GEOMATICS ENGINEERING

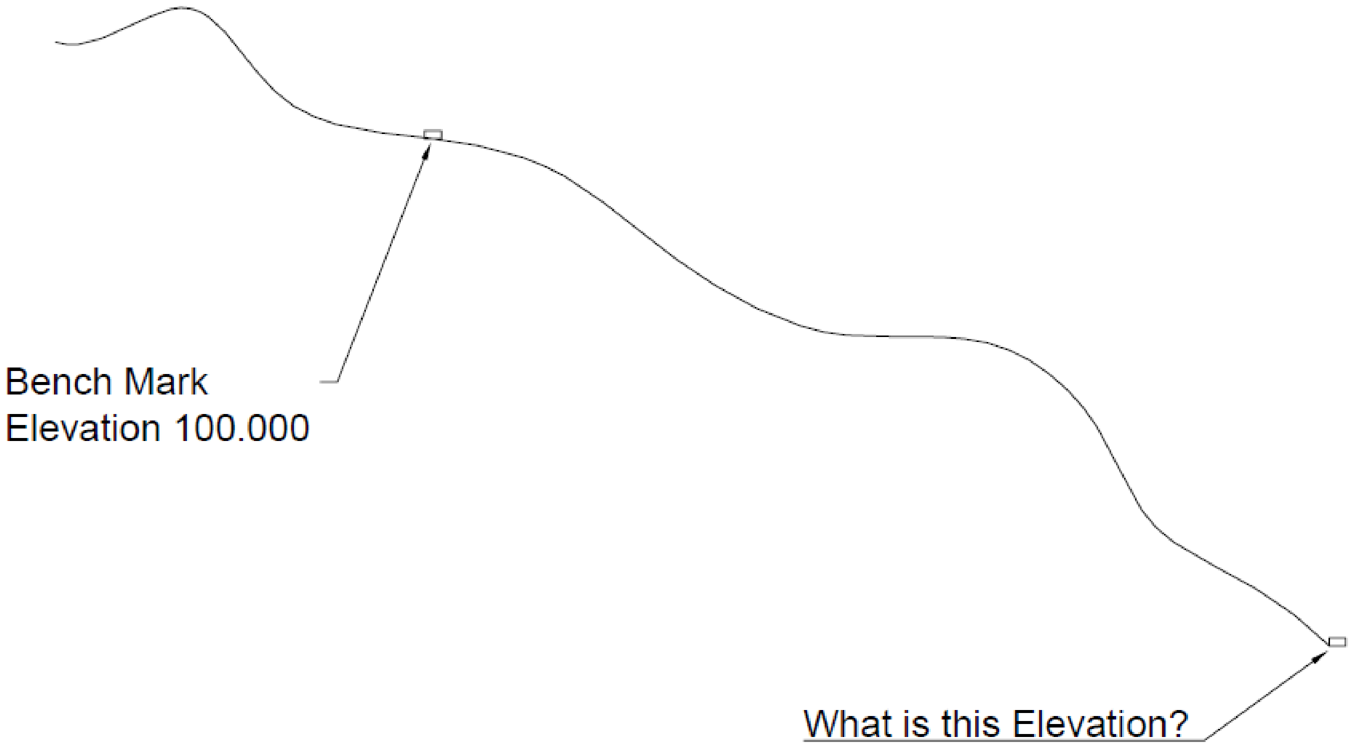
CHAPTER 4

Introduction and Methods of Leveling
Methods of Leveling
Contouring

Contents

What is Leveling?

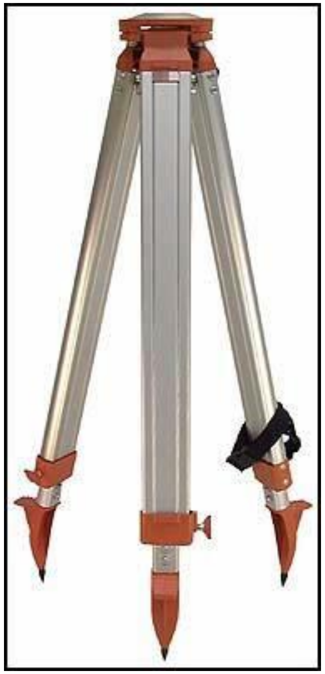
- The process of finding the elevation at a specified location relative to another known elevation.



Leveling Equipment

- **Level**
  - Levels are instruments used to establish a horizontal line of sight.

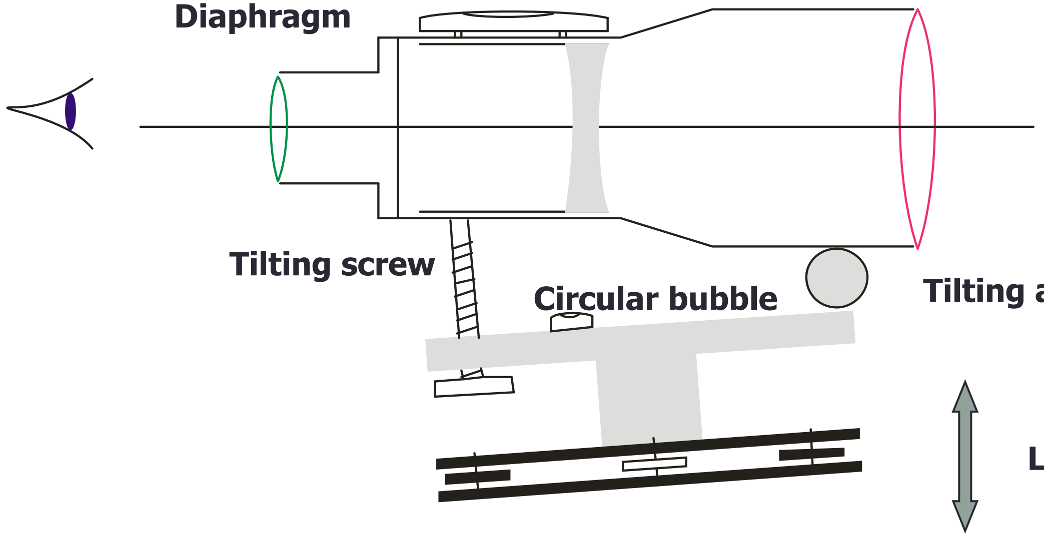
- Field book,
- Pencils,
- Ruler or straight edge
- Stakes,
- Hammer,
- Paint,
- Ribbon



Tripod

Leveling rod

Tilting Level



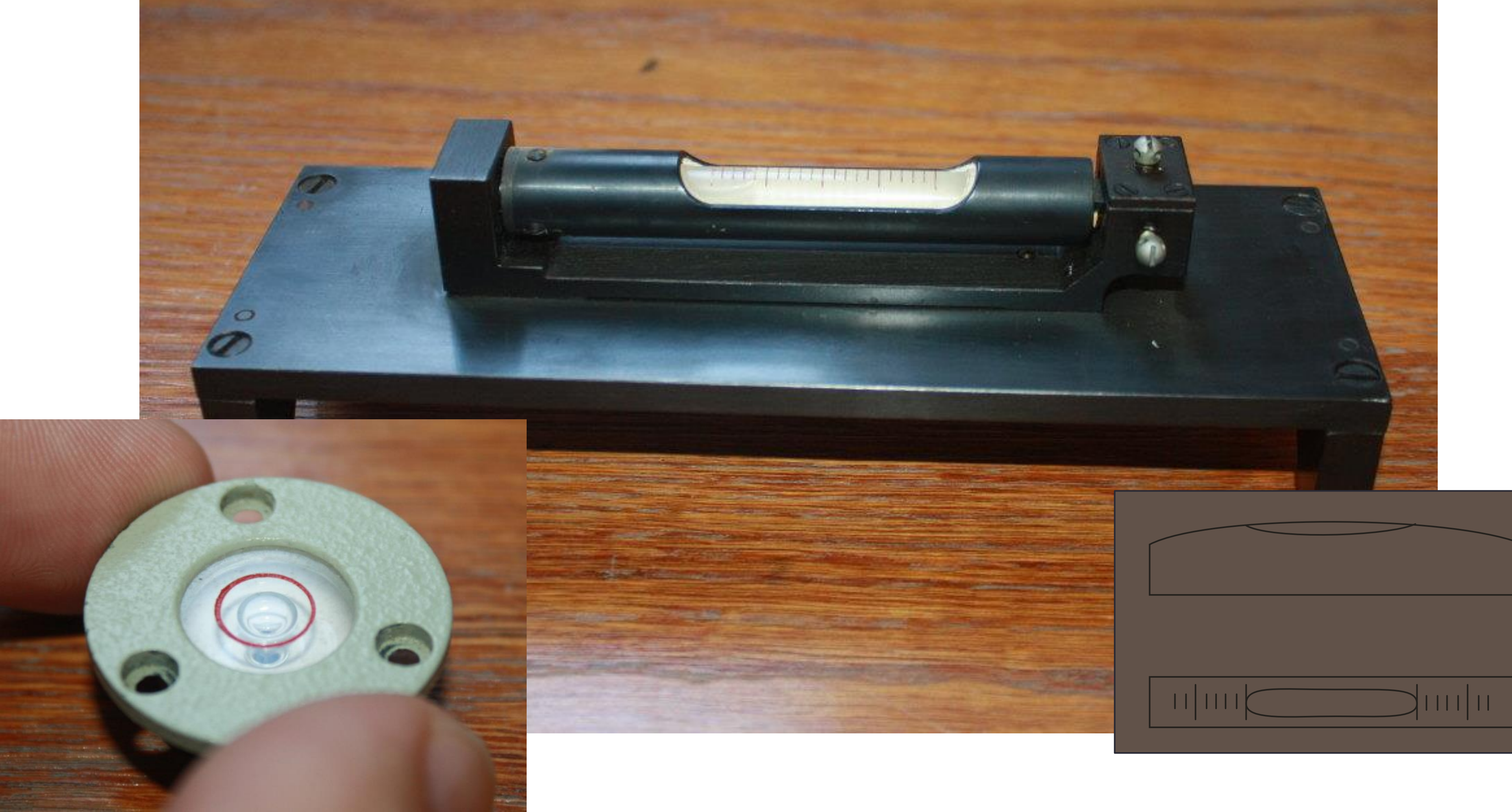
Clamping screw - to fix the telescope in one vertical plane

Tangent screw (slow motion screw) - to finely rotate the telescope along a vertical axis

How to set the line of sight to be exactly horizontal?

More general: how to set anything to be exactly horizontal?

