Leveling

By

Dr .Balendra Mouli Marrapu

B.E (AU), M-Tech, PhD (IIT Roorkee)

Introduction

- It is the art of determining relative heights of different points on or below the surface of the earth is called LEVELLING,
- It deals with measurements in the vertical plane.
- For execution of Engineering Projects it is very necessary to determine elevations of different points along the alignment of proposed project.

Purpose of Levelling

- To prepare a contour map for fixing sites for reservoirs, dams etc. & to fix the alignment of roads, railways, irrigation canals etc.
- To determine the altitudes of different important points on a hill or to reduced levels of different points on or below the surface of the earth.
- To prepare a longitudinal & cross section of a project (roads, railways, irrigation canals etc) in order to determine the volume of earth work.
- To prepare a layout map for water supply , sanitary or drainage schemes.

Terms used in Levelling

Level Surface: The surface which is parallel to the mean spheroidal surface of the earth is known as level surface.

Level line – any line lying on a level surface is called a level line.

Datum Surface or line : This is an imaginary level surface or level line from which the vertical distances of different points (above or below this line) are measured.

Mean Sea Level (MSL): It is obtained by making hourly observations of the tides at any place over a period of 19 years. MSL adopted by Survey of India is now Bombay which was Karachi earlier.

Reduced Level (RL): The vertical distances or Height or depth of a point above or below the assumed datum is called Reduced level. It may be positive or negative.

Line of Collimation: It is the imaginary line passing through the intersection of the cross hairs at the diaphragm and the optical center of the object glass and its extensions, it is also called line of sight or collimation.

Axis of the Telescope: This axis is an imaginary line passing through the optical center of the object glass and the optical centre of the eye piece.

Bench Mark (BM): These are fixed reference point or marks of known elevation or RL determined with reference to the datum line.

These are very important marks. They serve as reference points for finding the RL of new points or for conducting levelling operations in projects involving roads, railways, etc.

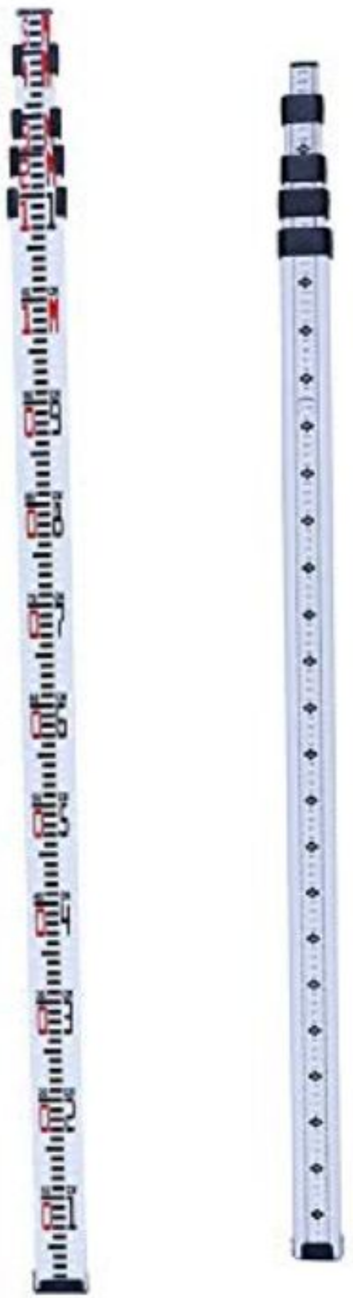
GTS Bench mark (Great Trigonometrical Survey): These Bench marks are established by national agency like Survey of India Department at a large interval all over the country (100 km. interval). They are established with highest precision. Their position and elevation above MSL is given in a special catalogue known as GTS Maps.

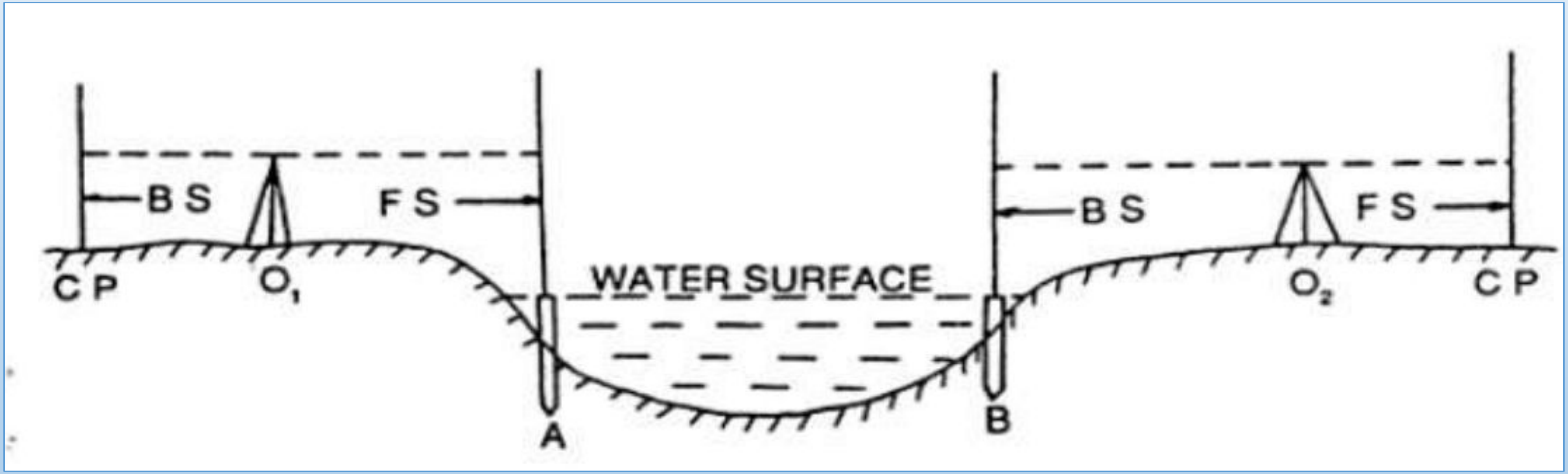
Permanent Bench Mark: These are fixed points or marks established by Government departments like PWD, Railway, Irrigation, etc. RLs of these points are determined with reference to GTS Bench mark (10 km. interval) & are kept on permanent points like the plinth of building, parapet of bridge or culvert etc.

Arbitrary Bench mark: When the RLs of some fixed points are assumed, they are termed arbitrary bench-marks. These are adopted in small survey operations.

