# LEVELLING

***RCI4C001 SURVEYING***

***Module II***

*Levelling: Use of dumpy level and levelling staff.Temporary and Permanent adjustment of dumpy level, Reduction of levels by height of instrument and rise and fall method. Curvature and refraction error, sensitiveness of level tube, reciprocal levelling, levelling difficulties and common errors, Automatic and Electronic or Digital levels*

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# Levelling:



***What is levelling ?***

It may be defined as

1) the art of determining the elevations of given points above or below a datum line

   or

2) Establishing given points of required heights above or below the datum line.

***Uses of levelling:***

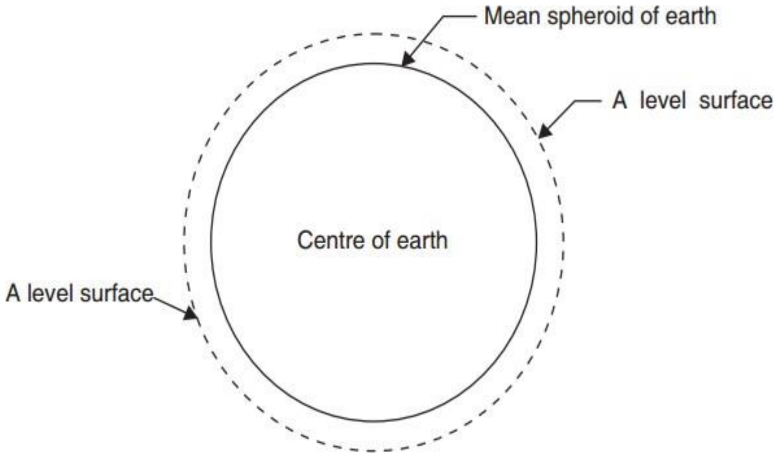
- to determine or to set the plinth level of a building.
- to decide or set the road, railway, canal or sewage line alignment.
- to determine or set various levels of dams, towers, etc.
- to determine the capacity of a reservoir.

# Leveling Definitions:



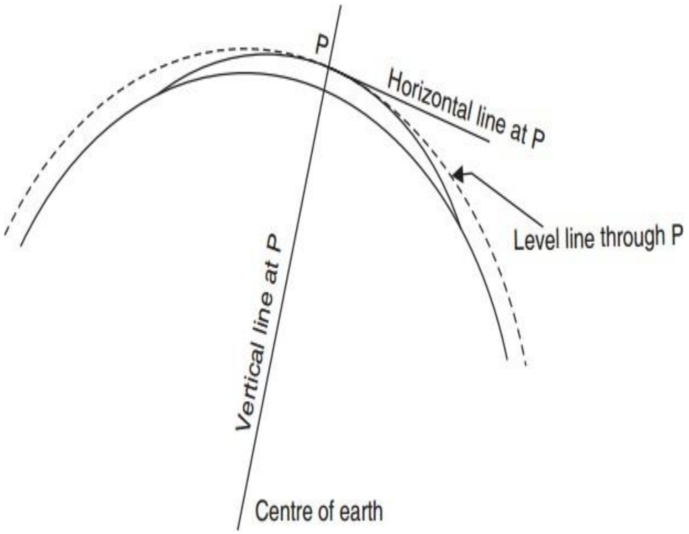


*Level Surface*- A surface parallel to the mean spheroid of the earth is called a level surface. All points lying on a level surface are equidistant from the centre of the earth.




*Level Line -* The line drawn on the level surface is known as a level line. This line is perpendicular to the direction of gravity at all points

*Horizontal Surface/Plane-* A surface/plane tangential to level surface at a given point is called horizontal surface/plane at that point.




*Horizontal Line/Axis –* A horizontal line **through a point** is line drawn on Horizontal surface through that point. This line is perpendicular to the direction of gravity at the point.

# Leveling Definitions:



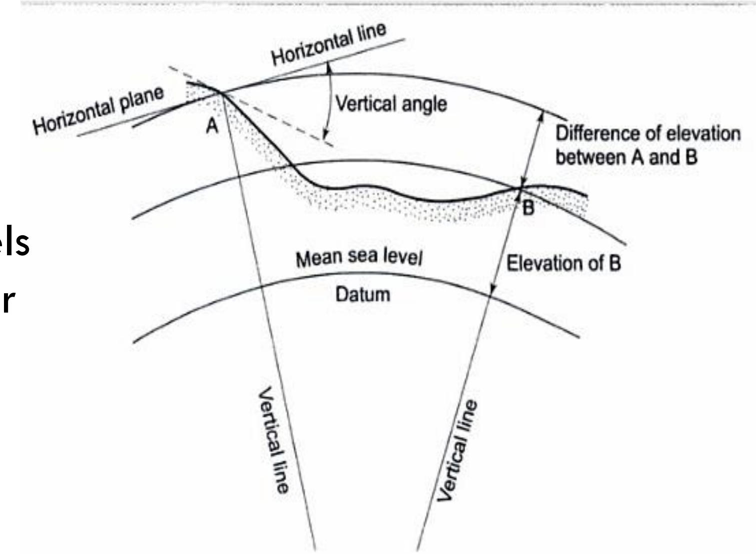


Fig. 6.1 Levelling terms

*Datum-* Elevations of points are determined relative to reference surface, such reference surface is called a Datum. All the points are at the same altitude. Or
The level of a point or the surface with respect to which levels of other points or planes are calculated, is called a datum or datum surface

*Vertical Line /Axis*–vertical line is the line **passing through point** on earth surface and earth center.

*Mean Sea Level (MSL)*: MSL is the average height of the sea for all stages of the tides. At any particular place MSL is established by finding the mean sea level (free of tides) after averaging tide heights over a long period of at least 19 years.

*Reduced Levels (RL):* The level of a point taken as height above the datum surface is known as RL of that point.

# Leveling Definitions:



Benchmarks: A benchmark is a relatively permanent reference point, the elevation of which is known (assumed or known with respect to mean sea level ( MSL). It is used as a starting point for levelling or as a point upon which to close for a check.

GTS Benchmark- These benchmarks are established by a national agency such as Survey of India. They are established at several points all over the country with highest precision. In India elevation of all such bench marks are established with respect to mean sea level (MSL) at Karachi. A bronze plate provided on the top of a concrete pedestal with its elevation engraved serves as GTS bench mark

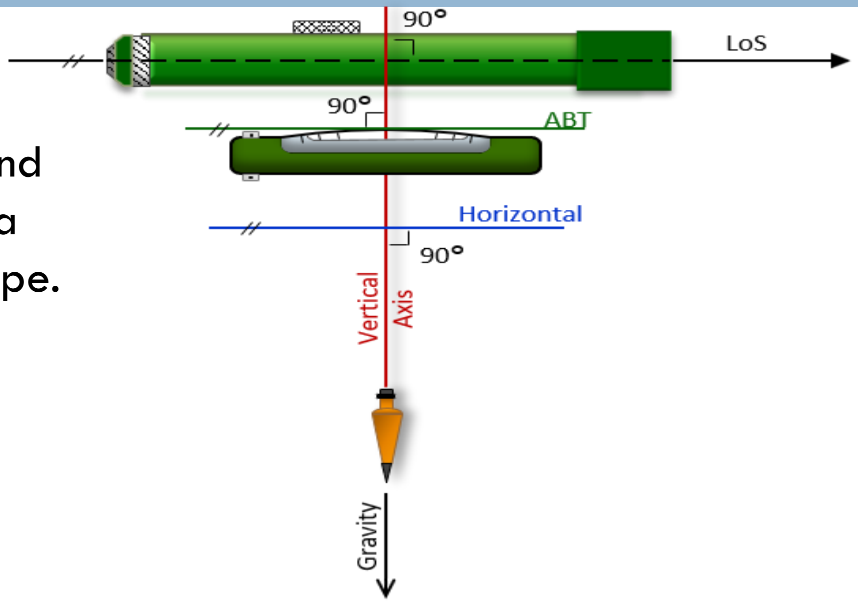
Permanent Benchmark- These are the benchmarks established by state government agencies like PWD. They are established with reference to GTS benchmarks. They are usually on the corner of plinth of public buildings.

Arbitrary Benchmark- In many engineering projects the difference in elevations of neighbouring points is more important than their reduced level with respect to mean sea level. In such cases a relatively permanent point, like plinth of a building or corner of aculvert, are taken as benchmarks, their level assumed arbitrarily such as 100.0 m,300.0 m, etc.

Temporary Benchmark: This type of benchmark is established at the end of the day'swork, so that the next day work may be continued from that point. Such point should be on a permanent object so that next day it is easily identified.

# Levelling Instruments

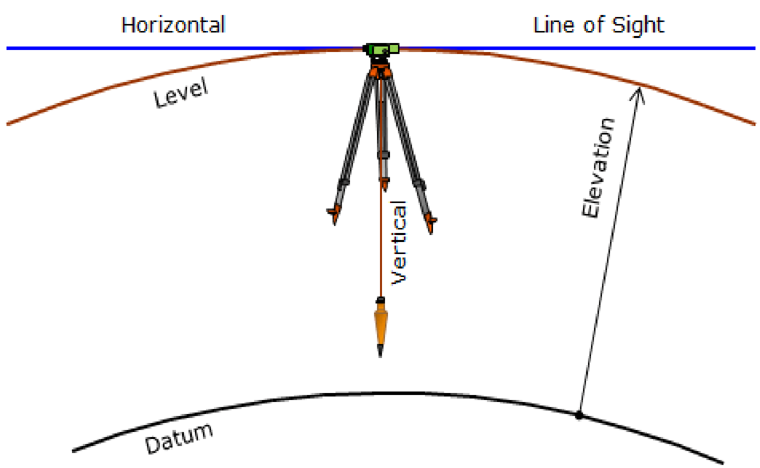





**Level**

A **level** is an instrument giving horizontal line of sight and magnifying the reading at a far away distance. It has a gravity-based provision, a bubble, to orient the telescope. It consists of the following parts:

- A telescope to provide a line of sight
- A level tube to make the line of sight horizontal and
- A levelling head to level the instrument.




At the instrument location, a horizontal line and level line coincide

**Types of levels:-**

(i)Dumpy level 2) Cooke's Reversible level
3) Cushing's Level 4) Wye (or, Y) level 5) Auto Level 4)

# DUMPY LEVEL (Important)



***1. Tripod stand*** The tripod stand consists of three legs which may be solid or framed. The legs are made of light and hard wood. The lower ends of the legs are fitted with steel shoes.

***2. Levelling head*** The levelling head consists of two parallel triangular plates having three grooves to support the foot screws.

***3. Foot screws*** Three foot screws are provided between the trivet and tribrach. By turning the foot screws the tribrach can be raised or lowered to bring the bubble to the centre of its run.

***4. Telescope*** The telescope consists of two metal tubes, one moving within the other. It also consists of an object glass and an eye-piece on opposite ends. A diaphragm is fixed with the telescope just in front of the eye-piece. The diaphragm carries cross-hairs. The telescope is focussed by means of the focussing screw and may have either external focussing, or internal focussing.