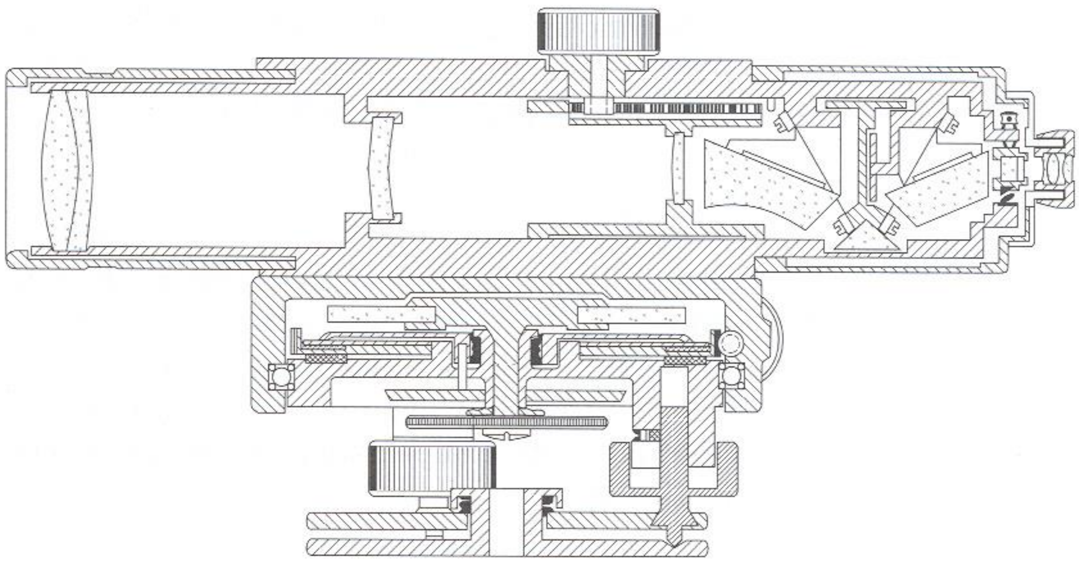
The bubble tube



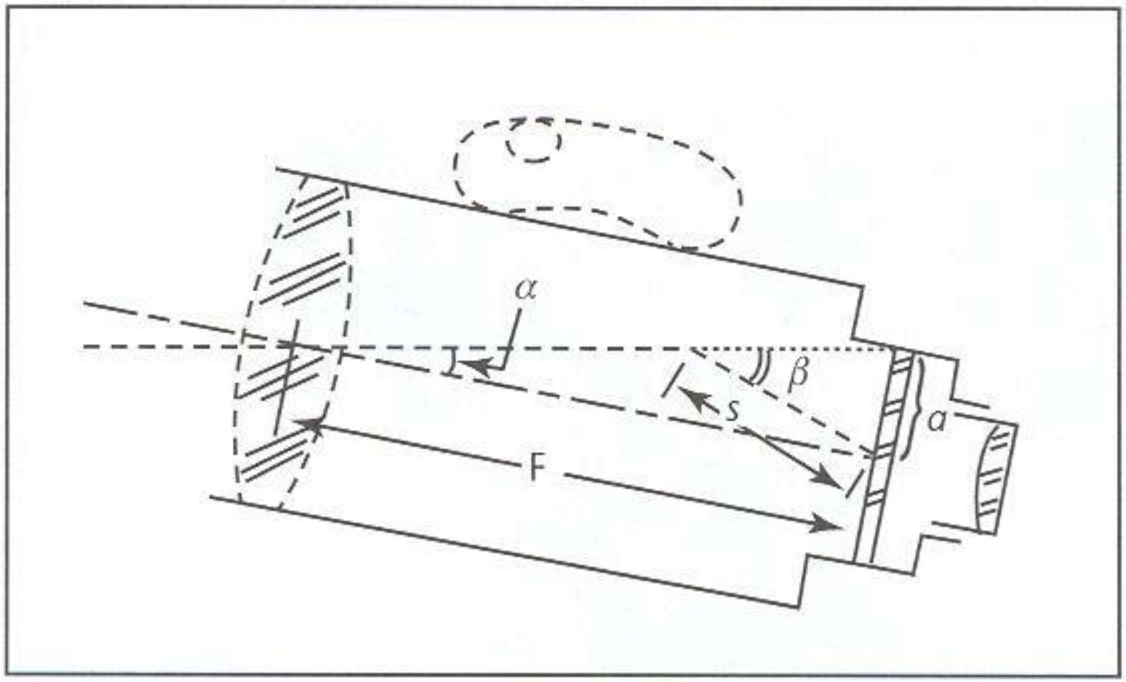
Automatic level

We must adjust the bubble tube before every reading when using the tilting level -> takes a lot of time, may cause blunders (large mistakes in the observations)

An automatic level contains an optical device, which compensates the tilting of the telescope - called compensator.



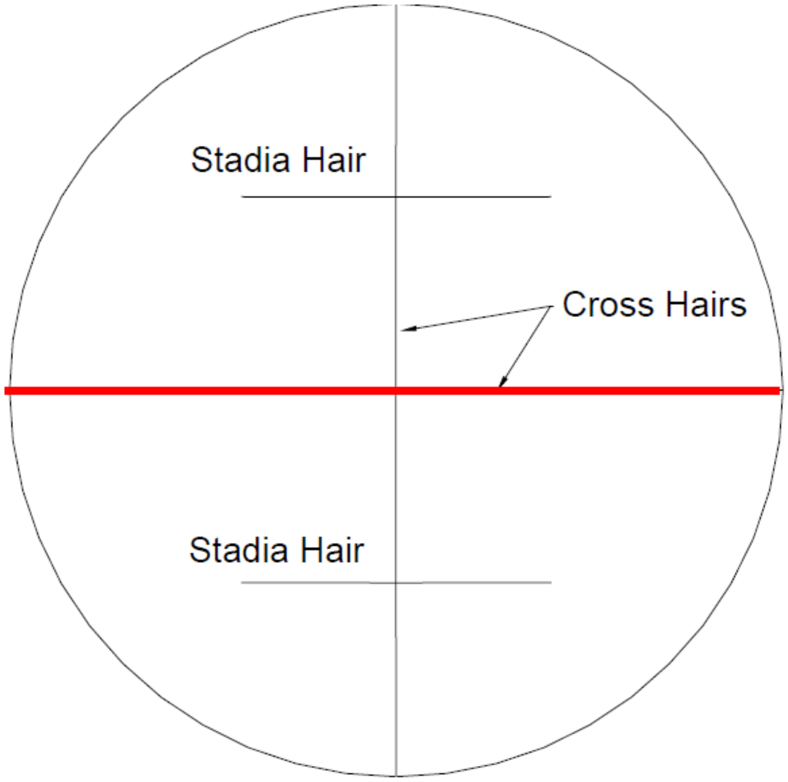
Operation of the compensator



Advantage: faster observations, elimination of a possible reason of blunders
Disadvantage: vibrations (wind, traffic, etc.) have a bad impact on the operation of the compensator

Arrangement of Cross Hairs

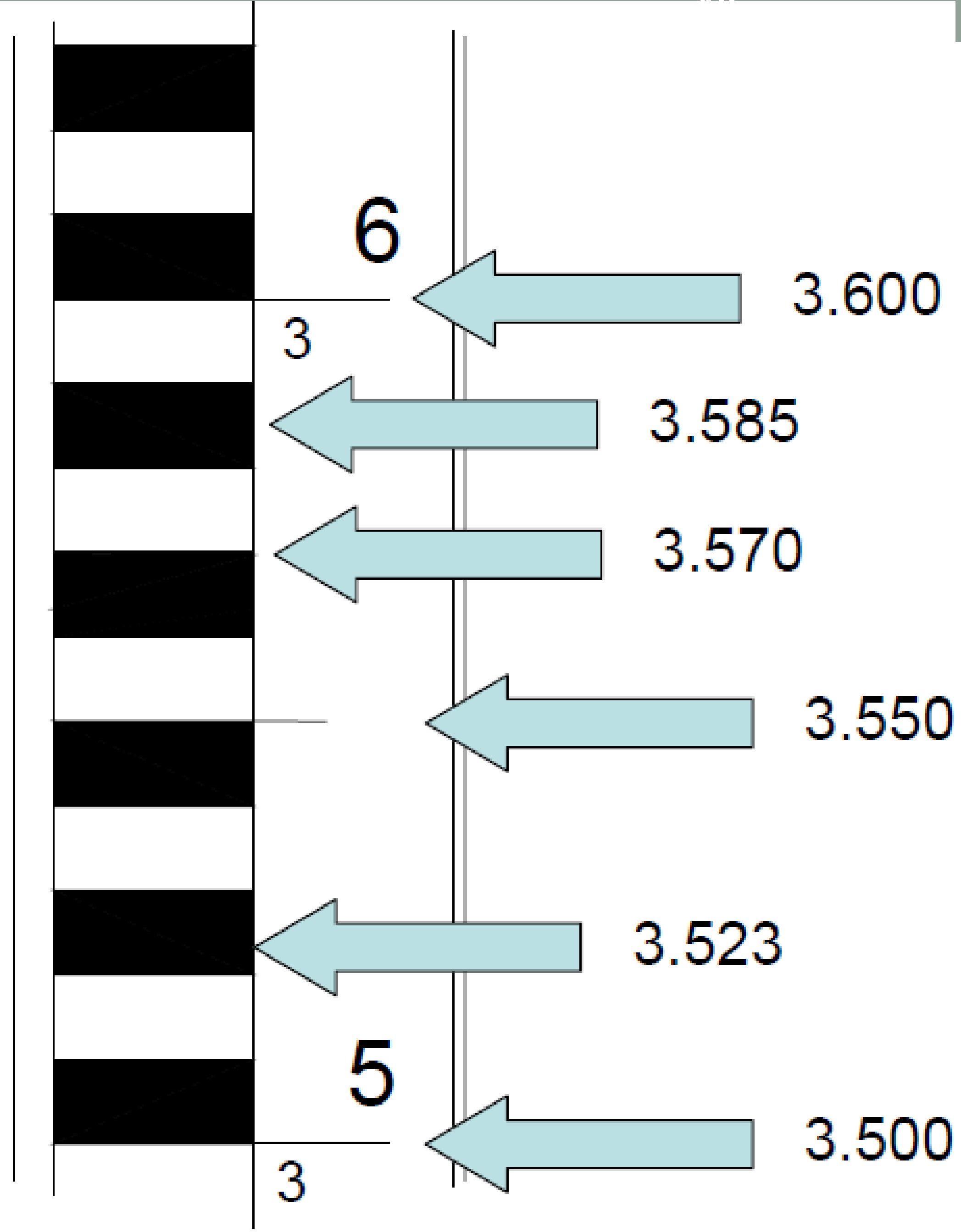
- When you sight through the telescope, you will see a vertical and a horizontal cross hair and two horizontal stadia hairs.