Temporary Bench mark: When the Bench marks are established temporarily at the end of a day’s work, they are said to be temporary Bench mark . They are generally made on the root of tree, the parapet of a nearby culvert etc


SOKKIA




B S
F S
B S
F S
WATER SURFACE
C P
O1
A
B
O2
C P

Types of Levelling Equipments

- Dumpy level
- Tilting level
- Automatic level
- Digital Auto level

Tilting level

Automatic level

Advantage of automatic level

Much simpler to use

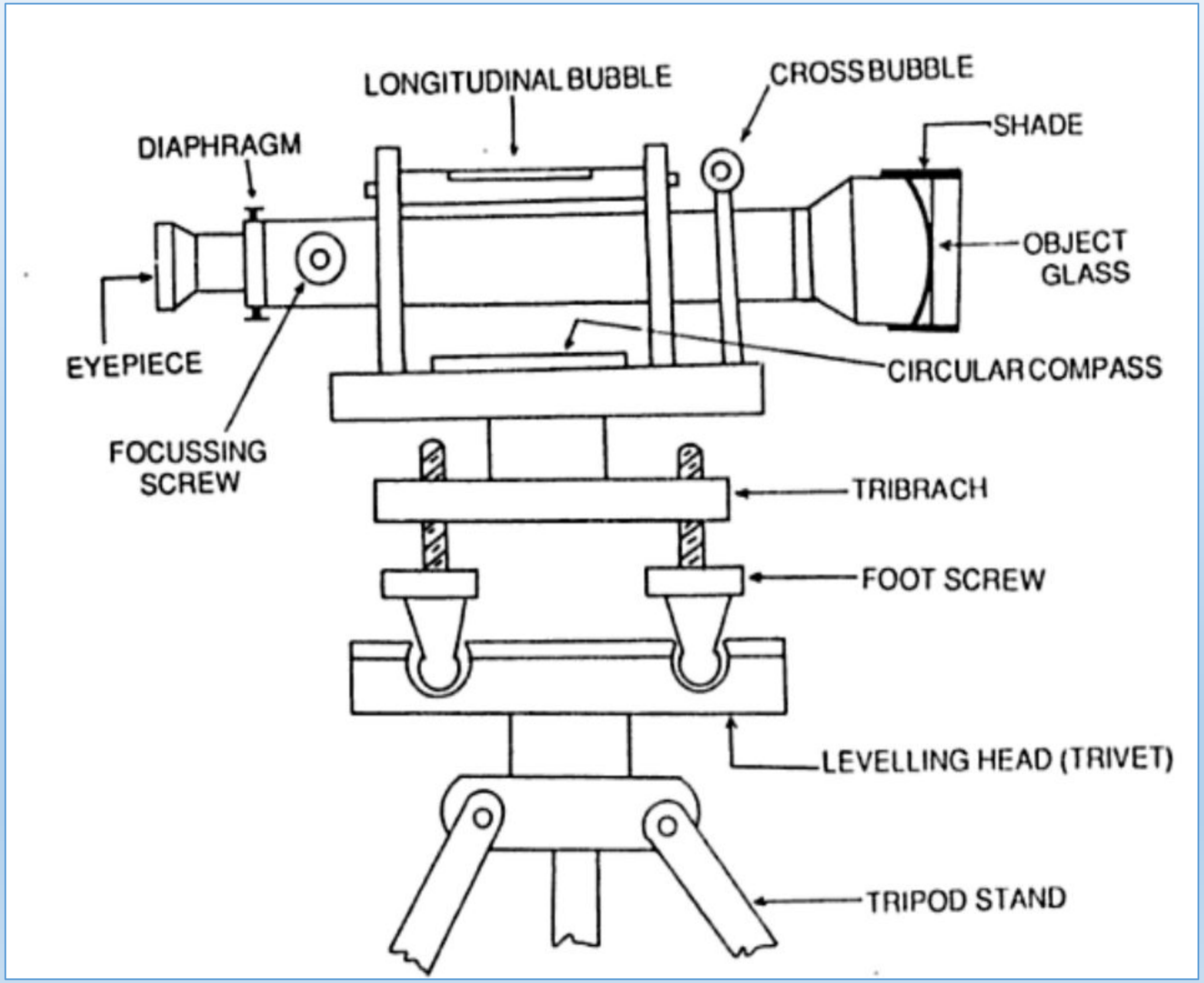
- **High precision:** Mean elevation error on staff graduated to 5mm division varies between +0.5 to 0.8 mm per km of forward and backward levelling.
- **High speed:** In fly levelling the progress achieved by various level-wise compared.

Dumpy level

It is simple compact and stable. The telescope is rigidly fixed to its support therefore cannot be rotated about its longitudinal axis. A long bubble tube is attached to the top of telescope.

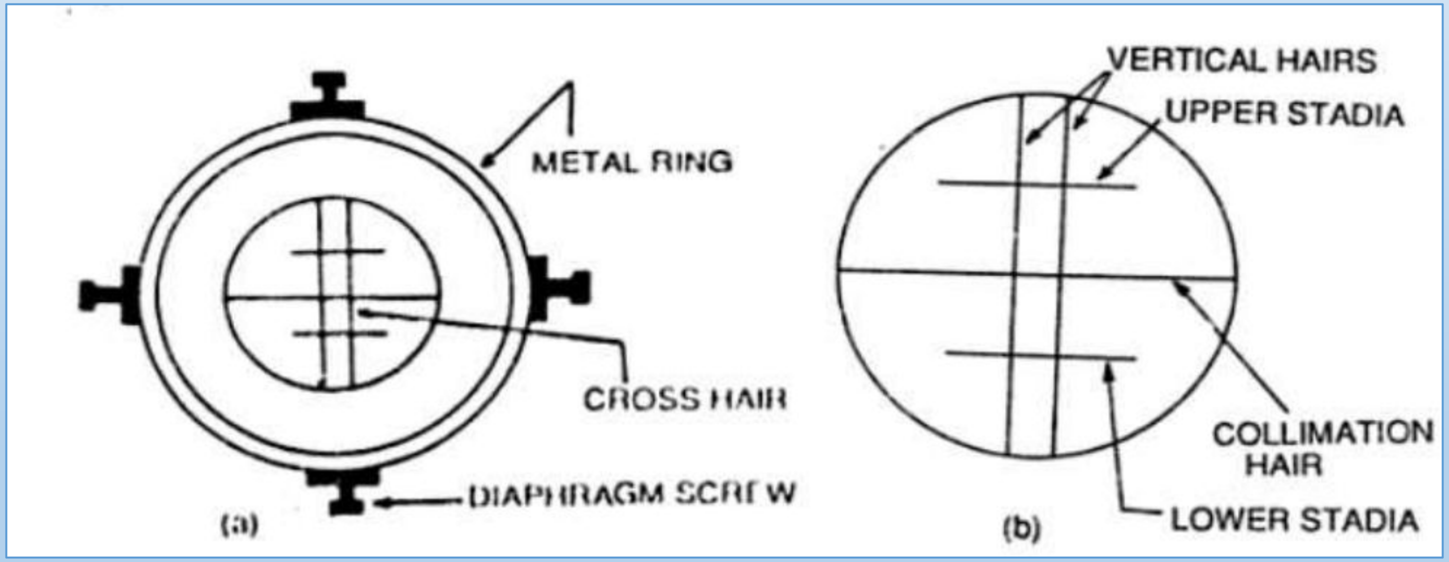
The instrument is stable and retains its permanent adjustment for long time. This instrument is commonly used

Dumpy level


LONGITUDINAL BUBBLE
CROSS BUBBLE
SHADE
DIAPHRAGM
OBJECT GLASS
EYEPIECE
CIRCULAR COMPASS
FOCUSSING SCREW
TRIBRACH
FOOT SCREW
LEVELLING HEAD (TRIVET)
TRIPOD STAND

Diaphram

A frame carrying cross hairs usually made of either silk thread or platinum wire and placed at the plane at which vertical image of the object is formed by the objective.



Components of Dumpy level

Tripod: The tripod stand consist of three legs which may be solid or framed to support the above three parts of the level.

Levelling head: Levelling head generally consists of two parallel plates with 3 foot screws. Upper plate is known as Tribrach and lower plate is trivet which can be screwed on to the tripod. Levelling head has to perform 3 distant functions :

- To support the telescope
- To attach the level to the tripod
- To provide a means for level (foot screws) to bring the bubble of tube level at the centre of its run.

