is defined locally by the surveyors for the purpose of the survey. Based on the TBM the survey may then later be reduced to absolute levels if the level of TBM is known

# Important Definition in Levelling

## Height of Instrument (HI)

- The elevation of the line of sight established by the instrument

## Backsight (BS)

- The reading on the rod when held on a known or assumed elevation
- Backsights are used to establish the height of instrument
- A sighting with a level back to a point of known elevation

## Foresight (FS)

- The reading on the rod when held at a location where the elevation is to be determined
- Foresights are used to establish the elevation at another location, often a turning point
- A sighting with a level to determine the elevation of a point

## Intermediate Foresight (IFS)

- The reading on the rod when held at a location where the elevation is to be determined but not used as a turning point
- A foresight to a point at which you want to know the elevation but which will not be used as a turning point



# Important Definition in Levelling

## Reduced Level

- The vertical distance measured above or below the mean sea level or benchmark is called as reduced level

## Datum

- Any level surface to which elevations are referenced

## Assumed Datum

- Is established by giving a temporary benchmark an assumed value to which all levels in the local area will be reduced. It is not good practice to assume a level which is close to the actual MSL value, as it creates potential for confusion

# Important Definition in Levelling

## Change/Transfer Point (CP/TP)

- It is a point on which fore-sights and back-sight are taken

## Peg Test

- Surveying operation carried out to determine if the levelling bubble and telescope line-of-sight are parallel

## Elevation of Instrument

- Elevation of the telescope cross hairs

## Closure Error

- Difference in elevation determined from the levelling survey and the known elevation of a benchmark

# Order of Levelling

<b>Order</b>	<b>Purpose</b>	<b>Maximum close</b>
Precision order	Deformation surveys	0.001 x km
First order	Major levelling control	0.003 x km
Second order	Minor levelling control	0.007 x km
Third order	Levelling for construction	0.012 x km

# Levelling Method

## Measuring Vertical Distance by Taping or Electronic Methods

- ❖ Using a tape or a graduated rod to measure the vertical distance between two points. Only applicable when an unobstructed vertical line between the two points exists
- ❖ In certain situation, especially on construction projects, reflector less electronic distance measurement (EDM) devices are replacing the tape for measuring vertical distance on construction sites

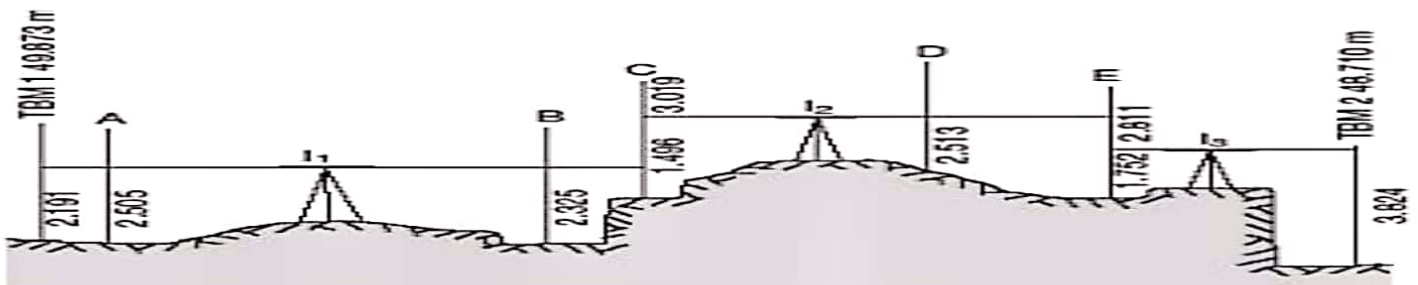
### Example:

- Measuring the depths of mine vertical space
- Construction layout of multi-storey buildings
- Depth of long narrow excavation for water line

# Levelling Method

## Differential Levelling

- ❖ The most common method used to determine differences in elevation
- ❖ A horizontal line of sight is established and readings are made using a telescope and graduated rods
- ❖ Basic theory:
  - Add rod readings to the elevation of the benchmark to get the elevation of the line of sight
  - Subtract rod readings from the elevation of the line of sight to establish the elevation of unknown points



# Levelling Method

## Barometric Levelling

- ❖ Using a barometer to find relative elevations by the difference in air pressure
- ❖ Biggest drawback is that air pressure is affected by other things besides elevation such as changes in temperature or weather
- ❖ Requires a control barometer to make adjustments for the temperature and weather
- ❖ In the best of circumstances accuracy can be established with  $\sim 3$  feet



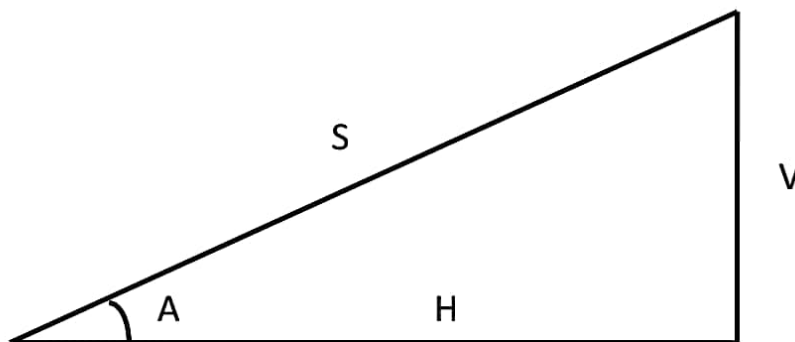
# Levelling Method

## Trigonometric Levelling

- ❖ Same procedure that we used in distance measurement
- ❖ Requires the inclined (slope) distance or horizontal distance between the two points the vertical angle from a horizontal plane

V elevation = (sin A) [slope distance (S)]

V elevation = (tan A) [horizontal distance (H)]



# Levelling Method

## Precise Levelling

- ❖ Accuracy obtained by quality of instruments and care taken in the field
- ❖ High quality automatic levels are utilized





# Levelling Method

## Precise Levelling

- ❖ Level rods are equipped with rod level, rod shoe (to allow better setting on BM's); scale (on rod) is made of invar steel (not affected by temp – generally called Invar Rod)
- ❖ Reading either taken by optical micrometer or a process called 3-wire levelling is used (all 3 wire are read and averaged)
  - Optical micrometer: line of sight deflected by turning micrometer screw to read subdivision on rod
    - Rod division is read as normal & then fractional reading taken from micrometer screw, thus on normal rod readings to 0.0001' are possible

## Allowance Error

- ❖ Allowance error (ft) =  $\pm 0.007 \sqrt{\text{number of 100 feet in the closed circuit}}$
- ❖ Allowance error (ft) =  $\pm 0.005 \sqrt{\text{circuit length in miles}}$
- ❖ Allowance error (mm) =  $\pm 5 \sqrt{\text{number of the instrument BS reading}}$

# Levelling Equipment

- ❖ Most common levelling instrument today is the Automatic or Self-levelling level – Has an internal compensator that automatically provides a horizontal line of sight and maintains this through gravity
  
- ❖ Differential Levelling: Most common type today
  - Determine the difference in elevation using a horizontal line of sight and readings on graduated rod
  - Circuit must be closed on BM of origin or on BM of equal accuracy
  - Process:
    - Reading on point of known elevation (BS)
    - $BS \text{ reading} + BM \text{ elevation} = HI$
    - Reading on point of unknown elevation (FS)
    - $HI - FS = \text{elevation of new point}$

# Levelling Equipment

## Modern Tilting Level

- ❖ Small up/down motion of telescope is possible. Adjustment of level bubble needed before measurement
- ❖ This type of level is fitted with a circular bubble for preliminary approximate levelling and a main bubble which is attached to the telescope. For each observation (not setup) the main bubble is viewed through an eyepiece and the telescope tilted by a fine screw to bring the two ends of the bubble into coincidence