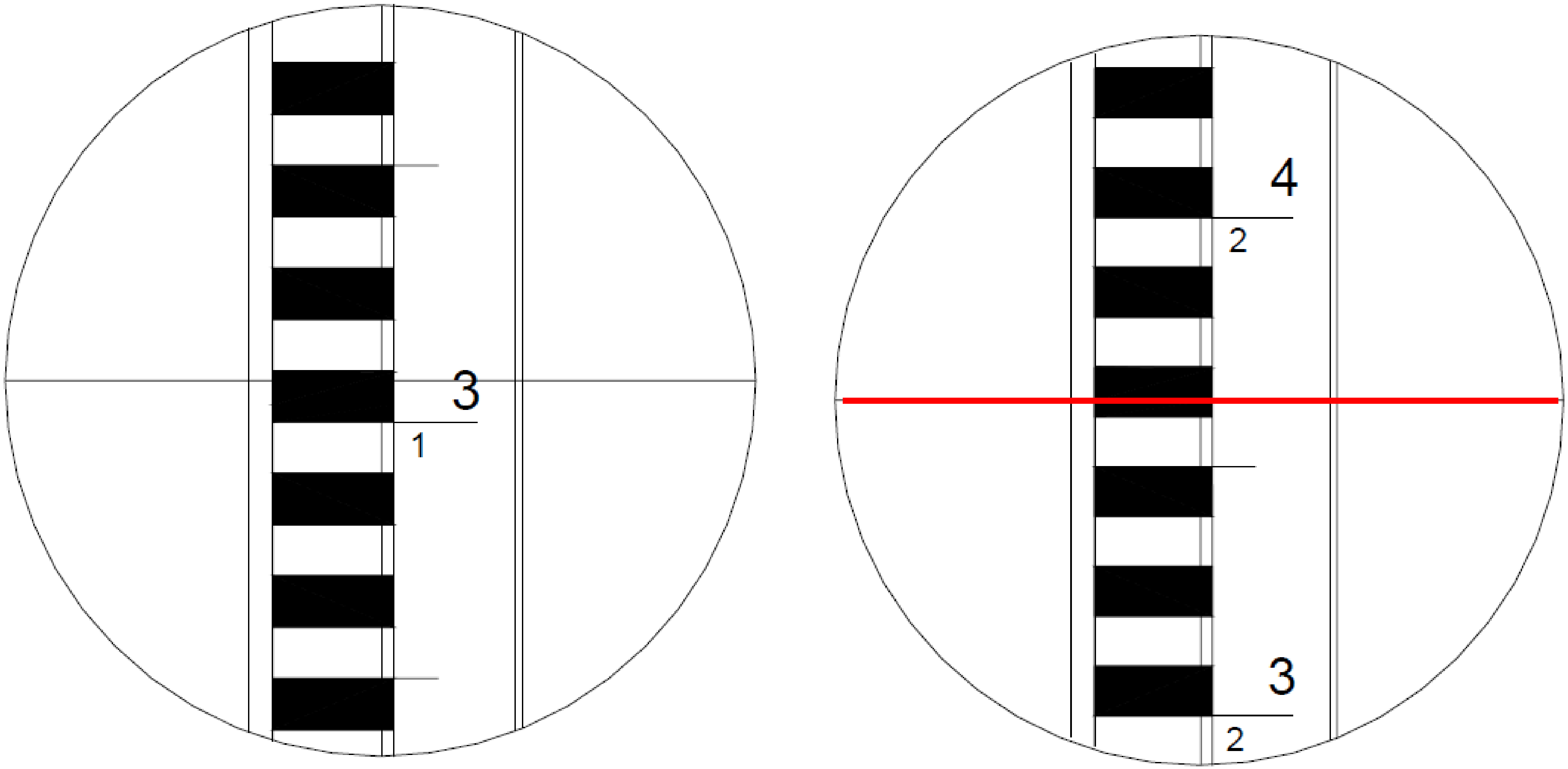
Reading the Rod

- Rod readings are taken using the center cross hairs.
- **For now, ignore the presence of the stadia hairs.**

- Rod readings are taken to three decimal places (or the nearest millimeter).
- Rod readings can be read to two decimal places with certainty.
- **Estimate** the third decimal place



What is the reading for this road sighting?



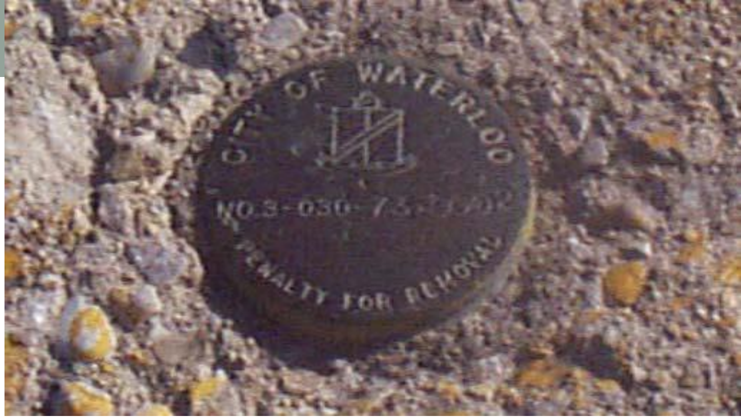
Duties of the Rod Person

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

Waving

- Waving is the procedure used to ensure that the rod is plumb when a reading is taken.
- The method consists of slowly rocking the top of the rod, back and forth.
- The instrument person continuously reads the rod and selects the **lowest value.**

Definitions



Vertical line

- It follows the direction of gravity at any point on the earth's surface and is indicated by a plumb at that point.

Horizontal line

- A line at any point which is perpendicular to the vertical line at that point.

Level surface

- It is a continuous surface that is perpendicular to the plumb line.

Mean Sea Level

- The average height of the sea's surface for all stages of the tide over a very long period (usually 19 years)

Datum

- Any level surface to which elevations are referred (e.g., mean sea level)

Bench Mark (BM)

- A permanent object that has a **known elevation** above or below a datum**.**

Definitions

Temporary Benchmark (TBM)

- A moveable object that has a known elevation.

- **Turning Point (TP)**
  - An object used when determining the elevation of other points.

- **Height of Instrument (HI)**
  - The elevation of the line of sight established by the instrument from the ground level.

Definitions

Backsight (BS)

- The reading on the rod when held on a known or assumed elevation point or station. **Backsights are used to establish the height of instrument (HI)**.

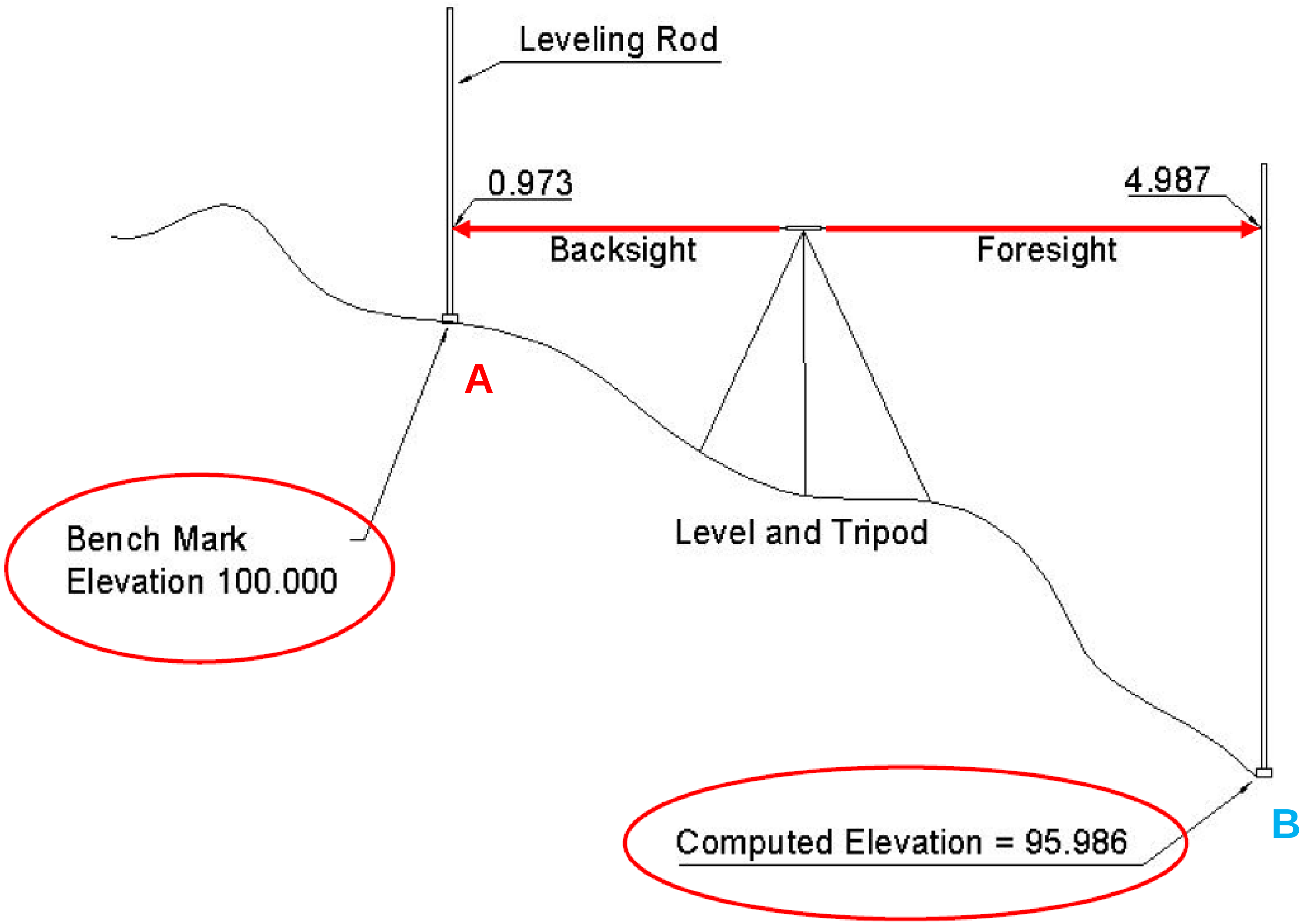
Foresight (FS)

- The reading on the rod when held at a location where the elevation is to be determined. Foresights are used to establish the elevation at another location, **often a turning point.**

Intermediate Foresight (IFS)

- The reading on the rod when held at a location where the elevation is to be determined **but not used as a turning point**.

Basic Theory



Calculations

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

  Height of Instrument = **Known Elevation (Point A Elevation)** + Backsight

- and

  Turning point Elevation (Point B) = **Height of Instrument** – Foresight

- For the previous example:

  Height of instrument = Known Elevation + Backsight

  = 100.000 + 0.973

  = 100.973 m

- and

  Turning point Elevation (Point B) = Height of Instrument – Foresight

  = 100.973 – 4.987

  = 95.986 m

Booking Work

- Most typical booking framework

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
BM					100.000
	0.973				
TP #1				4.987	

Format 1

Format 2

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
BM	0.973				100.000
TP #1				4.987	

Booking Work

- Most typical booking framework (Height of Instrument calculation)

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
BM					100.000
	0.973	100.973			
TP #1				4.987	95.986