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

Telescope: Telescope is an optical instrument used for magnifying and viewing the images of distant objects. It consists of two lenses. The lens fitted near the eye is called the eye piece and the other fitted at the end near to the object is called the objective lens.

Level Tube: Also known as Bubble Tube consists of a glass tube placed in a brass tube which is sealed with plaster of paris. The whole of the interior surface or the upper half is accurately ground so that its longitudinal section, is an arc of a circle. Level tube is filled with either or alcohol, the remaining space is occupied by an air bubble. The centre of air bubble always rest at the highest point of the tube.

Temporary Adjustment of Level

1. Selection of suitable position
2. Fixing level with tripod stand
3. Approximate levelling by legs of tripod stand
4. Perfect levelling by foot screws
5. Focussing the eye-piece
6. Focussing the object glass
7. Taking the staff readings

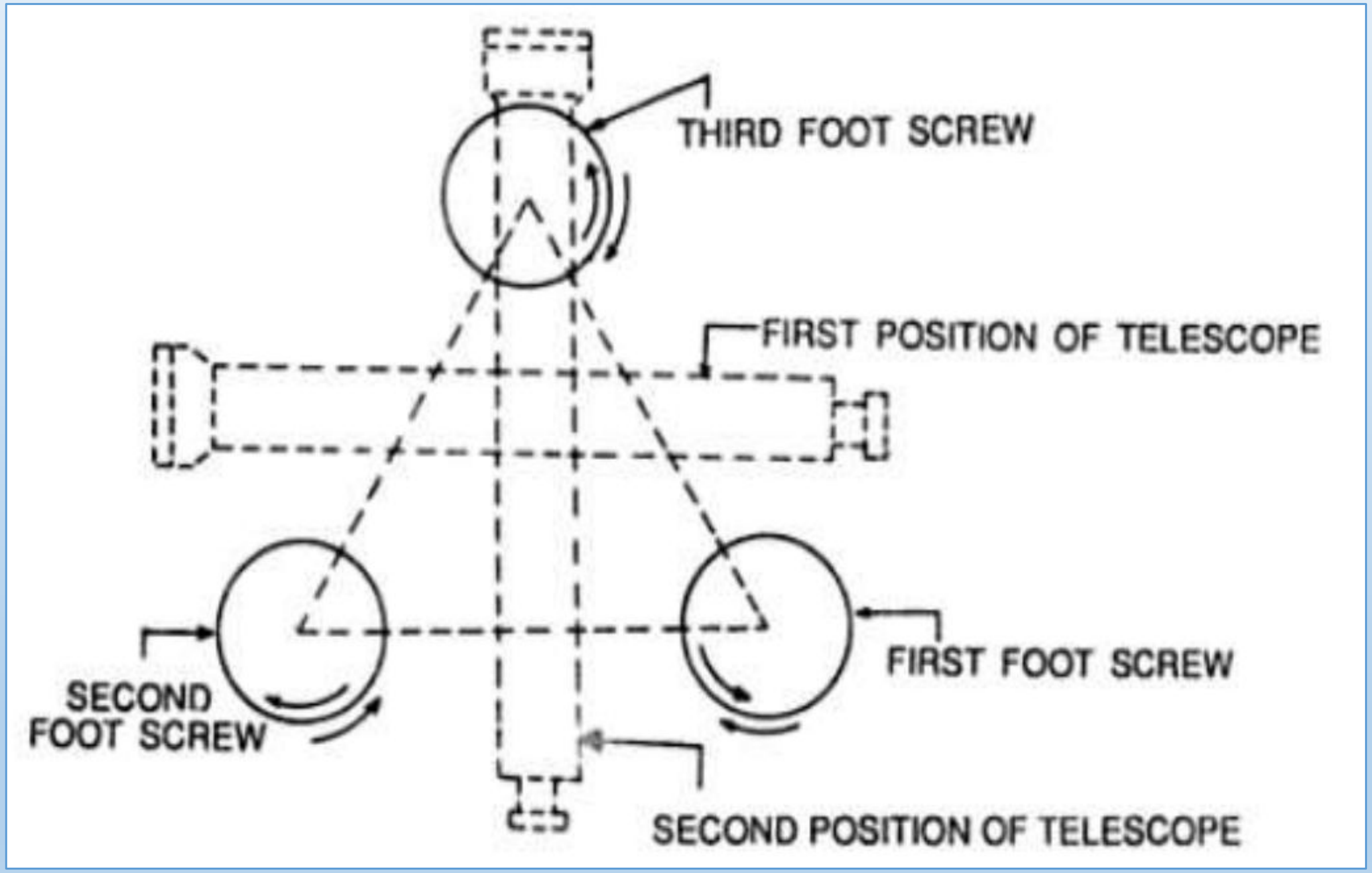
Temporary Adjustment of Level

Selection of suitable position: A sutaible position is selected for setting the level. From this position , it should be possible to take the greatest number of observation without difficulty.

Fixing level with tripod stand: The tripod stand is placed at the required position with its legs well apart, and pressed firmly into the ground. The level is fixed on the tripod stand according to the fixing arrangement provided.

Approximate levelling by legs of tripod stand: The foot screws are brought to the center of their run. Two legs of the tripod stand are firmly fixed into the ground. Then the third leg is moved to the left or right , in or until the bubble is approximately at the centre of its run.

Perfect levelling by foot screws: longitudinal bubble on the top of the telescope. Bubble brought to the center by turning the foot screw equally either both inward or outward. Then telescope turned through 90^0. And brought over the third foot screw , and the bubble is brought to the center by turning this foot screw clockwise and anticlockwise. The telescope again brought to its original position. And bubble to the centered the process repeated several times until bubble remain its central position.


THIRD FOOT SCREW
FIRST POSITION OF TELESCOPE
SECOND FOOT SCREW
FIRST FOOT SCREW
SECOND POSITION OF TELESCOPE

Focussing the eye-piece – a piece of white paper is held in front of the object glass and the eye piece is moved in or out by turning it clockwise or anticlockwise until the cross hairs can be seen clearly.

Focussing the object glass – telescope directed toward the levelling staff. Looking through the eye piece, the focusing screw is turned clockwise or antilock wise until the graduation of staff is visible.

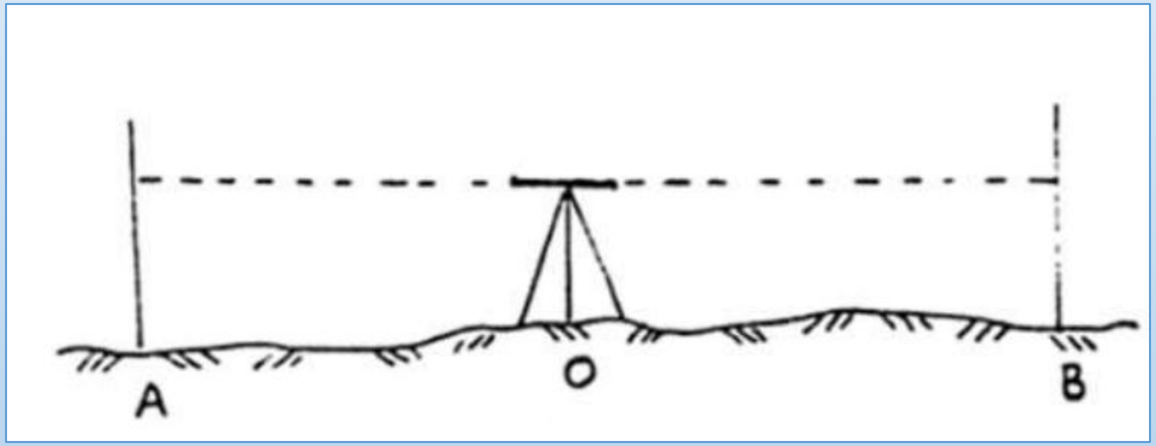
Taking the staff readings- finally the leveling of the instrument is verified by turning the telescope in any direction. When the bubble remain in the central position for any direction of the telescope.