# Levelling Equipment

## Dumpy Level

- ❖ Levels by the help of bubble tube. Adjustment of level bubble needed only once after level set up
- ❖ These are more basic levels often used in construction work. The telescope is rigidly attached to a single bubble and the assembly is adjusted either by means of a screwed ball-joint or by foot screws which are adjusted first in one direction, then at 90°



# Levelling Equipment



# Levelling Equipment

## Automatic Level

- ❖ Automatic levels-Levelled automatically by compensators. Self levelled instruments
- ❖ An automatic level, self-levelling level or builder's auto level, includes an internal compensator mechanism (a swinging prism) that, when set close to level, automatically removes any remaining variation from level
- ❖ This reduces the need to set the instrument truly level, as with a dumpy or tilting level. Self-levelling instruments are the preferred instrument on building sites, construction and surveying due to ease of use and rapid setup time
- ❖ This more modern type of level is now in general use. It has a compensator which consists of an arrangement of three prisms. The two outer ones are attached to the barrel of the telescope. The middle prism is suspended by fine wiring and reacts to gravity. The instrument is first levelled approximately with a circular bubble; the compensator will then deviate the line of sight by the amount that the telescope is out of level



# Levelling Equipment

## Tripod

- ❖ A tripod for supporting the levelling instrument
- ❖ Tripods provide a fixed base for all types of surveying instruments and sighting equipment. Instrument manufactures have standardized surveying tripods

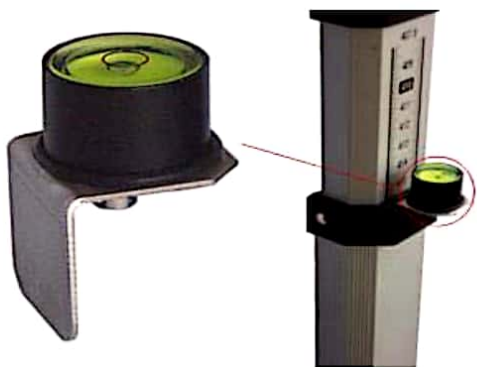




# Levelling Equipment

## Staff Bubble

- ❖ These are generally a small circular bubble on an angle plate which is held against one corner of the staff to ensure that the staff is held in a vertical position. If the staff is not held vertical, the reading will be too large and may be significantly in error
- ❖ A staff bubble shall be used at all times. If one is not available, the "chainman" (staff operator) shall rock the staff slowly back and forth about the vertical in a line towards the instrument. The observer notes the smallest reading which will occur when the staff is vertical



# Levelling Equipment

## Leveling Rod (Staff)

- ❖ Levelling rods are graduated scale, held vertically over the points and viewed through the telescope of the level where the central horizontal hair of telescope cuts the rod is called the rod reading and this is equal to vertical distance between the line of sight of the level and the point on which the rod is held. Rods are usually made of wood although aluminium alloy and fibber glass rods are also available. The length of rod is generally in the range of 3-5m and they may be hinged or telescopic for convenience in transporting
- ❖ The graduation is usually in alternate blocks and spaces of 10 mm with numbering in meters and decimetres. The subdivisions are painted in various colours on black on white, red on white or red on yellow. The rods should be protected from sun, rain in inclined storage and drops and hits. The base plate should not be subjected to strong bangs or hits while putting the rod over a point



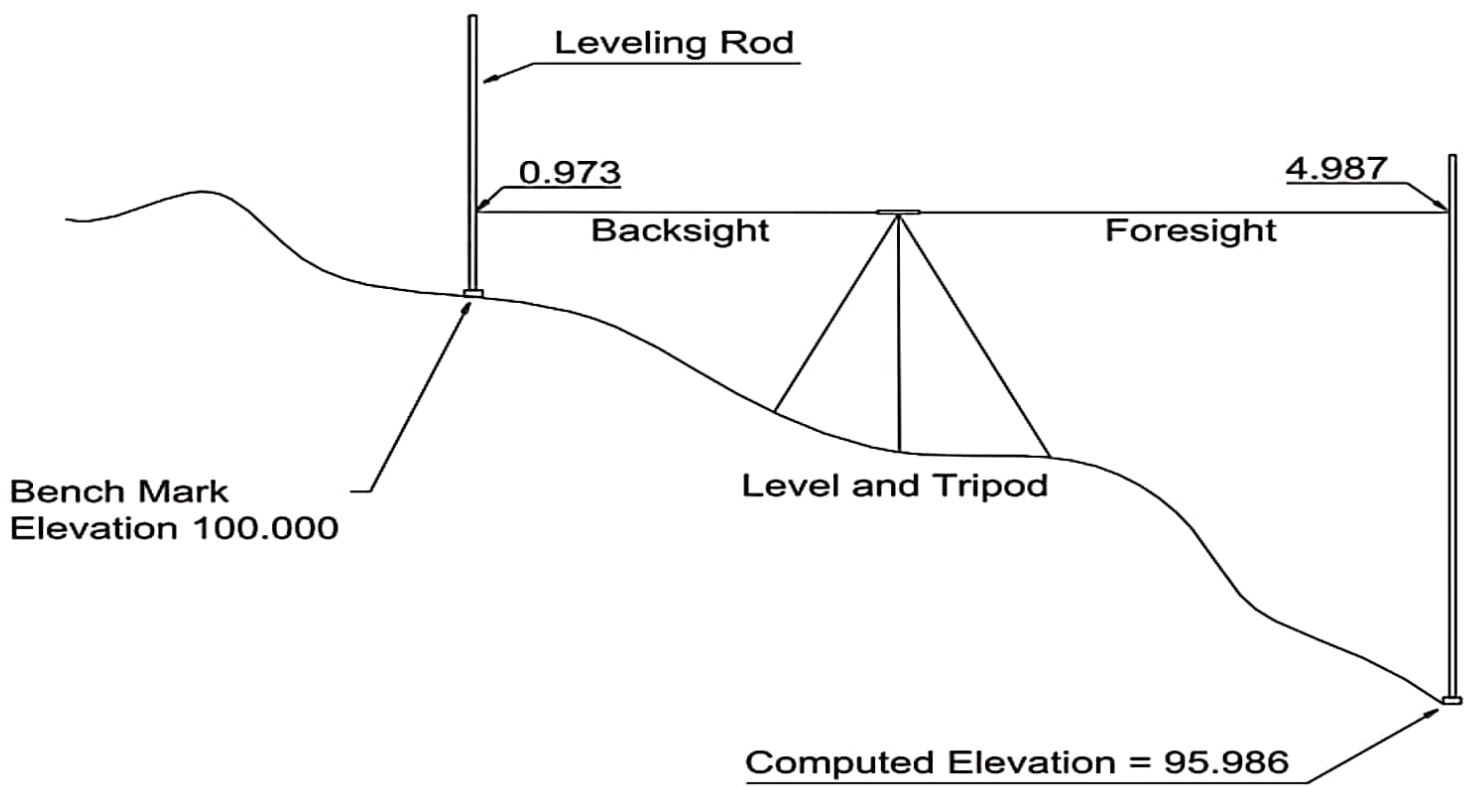
# Care of Equipment

- ❖ Ensure that tripod screws and hinges are kept tight
- ❖ Always transport the level in a padded box
- ❖ When removing from the box lift it by the centre and not by the eyepiece or objective end of the telescope
- ❖ Crew it firmly onto the tripod, whilst holding it in one hand
- ❖ When carrying the level tripod assembly in the field, support it over the shoulder or, in bush, crooked over an arm with the telescope unclamped (i.e. free to rotate)

# Care of Equipment

- ❖ Automatic levels should not be carried in a vertical or near-vertical position, as the compensator will swing about and be prone to damage
- ❖ Staff is too much of a precision item of equipment.
- ❖ Staff shall be transported in their protective cases to protect the face from damage
- ❖ Wooden staff which become wet should be dismantled and dried out before storing away
- ❖ Any moisture which is evident in an instrument must be allowed to disperse by storing the level out of its case in a warm room. Should it persist after several days the instrument may require specialist servicing