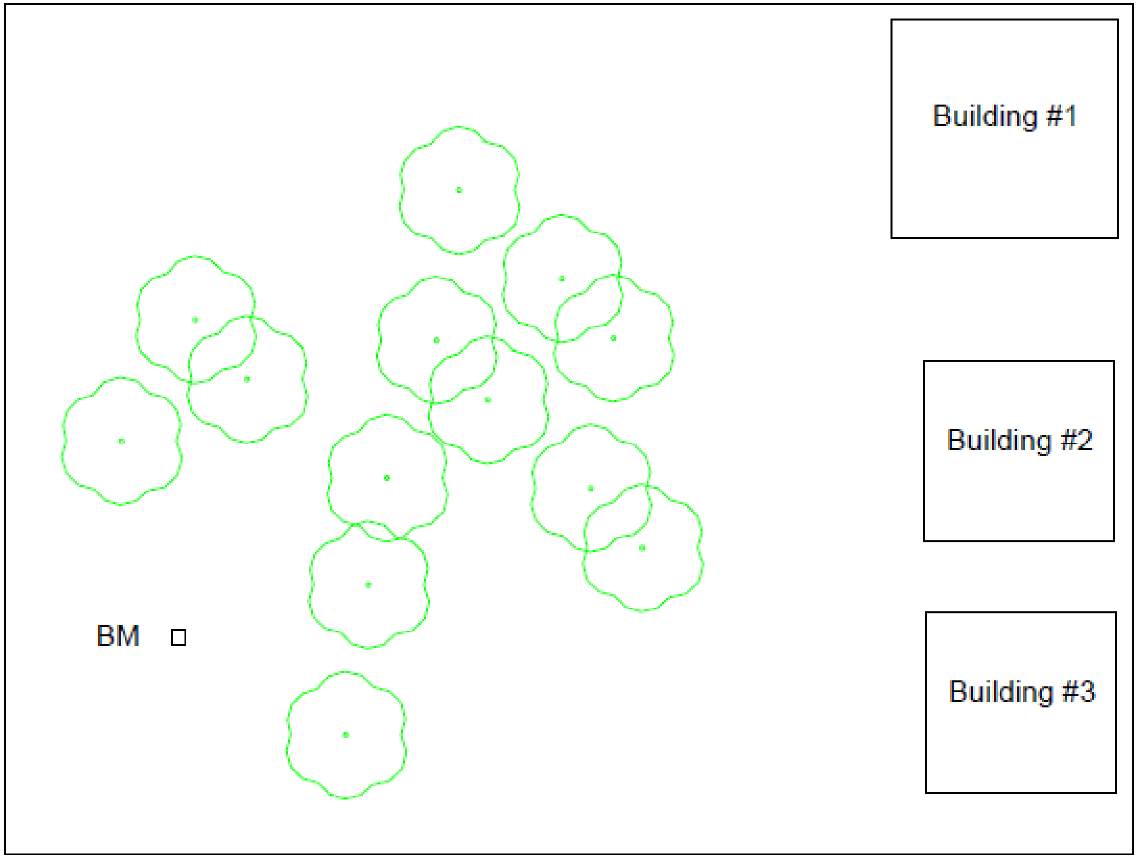
Format 1

Format 2

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
BM	0.973	100.973			100.000
TP #1				4.987	95.986

Differential Leveling

- Consider the following case. You are asked to establish the floor elevations associated with the three buildings (as shown below) but the nearest bench mark is located on the far side of a wooded area.

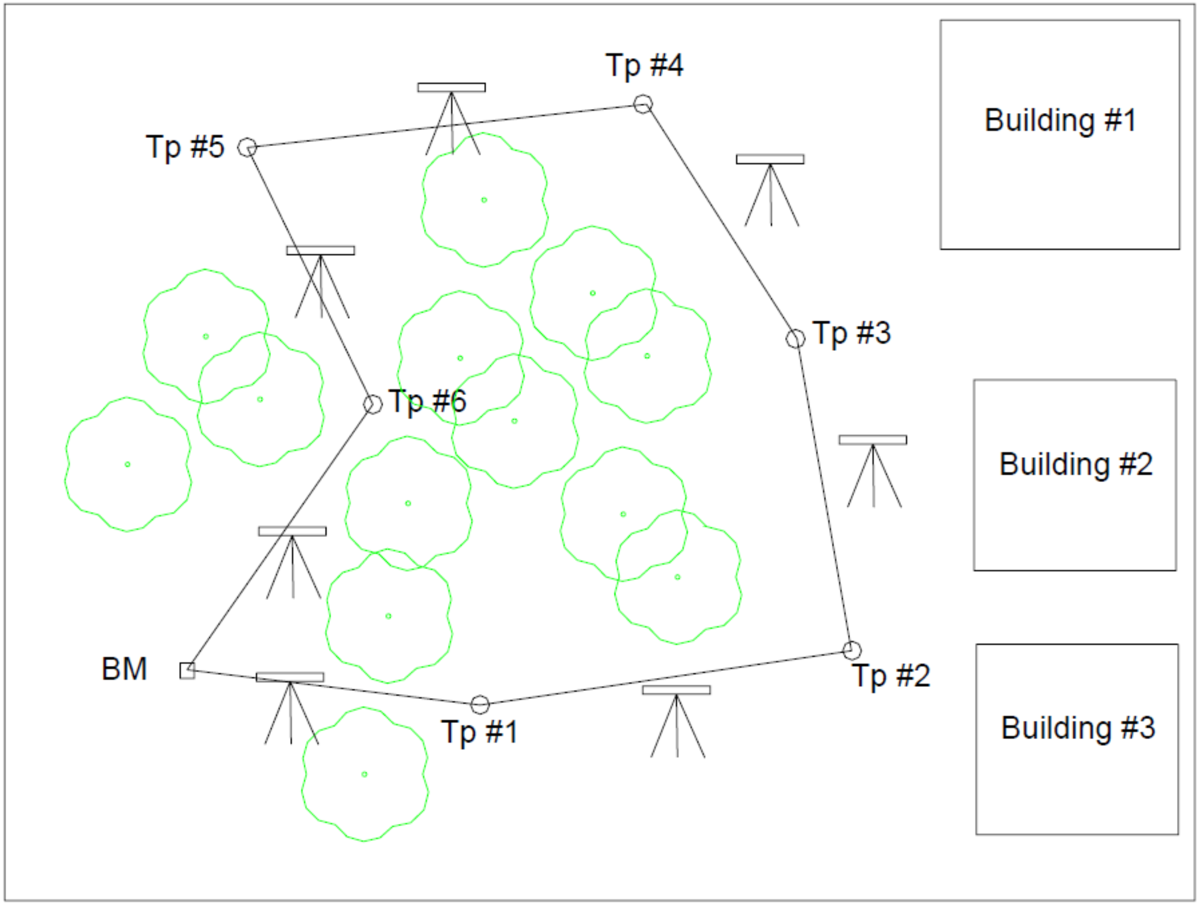


Differential Leveling

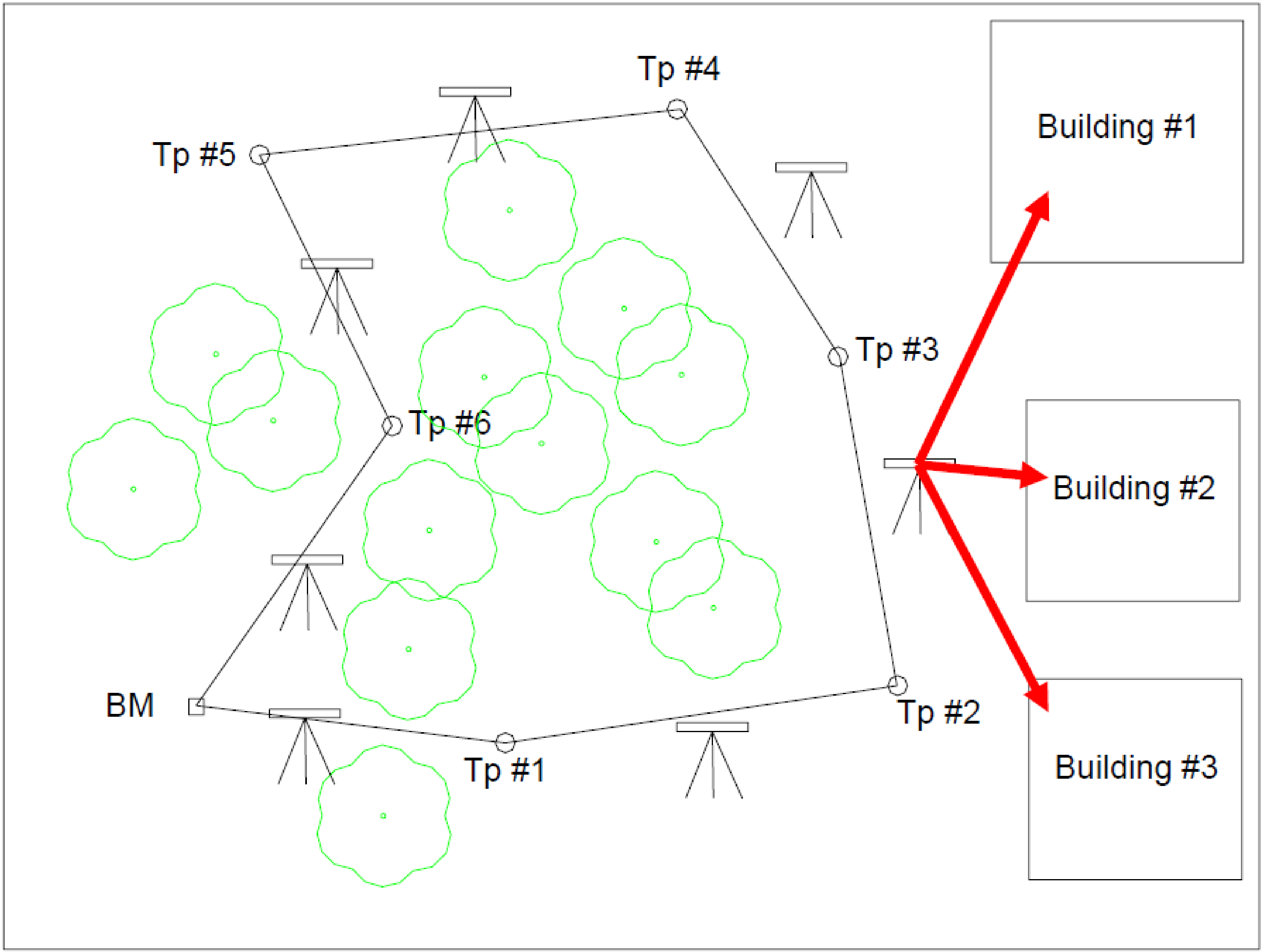
- In this case (and most practical cases) our survey site and the benchmark are far apart and/or obstructed by trees (or buildings or hills, etc.).
- In order to transfer the benchmark elevation to another site, a process called **differential leveling** is used.
- With differential leveling, we make use of **turning points** (TP's).
- Recall that turning points are selected locations where we use a foresight to establish the elevation.
- We then move the instrument to a new location and take another backsight to establish a new height of instrument.
- We can then repeat the "foresight/move the instrument/backsight" sequence until we establish the elevation at our desired location.

Differential Leveling

- For our woodlot example, we would need to establish several turning points (TP's) in order to transfer the benchmark elevation around/through the woodlot as shown below.
- We will use differential leveling in order to obtain the floor elevations at three buildings. We will use 6 turning points (TP's), creating a level loop around the wood lot.



- On the third instrument set-up, we will use 3 **intermediate foresights** (IFS) to establish the building elevations.



