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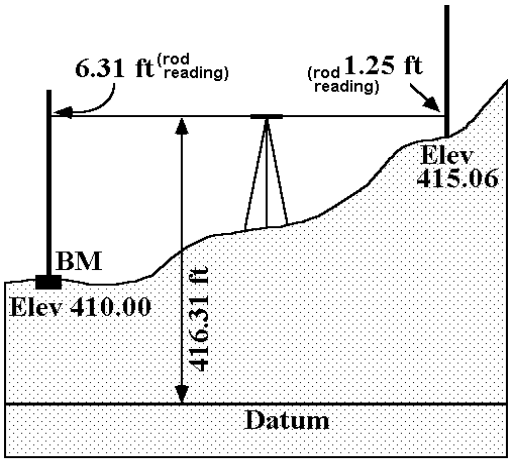
Engineering Surveying
Theory 4: Levelling: Definitions, Setting up and Booking

Introduction and Definitions

Levelling is the operation performed in surveying to determine and establish elevations of points, to determine differences in elevation between points and for control in construction works.

Terms and Definitions:

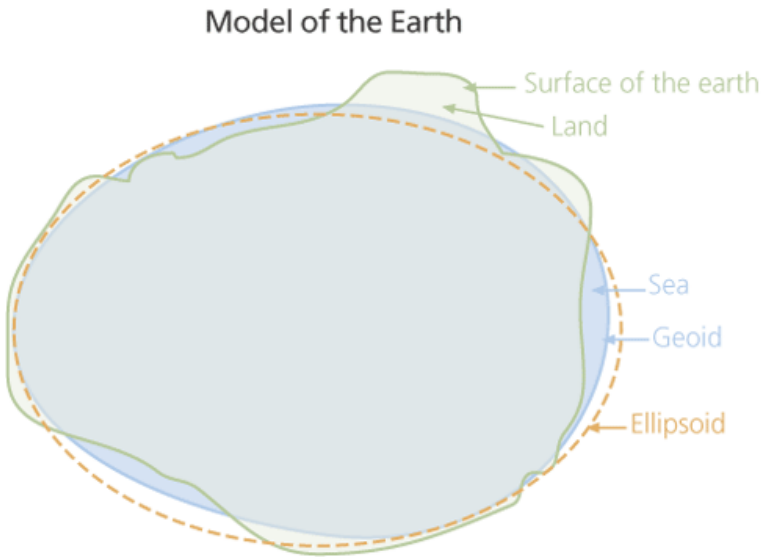
- **A mean sea level** is obtained by averaging the height of the surface of the sea for all stages of tides for a long period (usually 19 yrs). It is used as a reference datum.
- **The elevation** of a particular point is the vertical distance above or below a reference datum.
- **Difference in elevation** between two points is the vertical distance between the level surfaces in which the points lie.



Definitions

- **Benchmark (BM)** is a fixed point of known elevation above the datum. It is set as a survey marker in order to provide a starting point for the determination of the elevation of other points. A permanent object is used as a marker.
- **Reduced level (RL)** of a point is the height with respect to a datum. The term elevation or altitude is synonymously used depending on the datum use.
- **Datum:** Is any surface to which elevations are referred. The mean sea level offered a convenient world datum over, commonly given and so elevations are below sea level.

Introduction and Definitions



Methods of Levelling

Three principle methods are used for determining difference in elevation:

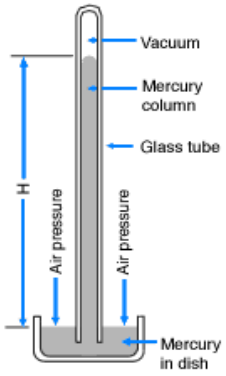
1. ***Barometric levelling:*** Measured atmospheric pressure. Not accurate, the pressure does not remain constant during the day. This method used for (Reconnaissance exploratory surveying)