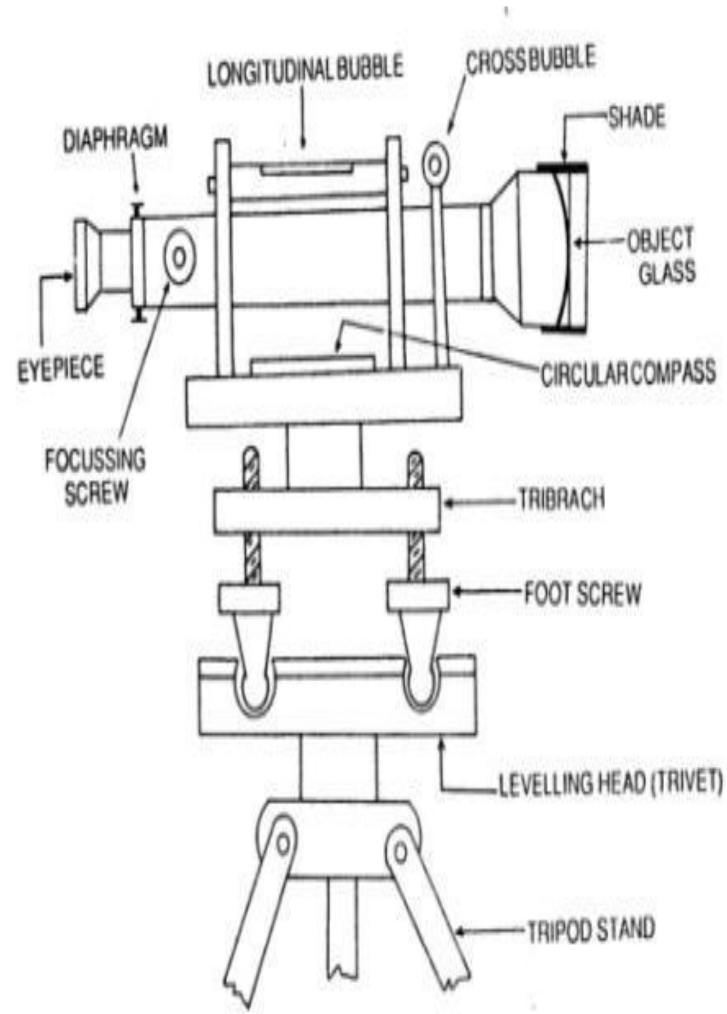
In the external focussing telescope, the diaphragm is fixed to the outer tube and the objective to the inner tube. By turning the focussing screw the distance between the objective and diaphragm is altered to form a real image on the plane of cross-hairs.

In the internal focussing telescope, the objective and eye-piece do not move when the focussing screw is turned. Here, a double concave lens is fitted with rack and pinion arrangement between the eye-piece and the objective. This lens moves to and fro when the focussing screw is turned and a real image is formed on the plane of cross-hairs.

***5. Bubble tubes*** Two bubble tubes, one called the longitudinal-bubble tube and other the cross-bubble tube, are placed at right angles to each other. These tubes contain spirit bubble. The bubble is brought to the centre with the help of foot screws. The bubble tubes are fixed on top of the telescope.

***6. Compass*** A compass is provided just below the telescope for taking the magnetic bearing of a line when required.

The compass is graduated in such a way that a 'pointer', which is fixed to the body of compass, indicates a reading of 0° when the telescope is directed along the north line.



# Levelling Instruments



**Levelling Staff**

The levelling staff is a rectangular rod having graduations.

The staff is provided with a metal shoes at its bottom to resist wear and tear. The foot of the shoe represents zero reading. Levelling staff may be divided into two groups :-

**1.Self reading staff:** This staff reading is directly read by the instrument man through telescope.

*1.Solid staff:* It is a single piece of 3 m.

*2.Folding staff :*A staff of two pieces each of 2 m which can be folded one over the other.

*3.Telescopic staff*:A staff of 3 pieces with upper one solid and lower two hollow. The upper part can slide into the central one and the central part can go into the lower part. Each length can be pulled up and held in position by means of brass spring. The total length may be 4 m or 5 m.

**2.Target staff:** If the sighting distance is more, instrument man finds it difficult to read self reading staff. In such case a target staff shown in may be used. Target staff is similar to self reading staff, but provided with a movable target.

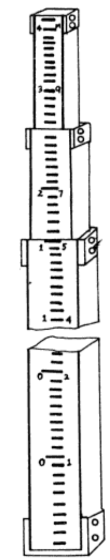


Fig. 5.6 Telescopic Metric Staff

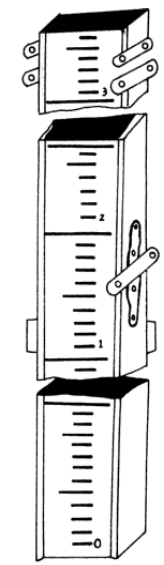
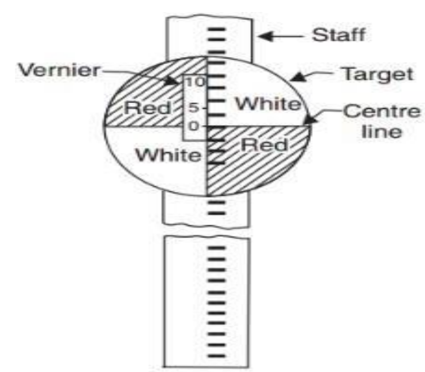


Fig. 5.7 Folding Metric Staff



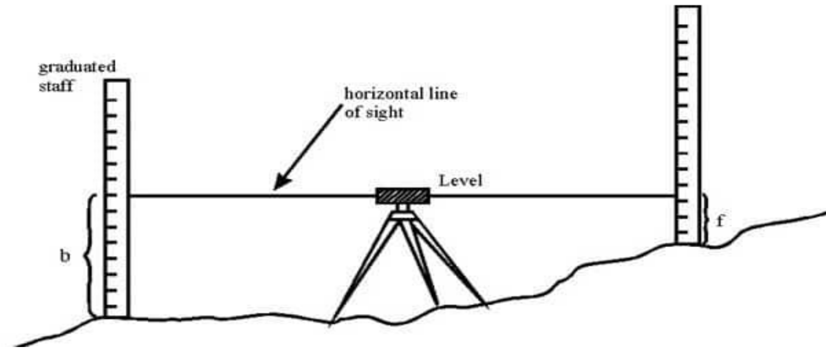

(c) Target staff

# Types of Leveling



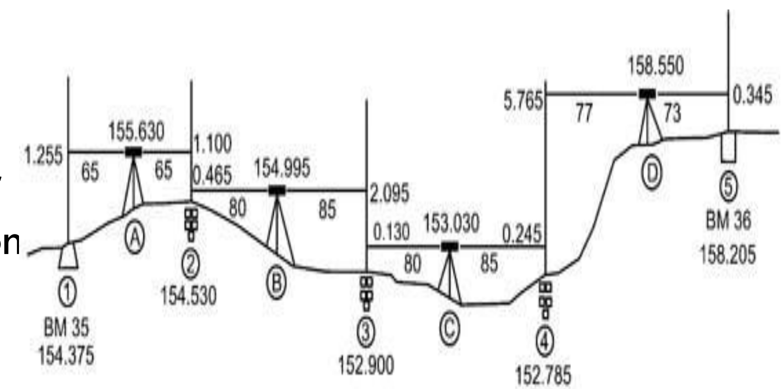
**Simple Leveling**

It is a simple and basic form of leveling in which the leveling instrument is placed between the points which elevation is to be find. Leveling rods are placed at that points and sighted them through leveling instrument. It is performed only when the points are nearer to each other without any obstacles



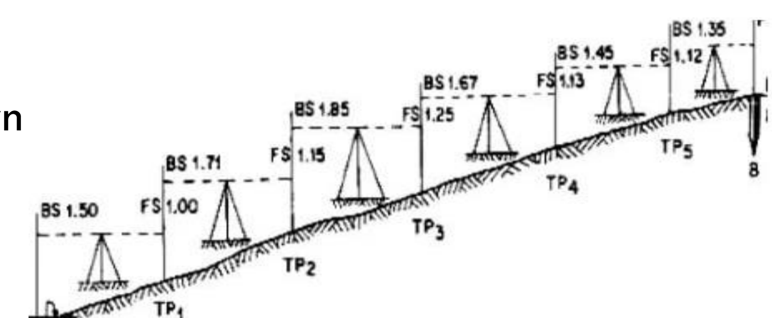

**Differential Leveling**

Differential leveling is performed when the distance between two points is more. In this process, number of inter stations are located and instrument is shifted to each station and observed the elevation of inter station points. Finally difference between original two points is determined




**Fly Leveling**

The levelling operation in which only BS and FS readings are taken and no intermediate sights are observed is known as fly levelling. It is done for connecting the benchmark to the starting point of any project. In such levelling, no horizontal distances are required to be measured

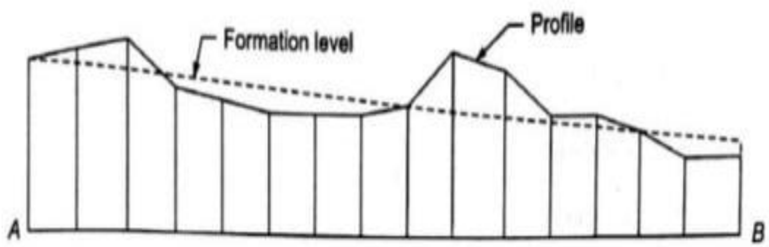


# Types of Leveling



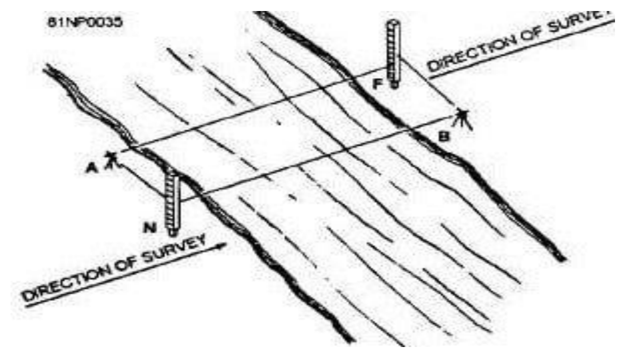
**Profile Leveling**

Profile leveling is generally adopted to find elevation of points along a line such as for road, rails or rivers etc. In this case, readings of intermediate stations are taken and reduced level of each station is found. From this cross section of the alignment is drawn.



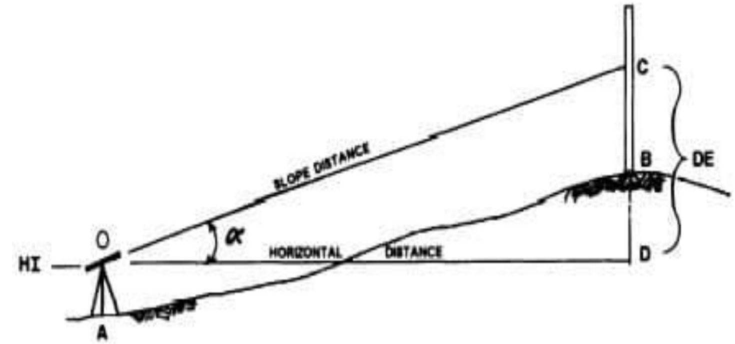

**Reciprocal Leveling**

When it is not possible to locate the leveling instrument in between the inter visible points, reciprocal leveling is performed. This case appears in case of ponds or rivers etc. in case of reciprocal leveling, instrument is set nearer to 1st station and sighted towards 2nd station.




**Trigonometric Leveling**

The process of leveling in which the elevation of point or the difference between points is measured from the observed horizontal distances and vertical angles in the field .In this method, trigonometric relations are used to find the elevation of a point from angle and horizontal distance

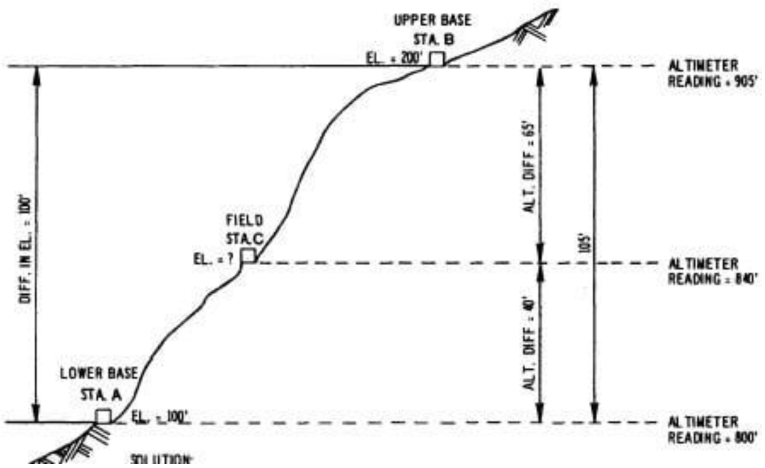


# Types of Leveling



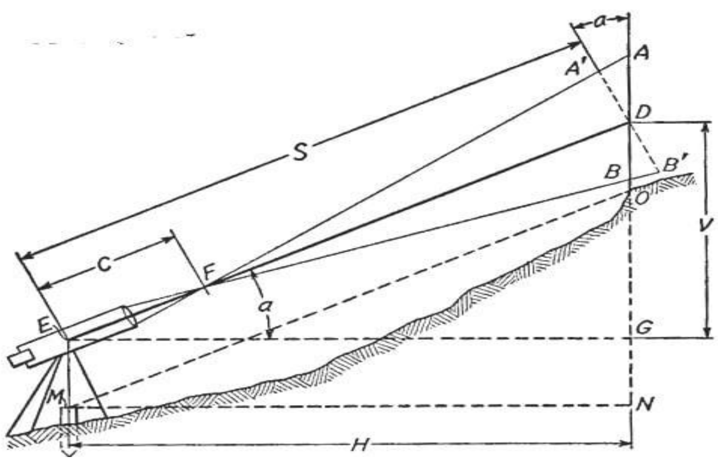
**Barometric Leveling**

Barometer is an instrument used to measure atmosphe at any altitude. So, in this method of leveling, atmospheric pressure at two different points is observed, based on which the vertical difference between two points is determined. It is a rough estimation and used rarely.