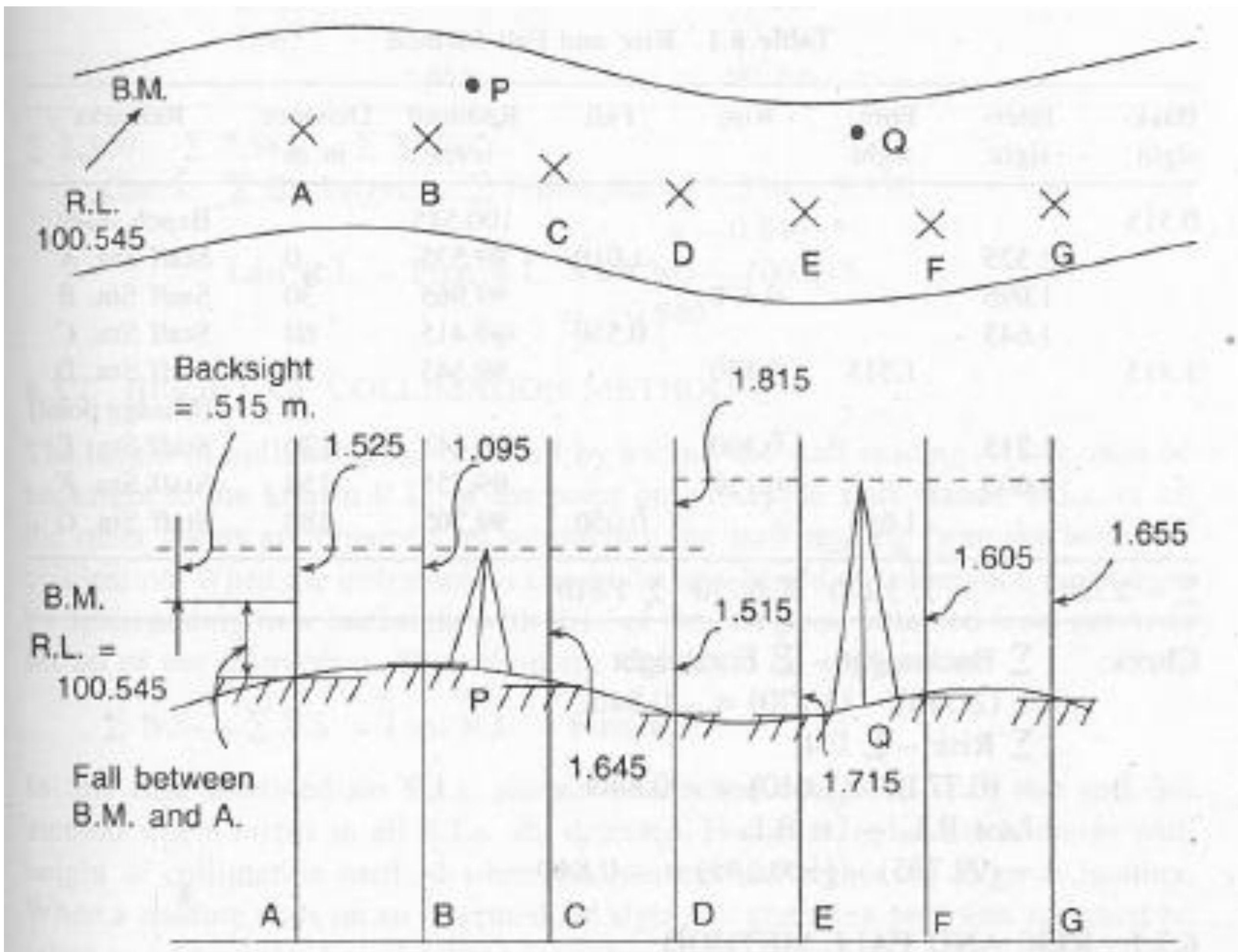
Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
Bench mark	0.992				100.000
TP #1	1.278			1.010	
TP #2	0.999			0.654	
Building #1			1.23		
Building #2			1.45		
Building #3			1.01		
TP #3	0.785			1.700	
TP #4	0.765			0.843	
TP #5	1.178			1.245	
TP #6	1.132			0.732	
Bench mark				0.943	
Sums	7.129			7.127	

- As before, we computed the sum of the backsights and compared that value with the sum of the foresights. We do not use the IFS values when checking our closure error. For our example, the results are within acceptable limits.

Station	BS (+)	HI	IFS (-)	FS (-)	Elevation
Bench mark	0.992	100.992			100.000
TP #1	1.278	101.26		1.010	99.982
TP #2	0.999	101.605		0.654	100.606
Building #1			1.23		100.38
Building #2			1.45		100.16
Building #3			1.01		100.60
TP #3	0.785	100.690		1.700	99.905
TP #4	0.765	100.612		0.843	99.847
TP #5	1.178	100.545		1.245	99.367
TP #6	1.132	100.945		0.732	99.813
Bench mark				0.943	100.002

METHODS OF REDUCING LEVELS

- Figure shows the plan, and sectional elevation of a roadway along which a line of level is being taken. The figure also explains the different terms used in connection with differential leveling.



Rise and Fall Method

- Each reading is entered on a different line in the applicable column, except at change points where a foresight and a back sight occupy the same line.
- This is to connect the line of sight of one set up of the instrument with the line of sight of the second set up of the instrument.
- R.L. of **change or turning point D** is obtained from the first line of sight by comparing intermediate sight 1.645 with foresight 1.515, i.e. a rise of 0.130m. For the reduced level of next point E, back sight 1.815 is compared with intermediate sight 1.715, i.e. rise of 0.100 m.
- At the end of the table arithmetic checks are shown.

Rise and Fall Method

Back-sight	Inter-sight	Fore-sight	Rise	Fall	Reduced level	Distance in m	Remarks
0.515					100.545		Bench mark
	1.525			1.010	99.535	0	Staff Stn. *A*
	1.095		0.430		99.965	30	Staff Stn. *B*
	1.645			0.550	99.415	60	Staff Stn. *C*
1.815		1.515	0.130		99.545	90	Staff Stn. *D* (Change point)
	1.715		0.100		99.645	120	Staff Stn. *E*
	1.605		0.110		99.755	150	Staff Stn. *F*
		1.655		0.050	99.705	180	Staff Stn. *G*
Σ = 2.330		Σ 3.170	Σ 0.770	Σ 1.610			

Check: Σ Back-sight – Σ Fore-sight
= (2.330) – (3.170) = – 0.840
Σ Rise – Σ Fall
= (0.770) – (1.610) = – 0.840
Last R.L. – 1st R.L.
= (99.705) – (100.545) = – 0.840

Calculation Examples:
= 0.515-1.525 = -1.010 (Fall)
= 1.525 – 1.095 = 0.430 (Rise)
= 1.645 – 1.515 = 0.13 (Rise)
= 1.815 – 1.715 = 0.10 (Rise)

Elevation = Previous point reduced Level ± (rise or fall)
+ve for rise and –ve for fall

Height of Collimation/Instrument Method

- The height of collimation or instrument is obtained by adding the staff reading which must be backsight to the known R.L. of the point.
- Reduced levels of all other points are obtained by subtracting the staff reading from the height of the collimation or instrument.
- When the instrument is changed a new height of collimation is obtained by again adding new backsight with R.L. of the last point obtained from previous set up of the instrument.
- The arithmetic checks are applied.

Height of Collimation Method

Height of Instrument = B.M. or Known point Elevation + Back sight reading

Reduced Level of a point = Height of Instrument – Inter or Fore Sight reading

Back-sight	Inter-sight	Fore-sight	Ht. of collimation	Reduced level	Distance	Remarks
0.515			101.060	100.545		B.M.
	1.525			99.535 =101.060-1.525 m		
	1.095			99.965 =101.060-1.095 m		
	1.645			99.415 =101.060-1.645 m		
1.815		1.515	101.360	99.545 =101.060-1.515 m		
	1.715			99.645 =101.360-1.715 m		
	1.605			99.755 =101.360-1.605 m		
		1.655		99.705 =101.360-1.655 m		
Σ 2.330	Σ 7.585	Σ 3.170				

Check: Σ Backsights – Σ Foresights = 2.330 – 3.170

= – 0.840

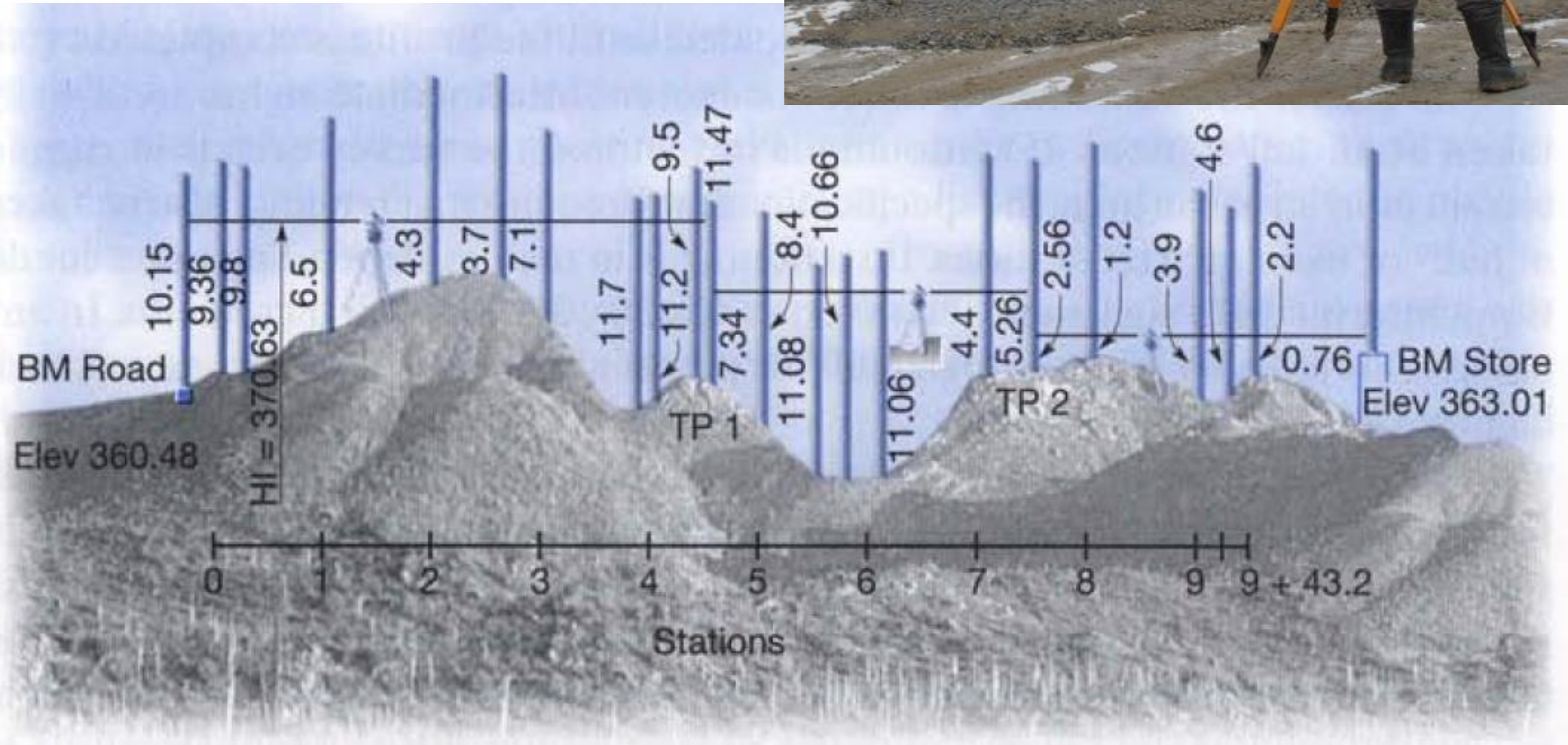
Last R.L. – First R.L. = 99.705 – 100.545

= – 0.840

Profile Leveling

- It shows a profile, that is, a line depicting ground elevations at a vertical section along a survey line.
- This is necessary before a rail road, highway, transmission line, side walk or sewer line can be designed.
- Usually a line of level run along the center line of the proposed work.
- Levels are taken every 15 m or 30 m interval, at critical points where there is a sudden change of levels, at the beginning or ending of a curve.
- The basic objective is to plot accurately the elevation of the points along the line of levels.
- Procedure is same as described in differential leveling.
- After getting the data (foresights, inter sights and back sights), it is necessary to plot the profile or longitudinal section.
- To show the distortions of the ground the elevations are plotted on a much larger scale after taking suitable datum.
- After the profile section it is necessary to have a smooth surface: this is known as grade line which is selected on various considerations like: (1) minimum amount of cutting and filling of earth work; (ii) balancing the cut and fill; and (iii) keeping the slope within allowable limit

Profile Leveling



Profile Leveling

If points ‘A’ and ‘G’ are joined by a straight line the slope of the line becomes (99.705 – 99.535)/180 or 1/1059 which is very small and is within allowable limit. This may not, however, ensure equal volume of cut and fill and suitable adjustments of grade line may be necessary to ensure this condition.