Pressure difference in mercury = pgh

- P = mercury density
- g = gravitational attraction
- h = height of mercury

Pressure difference,Pair = pgh

- P = air density
- g = gravitational attraction
- h = height of a point



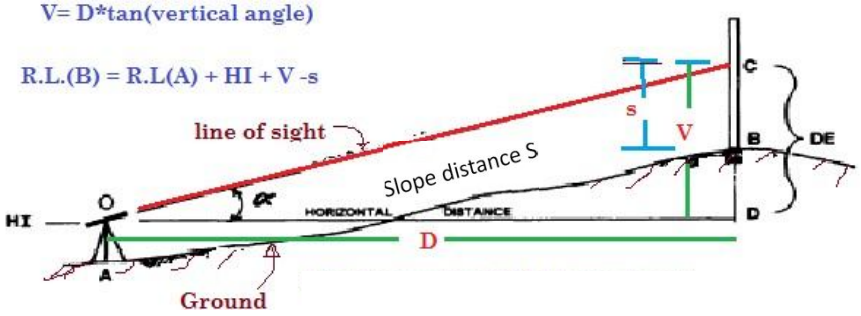
P_{atm}	Altitude	P_{atm}	Altitude
101.325 kPa	Sea Level (0m)	29.92 In Hg	Sea Level (0 ft)
97.71 kPa	305 m	28.86 In Hg	**1,000 ft**
94.21 kPa	610 m	27.82 In Hg	**2,000 ft**
89.88 kPa	**1,000 m**	26.55 In Hg	3,281 ft
84.31 kPa	1,524 m	24.90 In Hg	**5,000 ft**
79.50 kPa	**2,000 m**	23.48 In Hg	6,562 ft
69.68 kPa	3,048 m	20.58 In Hg	**10,000 ft**
54.05 kPa	**5,000 m**	15.96 In Hg	16,404 ft
46.56 kPa	6,096 m	13.75 In Hg	**20,000 ft**
37.65 kPa	7,620 m	11.12 In Hg	**25,000 ft**
32.77 kPa	8,848 m*	9.68 In Hg	29,029 ft*
26.44 kPa	**10,000 m**	7.81 In Hg	32,808 ft
11.65 kPa	15,240 m	3.44 In Hg	**50,000 ft**
5.53 kPa	**20,000 m**	1.63 In Hg	65,617 ft

Methods of Levelling

2. Trigonometry levelling (Indirect method): It is the process of levelling in which the elevations of points are computed from the vertical angle and horizontal distances measured in the field, it is called (Stadia levelling).

V= D*tan(vertical angle)

R.L.(B) = R.L(A) + HI + V -s



Measured:

α: *Vertical angle.* **D**: *Horizontal distance.* **Hi**: *Height of instrument*

V: *Height of target.* **S**: *Slope distance.*

−**Required**: **Find V**?

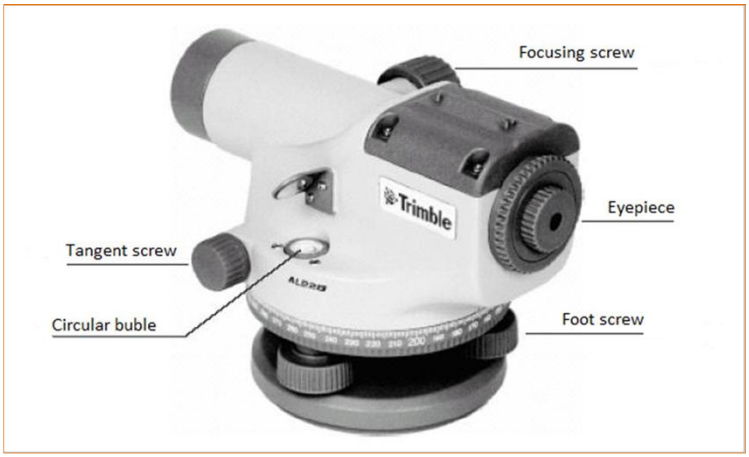
$V = S \times Sin\,\alpha$ $Or, V = D \times Tan\,\alpha$