# Basic Theory



# The Use of Levelling

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

# Calculations

For our leveling, we need to apply two very simple equations:

Height of Instrument = Known Elevation + Backsight

and

TP Elevation = Height of Instrument – Foresight

For the previous example:

Height of instrument = Known Elevation + Backsight

$$= 100.000 + 0.973$$

$$= 100.973$$

and

TP Elevation = Height of Instrument – Foresight

$$= 100.973 - 4.987$$

$$= 95.986$$

# Booking

## Level Book

- ❖ All levelling shall be booked in either level books or levelling sheets which shall be retained as permanent records
- ❖ Level books shall be numbered so that they can be referenced on station history and inspection forms. They should be stored in fire-proof storage as for original record. They should also include an index
- ❖ Levelling sheets shall be filed in time-sequential order in site files, and also need to be in fire-proof storage as for level books



# Booking

## Booking

- ❖ Level books or loose-leaf levelling sheets shall be numbered and indexed in a register
- ❖ Details of the site, work, date, observer, chainman, booker, weather, wind, instrument and any other relevant items shall be entered
- ❖ Enter the first observation (which is on a known point) in the Backsight column, and sufficient detail in the Remarks column to identify it. Enter the point's R.L. zero from the site register or plate on the BM, etc.
- ❖ Enter all other points on subsequent lines as intermediates except the point chosen as the foresight. Identify them in the Remarks column as above. Enter the foresight on a further line in the Foresight column.
- ❖ Change the instrument to the next setup. Enter the following backsight on the same line as the previous foresight but in the Backsight column
- ❖ Repeat the above procedure at each setup on the outward run then reverse it to work back to the starting point on the return run. The furthest point out is treated as for all other change points

# Booking

- ❖ Every surveyor in North America records his/her level surveys in the same manner using the six columns displayed on the left-hand pages of your survey field book
- ❖ The columns are typically labeled as: station, backsight (BS), height of instrument (HI), intermediate foresight (IFS), foresight (FS), and the last column contains the elevation values
- ❖ We will use the column labeled IFS later. Here is how we would record our values for the previous example

## Height of Plane and Collimation Method (HPC)

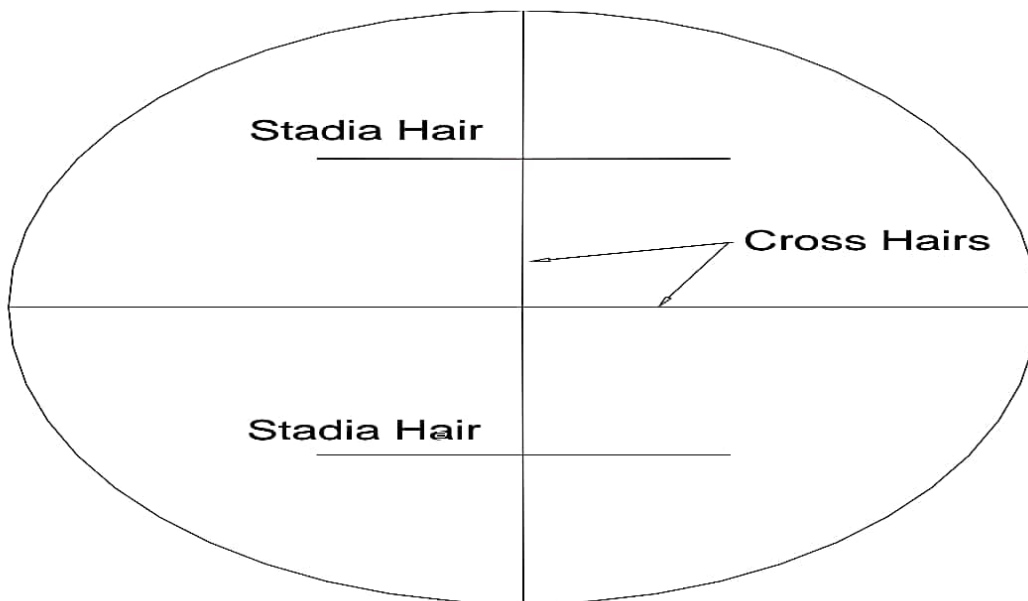
BS	IS	FS	Rise	Fall	RL	Corr	Corr RL	Remarks

## Rise and Fall Method (RF)

BS	IS	FS	HPC	RL	Corr	Corr RL	Remarks

# Arrangement of Cross Hairs

- ❖ When you sight through the telescope, you will see a vertical and a horizontal cross hair and two horizontal stadia hairs

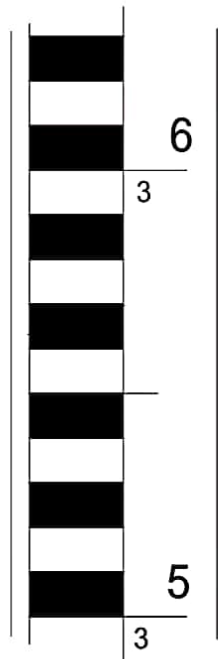


## Reading the Rod

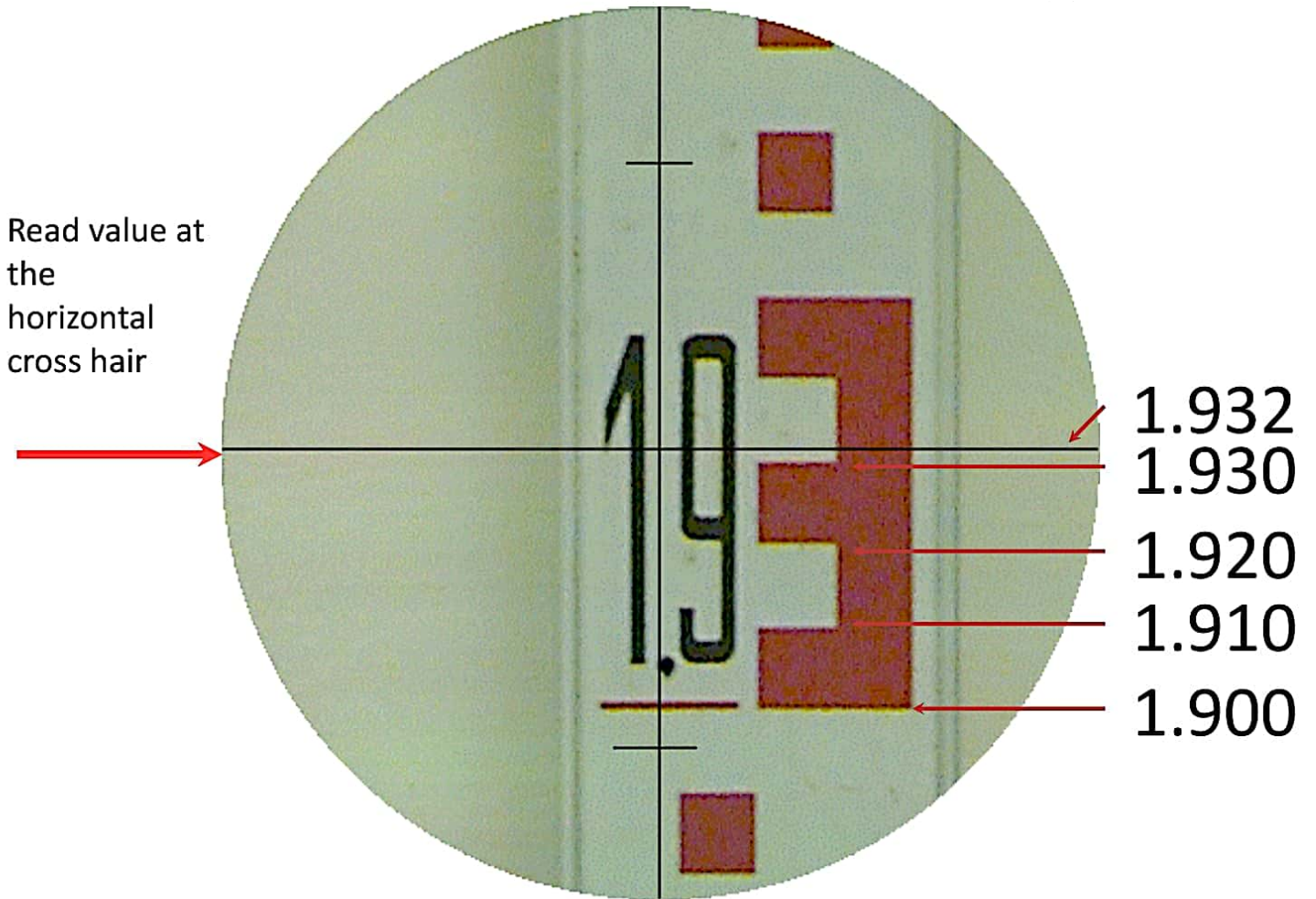
- ❖ Rod readings are taken using the centre cross hairs
- ❖ For now, ignore the presence of the stadia hairs
- ❖ Rod readings are taken to three decimal places (or the nearest millimetre)
- ❖ Rod readings can be read to two decimal places with certainty
- ❖ Estimate the third decimal place