**Stadia Leveling**

It is a modified form of trigonometric leveling in which Tacheometer principle is used to determine the elevation of point. In this case the line of sight is inclined from the horizontal. It is more accurate and suitable for surveying in hilly terrains.



# Fundamental Lines In A Dumpy Level



In a properly adjusted dumpy level, desired relations among fundamental lines are

1. Axis of the level tube is perpendicular to the Vertical axis
2. Horizontal cross hair should lie in a plane perpendicular to the Vertical axis, so that it will lie in a Horizontal plane when the instrument is properly leveled.
3. The Line of sight is parallel to the axis of the level tube.
4. The optical axis, the axis of the objective lens and the line of sight should coincide.

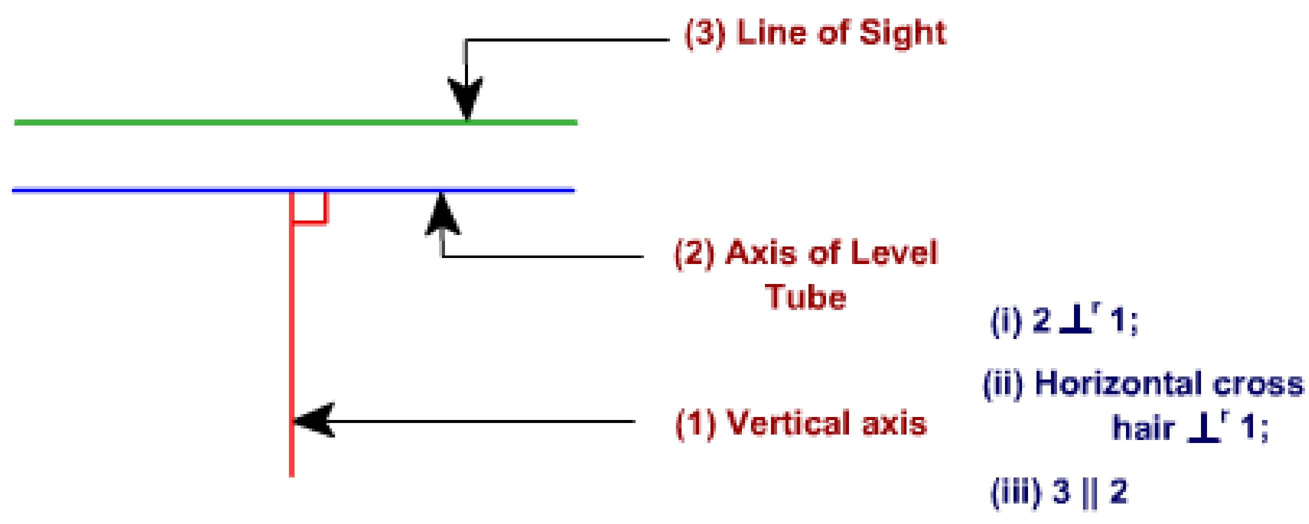



Figure 12.2 Desired relations between Fundamental lines

# Temporary Adjustments of A Level



The adjustments to be made at every setting of the instrument are called temporary adjustments. The following three adjustments are required for the instrument whenever set over a new point before taking a reading:

(i) Setting (ii) Levelling and (iii) Focussing.

**Setting**

Tripod stand is set on the ground firmly so that its top is at a convenient height. Then the level is fixed on its top. By turning tripod legs radially or circumferentially, the instrument is approximately levelled.

Some instruments are provided with a less sensitive circular bubble on tribrach for this purpose.

**Levelling**

Leveling of the instrument is done to make the vertical axis of the instrument truly vertical

The procedure of accurate levelling with three levelling screw is as given below:

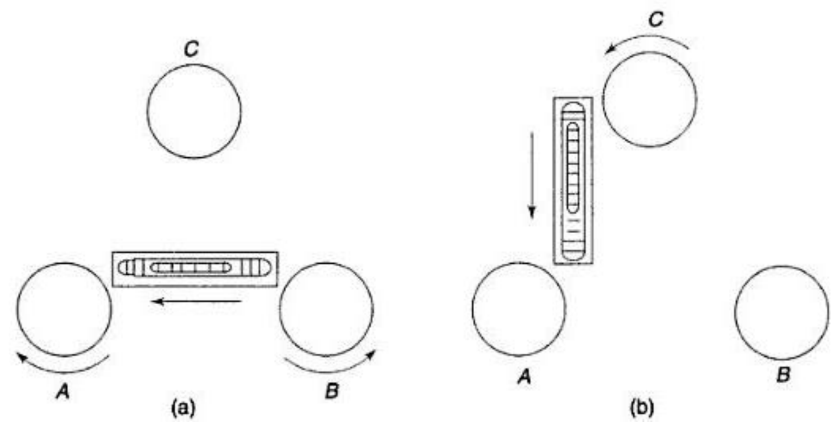
i. Loosen the clamp and turn the telescope until the bubble axis is parallel to the line joining any two screws .
ii. Turn the two screws inward or outward equally and simultaneously till bubble is centred.
iii. Turn the telescope by 90° so that it lies over the third screw and level the instrument by operating the third screw.

# Temporary Adjustments of A Level



iv. Turn back the telescope to its original position and check the bubble. Repeat steps (ii) to (iv) till bubble is centred for both positions of the telescope.

v. Rotate the instrument by 180°. Check the levelling.




**Focussing**

Focussing is necessary to eliminate parallax while taking reading on the staff. The following two steps are required in focussing:

- Focussing the eyepiece: For this, hold a sheet of white paper in front of telescope and rotate eyepiece in or out till the cross hairs are seen sharp and distinct.
- Focussing the objective: For this telescope is directed towards the staff and the focussing screw is turned till the reading appears clear and sharp.

# Permanent Adjustments of A Level



The permanent adjustments of different level are made to establish the fixed relationships between its fundamental lines. It indicates the rectification of instrumental errors

*In a dumpy level, there are only two adjustments as the telescope is rigidly fixed to the spindle.*

1. *The axis of the bubble tube should be perpendicular to the vertical axis*
2. *The line of collimation should be parallel to the axis of the bubble tube.*

# Permanent Adjustments of A Level



**First Adjustment:**

To make the axis of the bubble tube perpendicular to the vertical axis.

**Object:**

The object of this adjustment is to ensure that if the instrument is once levelled up, the bubble remains in the centre of its run for all positions of the telescope.

**Necessity:**

The adjustment is made only for the convenience of taking readings quickly. Since it is necessary that the bubble should be central while taking any reading, much time is wasted if this adjustment is not made as in that case the bubble has to be brought in centre every time for each pointing of telescope.

**Test:**

(i) Set-up the level on firm ground and level it carefully by tripod-legs and foot-screws. The bubble will now be central in two positions at right angles to each other, one being parallel to a pair of foot-screw and the other over the third foot-screw.

(ii) Bring the telescope over a pair of foot-screws or over the third foot-screw and turn it through 180 in the horizontal plane. If the bubble still remains central, the adjustment is correct.

# Permanent Adjustments of A Level



**Adjustment:**

(i) If the bubble does not remain in the centre, note down the deviations of the bubble from the centre, say it is '2n' division over the bubble half way back i.e., 'n' divisions by raising or lowering end of the bubble tube by means of capstan headed must and the remaining half with the pair of foot-screws beneath the telescope at its present position.

(ii) Turn the telescope through 90° so that it lies over the single foot- screw below the telescope or parallel to a pair of this screw or pair of foot -screws and bring the bubble in the centre of its run by means of this screw pair of foot-screws.

(iii) Rotate the telescope and see if the bubble remains central for all positions of the telescope. If not repeat the whole process until the adjustment is correct.

# Permanent Adjustments of A Level



**Second Adjustment:**
To make the Line of collimation parallel to the axis of the bubble tube

**Object:**
The object of this adjustment is to set the line of collimation parallel to the bubble axis so that when the bubble is centered, the line of collimation should become exactly horizontal and not remain inclined as otherwise it would be.

**Necessity:**
The whole function of a level is to furnish a horizontal line of collimation, which is possible only if the above condition is satisfied.

**Test and Adjustments:**
The collimation error may be tested by any of the following three methods and then the necessary adjustments are made ***(concentrate on Two-Peg Method)***

.

# Permanent Adjustments of A Level

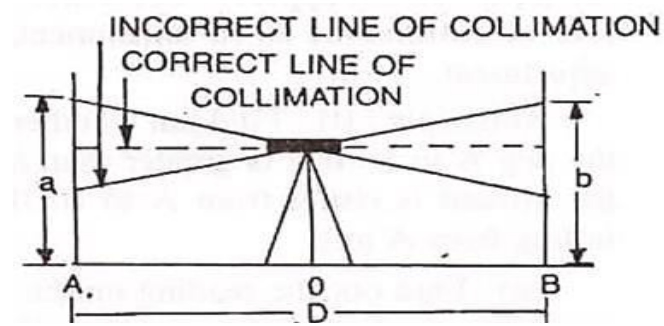


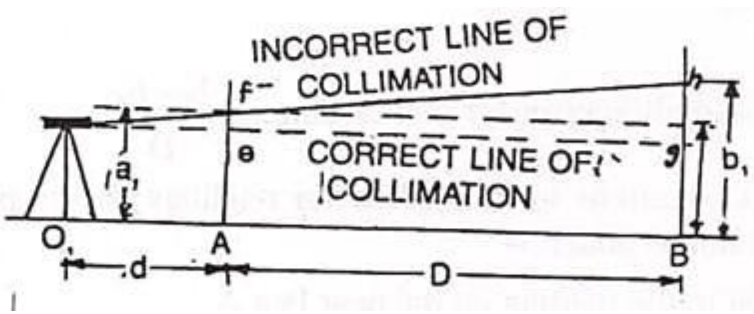
**Two-Peg Method.:**

**Test:**

(i) Drive two pegs A and B at a distance of (D) metres say 60 to 100 metres on a fairly level ground. Drive another peg at O exactly midway between A and B

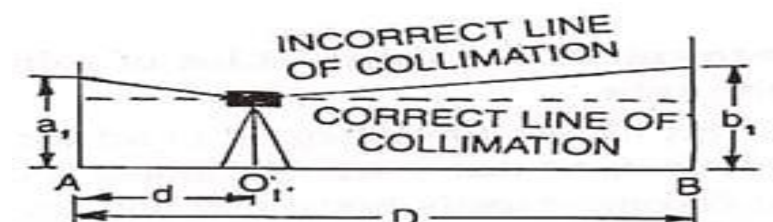
(ii) Set up and level the instrument at O and take the staff readings on A and B. The bubble must be in the centre while the readings are being taken. Let the staff readings on A and B, be a and b respectively.




(iii) Shift the level and set it up a point $O_1$, d metres away from A (or B) and along the same line BA (Fig. 7.37). levels the instrument accurately and take staff readings on A and B with the bubble central. Let the readings be $a_1$ and $b_1$ respectively.

(The level may also be set up at a point between A and B, d metres away from A or B)



# Permanent Adjustments of A Level



(iv) Find the difference between the staff readings a and b, and that between the staff readings $a_1$ and $b_1$.

The difference of staff readings a and b gives the true difference in elevation between A and B as the instrument was set up exactly midway between A and B and that the back and for sight distances were exactly difference, whereas the difference between $a_1$ and $b_1$ gives the apparent difference. *If the two differences are equal, the line of collimation is in adjustment, otherwise it is inclined and needs adjustment.*

**Adjustment:**

(i) Find out whether the difference is a rise or a fall from the peg A to B. If a is greater than b, the peg A is lower than peg B and the ground is rising from A to B. If b is greater than a, the ground is falling from A to B.