Level Instrument

3. Direct method by using (Level instrument and staff).

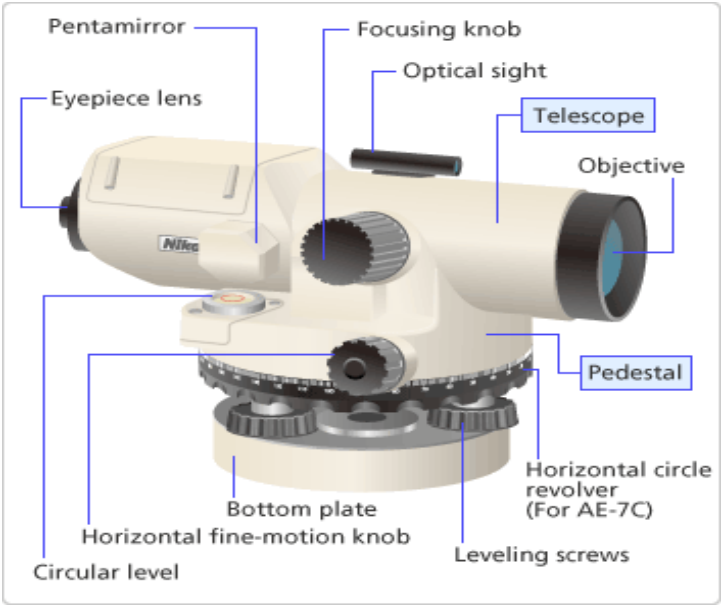
Our Subject:

1. Level instrument:



Level Instrument

Level Instrument



Types of Level

1. **Dumpy level:** is an optical surveying leveling instrument consisting a telescope tube firmly secured in two collars fixed by adjusting screws to the stage by the vertical spindle.

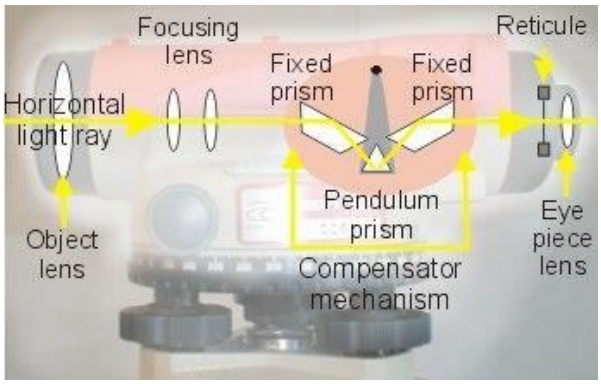
Types of Level

2. **Tilting level:** It consists of a telescope attached with a level tube which can be tilted within few degrees in vertical plane by a tilting screw.

3. **Digital level:** Digital levels read a bar-code staff electronically and display the read-out for the user to write down. Some digital levels also record the measurements automatically,removing the need to write down the measurements and reducing the chance of human error.

Types of Level

4. **Automatic level:** is a Professional Leveling Tool used by Contractors, Builders, Land Surveying Professionals, or the Engineer who demands accurate leveling every time. Auto levels set up fast, are easy to use, and save time and money on every job. The basic principle of optical leveling is to create a line of sight through the telescope that is normal to the direction of gravity at that point.



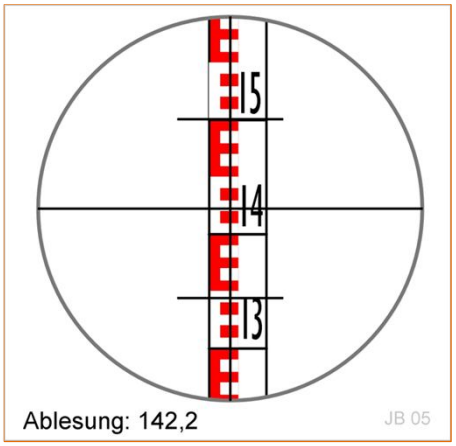
Level Instrument

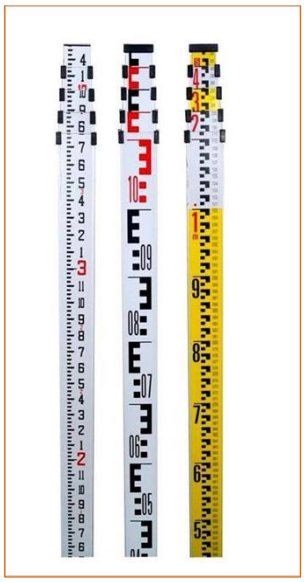
2. Tripod: A tripod is a three-legged stand used to support a level.