Types of Levelling operation

- Simple levelling
- Differential Levelling
- Fly Levelling
- Longitudinal or Profile Levelling
- Cross-sectional Levelling
- Check Levelling

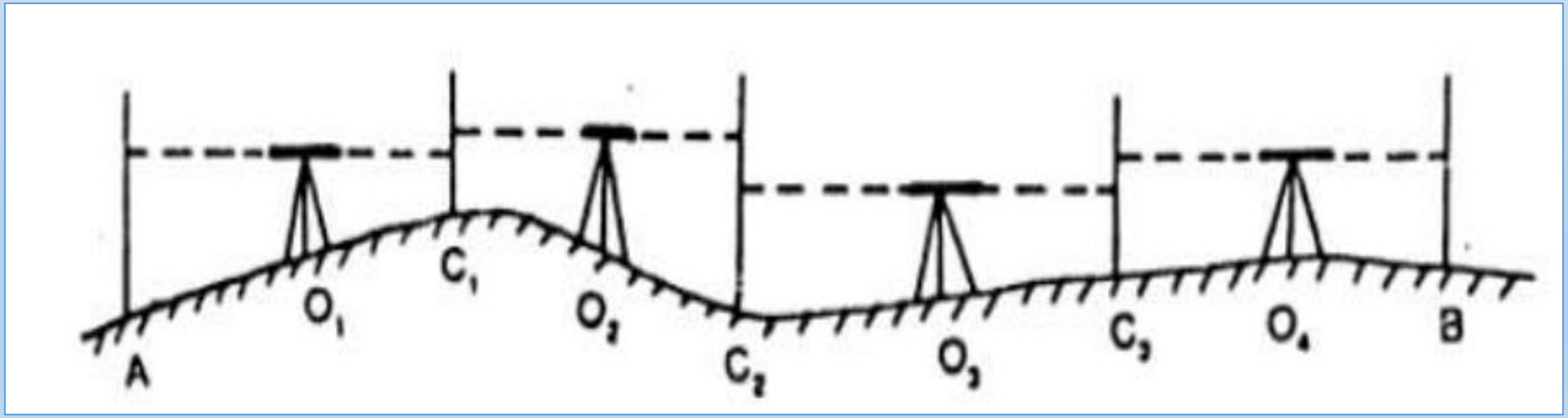
Simple levelling

When the difference of level between two points is determined by setting the levelling instrument midway between the points, the process is known as simple levelling.



Differential levelling

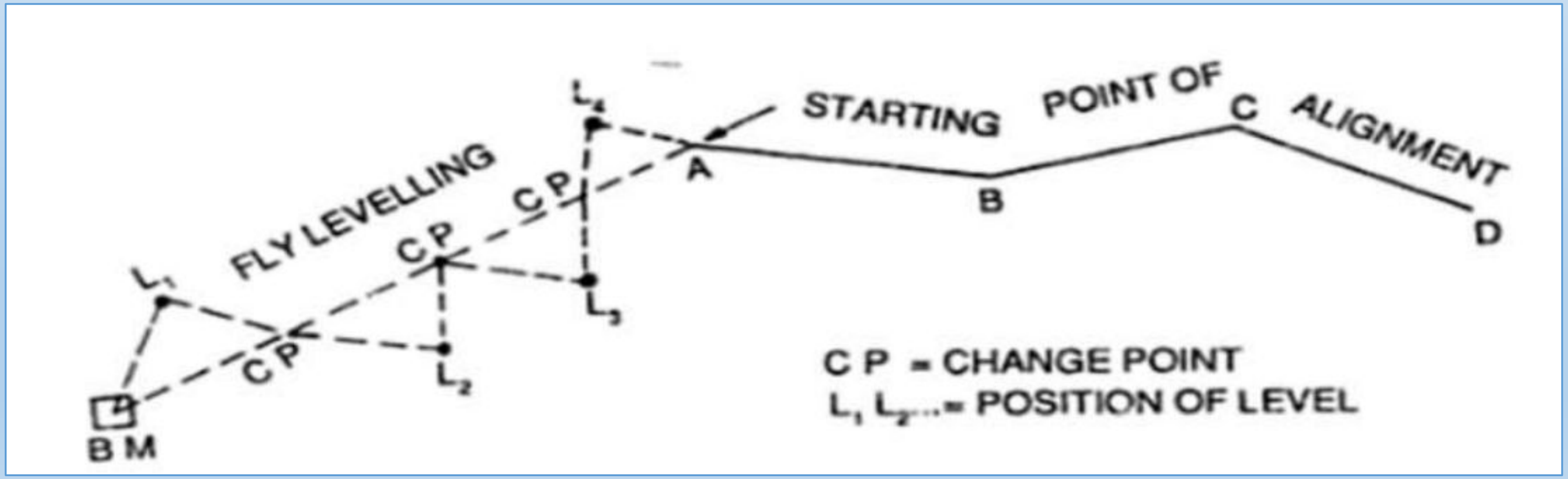
- If the difference in elevation between them is too great.
- If there are obstacles intervening. In such case it is necessary to set up the level in several positions and to work in series of stages.
- This method is also known as compound levelling or continuous levelling.



Fly levelling

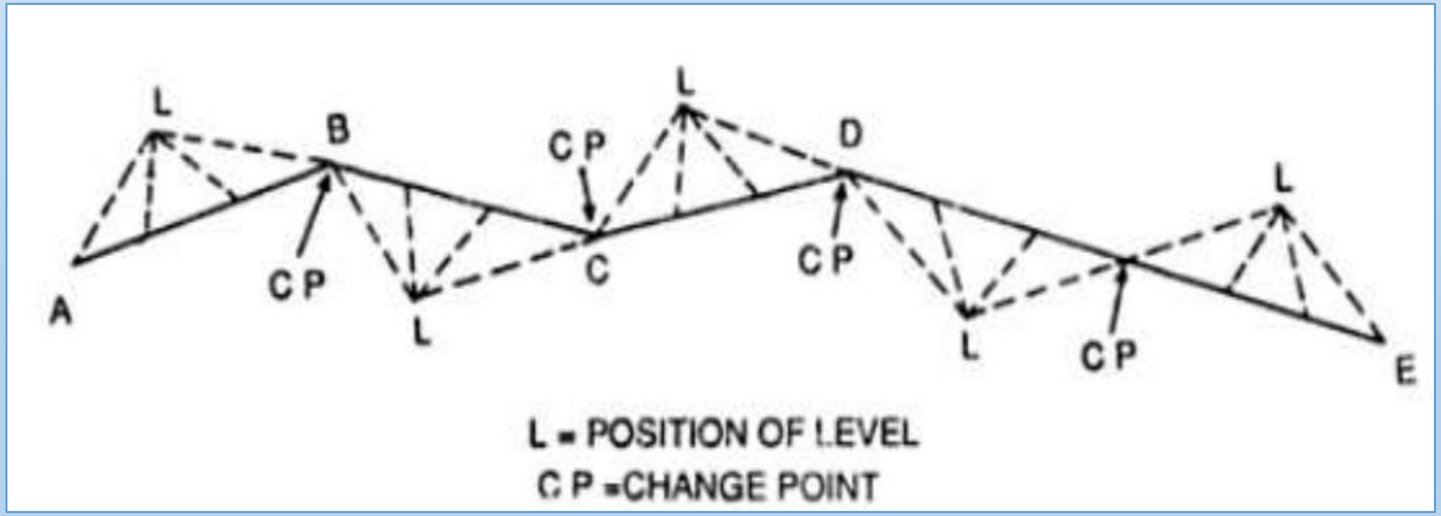
When Differential levelling is done in order to connect a bench mark to the starting point of the alignment of any project, it is called fly levelling.