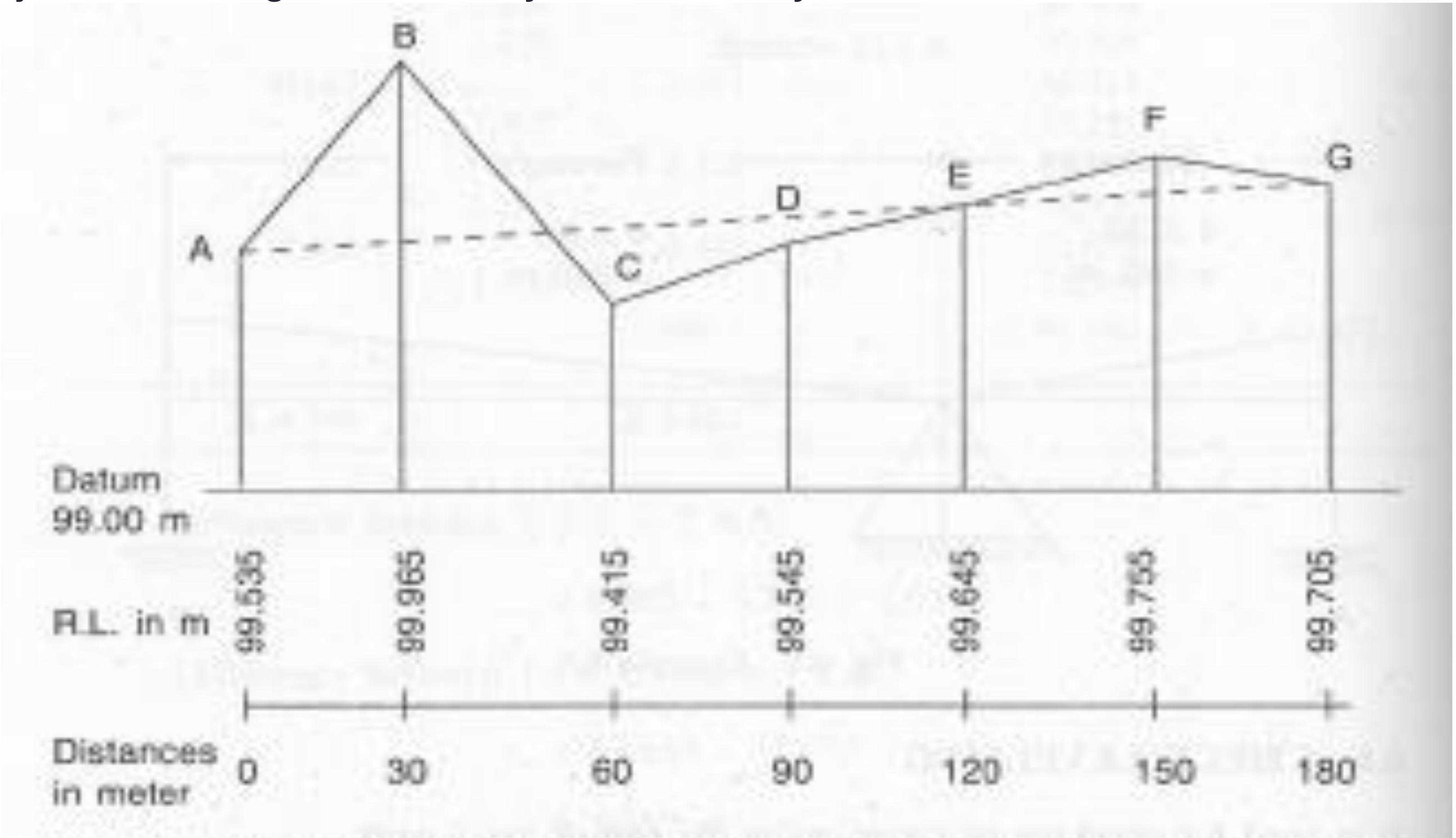


Fig. 6.8 Longitudinal section. Scale: horizontal 1 cm = 15 m, vertical 1 cm = 20 cm.

Example

- The leveling shown in the field sheet given below was undertaken during the layout of a sewer line. Determine the height of the ground at each observed point along the sewer line and calculate the depth of the trench at points X and Y if the sewer is to have a gradient of 1 in 200 downwards from A to B and is to be 1.280 m below the surface at A.

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

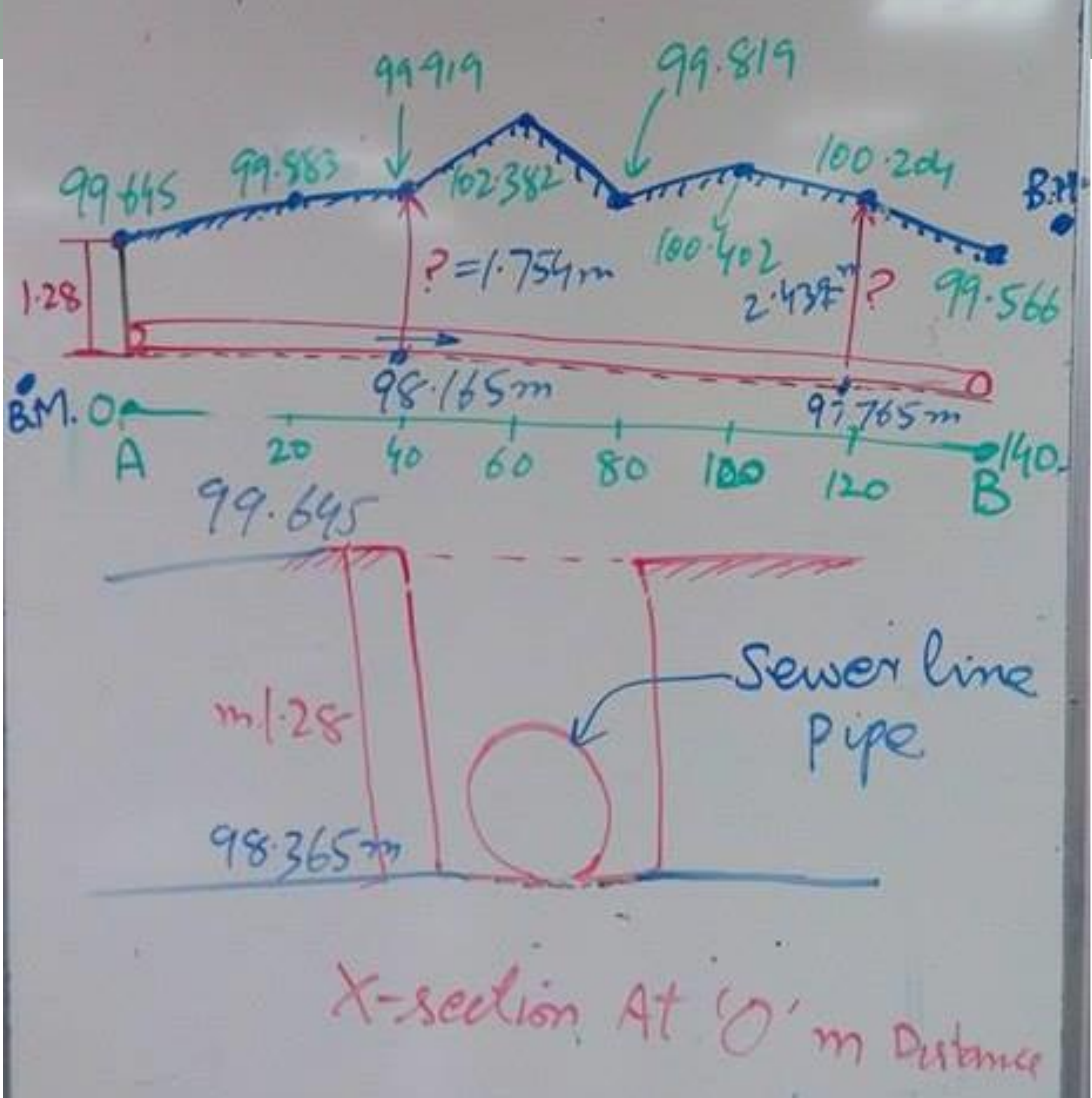
Solution to Example

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				

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

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

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



99.919
99.819
99.645
99.883
102.382
100.204
B.M
1.28
? = 1.754m
100.402
2.437m ?
99.566
98.165m
97.765m
B.M. 0
A
20
40
60
80
100
120
140
B
99.645
m 1.28
98.365m
Sewer line Pipe
X-section At '0' m Distance

Solution to Example

- R.L. of sewer line at A = 99.645 – 1.280 = 98.365 m
- At X, 40 m from A:

  R.L. = 98.365 – (40/200) = 98.165 m
- At Y, 120 m from A:

  R.L. = 98.365 – (120/200) = 97.765 m
- Hence depth of trench at X = 99.919 – 98.165

  = 1.754 m
- Depth of trench at Y = 100.204 – 97.765

  = 2.439 m

Cross Sectional Leveling

- For laying a pipeline or sewer line only longitudinal section is adequate because the width of the line is small.
- In the case of roads and railways apart from longitudinal section, cross sections at rights angles to the center line of the alignment are required at some regular intervals.
- This is necessary to know the topography of the area which will be required for the roads and railways and also to compute the volume of cut and fill for the construction work.
- Cross-section is usually plotted in the same horizontal and vertical scale.