3. Level staff:

- The vertical distance above or below the horizontal surface is read off a levelling staff. It may be either telescope or folding extending to a length of 4m or 5m.
- The staff must be held vertically as any leaning of the staff will result in a level reading which is too great.
- The material of level staff maybe steel, wood or aluminium.

Level Staff





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Setting up of level

LevelAdjustment:

The following steps are taken when using a level to measure heights

1. Set up the tripod.
2. Ensure the top is level.
3. Push legs firmly into the ground.
4. Attach level.
5. Use foot screws to centralise the circular bubble: The three-screw instrument can be manipulated by moving the screws one at a time, or at least two at a time. After the bubble has been cantered, the instrument can be revolved to check that the circular bubble remains cantered.
6. Test to see if the compensator is working.
7. Remove parallax.

- Once the level is set up its important that the line of sight is horizontal. When the foot screws have been used to centralise the circular bubble, it is assumed that the compensator has set the line of sight to be horizontal.
- If the line of sight is not horizontal when the instrument has been levelled, the level has a collimation error.

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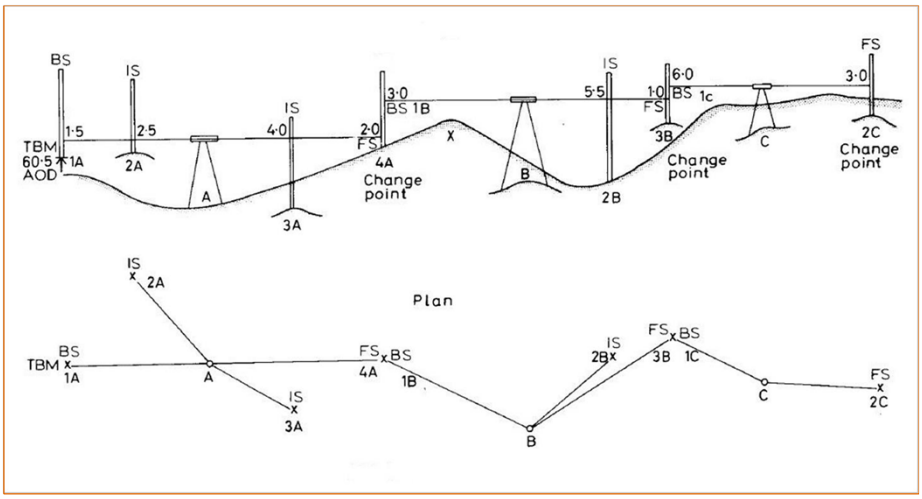
Principles of Levelling

- Terminologies:

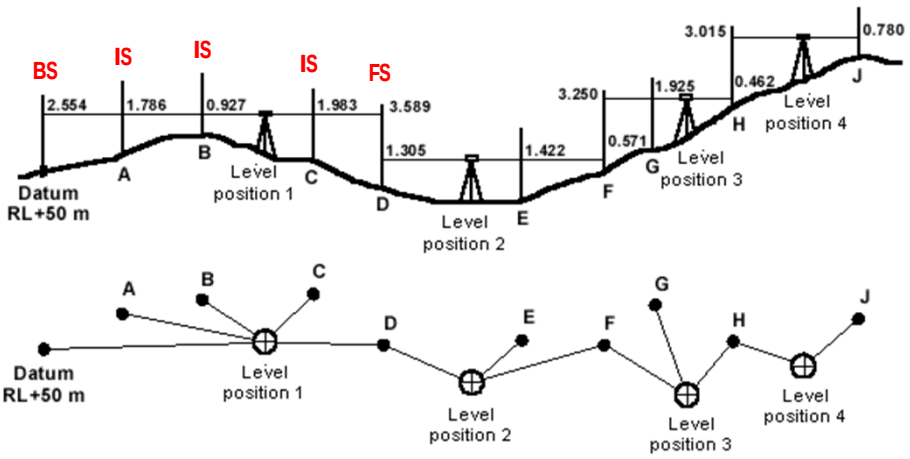
- ***Bench mark (B.M.):*** Is permanent point with known elevation. They are bronze disks or plugs set usually into vertical wall faces.
- ***Temporary bench mark (T.B.M.):*** Is a semi-permanent point of known elevation (nail of street, corner of building, etc.).
- ***Back sight (B.S.):*** Is a rod reading taken a point of known elevation, to establish the elevation of the instrument line of sight.
- ***The height of instrument (HI)*** is the elevation of the line of sight through the level ($HI = BM + BS$).
- ***Foresight (F.S.):*** A rod reading taken on turning point, bench mark, or temporary bench mark to determine its elevation ($HI - FS = elevation\ of\ TP$).
- ***Turning point (T.P.):*** Is a point temporary used to transfer an elevation.
- ***Intermediate sight or foresight (I.S or I.F.S)*** is a rod reading taken at any other point where the elevation is required ($HI - IS = elevation$).

- Note: The rod must be vertical.
- Note: Lower reading will occur when rod is plumb (when the rod perpendicular to the line of sight).

Figure



Figure



Levelling

Construction and use of bench marks:

- Bench marks are permanent reference marks or points whose reduced levels are accurately determined by levelling.They are classified into two namely:

1. Permanent or Ordinance bench marks (OBM), and
2. Temporary or transferred bench marks (TBM)

Methods of Levelling for Booking

There are two methods of levelling for booking and reducing of elevation (level) of points from the observed staff readings (data).The methods are as follows:

1. Collimation Method or Height of Instrument (HI) method:

- In this method each section highlighted by different shades is determined by adding the elevation of the point to the back sight reading taken at that point. The **H.I. remains unchanged** for all the staff readings taken within that section and therefore, the levels of all the points lying in that section are reduced by subtracting the corresponding staff readings, i.e., I.S. or F.S., from the H.C. of that section.

- $H.I = Elev.B.M. + B.S.$
- $Elev.T.P = H.I. - F.S.$
- $Elev.Point = H.I. - I.S.$

Field Book Format (HI Method)

1. Standard levelling field book format (HI method):

Location	Date	Observer	Booker	Temp.	Weather

Station	B.S.	I.S.	F.S.	H.I.	R.L.	Remark
A	0.628			**100.628**	100.000	B.M.
B		1.564		**100.628**	**99.064**	
C		1.000		**100.628**	**99.628**	
D	2.259		1.210	**101.677**	**99.418**	
E			0.991		**100.686**	
Summation	**2.887**		**2.201**			

$HI = BS + \text{RL}$, $Elev. = HI - F.S \text{ or } I.S$

$for\ checking$: $\sigma\ B.S. - \sigma\ F.S. = R.L\ (last) - R.L\ (first)$ **= 0.686**

2. Rise and Fall method:

In this method, the rises and the falls are found out for the points lying within each section. Adding or subtracting the rise or fall to or from the reduced level of the backward station obtains the level for a forward station.

- $\Sigma B.S. - \Sigma F.S. = \Sigma Rise - \Sigma Fall = Last\ R.L. - First\ R.L.$
- $Rise\ or\ fall = B.S. - F.S. = B.S. - I.S. = I.S. - I.S. = I.S. - F.S.$
- $R.L. = R.L.\ latest + (Rise + or\ fall -)$

Location	Date	Observer	Booker	Temp.	Weather

Station	B.S.	I.S.	F.S.	Rise	Fall	R.L.	Remark
A	0.628					100.000	B.M.
B		1.564			**0.936**	**99.064**	
C		1.000		**0.564**		**99.628**	
D	2.259		1.210		**0.210**	**99.418**	
E			0.991	**1.268**		**100.686**	
Summation	**2.887**		**2.201**	**1.832**	**1.146**		

Example (1):

Find the R.L. of the points from the following staff readings tabulated in the table below?