# Reading the Rod

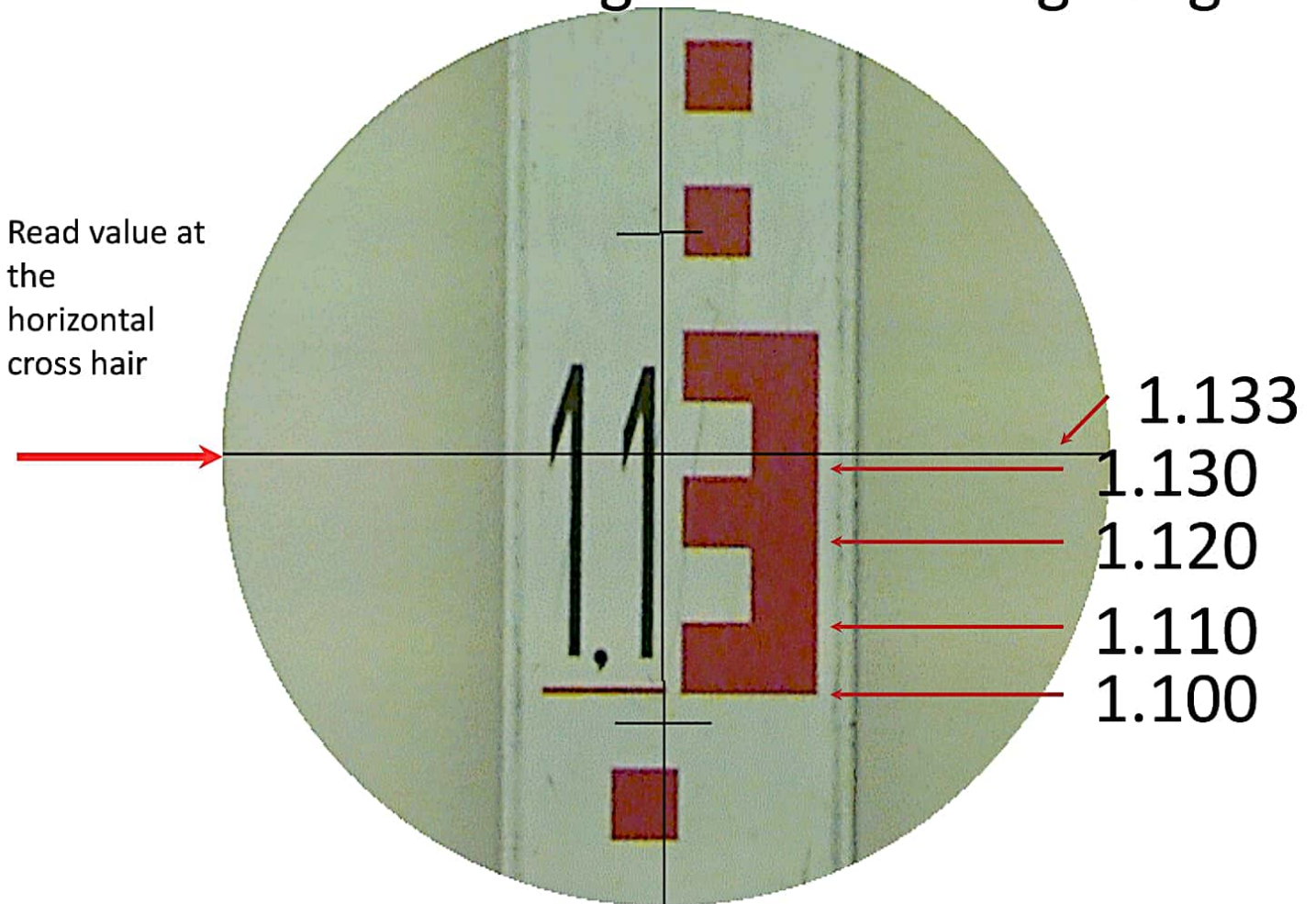
- ❖ The rod is delineated to the nearest hundredth of a metre (centimetre)



What is the reading for this rod sighting?

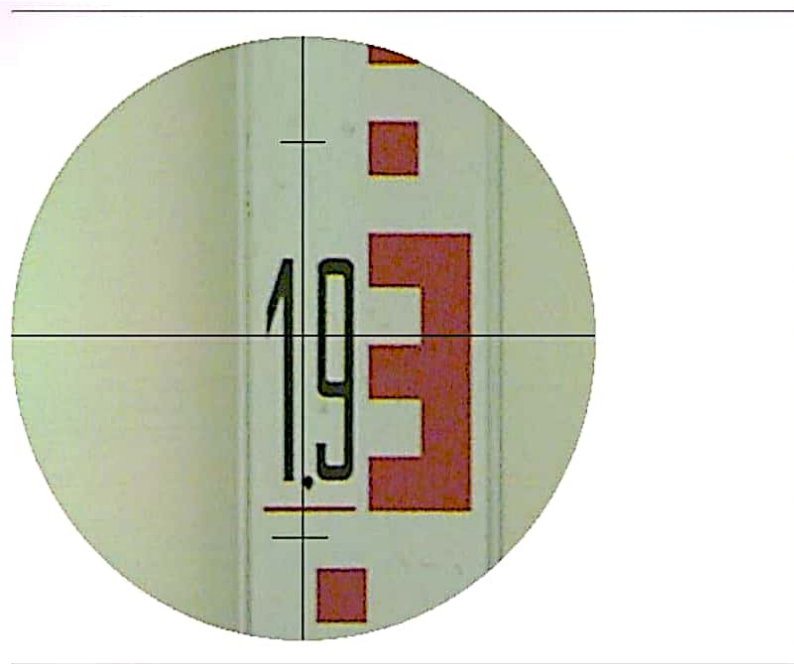


What is the reading for this rod sighting?