Fly levelling is also done to connect the BM to any intermediate point of the alignment for checking the accuracy of the work.



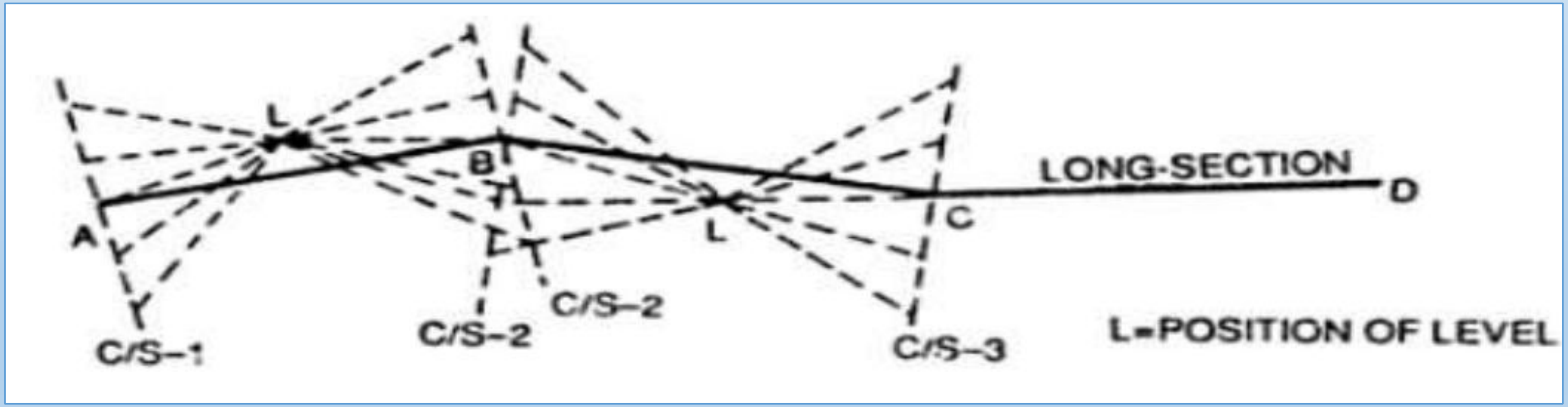
Longitudinal or profile levelling

The operation of taking levels along the centre line of any alignment (road, railway, etc.) at regular intervals is known as longitudinal levelling. This operation is undertaken in order to determine the undulations of the ground surface along the profile line.



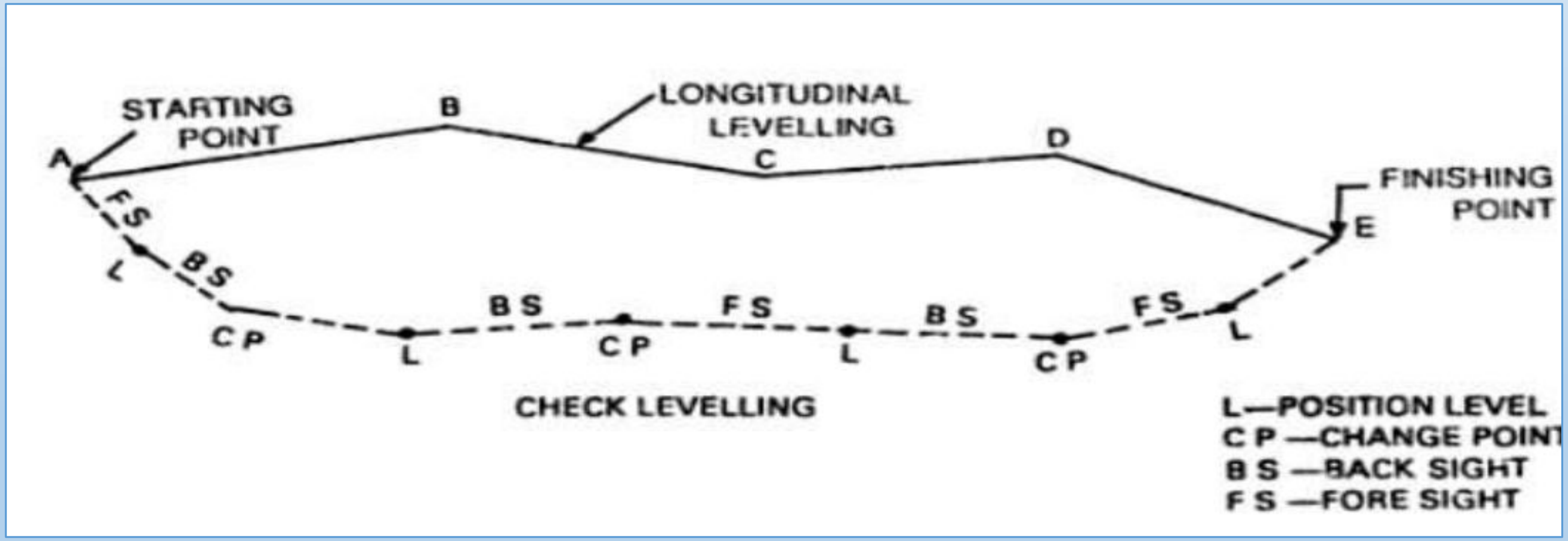
Cross Sectional levelling

The operation of taking levels transverse to the direction of longitudinal levelling is known as cross sectional levelling. This operation is undertaken in order to know the nature of the ground across the centre line of any alignment.



Check levelling

The fly levelling done at end of the day's work to connect the finishing point with the starting point on the particular day is known as check levelling. It is undertaken in order to check the accuracy of the day's work.



Station	A	B	C	D
F.B.	N 10°30’ E	N 80° W	S 40° W	S 80° E
B.B	N 81° W	S 11° W	S 80° E	N40°30’E

Example 6.8 The following staff readings were obtained when running a line of levels between two benchmarks A and B.

1.085 (A), 2.036, 2.231, 3.014, change point, 0.613, 2.003, 2.335, C.P., 1.622, 1.283, 0.543, C.P., 1.426, 1.795, 0.911.

Enter and reduce the readings in an accepted form of field book. The reduced levels of the bench marks at A and B were known to be 43.650 m and 41.672 m respectively.

It is found after readings have been taken with the staff supposedly vertical as indicated by a level on the staff that the level is 5° in error in the plane of the staff and instrument. Is the collimation error of the instrument elevated or depressed? What is its value in seconds if the backsights and foresights averaged 30 m and 60 m respectively? (L.U)

Example 6.8 The following staff readings were obtained when running a line of levels between two benchmarks *A* and *B*.