(ii) Find out the reading on the far peg B at the same level are of $a_1$ by adding the true difference to $a_1$ if it is a fall, or by subtracting the true difference from $a_1$ if it is a rise. Let the reading be $b_2$

$$\therefore \; b_2 = a_1 + \text{true difference} \begin{bmatrix} +\text{sign for fall} \\ -\text{sign for rise} \end{bmatrix}$$

# Permanent Adjustments of A Level



(iii) If $b_1$ is greater than $b_2$, the line of collimation is Inclined upwards and if $b_1$ is smaller than $b_2$, the line of collimation is inclined downwards. $b_1 - b_2$ (difference of $b_1$ and $b_2$) is the collimation error in the distance "D".

∴ **the collimation error for unit distance:** $= \frac{b_1 - b_2}{D}$

(iv) The corrections to be applied for readings on the pegs A and B may be found out as under:

Correction to the reading on the near Peg A,

$$C_n = \frac{d}{D}(b_1 - b_2)$$

Correction to the reading on the far peg B,

$$C_f = \frac{(d + D)}{D}(b_1 - b_2)$$

*These corrections are additive if the of collimation is inclined downward and subtractive if the same is inclined upwards.*

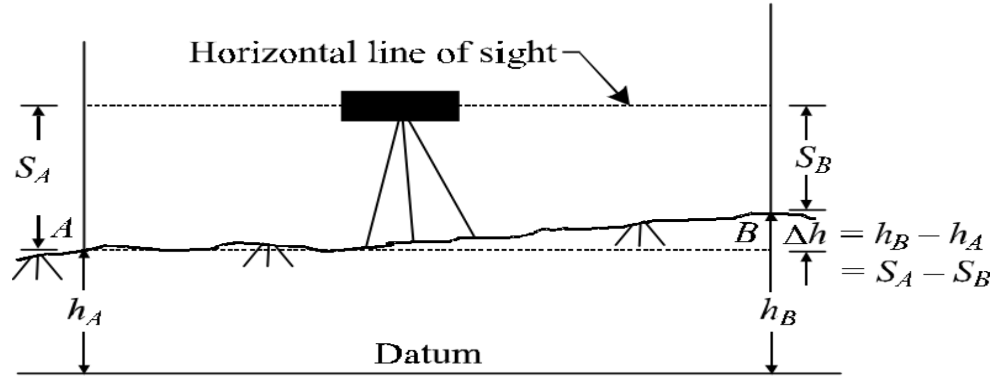
The correct reading on the near peg $A = a_1 \pm C_n$

" " " far peg $B = b_1 \pm C_f$

# Technical Terms in Levelling Operations

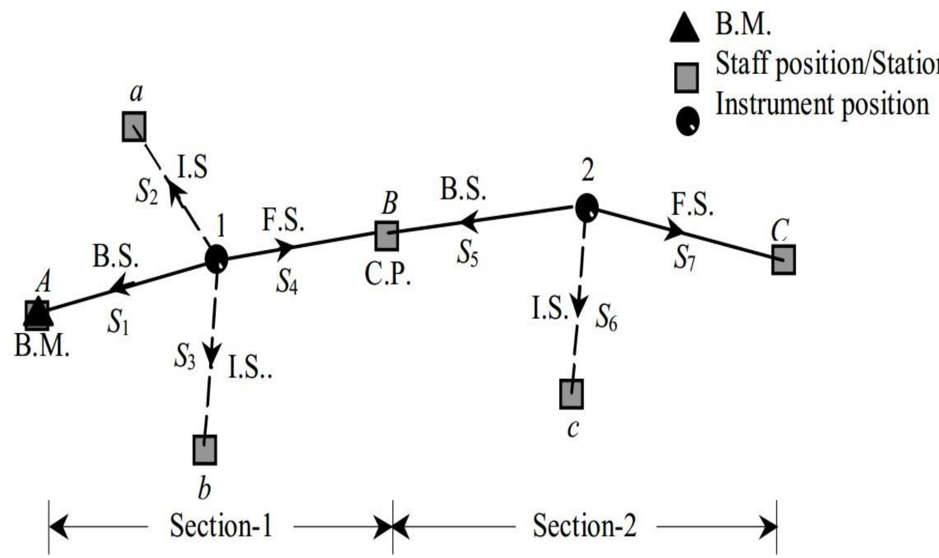


**Height of instrument (H.I.) or height of collimation:** For any set up of the level, the elevation of the line of sight is the height of instrument. (H.I. = hA+ SA in Fig.)




**Station:** A station is the point where the levelling staff is held. (Points A, a, b, B, c, and C in Fig.)

**Back sight (B.S.):** It is the first reading taken on the staff after setting up the level usually to determine the height of instrument.
It is usually made to some form of a bench mark (B.M.) or to the points whose elevations have already been determined.




When the instrument position has to be changed, the first sight taken in the next section is also a back sight. (Staff readings S1and S5 in Fig)

# Technical Terms in Levelling Operations



**Fore sight (F.S.):** It is the last reading from an instrument position on to a staff held at a point.It is thus the last reading taken within a section of levels before shifting the instrument to the next section, and also the last reading taken over the whole series of levels. (Staff readings S4 and S7in Fig.).

**Change point (C.P.) or turning point:** A change point or turning point is the point where both the fore sight and back sight are made on a staff held at that point. A change point is required before moving the level from one section to another section. By taking the fore sight the elevation of the change point is determined and by taking the back sight the height of instrument is determined.The change points relate the various sections by making fore sight and back sight at the same point.(Point B in Fig).

**Intermediate sight (I.S.):** The term 'intermediate sight' covers all sightings and consequent staff readings made between back sight and fore sight within each section.Thus, intermediate sight station is neither the change point nor the last point. (Points a, b, and c in Fig. ).

# Technical Terms in Levelling Operations



**Reduced level (R.L.):** Reduced level of a point is its height or depth above or below the assumed datum.It is the elevation of the point.

**Rise and fall:** The difference of level between two consecutive points indicates a rise or a fall between the two points. In Fig. , if (SA– SB) is positive, it is a rise and if negative, it is a fall. Rise and fall are determined for the points lying within a section.

**Section:** A section comprises of one back sight, one fore sight and all the intermediate sights taken from one instrument set up within that section.

**Parallax:** is a displacement or difference in the apparent position of an object viewed along two different lines of sight, and is measured by the angle or semi-angle of inclination between those two lines.

**Focal length-** The distance from the focal point of a lens or mirror to the reflecting surface of the mirror or the centre point of the lens. The focal length of an optical system is a measure of how strongly the system converges or diverges light.

# Differential Leveling: Principle

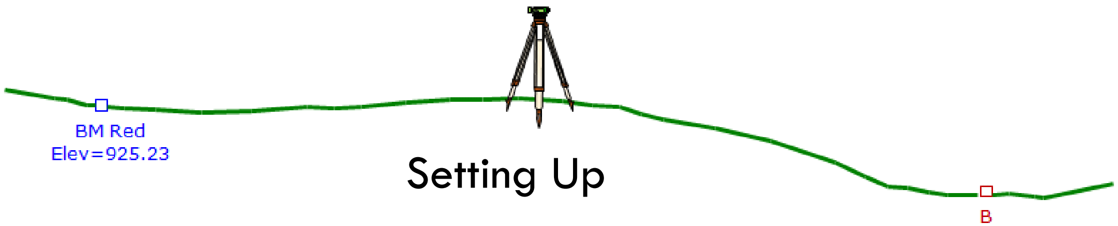




Differential leveling **uses the vertical distance difference between two points to transfer an elevation from one point to another.**

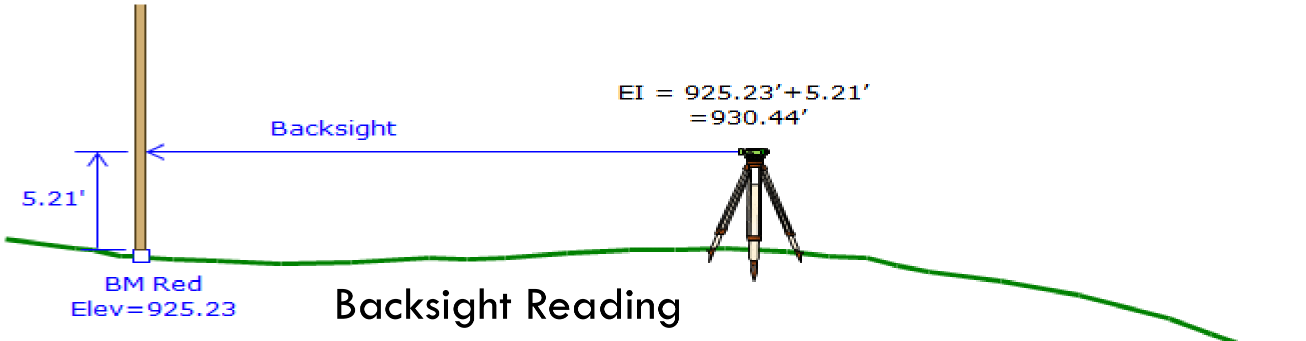
*A summary of process:*

1. A Level is setup between two points, one whose elevation is known




Setting Up

2.A backsight (BS) reading is taken on the known point using a rod divided into meters and subdivisions thereof. This determines how far above the LoS is above the known point. Adding the BS reading to the point elevation gives the elevation of the instrument (EI or Height of the Instrument, HI).



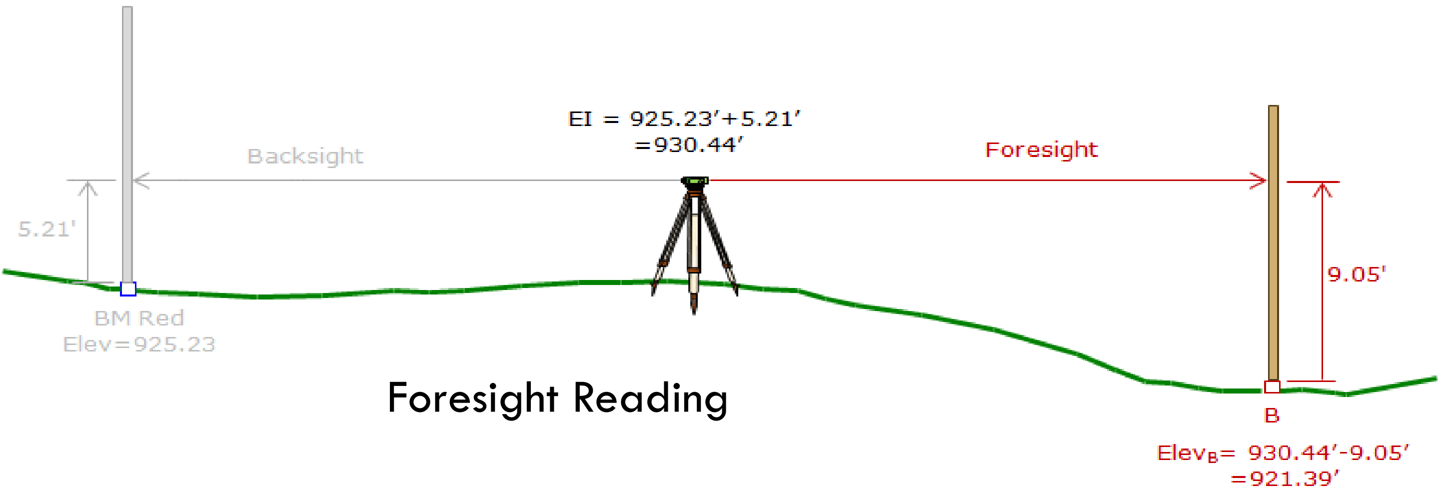

Backsight Reading

# Differential Leveling: Procedure





3.A foresight (FS) reading is taken on the unknown point to determine how far above it the LoS is. Subtracting the FS reading from the instrument elevation gives the point elevation.