Cross Sectional Leveling

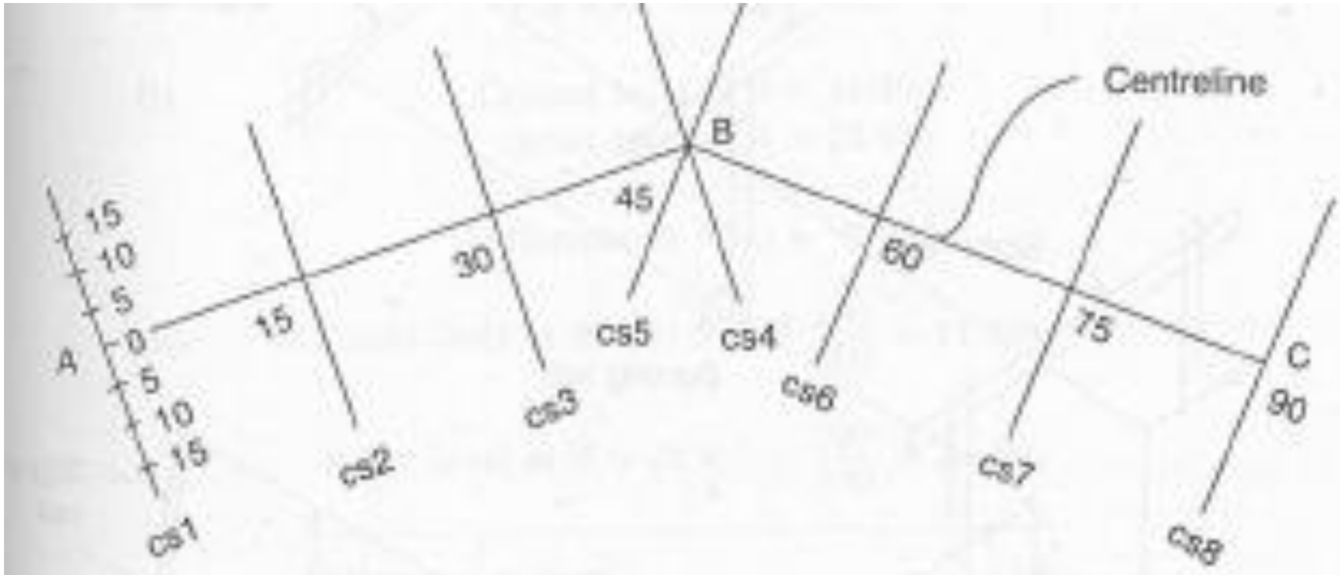


Fig. 6.9(a) Plan

Station	Distance (m) L	Distance (m) C	Distance (m) R	B.S.	I.S.	F.S.	H.I.	R.L.	Remarks
B.M				1.415			106.820	105.405	
A		0			1.875			104.945	
	5				1.795			105.025	
	10				1.625			105.195	
	15				1.540			105.280	
			5		1.535			105.285	
			10		1.685			105.135	
			15		1.805			105.015	

Cross Sectional Leveling

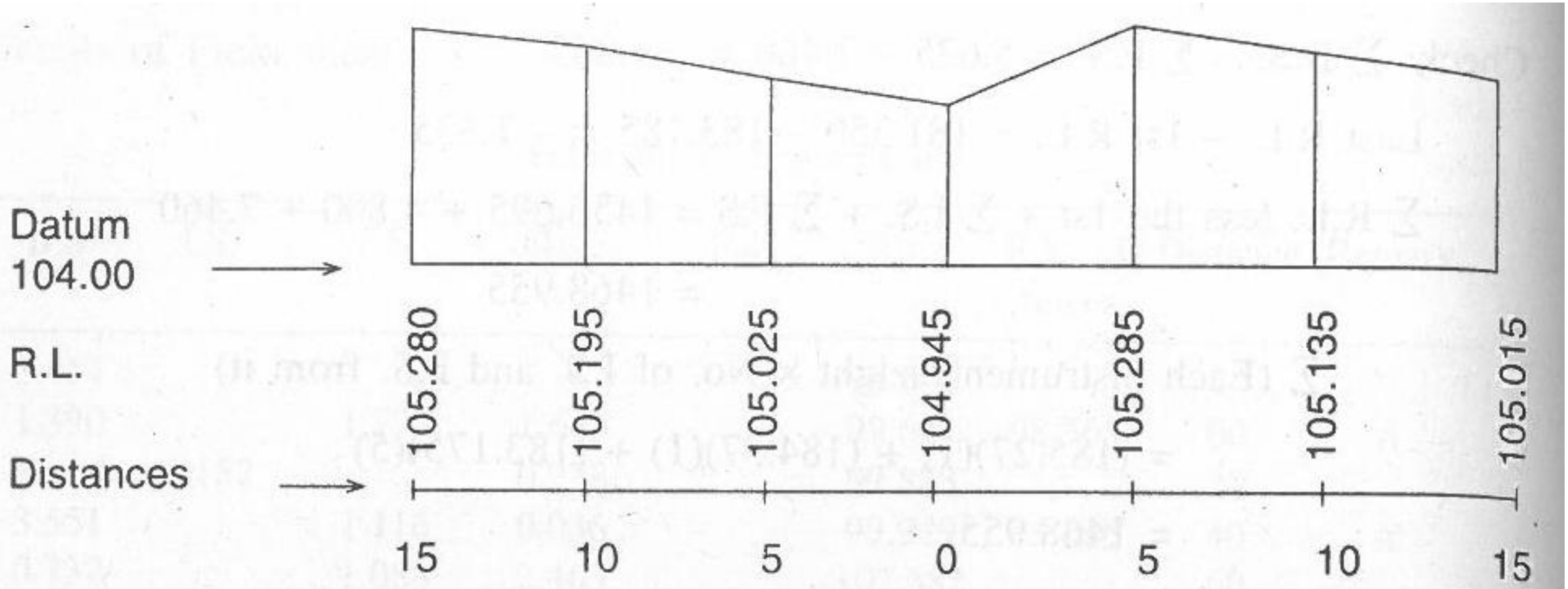


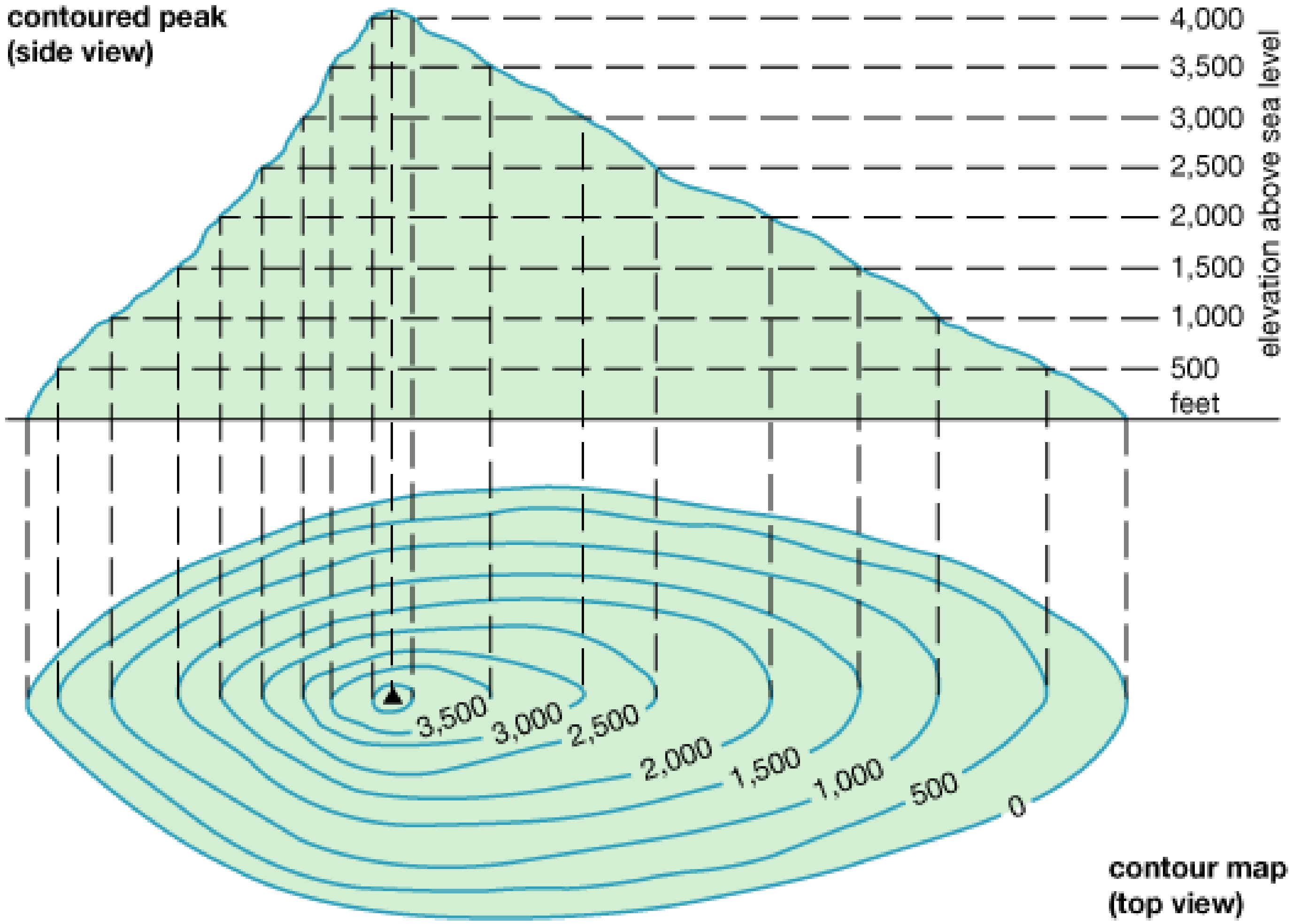
Fig. 6.9(b) Cross section Cs1. Scale: Horizontal 1 cm = 2.5 m, Vertical 1cm = 0.5m.