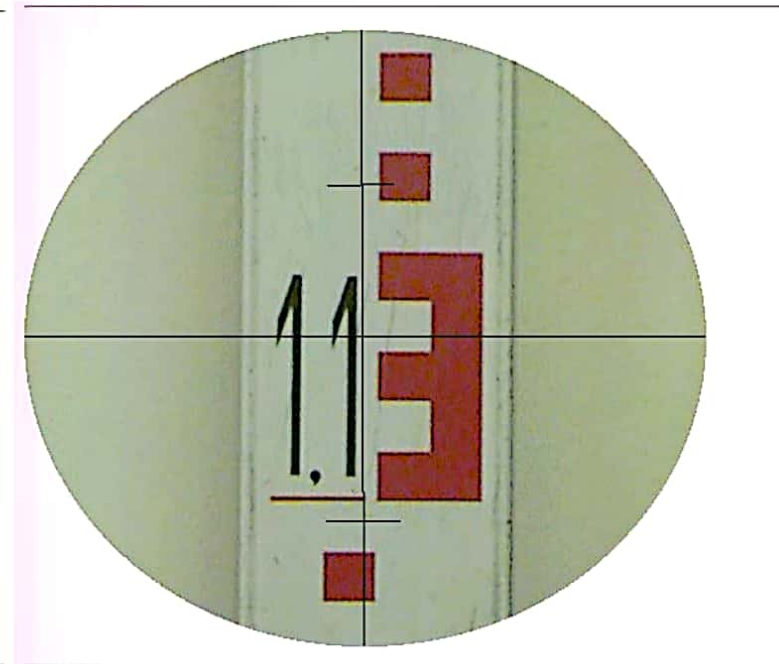


# Reading the Rod

What is the reading for this rod sighting?



1.932

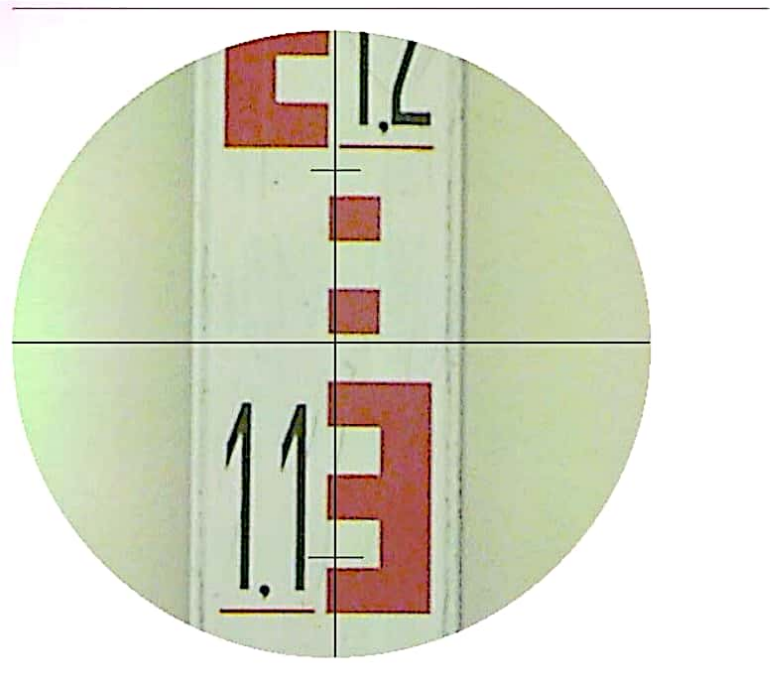


1.133

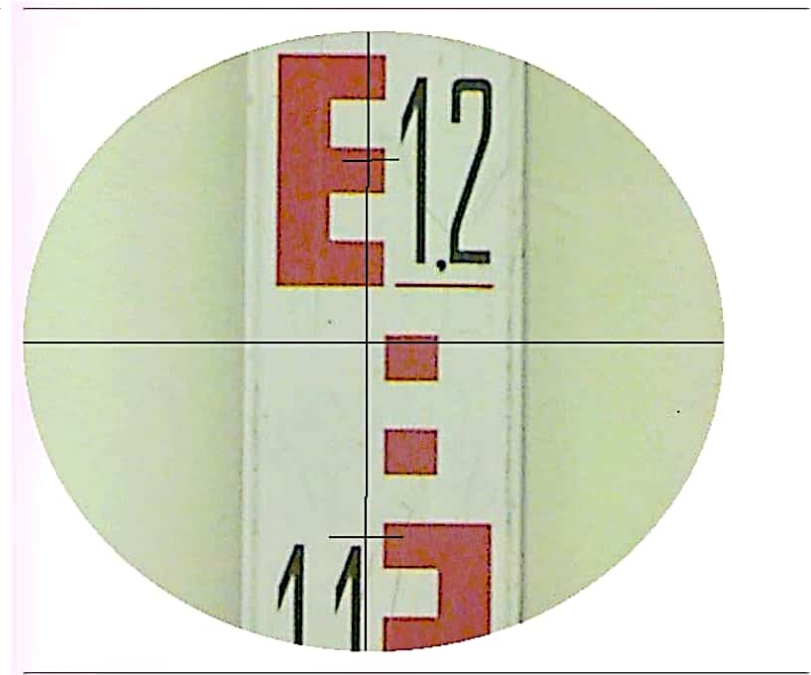


# Reading the Rod

What is the reading for this rod sighting?



1.158



1.188

## Position of Rod

- ❖ The rod must be plumb to give a correct reading
- ❖ No matter how much care is taken by the instrument person when reading the rod, if the rod is not perfectly vertical when read, errors will result

# Closure

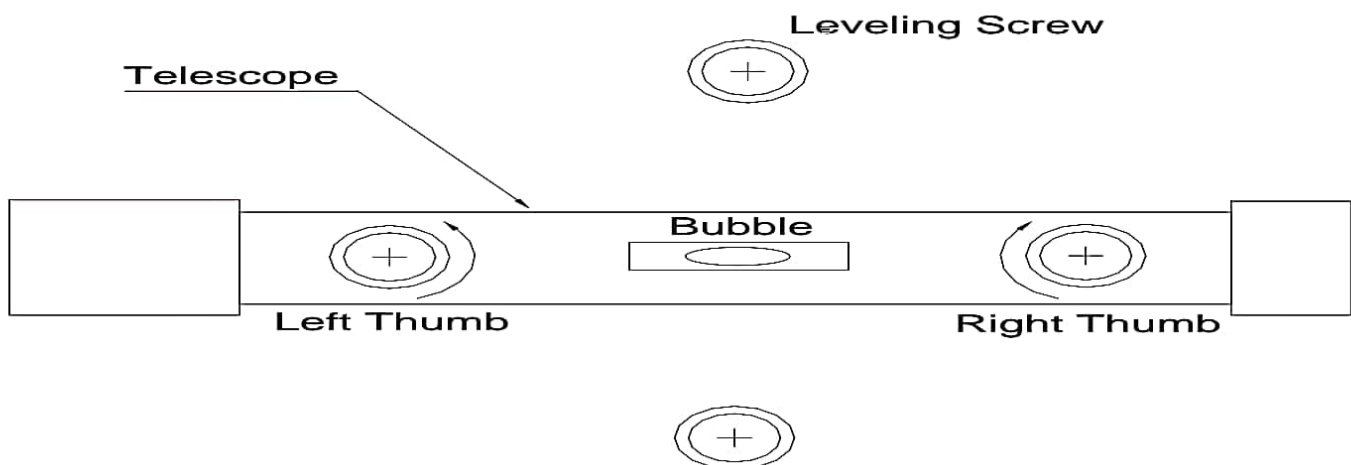
- ❖ For all differential leveling, it is good practice to close the leveling loop
- ❖ Closing the loop is accomplished by returning to the original starting point
- ❖ If we were to complete our level loop with complete accuracy, our computed final elevation would be exactly the same as the benchmark elevation used to initiate the survey
- ❖ This comparison of the starting elevation and the computed ending elevation is termed closure
- ❖ The accuracy of the survey can be easily determined by comparing the sum of the backsights with the sum of the foresights. They should be equal
- ❖ Depending on the precision required, permissible values for the closure of a level loop can be specified

# Carry and Setting Out the Level

- ❖ Always carry it in container
- ❖ Screw the head snugly on the tripod
- ❖ For bull eye's bubble, alternately turn one screw and then the other two
- ❖ On site-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 levelling the instrument