1.085 (A), 2.036, 2.231, 3.014, change point, 0.613, 2.003, 2.335, C.P., 1.622, 1.283, 0.543, C.P., 1.426, 1.795, 0.911.

Enter and reduce the readings in an accepted form of field book. The reduced levels of the bench marks at *A* and *B* were known to be 43.650 m and 41.672 m respectively.

It is found after readings have been taken with the staff supposedly vertical as indicated by a level on the staff that the level is 5° in error in the plane of the staff and instrument. Is the collimation error of the instrument elevated or depressed? What is its value in seconds if the backsights and foresights averaged 30 m and 60 m respectively? (L.U)

Distance	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
	1.085			44.735	43.650	A 43.650
		2.036			42.699	
		2.231			42.504	
	0.613		3.014		41.721	
		2.003			40.331	
	1.622		2.335		39.999	
		1.283			40.338	
	1.426		0.543		41.078	
		1.795			40.709	
			0.911		41.593	B 41.672
	Σ 4.746		Σ 6.803			

Example 6.8 The following staff readings were obtained when running a line of levels between two benchmarks *A* and *B*.

1.085 (A), 2.036, 2.231, 3.014, change point, 0.613, 2.003, 2.335, C.P., 1.622, 1.283, 0.543, C.P., 1.426, 1.795, 0.911.

Enter and reduce the readings in an accepted form of field book. The reduced levels of the bench marks at *A* and *B* were known to be 43.650 m and 41.672 m respectively.

It is found after readings have been taken with the staff supposedly vertical as indicated by a level on the staff that the level is 5° in error in the plane of the staff and instrument. Is the collimation error of the instrument elevated or depressed? What is its value in seconds if the backsights and foresights averaged 30 m and 60 m respectively? (L.U)

Example 6.8 The following staff readings were obtained when running a line of levels between two benchmarks *A* and *B*.

1.085 (A), 2.036, 2.231, 3.014, change point, 0.613, 2.003, 2.335, C.P., 1.622, 1.283, 0.543, C.P., 1.426, 1.795, 0.911.

Enter and reduce the readings in an accepted form of field book. The reduced levels of the bench marks at *A* and *B* were known to be 43.650 m and 41.672 m respectively.

It is found after readings have been taken with the staff supposedly vertical as indicated by a level on the staff that the level is 5° in error in the plane of the staff and instrument. Is the collimation error of the instrument elevated or depressed? What is its value in seconds if the backsights and foresights averaged 30 m and 60 m respectively? (L.U)

Distance	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
	1.085			44.735	43.650	A 43.650
		2.036			42.699	
		2.231			42.504	
	0.613		3.014		41.721	
		2.003			40.331	
	1.622		2.335		39.999	
		1.283			40.338	
	1.426		0.543		41.078	
		1.795			40.709	
			0.911		41.593	B 41.672
	Σ 4.746		Σ 6.803			

Table 6.13 Example 6.9

B.S.	I.S.	F.S.	Distance (m)	Remarks
3.417				B.M. 98.002 m
1.390		1.774	0	
	1.152		20	
3.551		1.116	40	Point *X*
0.732		1.088	60	
2.384		3.295	80	
	1.801		100	
	1.999		120	Point *Y*
1.936		2.637	140	Point *B*
		1.161		B.M. 100.324

B.S	I.S	F.S	H.I	R.L
3.417			101.419	98.002
1.390		1.774	101.035	99.645
	1.152			99.883
3.551		1.116	103.47	99.919 point X
0.732		1.088	103.114	102.382
2.384		3.295	102.203	99.819
	1.801			100.402
	1.999			100.204 Point Y
1.936		2.637	101.502	99.566 PotinB
		1.161		100.341
Σ 13.41		11.071		

98.002 − 100.341
−2.339

1.721
0.613
4.23
2.003
10.331

13.41
11.071
2.339

B.S.	I.S.	F.S.	Rise	Fall	R.L.	R.L. of sewer	Distance	Remark
3.417					98.002			
1.390		1.774	1.643		99.645	98.365	00	*A*
	1.152		0.238		99.883		20	
3.551		1.116	0.036		99.919	98.165	40	*X*
0.732		1.088	2.463		102.382		60	
2.384		3.295		2.563	99.819		80	
	1.801		0.583		100.402		100	
	1.999			0.198	100.204	97.765	120	*Y*
1.936		2.637		0.638	99.566		140	Point *B*
		1.161	0.775		100.341			B.M. 100.324
Σ 13.410		Σ 11.071	Σ 5.738	Σ 3.399				

$$\sum \text{B.S.} - \sum \text{F.S.} = 13.410 - 11.071 = 2.339$$

$$\sum \text{Rise} - \sum \text{Fall} = 5.738 - 3.399 = 2.339$$

$$\text{Last R.L.} - \text{First R.L.} = 100.341 - 98.002 = 2.339$$

Example 6.10 In running fly levels from a benchmark of R.L. 183.185, the following readings were obtained:

Backsight: 2.085, 1.025, 1.890, 0.625
Foresight: 1.925, 2.820, 0.890

From the last position of the instrument five pegs at 25 meters interval are to be set out on an uniformly falling gradient of line 100 with the 1st peg to have a R.L. of 182.350. Determine the staff readings required for setting the tops of the five pegs on the given gradient [AMIE, Summer 1986]

Solution The data and the required readings are given in a tabular form.

Table 6.15 Example 6.10

S. No.	Dist.	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
1		2.085			185.270	183.185	B.M.
2		1.025		1.925	184.370	183.345	
3		1.890		2.820	183.440	181.550	
4		0.625		0.890	183.175	182.550	
5	0		0.825			182.350	Peg 1
6	25		1.075			182.100	Peg 2
7	50		1.325			181.850	Peg 3
8	75		1.575			181.600	Peg 4
9	100			1.825		181.350	Peg 5
		$\Sigma 5.625$	$\Sigma 4.800$	$\Sigma 7.460$			

Check: $\sum$ B.S. $-$ $\sum$ F.S. $= 5.625 - 7.460 = -1.835$

Last R.L. $-$ 1st R.L. $= 181.350 - 183.185 = -1.835$

$\sum$ R.L. less the 1st $+ \sum$ I.S. $+ \sum$ F.S $= 1456.695 + 4.800 + 7.460$

$= 1468.955$

$\sum$ (Each instrument height $\times$ No. of I.S. and F.S. from it)

$= (185.27)(1) + (184.37)(1) + (183.175)(5)$

$= 1468.955$

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	2.285						B.M No. 1
2	1.650						
3		2.105					
4	×		1.960				
5	2.050		1.925		0.300		
6		×		×		232.255	B.M No. 2
7	1.690		×	0.340			
8	2.865		2.100				
9			×	×		233.425	B.M No. 3

The following consecutive readings were taken with a level and 3 m levelling staff on continuously sloping ground at a common interval of 20 m.