Foresight Reading

4. The elevation of B is determined by adding the difference between the BS and FS readings:

$Elev_B = Elev_{Red} + (BS_{Red} - FS_B)$

*The instrument is moved to a position between B and the next point and the process repeated.*

# Reduction Of Level



The observed staff readings as noted in a level book are further required to be manipulated to find out the elevation of points. *The operation is known as reduction of level.*

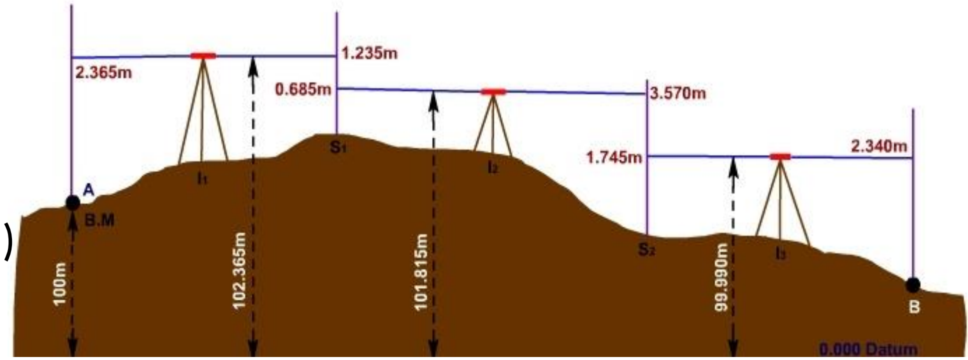
There are two methods for reduction of levels:

- Rise and Fall method and
- Height of instrument method.

# Rise and Fall Method



*For the same set up of an instrument, Staff reading is more at a lower point and less for a higher point. Thus, staff readings provide information regarding relative rise and fall of terrain points.*




In brief,

Fall (F) = Foresight (F.S.) – Back-sight (B.S.)

Fall (F) = Intermediate sight (I.S.) – Back-sight (B.S.)

Rise (R) = Back-sight (B.S.) - Foresight (F.S.)

Reduced Level (R.L.) = Precede Reduced Level + Rise (R)

Reduced Level (R.L.) = Precede Reduced Level – Fall (F)

| | Staff Reading | | Difference in Elevation | | Elevation | |
|---|---|---|---|---|---|---|
| Points | B.S (m) | F.S.(m) | Rise (m) | Fall (m) | R.L (m) | Remark |
| A | 2.365 | | | | 100.000 | B.M. |
| $S_1$ | 0.685 | 1.235 | 1.130 | | 101.130 | $T.P._1$ |
| $S_2$ | 1.745 | 3.570 | | 2.885 | 98.245 | $T.P._2$ |
| B | | 2.340 | | 0.595 | 97.650 | |

In case of Rise and Fall method for Reduction of level, following arithmetic checks are applied to verify calculations.

$$\sum_{B.S.} - \sum_{F.S.} = \sum_{Rise} - \sum_{Fall} = \text{Last R.L. - First R.L.}$$

# Rise and Fall Method



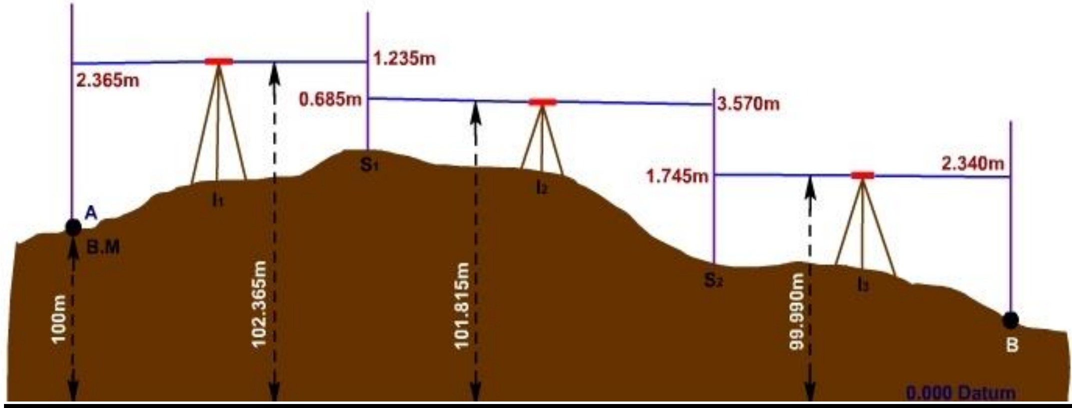
*Rules of booking*

a. The first and last reduced level is on an Ordnance Bench Mark (OBM) or a Temporary Bench Mark (TBM)
b. There is a rise when the first staff reading is larger than the second staff reading in any consecutive pair of staff readings.
c. There is a fall when the first staff reading is less than the second staff reading in any consecutive pair of staff readings.
d. In order to obtain the new reduced level, add the rise and subtract the fall from the preceding reduced level entering on the same line as the rise or fall.

# Height of Instrument Method/ Height of Collimation Method



*In any particular set up of an instrument height of instrument, which is the elevation of the line of sight, is constant. The elevation of unknown points can be obtained by subtracting the staff readings at the desired points from the height of instrument.*




In brief,

Heights of collimation (H.I.)= Reduced Level (R.L.) + Back-sight (B.S.)

Reduced Level (R.L.) = Heights of collimation(H.I.) - Foresight (F.S.)

Reduced Level (R.L.) = Heights of collimation (H.I.) - Intermediate sight (I.S.)

Calculation checks,

Simple Check : Σ F.S. - Σ B.S. = First R.L. - Last R.L.

Full check: Σ I.S. + Σ F.S. + Σ (R.L. except the first) = Σ (each H. of C. x number of applications)

| | Staff Reading | | Height of Instrument (m) | R.L. (m) | Remarks |
|---|---|---|---|---|---|
| Points | B.S (m) | F.S.(m) | | | |
| A | 2.365 | | 102.365 | 100.000 | B.M. |
| $S_1$ | 0.685 | 1.235 | 101.815 | 101.130 | $T.P._1$ |
| $S_2$ | | 3.570 | | 98.245 | $T.P._2$ |
| B | | 2.340 | | 97.650 | |

# Height of Instrument Method



Rules of booking

a. The survey starts from a known level which is the Ordnance Bench Mark (OBM) or a Temporary Bench Mark (TBM). This is to obtain the first reading from the instrument position which is the back sight.
b. The height of collimation is the addition of the back sight and reduced level, entered on the same line.
c. An intermediate sight will occur between the back sight and foresight.
d. d. Foresight is the last reading from an instrument position.

# Reduction Of Level Methods



*Comparison of the two systems*

| Collimation System | Rise-and-Fall System |
|---|---|
| 1. It is rapid as it involves few calculation. | It is laborious, involving several calculations. |
| 2. There is no check on the RL of intermediate points. | There is a check on the RL of intermediate points. |
| 3. Errors in intermediate RLs cannot be detected. | Errors in intermediate RLs can be detected as all the points are correlated. |
| 4. There are two checks on the accuracy of RL calculation. | There are three checks on the accuracy of RL calculation. |
| 5. This system is suitable for longitudinal levelling where there are a number of intermediate sights. | This system is suitable for fly levelling where there are no intermediate sights. |

# Curvature and refraction error



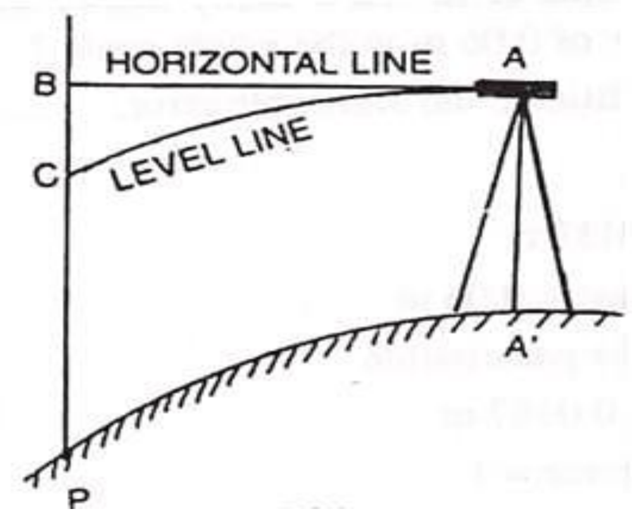
**Curvature:**

Earth has a curved face which is assumed to be a level surface but the line of sight as furnished by the levelling instrument is horizontal and not the level line. Therefore, all points on the line of sight are not equidistant from the surface of the earth and consequently the points read on the staff are not strictly at the same level as horizontal hair of the diagram.

The level line falls away from the horizontal line of sight and the vertical distance between the horizontal line and the level line denotes the effect of curvature of the earth.

In Fig 'A' is the instrument station and P the point where the staff is held. On looking through the telescope, we sight along AB, the horizontal line of sight, and take the staff reading PB. The point B is consider to be at the same level as A, but actually the points C and A are at the same level. The true reading is, therefore, PC

**The difference BC between the observed and true staff readings denotes the error due to curvature of the earth**



# Curvature and refraction error



**Determination of the error due to curvature of the earth:**

**In fig ,**

D= the length of the sight or the distance from the instruments to the staff station in kilometers

BC= he error due to curvature.

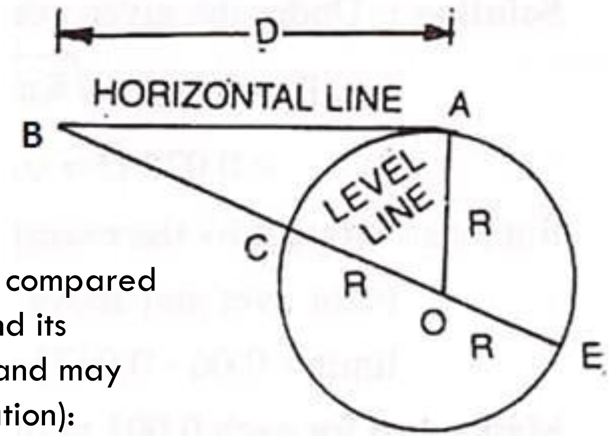
O= the center of the earth

R= the radius of the earth.

By Geometry, BC x BE =BA$^2$

Or BC (BC= CE) = BC$^2$

Or BC$^2$ +BC x CE=BA$^2$




(Since BC is usually very small as compared with the diameter of the earth and its square will still be much smaller and may therefore be neglected in calculation):

$$BC \times CE = BA^2$$

$$BC = \frac{BA^2}{CE} = \frac{D^2}{2R}$$

*taxing diameter of the earth as 12,742 kilometers ,we get:*

$$BC = \frac{D^2}{12,742}\ \text{Km}$$

$$= \frac{D^2 \times 1000}{12,742}\ \text{metres}$$

$$= 0.0785\ D^2\ \text{metres}$$

Hence the error in staff reading due to curvature of the earth = 0.0785 D$^2$ metres, where D is the distance from the level to the staff in kilometres.

The effect of curvature is to increase the staff reading i.e., this **error is positive and so the correction is negative.**

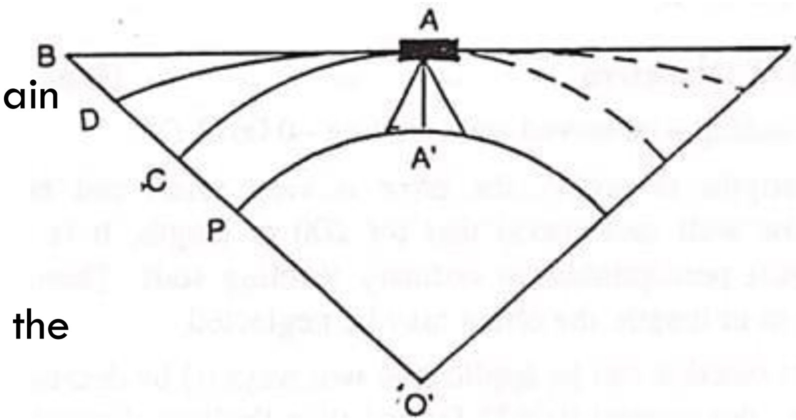
True staff reading = observed staff reading – 0.0785 D$^2$

# Curvature and refraction error



**Refraction:**

It is a well-established law of physics that rays of light passing through layers of different densities do not remain straight but are refracted or bent down towards the denser medium. Consequently, the ray of light from the staff to the instrument is not straight as AB in fig. but it follows a curved path AD concave towards the earth as the near the surface of the earth is denser than the upper layers of air.