# Setting Up the Level

- ❖ The legs of the tripod must be tightened securely
- ❖ The legs of the tripod should be firmly pressed into the ground with the tripod base plate roughly horizontal
- ❖ When leveling a four-screw level, the telescope is rotated until it is over two opposite screws as shown below

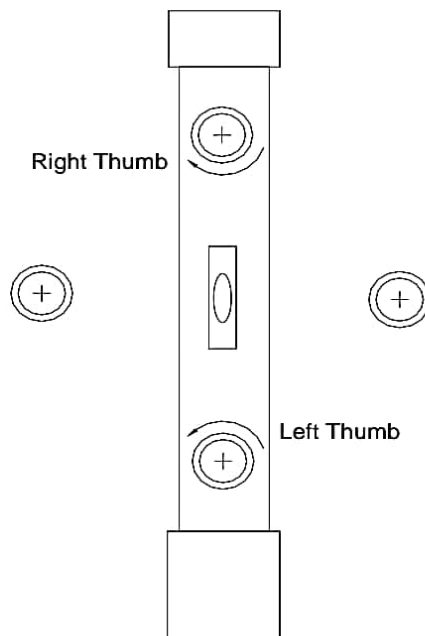


# Setting Up the Level

- ❖ The telescope is leveled by using the thumb and first finger of both hands to adjust the leveling screws until the bubble is approximately centred
  
- ❖ Rule 1
  - The leveling screws are ALWAYS turned in opposite directions by equal amounts simultaneously. If one screw is rotated faster than the other, the screws will either bind or the telescope will loosen
  
- ❖ Rule 2
  - The left thumb rule
  - The leveling bubble will always move in the direction of your left thumb

# Setting Up the Level

- ❖ Rotate the telescope 90 degrees until it is located over the other two leveling screws as shown



- ❖ Again, level the telescope using the leveling screws

# Setting Up the Level

- ❖ When the scope is level, rotate the telescope another 90 degrees and make any minor adjustments to level the instrument
- ❖ Rotate the scope another 90 degrees and again, make any minor corrections as required
- ❖ Continue rotating and leveling the scope until the instrument is fully level along both axes
- ❖ As a final check, gently spin your telescope and allow it to come to rest, no matter what direction it faces

Examine your leveling bubble

It should be exactly centred

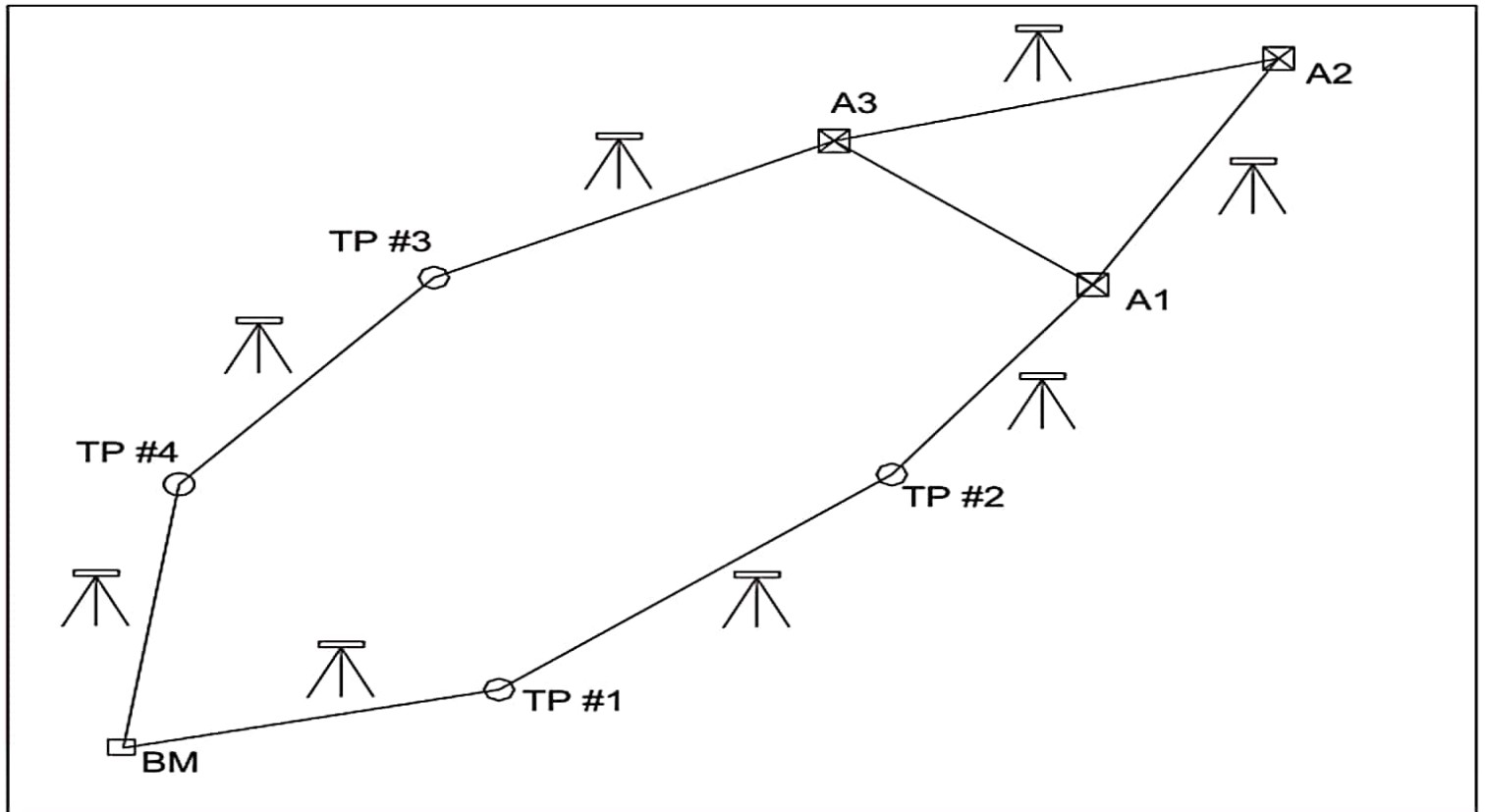
If it is not, repeat the entire leveling procedure



# Instrument Tests

- ❖ Complete the following tests and document them fully in your field book
  - Instrument Test 1 (level tube check)
  - Instrument Test 2 (cross hair check)
  - Instrument Test 3 (2 peg test)

# Field Survey



# Method of Levelling

## ❖ Height of Plane and Collimation Method (HPC)

- This method is simple and easy
- Reduction of levels is easy
- Visualization is not necessary regarding the nature of the ground
- There is no check for intermediate sight readings
- This method is generally used where more number of readings can be taken with less number of change points for constructional work and profile levelling

## ❖ Rise and Fall Method (RF)

- This method is complicated and is not easy to carry out
- Reduction of levels takes more time
- Visualization is necessary regarding the nature of the ground
- Complete check is there for all readings
- This method is preferable for check levelling where number of change points is more

# Plane and Collimation Method

- ❖ Example: calculate the reduced levels of the previous examples using the height of collimation method
- ❖ This method is based on the calculation of height of plane collimation (HPC) for each instrument position

Height of collimation method.							
BS	IS	FS	HPC	Initial RL	Adj	Adj RL	Remarks
2.191			52.064	49.873		49.873	TBM 1 49.873
	2.505			49.559	+0.002	49.561	A
	2.325			49.739	+0.002	49.741	B
3.019		1.496	53.587	50.588	+0.002	50.570	C (CP)
	2.513			51.074	+0.004	51.078	D
1.752		2.811	52.528	50.776	+0.004	50.780	E (CP)
		3.824		48.704	+0.006	48.710	TBM 2 48.710
<b>Checks</b>							
6.962	7.343	8.131		300.420			
$7.343 + 8.131 + 300.420 = 315.894$							
$[52.064 \times 3] + [53.587 \times 2] + [52.528] = 315.894$							
6.962		8.131		48.704			
8.131				49.873			
-1.169				-1.169			