Solution:

- **HI method:**

Station	B.S.	I.S.	F.S.	HI	R.L.	Remark
A	0.865				560.500	B.M.
B	1.025		2.105			T.P.
C		1.58				
D	2.230		1.865			T.P.
E	2.355		2.835			T.P.
F			1.760			
Σ						

- $HI = B.S. + F.S.$
- $Elev. = HI - F.S.\ or\ I.S.$

Solution

Station	B.S.	I.S.	F.S.	HI	R.L.	Remark
A	0.865			**561.365**	560.500	B.M.
B	1.025		2.105	**560.285**	**559.260**	T.P.
C		1.58			**558.705**	
D	2.230		1.865	**560.650**	**558.420**	T.P.
E	2.355		2.835	**560.170**	**558.815**	T.P.
F			1.760		**558.410**	
Σ	**6.475**		**8.565**			

$$For\ checking\colon\ \Sigma\, B.S. - \Sigma\, F.S.$$

$$= R.L.last\ -\ R.L.first$$

$$6.475 - 8.565\ =\ 558.41 - 560.500$$

$$-2.09\ = -2.09\ OK.$$

Example 2: same as example 1

- Rise and fall method:

Station	B.S.	I.S.	F.S.	Rise +	Fall	R.L.	Remark
A	0.865					560.500	B.M.
B	1.025		2.105				T.P.
C		1.58					
D	2.230		1.865				T.P.
E	2.355		2.835				T.P.
F			1.760				
Σ							

- $\boldsymbol{Rise\ or\ fall\ =\ B.S. - F.S. =\ B.S. - I.S. =\ I.S. - I.S. =\ I.S. - F.S.}$
- $\boldsymbol{R.L. = R.L.latest\ +\ (Rise\ +\ or\ fall -)}$

Solution:

Station	B.S.	I.S.	F.S.	Rise +	Fall -	R.L.	Remark
A	0.865					560.500	B.M.
B	1.025		2.105		**1.240**	**559.260**	T.P.
C		1.58			**0.550**	**558.705**	
D	2.230		1.865		**0.285**	**558.420**	T.P.
E	2.355		2.835		**0.605**	**558.815**	T.P.
F			1.760	**0.595**		**558.410**	
Σ	**6.475**		**8.565**	**0.595**	**2.68**		

- $\boldsymbol{For\ checking: \Sigma B.S. - \Sigma F.S. = R.L.last - R.L.first = \Sigma Rise - \Sigma fall}$
- $\boldsymbol{6.475 - 8.565 = 558.41 - 560.500 = 0.595 - 2.68}$
- $\boldsymbol{-2.09 = -2.09 = -2.09\ O.K.}$

Example (3): Find the R.L. of the points from the following data, using HI method?

Station	B.S.	I.S.	F.S.	HI	R.L.	Remark
1	1.622				83.198	B.M.
2	1.874		0.354			T.P.
3	2.032		1.780			T.P.
4		2.362				
5	0.984		1.122			T.P.
6	1.906		2.824			T.P.
7			2.036			
Σ						

- $\boldsymbol{HI = B.S. + F.S.}$
- $\boldsymbol{Elev. = HI - F.S.\ or\ I.S.}$

Solution:

Station	B.S.	I.S.	F.S.	HI	R.L.	Remark
1	1.622			**84.820**	83.198	B.M.
2	1.874		0.354	**86.340**	**84.466**	T.P.
3	2.032		1.780	**86.592**	**84.560**	T.P.
4		2.362			**84.230**	
5	0.984		1.122	**86.454**	**85.470**	T.P.
6	1.906		2.824	**85.536**	**83.630**	T.P.
7			2.036		**83.500**	
Σ	**8.418**		**8.116**			