Under normal atmospheric conditions, arc AD may be taken as circular and of radius seven times that of the earth. The effect of refraction is therefore 1/7th7 the of that of the curvature, but is of opposite nature.

$$BD = \frac{1}{7} BC$$

$$= \frac{1}{7} \; 0.0785 \, D^2$$

$$= \mathbf{0.0112 \, D^2 \text{ metres}}$$

*Hence the correction for refraction is additive to the staff reading.*

# Curvature and refraction error



**Combined Correction due to Curvature and Refraction:**

Since the effect of curvature is to increase the staff readings and that of refraction is to decrease them and also the effect of curvature is greater than that of refraction, the combined effect is therefore, to increase the staff readings, hence the combined correction is subtractive.

$$CD = BC - BD$$

$$= BC - \frac{1}{7} BC = \frac{6}{7} BC$$

$$= \frac{6}{7}\ 0.0785\ D^2$$

$$= 0.0673\ D^2 \text{ metres} \quad \ldots$$

**True staff reading = observed staff reading -0.0673 $D^2$**

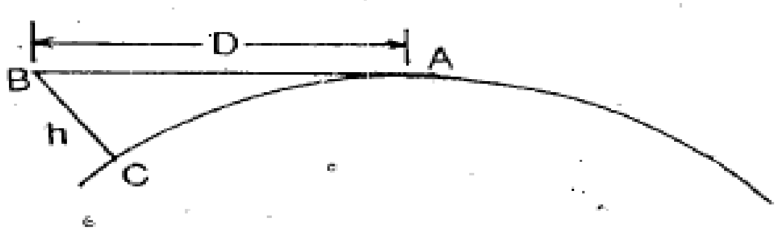
# Curvature and refraction error



*Application : Visible horizontal distance & dip of horizon*

Let AB = $D$ = visible horizon distance in kilometres

1.) $h$ = height of the point above mean sea level, in metres




Considering curvature and refraction corrections,

$$h = 0.0673\, D^2$$

$$D = \sqrt{\frac{h}{0.0673}}$$

2.) ***Dip of Horizon***

AB = $D$ = tangent to the earth at A

BD = horizontal line perpendicular to OB

$\theta$ = dip of horizon

The angle between the horizontal line and the tangent line is known as the dip of the horizon. It is equal to the angle subtended by the arc CA at the centre of the earth (Fig. 5.21).

$$\text{Dip } \theta = \frac{\text{arc CA}}{\text{radius of the earth}}, \text{ in radians}$$

$$\therefore \quad \theta = \frac{D}{R} \text{ in radians} \qquad \text{(Taking CA approx. equal to AB)}$$

# RECIPROCAL LEVELLING



By the principle of equalizing backsight and foresight distances ,i.e., if the level is placed exactly midway between two points and staff reading are taken to determine the difference of level, then the errors (due to inclined of collimation line, curvature and refraction) are automatically eliminated.

But in the case of a river or valley, it is not possible to set up the level midway between the two points on opposite banks. In such case the method of reciprocal levelling is adopted, which involves reciprocal observation both banks of the river or valley.

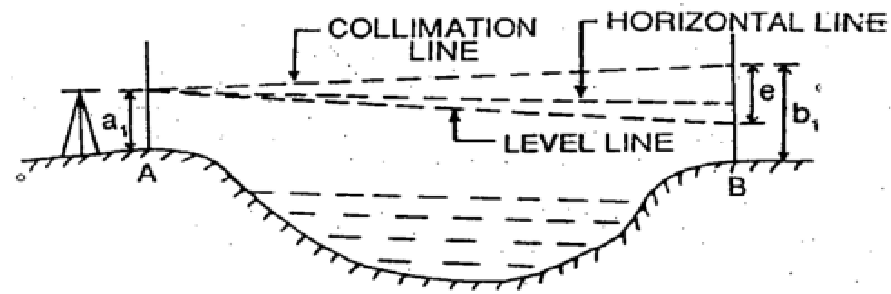
In reciprocal leveling, the level is set up on the both banks of the river or valley and two sets of staff readings are taken by holding the staff on both banks. In this case, it is found that the errors are completely eliminated and true difference of level is equal to the mean of the true apparent differences of level.

# RECIPROCAL LEVELLING

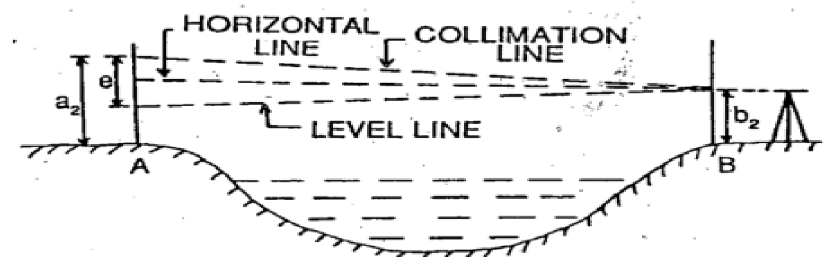


**Procedure:**

**1.** Suppose A and B are two points on an opposite bank of a river. The level is set up very near A and after proper temporary adjustment staff reading are taken at A and B. suppose reading a1 and b1




**2.** level is shifted and set up very near B and after proper adjustment, staff reading is taken as A and B. Suppose the reading are a2 and b2




*Let,*

*h= true difference of level between A and B*

*e= combine error due to curvature, refraction and collimation*

*(Error is +ve and –ve, here error is assumed +ve)*

First case:

Correct staff reading A=a1

Correct staff reading B=b1 – e

True difference of level between A and B

h= a1 – (b1-e) ……………………………..eq.1

Second case:

Correct staff reading B=b2

Correct staff reading a=a2 – e

True difference of level between A and B

h= (a2 - e) – b2 ………..eq.2

# RECIPROCAL LEVELLING



from (1) and (2)

$2h = a1 - (b1 - e) + (a2 - e) - b2$

$2h = a1 - b1 + e + a2 - e - b2$

$2h = (a1 - b1) + (a2 - b2)$

***$h = [(a1 - b1) + (a2 - b2)] / 2$***

***It may be observed that the error is eliminated and that the true difference is equal to the mean of two apparent differences of level between A and B.***

# Sensitiveness of a Level Tube



The sensitivity of a level is defined as the change of angle or gradient required to move the bubble by a set distance (usually 2mm).

If the vial has graduated divisions then the sensitivity refers to the angle or gradient change required to move the bubble by one of these divisions (often spaced at 2mm).

Sensitiveness or the sensitivity of a level tube is its capability of exhibiting small deviations of the tube from the horizontal.

Sensitiveness is sometimes designated in terms of the radius of curvature of the level tube, but the better way is to state the angle through which the axis must be tilted to cause the bubble to travel through one division of the scale (i.e., the angular value of one division of the level tube.)

# Sensitiveness of a Level Tube



**Measurement of Sensitiveness**

*To find either the radius of curvature of the level tube or the angular value of one division of the level tube*

(i) Select a base line of length 50 to 100 m on a fairly level ground and measure it accurately by a steel tape.

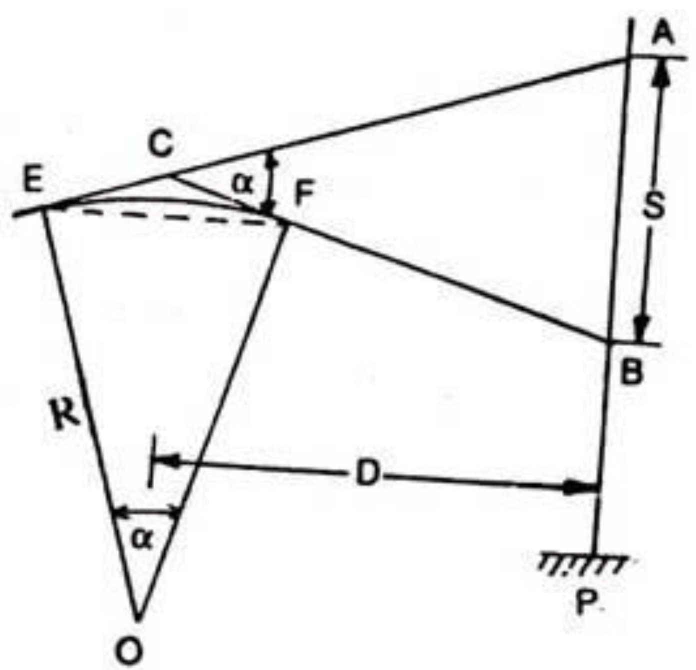
(ii) Set up and level the instrument at one end of the base line and hold the staff at other end 'P'.

(iii) By using the foot-screw beneath the telescope, bring the bubble near one end of its run (extreme left-hand position) and read both ends of the bubble.

(iv) Observe the staff reading in this position of the bubble (say it is AP)

(v) As before bring the bubble to the other end of the tube (extreme right-hand position) and note the two end readings of the bubble.

(vi) Again read the staff (say it is BP).



# Sensitiveness of a Level Tube



Let D = the horizontal distance between the instrument and the staff

AB= S = the average length of the staff interceptec between the upper and lower lines of sight (i.e., the difference of the two staff readings AB and BP).

= the angle between the lines of sight

n = the average number of divisions through which the centre of the bubble is moved.

In (iii) and (v) above, in each case, the position of both ends of the bubble is recorded and that of its centre can be deduced in terms of the tube graduations. These are say 'E' and 'F' in (iii) and (v) respectively.

OE = OF = R = the radius of curvature of the tube.

l = the length of one division on the tube, expressed in the same unit as D and S.

The length through which the centre of the bubble travels = the length of the are EF = nl.

Since is very small angle,

$$\alpha \approx \frac{AB}{BC} \approx \frac{S}{D} \text{ radians} \ldots \quad \ldots$$

Considering the Δs ACB and EOF as similar , Δs

$$\angle EOF = \angle ACB = \alpha$$

$$\angle EOF = \frac{\text{arc}EF}{\text{radius}OE} \text{ radians} \quad \ldots$$

or $$\alpha = \frac{nl}{R}$$

From (i) and (ii) above, we get

$$= \frac{S}{D} = \frac{nl}{R} \quad \ldots \quad \ldots$$

from the above equation, the radius of curvature,

$$R = \frac{nlD}{S} \quad \ldots \quad \ldots \quad \ldots$$

And the angular value of one division,

$$\frac{l}{R} = \frac{S}{Dn} \text{ (in radians)}$$

or $$\frac{1}{R}\ 206{,}265 = \frac{S}{Dn}\ 206{,}265 \text{ (in seconds)} \ldots\text{(E}$$

***Note:***

*1 radian = 206, 265 Seconds*

# Sensitiveness of a Level Tube



Sensitiveness of a bubble tube depends upon :

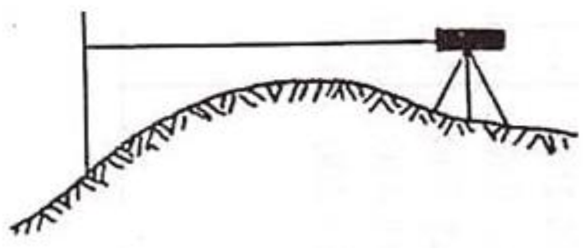
i) The radius of curvature of the internal surface i.e., larger the radius greater is the sensitiveness
ii) The diameter of the bubble i.e. larger the diameter, greater the sensitiveness.
iii) The length of the bubble i.e., larger the length greater is the sensitiveness.
iv) The viscosity and surface tension of the liquid i.e.lesser the viscosity more is its sensitiveness.
v) Smoothness of the finish of the internal surface of the tube i.e., greater the smoothness more is the sensitivity.
vi) Length of one division i.e. greater the length of one division more is the sensitiveness.

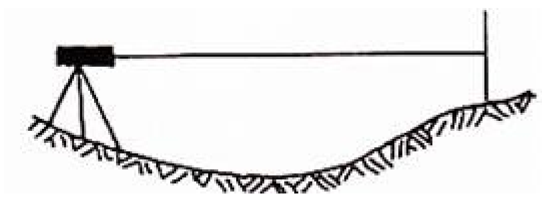
# Major Difficulties in Levelling



**Difficulty # 1. Levelling Across a Hill or a Hollow:**

In levelling across a hill, the level should not be set up on the top of the hill, but it should be set up on side shown in fig.. This reduces the number of instrument-settings.