0.605, 1.235, 1.860, 2.575, 0.240, 0.915, 1.935, 2.875, 1.825, 2.725

The reduced level of the 1st point was 192.120. Rule a page of a level field book and enter the above readings. Calculate the reduced levels of the points and also the gradient of the line joining the first and last points. [AMIE, Summer 1987]

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	1.385					100.00	B.M.
2		1.430			×	×	
3		×			0.395	×	
4			1.275	×		×	T.P.1
5	0.630		0.585	0.310		×	T.P.2
6		0.920			×	100.13	
7		×			0.210	×	
8			1.740		×	×	

The following consecutive readings were taken with a level and 3 m levelling staff on a continuously sloping ground.
0.602, 1.234, 1.860, 2.574, 0.238, 0.914, 1.936, 2.872, 0.568, 1.824, 2.722
Determine the reduced levels of all the points of R.L. if first point was 192.122 m.

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remarks
1	2.150					450.000	B.M. 1
2	1.645		?	0.500			
3		2.345			?		
4	?		1.965	?			
5	2.050		1.925		0.500		
6		?		?		451.730	B.M. 2
7	– 1.690		?	0.120			Staff held against ceiling
8	?		2.100		?		
9			?	?		449.000	B.M. 3
Sum	8.445						

Height of collimation method and rise and fall method.

Height of collimation method	Rise and fall method
a.It is more rapid, less tedious and It is as it involves few calculation. involving	more laborious and tedious , simpler several calculations
There is no check on the RL of the intermediate points.	There is a check on the RL of the intermediate points.
Errors in intermediate RL's cannot be detected.	Errors in intermediate RL's can be detected.
There are two arithmetic checks on the accuracy of RL calculation. ?BS -?FS = Last RL -First RL.	There are three arithmetic checks on the accuracy of RL calculation. ?BS -?FS = ?Rise -?Fall =Last RL -First RL
It is suitable in the case of L.S and C.S, Contour etc.	It is suitable in fly leveling where I intermediate sights are less.

Curvature correction, Refraction correction and combined correction

Curvature correction $C_C = 0.07849\ d^2$ (negative) m

Refraction correction $C_r = 0.01121\ d^2$ (positive) m

Combined correction. $C = C_C - C_r = 0.06728\ d^2$ (negative) m.

Note:

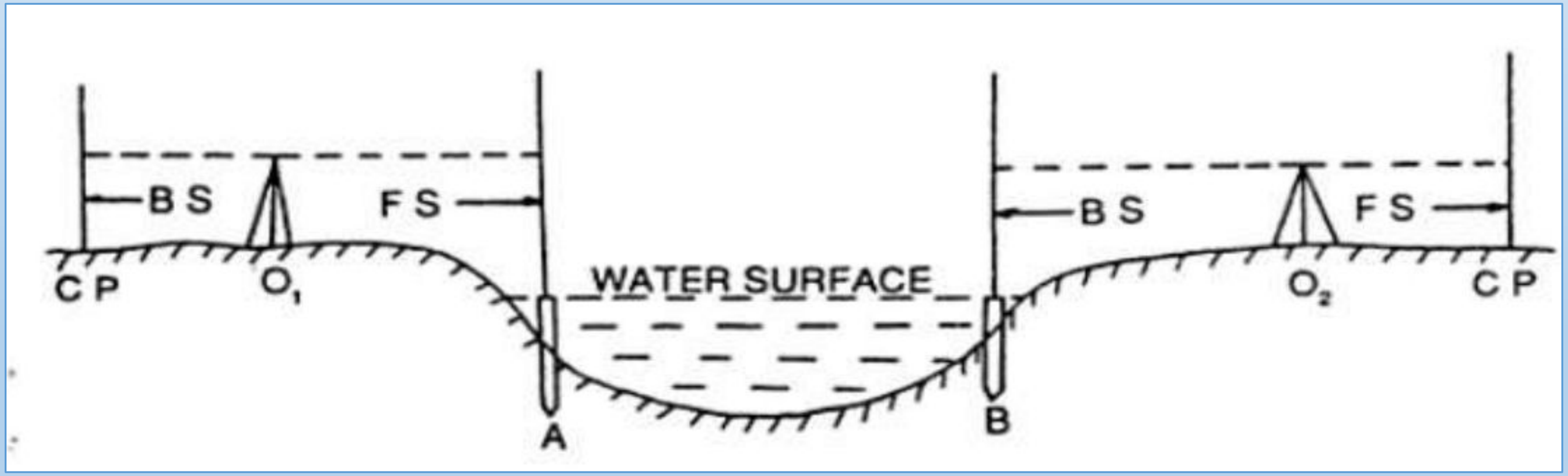
'd' is to be substituted in Km, while the corrections will be in m.

leveling problems.

- Levelling on Steep Slope.
- Levelling on Summits and Hollows.
- Taking Level of an Overhead Point.
- Levelling Ponds and Lakes too Wide to be Sighted across.
- Levelling across River.
- Levelling on Past High Wall.

Difficulties faced in levelling

- When the staff is too near the instrument
- Levelling across a large pond or lake
- Levelling across a river



Levelling across a large pond or lake

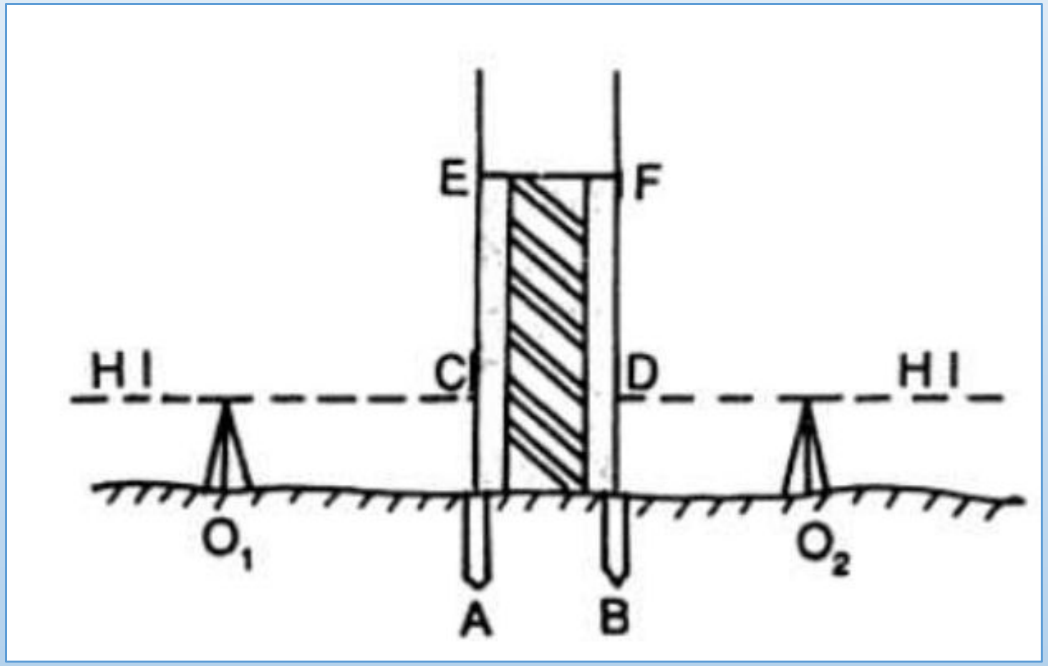
- We know that the water surface of still lake or pond is considered to be level.
- Therefore all points on the a water surface have the same R.L. Two peg A &B fix on opposite bank of the lake or pond.
- The top of the pegs are just flush with the water surface. The level is set up at O1 and RL of A is determined by taking FS on A. the RL of B is assume to be equal to that of A .
- Now the level is shifted and set up at O2 . Then by taking a BS on peg B, levelling is continued.