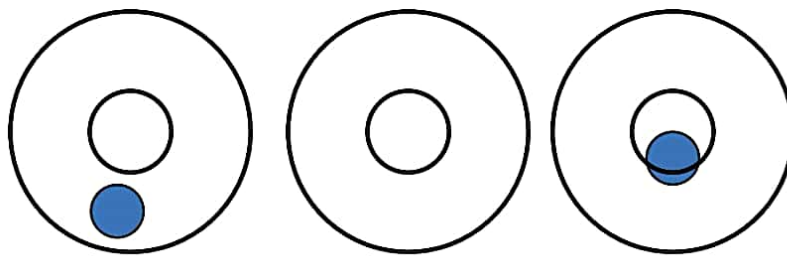
# Rise and Fall Method

- ❖ Example: calculate the reduced level of points A to E in the previous example using the rise and fall method
- ❖ Solution: all the readings for the survey from A to E are shown in the table below. These measurements would be taken from the field book used on site. Each row of the field book corresponds to a staff position and which is shown in the remarks column
- ❖ The calculations for this method follow a point by point basis starting at TBM1

Rise and fall method.

BS	IS	FS	Rise	Fall	Initial RL	Adj	Adj RL	Remarks
2.191					49.873		49.873	TBM 1 49.873
	2.505			0.314	49.559	+0.002	49.561	A
	2.325		0.180		49.739	+0.002	49.741	B
3.018		1.496	0.829		50.568	+0.002	50.570	C (CP)
	2.513		0.506		51.074	+0.004	51.078	D
1.752		2.811		0.288	50.776	+0.004	50.780	E (CP)
		3.824		2.072	48.704	+0.006	48.710	TBM 2 48.710
<b>Checks</b>								
	6.962	8.131	1.515	2.684	48.704			
	8.131		2.684		49.873			
	-1.169		-1.169		-1.169			

# 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 (hopefully)
- ❖ When the instrument is rotated the compensators ensure that a horizontal plane of collimation is swept out (hopefully)

# Elimination of Parallax

- ❖ Apparent difference in the position or direction of an object caused when the observer's position is changed
- ❖ 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

# Error in Levelling

## Systematic Error in Levelling

- ❖ Inclination of line of sight due to curvature of earth and refraction
  - Generally very minimal due to short sights
- ❖ Inclination due to maladjustment of instrument
  - Both can be alleviated by equalizing length of BS and FS legs
- ❖ Changes in scale of rod due to temperature
  - Usually ignored except in very precise work
  - Would use same process as tape correction
- ❖ Rod not held plumb
  - Minimized by carefully plumbing the rod or more commonly known as “Rocking the Rod” and taking the lowest reading



# Error in Levelling

## Natural Errors

- ❖ Curvature and refraction errors (Equalize BS and FS distances; set up the level as high as possible from the ground)
- ❖ Temperature variations (avoid heat, take shorter sights)
- ❖ Wind (not to level on windy days)
- ❖ Settlement of the instruments (avoid soft grounds, read quickly)

# Error in Levelling

## Personal Errors

- ❖ Bubble not centred (check the bubble before and after each sight)
- ❖ Parallax (move the eye up and down, check focusing)
- ❖ Rod handling (pay attention to bubble; be careful while rotating on the turning point)
- ❖ Poor turning point selection
- ❖ Mistakes

# Error in Levelling

## Personal Errors

- ❖ How to avoid personal errors?
  - selecting proper TP's
  - checking the bubble before and after each reading (unless an automatic level is being used)
  - using a rod bubble
  - keeping equal BS and FS lengths
  - running lines forward and backward
  - making the usual field-book arithmetic checks

# Error in Levelling

## Instrumental Errors

- ❖ Incorrect rod length
- ❖ Rod folding place error (values above the folding can be affected)
- ❖ Distortion of the base plate of rod (handle carefully)
- ❖ Loose screws on tripod legs (fix them)
- ❖ Non-horizontal crosshair (read at the centre)
- ❖ Non-horizontal line of sight (TILT ERROR)

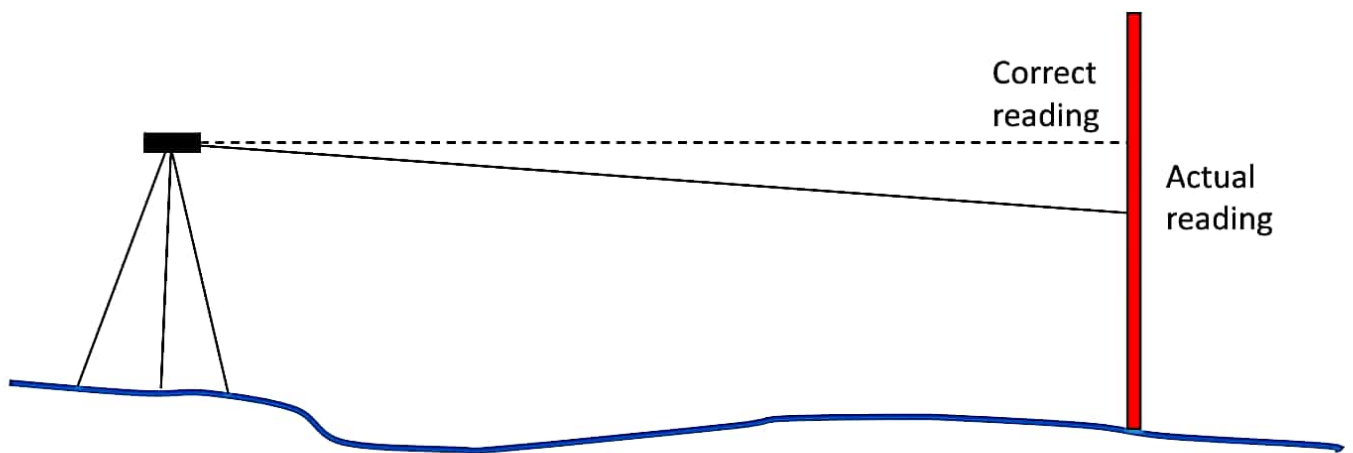
# Sources of Error

- ❖ Instrument not correctly levelled
- ❖ Telescope not correctly focused
- ❖ The wrong cross hair reading recorded (e.g. top instead of middle)
- ❖ Staff incorrectly read or not held vertical
- ❖ Staff incorrectly booked
- ❖ At all above are mistake (blunders) and cannot be corrected unless the work is repeated. A systematic error in levelling is the collimation error of the level

# Sources of Error

## ❖ Errors in the Equipment

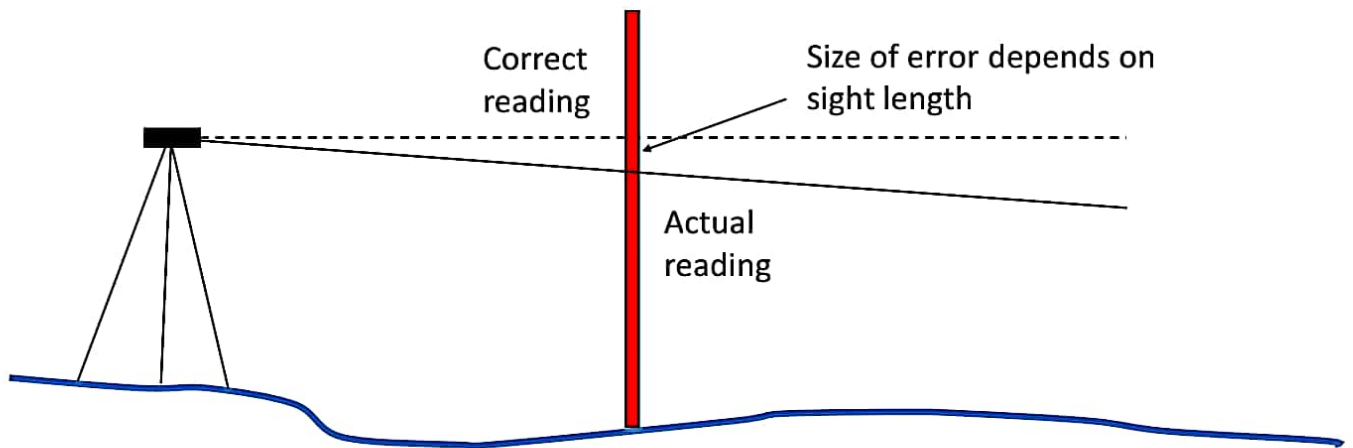
Collimation Error - Line of sight not horizontal