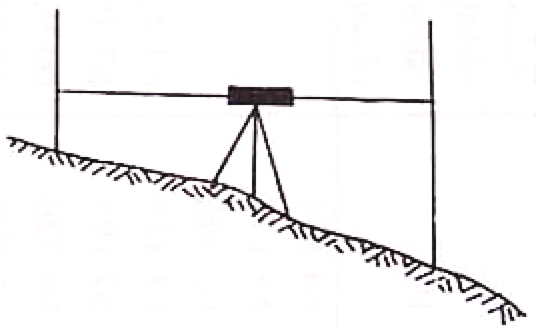




Similarly in levelling across a hollow, much time will be saved, if the instrument is set upon one side of the hollow as in  instead of in the bottom of the depression.

**Difficulty # 2. Levelling Up-Hill or Down-Hill:**

While levelling up-hill, the fore sight will be near the foot of the staff and the back sight heart the downhill the reverse is the case. The error due to non verticality of the staff is small when the staff reading is small, but it is serious when the line of sight strikes near the top and the reading is large, in which case the error can be avoided by keeping the staff vertical by using a plumb-bob., or by waving the staff and noting the smallest reading



# Major Difficulties in Levelling



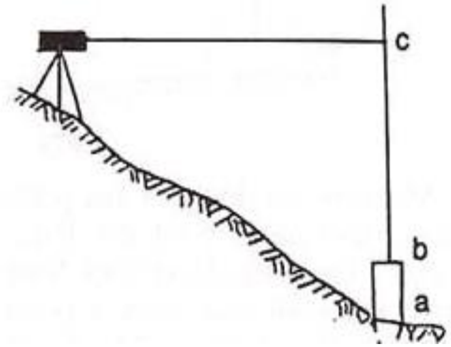
**Difficulty # 3. Staff Very Near the Instrument:**

When the staff is held very near the instrument, the graduations on the staff are not clearly visible. In such a case, a piece of white paper is moved up or down the staff until its edge is bisected by the line of collimation and the corresponding reading is taken. When the level is set up over the staff-station itself the staff reading may be taken by viewing through the object glass or by measuring the height of the centre of the object-glass with the staff

**Difficulty # 4. When the Staff-Station is too Low or too High:**

When the staff station is too low i.e., the line of collimation passes above the staff, a peg is driven and staff is held over the peg The staff reading (be) is taken and the height of the top of the peg (ab) above the ground is measured with a tape.
The required staff reading equals (ab + bc).

When the staff-station is too high i.e., above the line of sight as in the case of a the-beam, roof-girder, the stringcourse etc. the staff is held inverted on the point, and the reading is then taken. This reading being negative is entered in the level-book with a negative sign.
Therefore, if the inverted staff reading is back sight it is negative and if the same is fore sight, then it is positive.



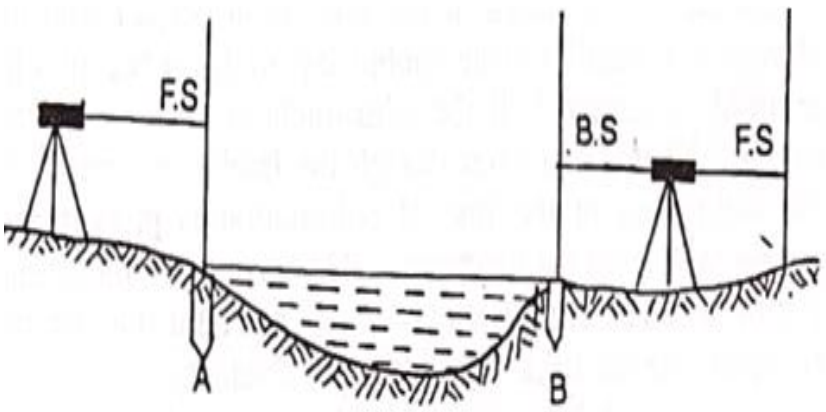
# Major Difficulties in Levelling



**Difficulty # 5. Levelling across a Pond or a Lake:**

This kind of difficulty can be got over by driving two pegs A and B flush with the water surface on opposite sides of a pond or a lake

- Evidently the top of the pegs are at the same level. The R.L. of the peg A is determined by taking a fore sight on it. This is also the R.L. of the peg B. The instrument is then shifted and set up on the other side and a back sight is taken on peg B, the two pegs A and B together, being considered as a single change point




**Difficulty # 6. Levelling across a River:**

The above method is not suitable in the case of fast flowing water of a river. In such a case, the method of reciprocal levelling employed to determine the true level between two point on opposite bank and the levelling is continued.

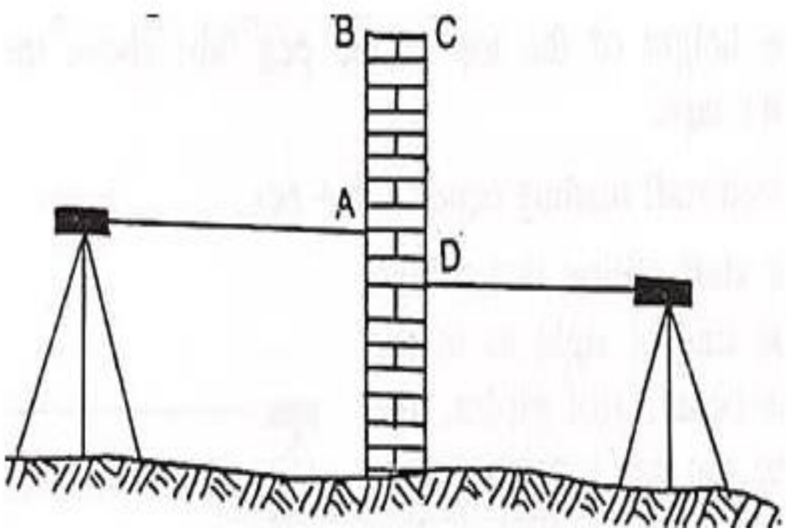
# Major Difficulties in Levelling



**Difficulty # 7. Levelling across Solid Obstruction like a Wall:**

The telescope is directed towards the wall where the line of sight cuts it)Measure height from this point 'A' to the top of the wall 'B' accurately with a steel tape. Find the R.L. of the top of the wall by adding the distance AB to the height of Instrument.

Shift the instrument to the other side of the wall and mark a point 'D' where the line of sight strikes it. Measure CD as before. The height of instrument in the second position is then equal to the R.L of the top of the wall minus CD. Then proceed as usual.



# Errors in Levelling



- Instrumental Error
- Personal Error
- Errors due to Natural Cause
- Error due to Earth's Curvature & Refraction

# Errors in Levelling



**Instrumental Error**

**Error in permanent adjustment of level :** For any major surveying work, instrument needs to be tested and if required, gets to be adjusted. For small works, bubble of the level tube should be brought to the centre before each reading and balancing of sights are to be maintained.

**Staff defective and/or of non-standard quality** : The graduation in staff may lack standard distance and thus may cause error in reading. In an ordinary leveling, the error may be negligible but in the case of precise leveling, the graduations are to be standardized with invar tape.

**Error due to defective level tube :** The bubble of the level tube may remain central even though the bubble axis is not horizontal due to its sluggishness or it may take considerable time to occupy central position, if it is very sensitive. Also, there may be irregularity in the curvature of the tube causing delirious effect.

**Error due to defective tripod :** The tripod stand should be strong and stable otherwise it causes setting of the instrument unstable and considerable time is required to make it level. The nuts provided at the joints of the legs to the tripod head should be well-tightened before mounting the instrument. The tripod should be set up on a stable, firm ground.

# Errors in Levelling



**Personal Error**

**Due to imperfection in temporary adjustment of the instrument**

These errors are caused due to careless setting up of the level, improper leveling of the instrument, lack in focus of eyepiece or/and objective and error in sighting of the staff.

**Careless set-up of the instrument:** If the instrument is not set up firmly, it gets disturbed easily. If the ground is not firm, it may settled down and on hard ground, it may get slipped.

**Imperfect leveling of the instrument** : Due to improper leveling of the instrument, bubble does not remain at the centre when the sights are taken resulting error in reading. To avoid the error, the bubble should be brought to the centre before each reading.

**Imperfect focusing** . If either the eye-piece or the objective or both are not properly focused, parallax and thus error in the staff readings occur. Due to movement of eyes if there is any apparent change in the staff reading the eye-piece and objective need proper focusing.

**Errors in sighting** : This occurs when the horizontal cross-hair does not exactly coincide with the staff graduation or it is difficult to see the exact coincidence of the cross hairs and the staff graduations. The error can be minimised by keeping the sight distance small

# Errors in Levelling



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**Error due to staff held Non-vertical** . If the staff is not held vertical, the staff reading obtained is greater than the correct reading. To reduce the error, the staff should be held exactly vertical or the staff man should be asked to waive the staff towards the instrument and then away from the instrument and the lowest reading should be taken.

**Errors in reading the staff:** These errors occur if staff is read upward, instead of downwards, read against the top or bottom hair instead of the central hair, mistakes in reading the decimal part and reading the whole meter wrongly.

**Errors in recording:** The common errors are entering a wrong reading (with digits interchanged or mistaking the numerical value of a reading called by the level man), recording in wrong column, e.g., B.S. as I.S., omitting an entry, entering the inverted staff reading without a minus sign etc.

**Errors in computing:** adding the fore sight reading instead of subtracting it and or subtracting a back sight reading instead of adding.

**Error due to Natural Cause**

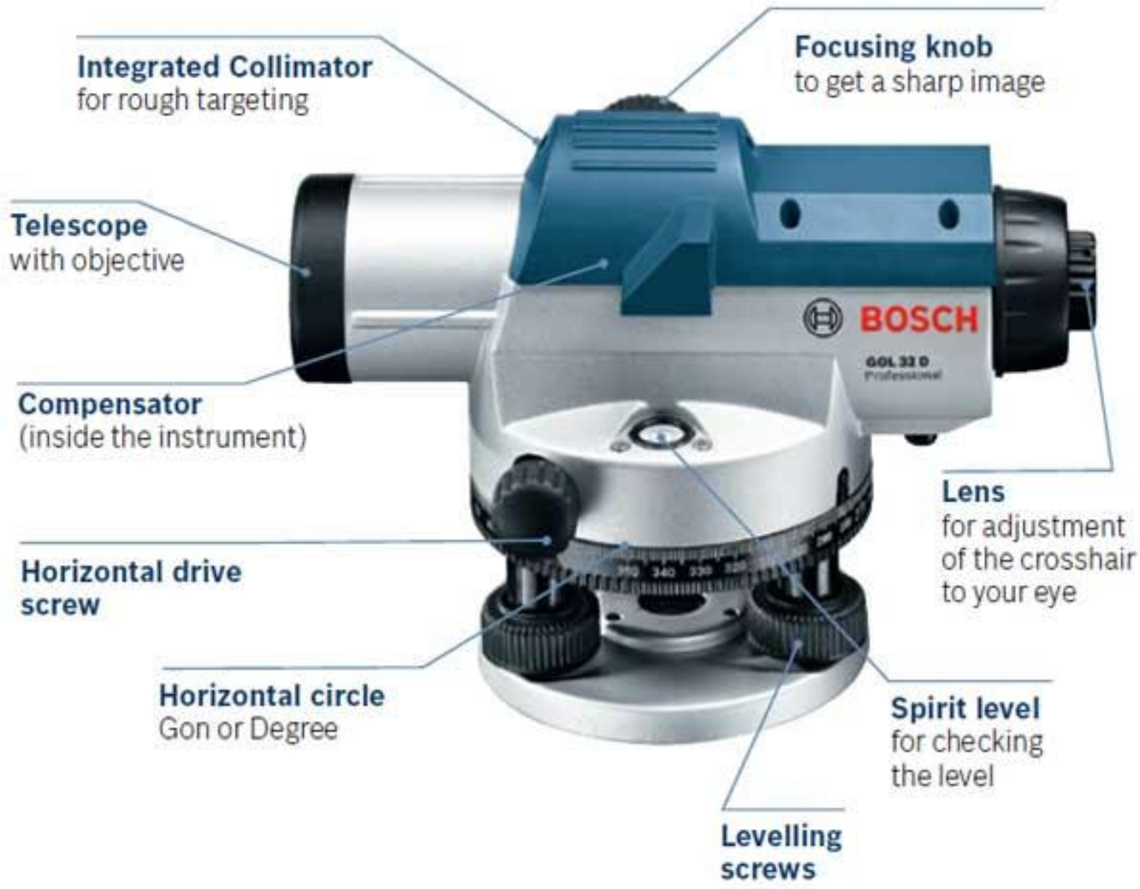
- ✓**Error due to curvature**
- ✓**Error due to refraction**

# AUTOMATIC LEVELS



Also known as **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. This reduces the need to set the instrument base truly level, as with a dumpy level

Self-levelling instruments are the preferred instrument on building sites, construction, and during surveying due to ease of use and rapid setup time. It's more difficult to get precise readings with a dumpy level. So if you want to get accurate measurements more quickly, an automatic level is a better choice.