Levelling across a river

In case of flowing water , the surface cannot be considered level, the water level on the opposite edges will be different. In such case the method of reciprocoal levelling is aopted. Two peg A &B are driven in opposite banck of river.

Levelling across a solid wall

Two peg A &B are driven on either side of wall, just touching it. The level is set up at O1 and a staff reading is taken on A. let this reading be AC. Then then the height of wall is measured by staff . Let the height be AE. The HI is found out by taking a BS on any BM or CP



RL of A = HI – AC

RL of E = RL of A + AE = RL of F

RL of B = RL of F – BF

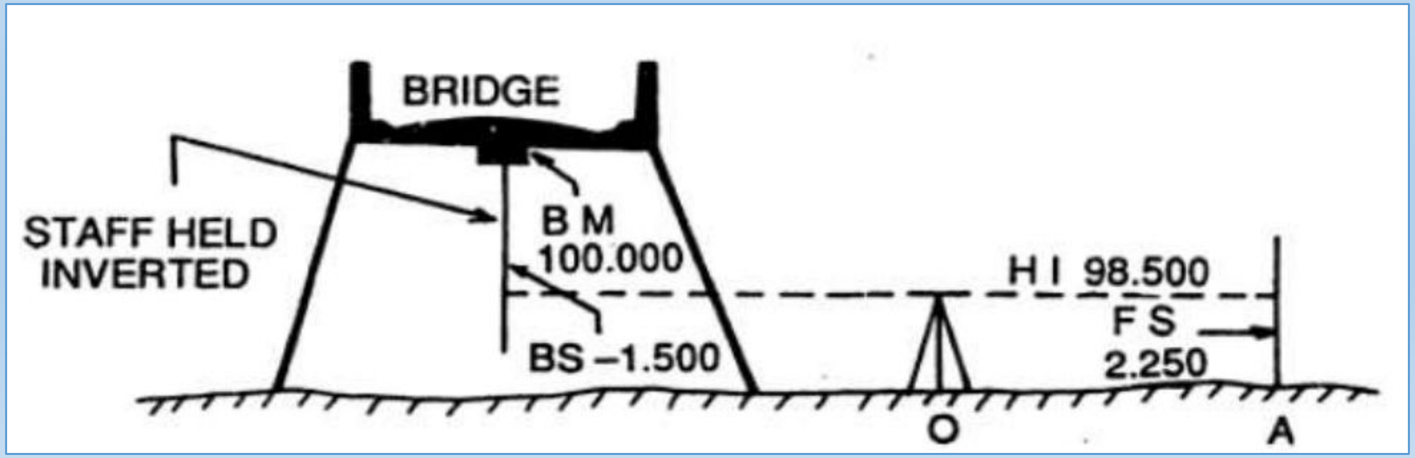
HI at O2 = RL of B + BD

When BM is above line of collimation

This happens when the BM is at the bottom of the bridge girder or bottom surface of the culvert. And that it is required to find out RL of A. the level is set up at O and staff is held inverted on the BM. The staff readig taken and noted with negative sign. Let BS & FS reading be – 1.5 and 2.250 respectively.

HI of instrument = 100 – 1.5 = 98.5

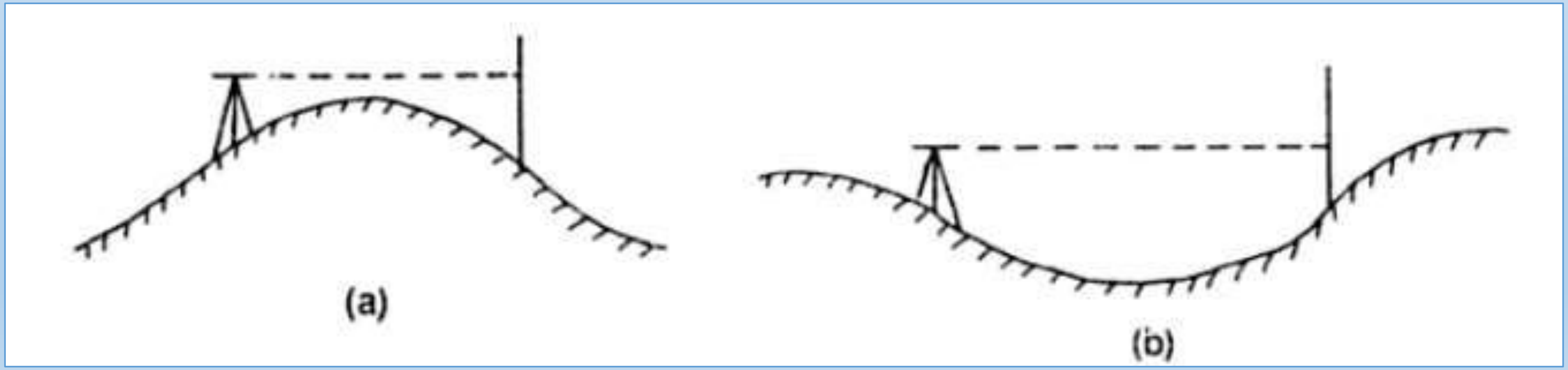
RL of A = 98.5 – 2.250 = 95.250



Levelling across a rising ground or depression

While levelling across high ground, the level should not be placed on the top of the ground , but on side so that the line of collimation just passes through the apex.

While levelling across a depression the level should be set up on one side and not at the bottom of the depression.



Sources of Errors in levelling

- Instrumental errors
- Personal errors
- Errors due to natural causes

Instrumental errors

- The permanent adjustment of the instrument may not be perfect. i.e. the line of collimation may not be parallel to the axis of the bubble tube.
- The internal arrangement of the focusing tube is not perfect.
- The graduation of the levelling staff may not be perfect.

Personal errors

- The instrument may not be levelled perfectly.
- The focusing of the eye-piece & object glass may not be perfect & the parallax may not be eliminated.
- The position of the staff may be displaced at the change point at the time of taking FS & BS readings.
- The staff may appear inverted when viewed through the telescope. By mistake, the staff readings may be taken upwards instead of downwards.
- The reading of the stadia hair rather than the central collimation hair may be taken by mistake.
- A wrong entry may be made in the level book.
- The staff may not be properly & fully extended.

Errors due to natural causes

- When the distance of sight is long, the curvature of the earth may affect the staff reading.
- The effect of refraction may cause a wrong staff reading to be taken.
- The effect of high winds & a shining sun may result in a wrong staff reading.

Factors affecting the sensitivity of a bubble

The sensitiveness of a bubble is defined the angular value of one division of the bubble tube. It means the capability of showing small angular movements of the tube vertically.

It can be increased by:

1. Increasing the internal radius of the tube.
2. Increasing the diameter of the tube.
3. Increasing the length of the tube.
4. Decreasing the roughness of the walls.
5. Decreasing the viscosity of the liquid.

Station	**A**	**B**	**C**	**D**	**E**
Line	AB	BC	CD	DE	EA
F.B.	80^0 10'	120^0 20'	170^0 50'	230^0 10'	310^0 20'
B.B.	259^0 0'	301^0 50'	350^0 50'	49° 30'	130^0 15'

Compute the interior angles and correct them for observational errors. Assuming the bearing of line CD is correct. Adjust the bearing of the remaining sides.

St^n	**Line**	**observed**		**Difference**	**IA**	**Corrected IA**	**Corrected**		**Remark**
		FB	**BB**				**FB**	**BB**	
A									
B									
C									
D									
E									