Example (4): The following consecutive readings were taken with a level and 5m staff, on continuously sloping level at a common interval of 20m, (0.385, 1.030, 1.925, 2.825, 3.730, 4.685, 0.625, 2.005, 3.110, 4.185). The R.L. of the first point was 208.125 list these reading in a levelling table, and calculated R.L. by rise and fall method, also **find the gradient of the line joining the first and last point?**

Solution:

Station	B.S.	I.S.	F.S.	Rise +	Fall	R.L.	Remark
1	0.385					208.125	B.M.
2		1.030					
3		1.925					
4		2.825					
5		3.730					
6	0.625		4.685				T.P.
7		2.005					
8		3.110					
9			4.485				
Σ							

- $Rise\ or\ fall = B.S. - F.S. = B.S. - I.S. = I.S. - I.S. = I.S. - F.S.$
- $R.L. = R.L.\,latest + (Rise + or\ fall -)$

Solution

- $\boldsymbol{For\ checking: \Sigma B.S. - \Sigma F.S. = R.L.last - R.L.first = \Sigma Rise - \Sigma fall}$
- $\boldsymbol{1.010 - 9.170 = 199.965 - 208.125 = 0 - 8.160}$
- $\boldsymbol{-8.160 = -8.160 = -8.160\ O.K.}$

Station	B.S.	I.S.	F.S.	Rise +	Fall -	R.L.	Remark
1	0.385					208.125	B.M.
2		1.030			**0.645**	**207.480**	
3		1.925			**0.895**	**206.585**	
4		2.825			**0.900**	**205.685**	
5		3.730			**0.905**	**204.780**	
6	0.625		4.685		**0.955**	**203.825**	T.P.
7		2.005			**1.380**	**202.445**	
8		3.110			**1.105**	**201.340**	
9			4.485		**1.375**	**199.965**	
Σ	**1.010**		**9.170**		**8.160**		

- $\boldsymbol{Gradiant = \frac{R.L\,(last) - R.L\,(first)}{D} = \frac{199.905 - 208.125}{8 * 20} * 100\% = -5.1\%}$

Example (5): Complete the table below and then check your result arithmetically?

Solution:

Station	B.S.	I.S.	F.S.	Rise +	Fall -	R.L.	Remark
1	2.285					232.460	B.M.1
2	1.650			0.020			
3		2.015					
4			1.960				
5	2.050		1.925		0.340		
6						232.255	B.M.2
7	1.690			0.340			
8	2.865		2.100				
9						233.425	B.M.3
Σ							

Solution

Station	B.S.	I.S.	F.S.	Rise +	Fall -	R.L.	Remark
1	2.285					232.460	B.M.1
2	1.650		**2.265**	0.020		**232.480**	
3		2.015			**0.365**	**232.115**	
4	**1.585**		1.960	**0.055**		**232.170**	
5	2.050		1.925		0.340	**231.830**	
6		**1.625**		**0.425**		232.255	B.M.2
7	1.690		**1.285**	0.340		**232.595**	
8	2.865		2.100		**0.410**	**232.185**	
9			**1.625**	**1.240**		233.425	B.M.3
Σ	**12.12**		**11.16**	**2.080**	**1.115**		

- $\boldsymbol{Rise\ or\ fall\ =\ B.S.-F.S.=\ B.S.-I.S.=\ I.S.-I.S.=\ I.S.-F.S.}$
- $\boldsymbol{R.L.=R.L.latest\ +\ (Rise\ +\ or\ fall-)}$
- $\boldsymbol{For\ checking:\ \Sigma B.S.-\Sigma F.S.=\ R.L.last-R.L.first\ =\ \Sigma Rise-\Sigma fall}$
- $\boldsymbol{12.12-11.16\ =\ 233.425\ -232.460\ =\ 2.080-1.115}$
- $\boldsymbol{0.965\ =\ 0.965\ =\ 0965\ O.K.}$