# AUTOMATIC LEVELS



**Principle**

It gets its name from an internal compensation system which automatically maintains a horizontal LoS if the instrument is disturbed.

The compensation system uses a combinations of fixed and free swinging prisms and mirrors. When the instrument is tilted the compensation system reacts to maintain a horizontal sight line at the observer's end.

The stylized cross-sectional views in Figure shows how the incoming horizontal LoS is reflected and refracted and emerges at the eyepiece in a parallel path.

The instrument is leveled using a circular bubble. The etched circle on the bubble glass is a general indicator of the compensator's operating range. If the bubble is outside the circle, the compensator may be at its physical limit and unable to maintain a horizontal LoS.

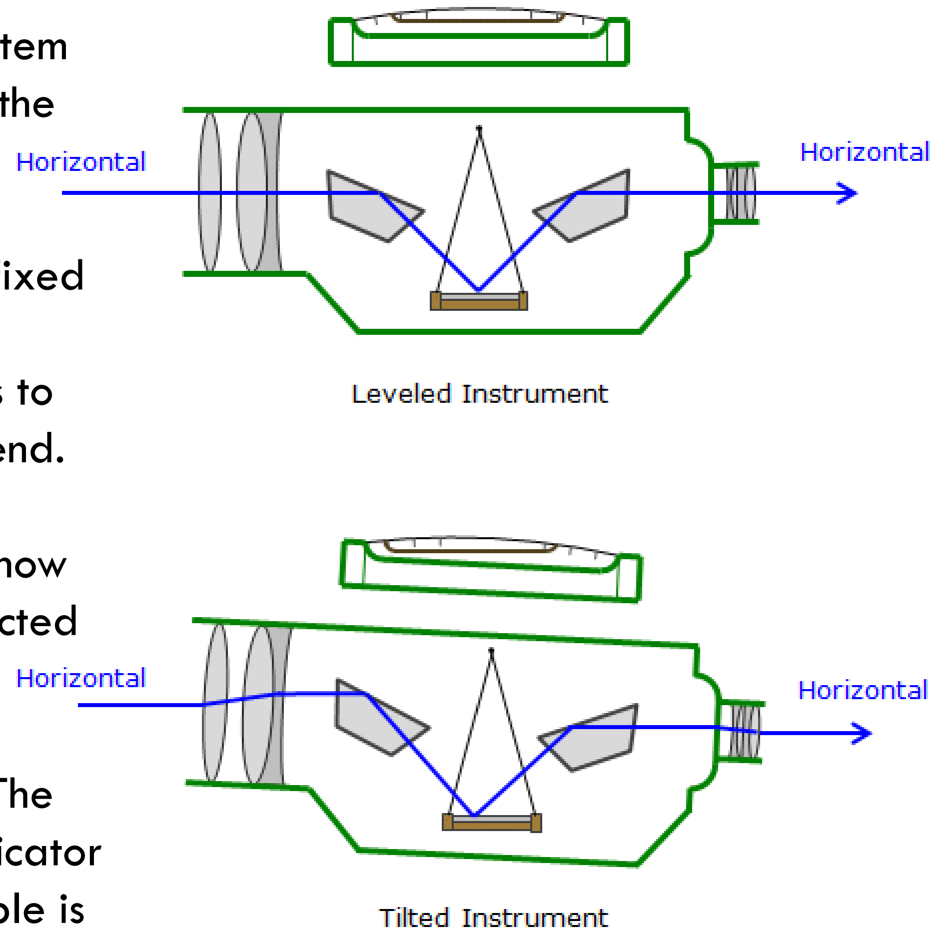



**Figure : Compensator Reacting**

# AUTOMATIC LEVELS



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***The main differences between an automatic level and a dumpy level:***

**Staff Readings** — The dumpy level reads the staff at an inverse proportion to what is shown, so you'll have to adjust your measurements accordingly. This isn't required for an automatic level, because the actual reading can be seen from the eyepiece.

**Bubble Adjustment** — To adjust the bubble on a dumpy level, you need to keep it parallel to the two leveling screws while it's at a right angle to the third. On an auto level, the bubble can be adjusted from any side and angle.

**Line of Sight Adjustment** — The line of sight has to be manually adjusted on a dumpy level, while the automatic builder's level has an internal compensator that does it automatically.

# AUTOMATIC LEVELS



**Advantages of Auto Level**

•Auto level is very easy to use.

•No adjustment for staff reading is required in auto level as the actual reading is seen from the eyepiece.

•The bubble can be adjusted from any side and any angle with any 3 screws available.

•The auto level has an internal compensator mechanism which automatically adjusts line of sight.

•The measurement accuracy of the auto level is higher.

•Auto level results are very reliable.

•Ease of use of auto level saves time and money.

•The price of the auto level is low and affordable.

**Disadvantages of Auto Level**

•Vertical angles cannot be measured.

•Horizontal angle is measured in the auto level is not very accurate.

# ELECTRONIC OR DIGITAL LEVELS



A **digital electronic level** is also set level on a tripod and reads a bar-coded staff using electronic laser methods. The height of the staff where the level beam crosses the staff is shown on a digital display.

This type of level removes interpolation of graduation by a person, thus removing a source of error and increasing accuracy. During night time, the dumpy level is used in conjunction with an auto cross laser for accurate scale readings.


# DIGITAL LEVELS



Traditionally various types of levels have been used for measurement of elevation differences such as

- dumpy level
- tilting level
- automatic level

Recently electronic digital levels have evolved as a result of development in electronics and digital image processing.

- Digital levels use electronic image processing to evaluate the special bar-coded staff reading.
- The observer is in effect replaced by a detector diode array, which derives a signal pattern from the bar-coded levelling staff.
- This bar-coded pattern is converted into elevation and distance values using a digital image matching procedure within the instrument.
- Automatic data conversion eliminates personal errors in reading the staff and the field data is stored by the instrument on its recording medium, thus further eliminating booking errors (**Schoffield, 2002**).

# DIGITAL LEVELS



**Salient features of digital levels**

A digital level offers the following advantages compared to the conventional levelling and recording procedures:

- ✓Correction of collimation error: Can be reliably determined and saved using the four integrated Check and Adjust procedures or it can be entered manually
- ✓Earth curvature correction: The measurements made are automatically free of the influence of the earth’s curvature.
- ✓Minimize human error :Fatigue-free observation as visual staff reading by the observer is not required.
- ✓User friendly menus with easy to read, digital display of results.
- ✓Measurement of consistent precision and reliability due to automation.
- ✓Automatic data storage eliminates booking and its associated errors.

# DIGITAL LEVELS



✓Automatic reduction of data to produce ground levels, thereby eliminating arithmetical errors.

✓Fast, economic surveys resulting in saving in time (up to 50% less effort has been claimed by manufacturers)

✓Data on the storage medium of the level can be downloaded to a computer enabling quick data reduction for various purposes.

✓Digital levels can also be used as conventional levels with the help of dual marked staff (bar coded on one side of the staff for automated reading and conventional graduation on other side of the staff) in case it is difficult to record readings digitally (e.g. for long distances).

# DIGITAL LEVELS



**Components of digital levels** *( from Schoffield 2002)*.

Main components of digital level consist of two parts: Hardware (Digital level and levelling staff) and Software.

**Digital levelling staff**

digital levelling staves have dual marking. One side is binary bar-coded for digital recording. For example, Sokkia SDL30 uses a RAB (RAndom Bi-directional Code) staff. The other side is marked as the conventional staff for conventional staff reading.

The staff is made from a glass-fiber-strengthened synthetic materia with low coefficient of thermal expansion for high accuracy. For highest precision work, Invar bar coded staves are also available.

**Digital level**

Typically digital level has the same optical and mechanical components as a normal automatic level.

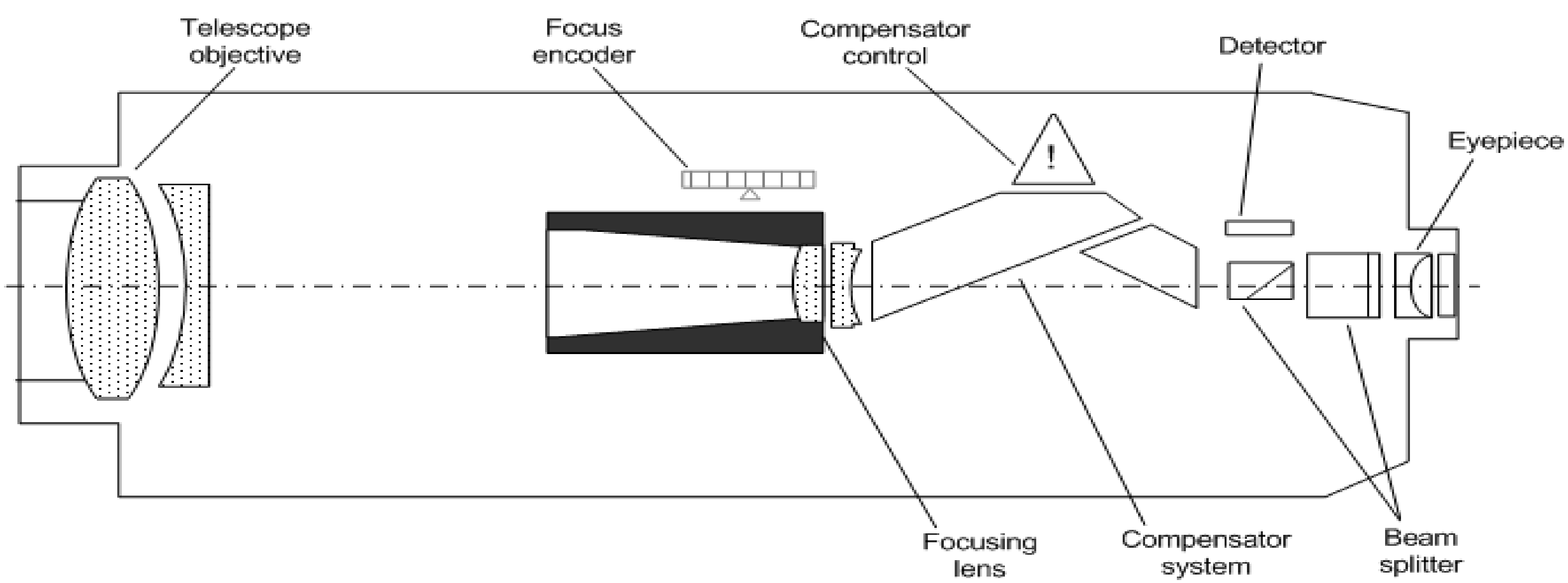
However, for the purpose of electronic staff reading a beam splitter is incorporated which transfers the bar code image to a detector diode array

# DIGITAL LEVELS



The light, reflected from the white elements only of the bar code, is divided into infrared and visible light components by the beam splitter. The visible light passes on to the observer, the infrared to diode array. The acquired bar code image is converted into an analogous video signal, which is then compared with a stored reference code within the instrument.

The image correlation procedure then obtains the height relationship by displacement of codes, while the distance from instrument to staff is dependent on the scale of code.




**Components of a typical digital level (Schoffield, 2002)**

# DIGITAL LEVELS



**Software**

The data processing is carried out on a microprocessor and the results are displayed on matrix display. The measurement process is initiated by an interactive keypad and data can be stored onboard.

Data from digital levels is stored onboard (e.g. REC module GRM10, GPC1 with NA2002/2003 or on PCMCIA cards with Topcon DL 101C/102C and DL 103/103AF) and can be transferred to computer for further processing.
For example, NA 2002 and 2003 from Leica Geosystems use DELTA/LEVNET software which can carry out adjustment, profiling, instrument tests, etc

**Examples a few digital levels :**Leica ,Topcon ,Trimble