# Sources of Error

## ❖ Errors in the Equipment

Collimation Error - Line of sight not horizontal



# Sources of Error

## Errors in the Equipment

- ❖ Collimation Error - Line of sight not horizontal
- ❖ Keep sight lengths from each instrument position the same
- ❖ Check collimation error using Two-Peg Test
- ❖ Check prism is not stuck (every reading)
- ❖ Parallax



# Sources of Error

## Errors in the Equipment

### ❖ Staff Errors

- Zero error - base may be worn - doesn't matter as long as
- same staff is always used
- May not be extended properly

### ❖ Tripod Errors

- Must be stable

# Sources of Error

## ❖ Field Errors

- Staff not vertical
- Use pond bubble on staff
- Rock staff and take minimum reading
- Unstable equipment
- Watch out for soft ground under tripod or staff
- Don't touch (or kick) tripod while doing observation

# Sources of Error

## ❖ Reading and Booking Errors

- Keep sightings short to estimate mm on staff accurately
- Double check all readings
- Write clearly
- Carry out calculation checks

## ❖ Weather

- Wind causes level to vibrate, heat

# Horizontal Collimation Test

❖ Equation:

$$\epsilon = \frac{RB - rA - rB + RA}{2}$$

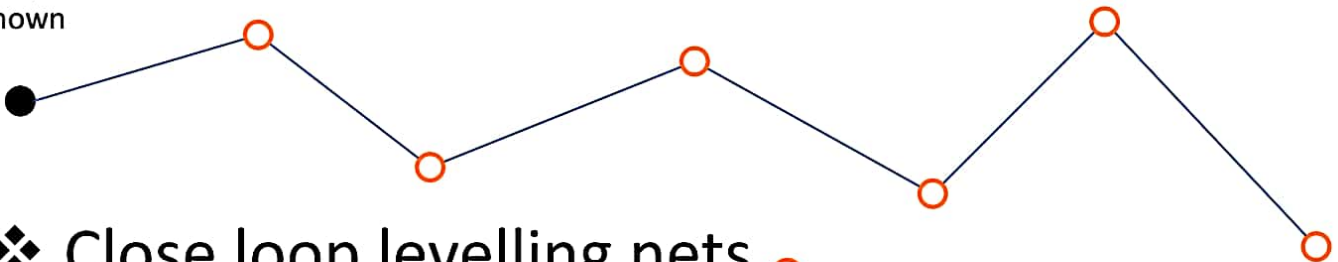


100 ft      100 ft      100 ft      69

# Types of Levelling Nets

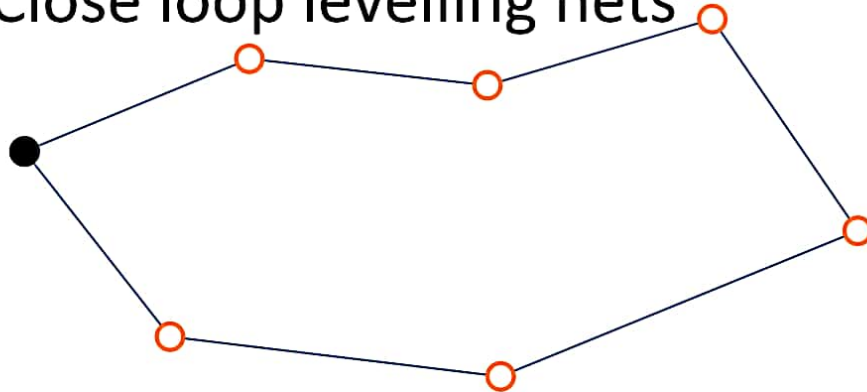
## ❖ Open levelling nets

Height  
Known



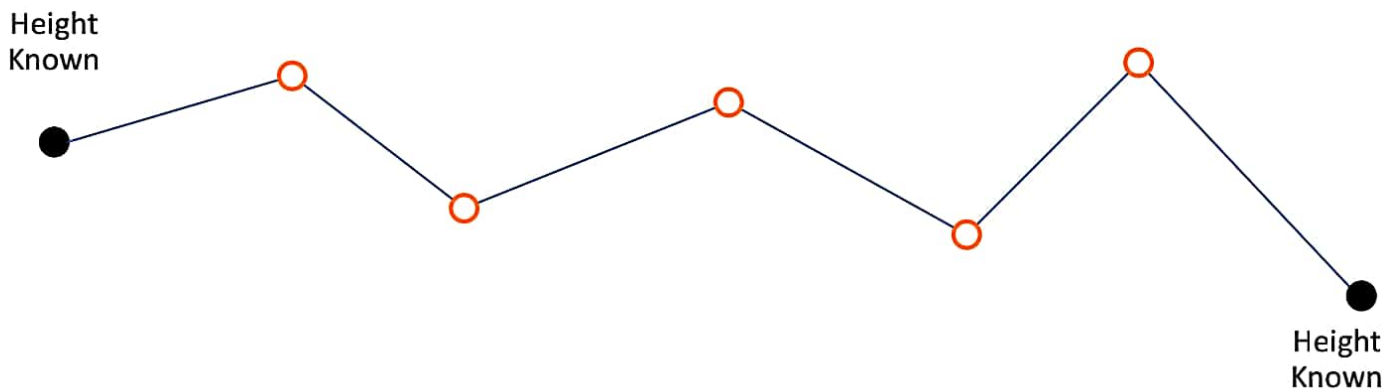
## ❖ Close loop levelling nets

Height  
Known



# Types of Levelling Nets

## ❖ Closed link or closed connecting levelling nets



# Levelling Summary

- ❖ Always Start and Finish at points of known level, e.g. T.B.M.
  
- ❖ For any instrument position:
  - First reading is a BS, last reading is a FS, may have IS in between
  - Either staff moves, or instrument moves, NEVER BOTH
  
- ❖ For each reading:
  - Check parallax, check compensator, rock staff, reduce as you go
  - Use solid points for CPs
  - Keep BS and FS same length
  - Each line of the booking form is for a single STAFF position

# Levelling Summary

- ❖ When the level has been set up we always start with a BS to a point whose RL is known, such as a TBM
- ❖ The last reading at any instrument position is always a FS, i.e. always end with a FS
- ❖ Either the instrument moves or the staff moves - never move both
- ❖ We must always finish levelling at a point of known RL value, such as a TBM
- ❖ Always close your levelling



# Levelling Summary

- ❖ Anchor tripod legs firmly
- ❖ Check the bubble level before and after each reading
- ❖ Take a 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

# Levelling Summary

❖ Calculation checks:

$$(BS) - (FS) = \text{Last RL} - \text{First RL}$$

$$(IS) + (FS) + (\text{RLs except first}) = (\text{each HPC} \times \text{no of applications})$$

❖ Allowable misclosure =  $5 \sqrt{N}$  mm, where N = Number of BS station

❖ If calculation checks OK, and misclosure allowable, then distribute misclosure cumulatively between each instrument position

$$HPC = RL + BS$$

$$RL = HPC - FS$$