Contouring

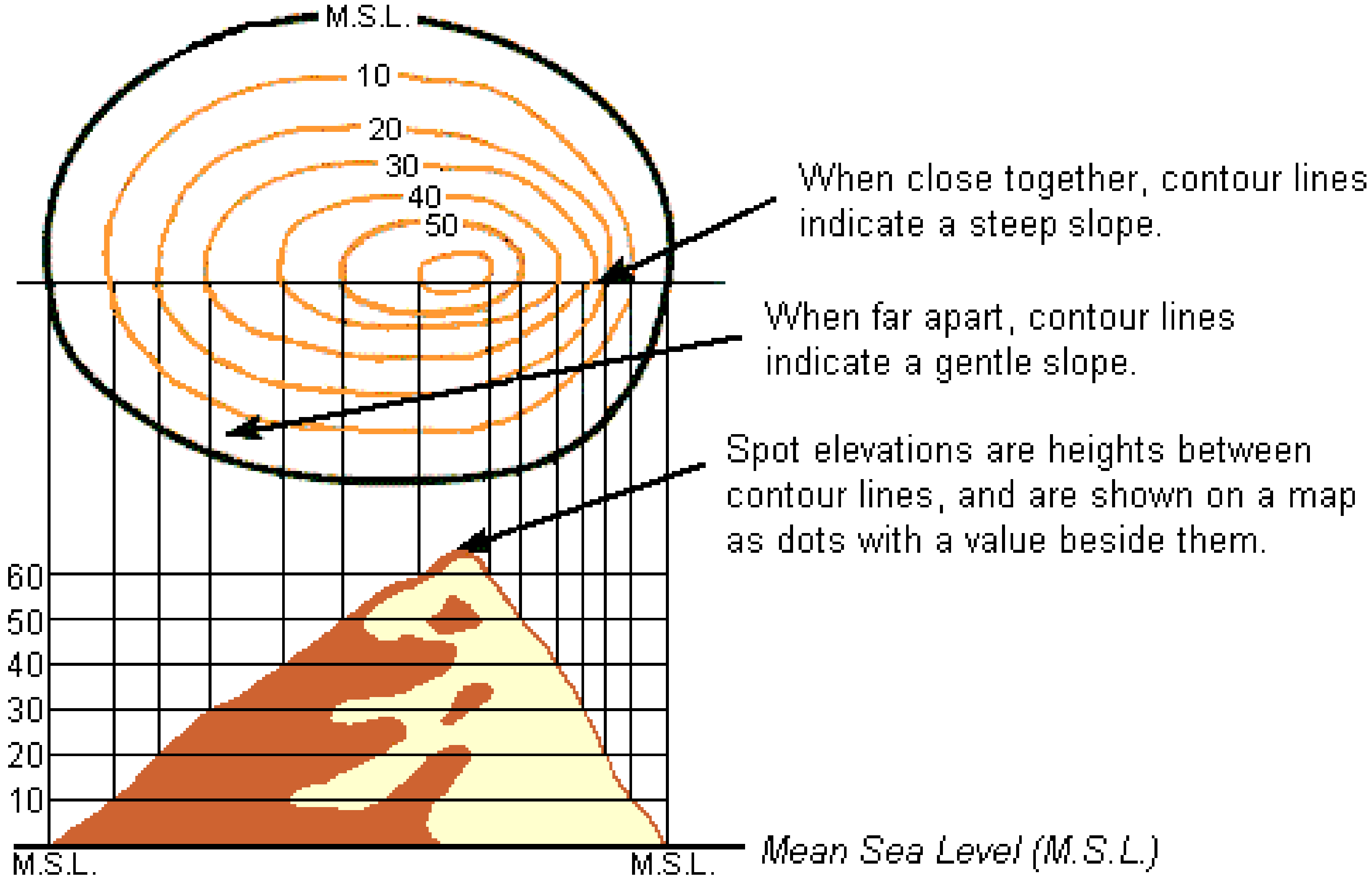
Introduction to contouring

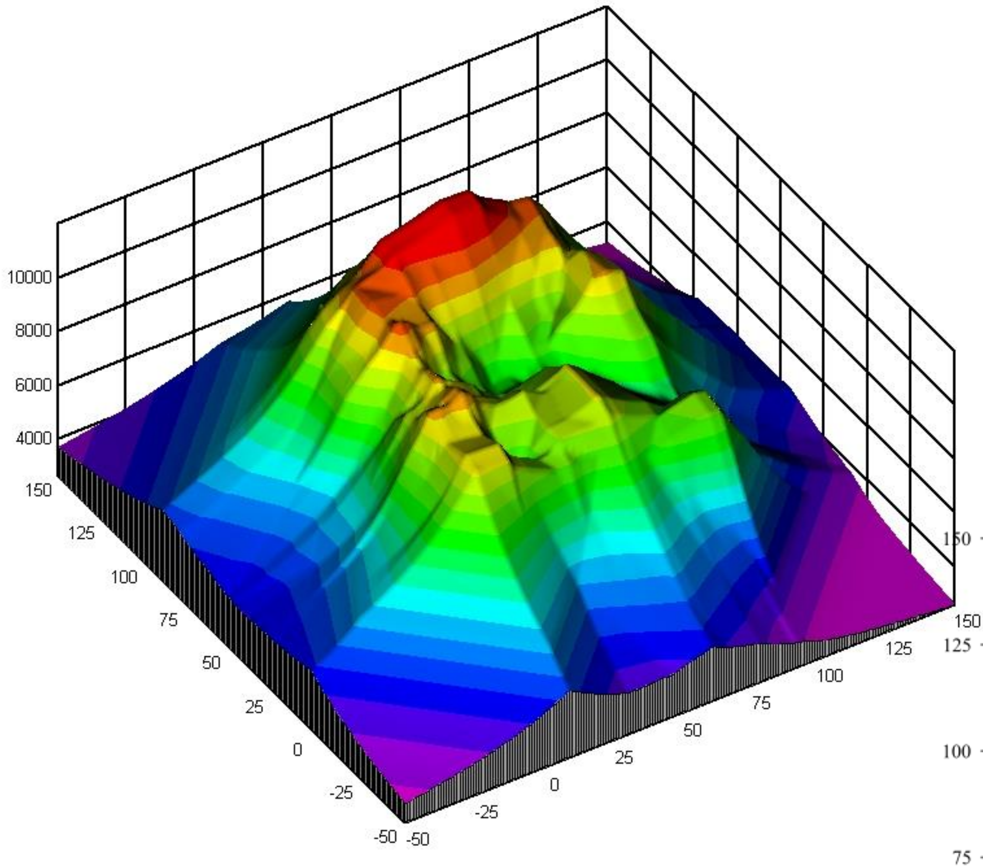
- Contour An imaginary line on the ground surface joining the points of equal elevation is known as contour.
- In other words, contour is a line in which the ground surface is intersected by a level surface obtained by joining points of equal elevation. This line on the map represents a contour and is called contour line.
- Contour Map
- A map showing contour lines is known as Contour map.
- A contour map gives an idea of the altitudes of the surface features as well as their relative positions in plan serves the purpose of both, a plan and a section.
- Contouring
- The process of tracing contour lines on the surface of the earth is called Contouring.

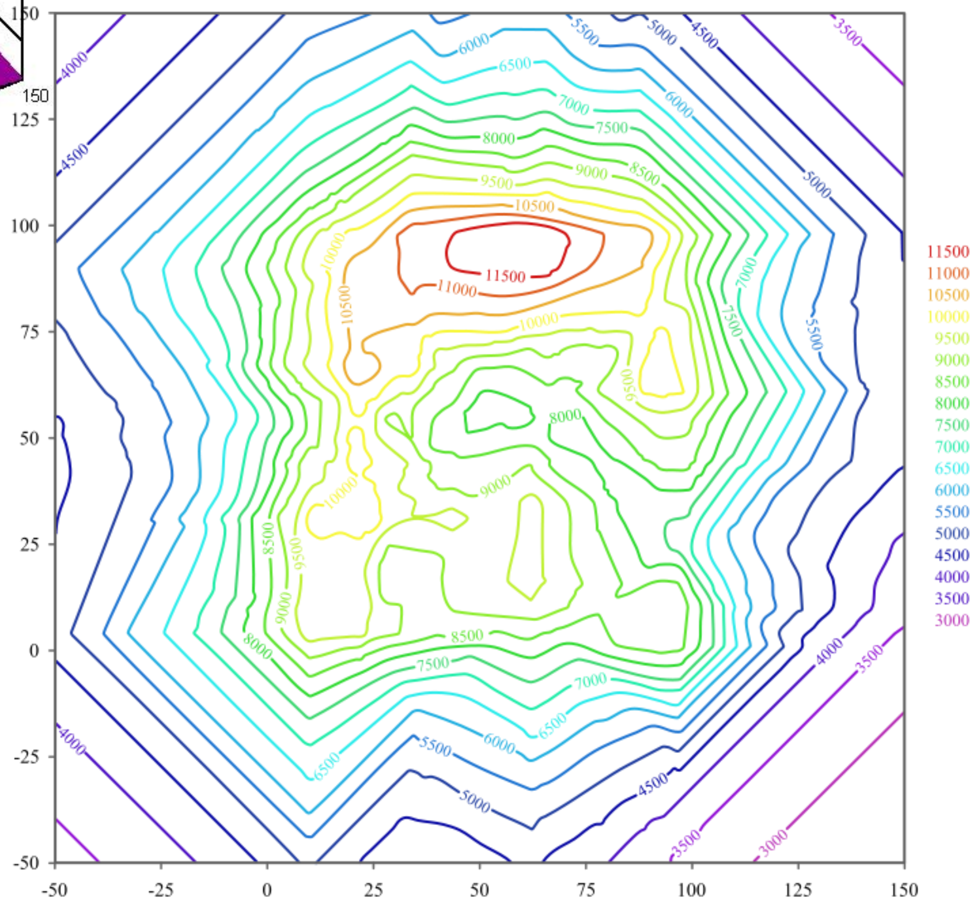
Introduction to contouring



Introduction to contouring







A two-dimensional contour graph of the three-dimensional surface

PURPOSE OF CONTOURING

Contour survey is carried out at the starting of any engineering project such as a road, a railway, a canal, a dam, a building etc.

i. For preparing contour maps in order to select the **most economical** site.

ii. To locate the alignment of a canal so that it should follow a **ridge line**.

iii. To mark the alignment of roads and railways so that the quantity of earthwork both in **cutting** and **filling** should be minimum.

iv. For getting information about the ground whether it is flat, undulating or mountainous.

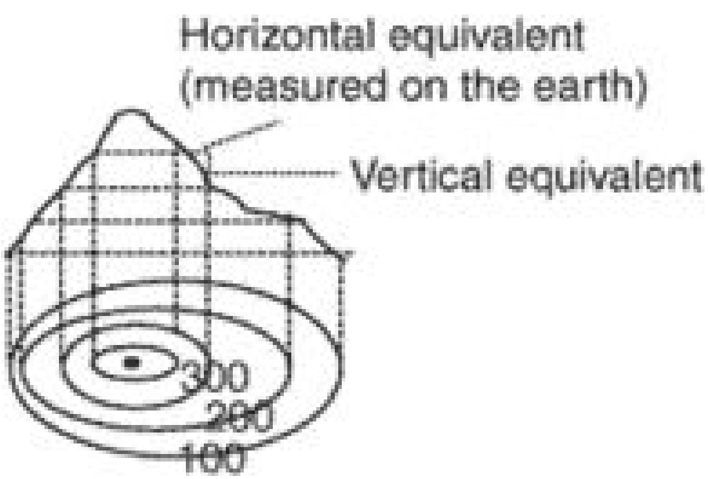
v. To find the **capacity of a reservoir** and volume of earthwork especially in a mountainous region.

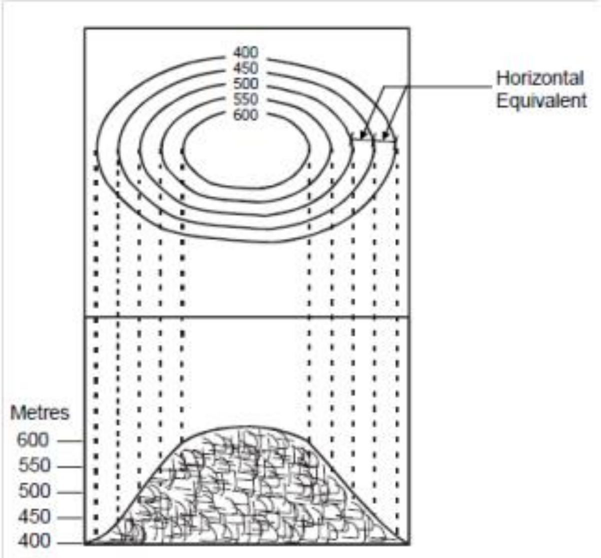
vi. To trace out the given grade of a particular route.

vii. To locate the physical features of the ground such as a **pond depression**, **hill**, **steep or small slopes**.

Important Definitions

- **CONTOUR INTERVAL**
- The constant vertical distance between two consecutive contours is called the contour interval.
- **HORIZONTAL EQUIVALENT**
- The horizontal distance between any two adjacent contours is called as horizontal equivalent.
- The contour interval is constant between the consecutive contours while the horizontal equivalent is variable and depends upon the slope of the ground.





Factors on Which Contour Interval Depends

- **The Nature of the Ground:** In flat and uniformly sloping country, the contour interval is small , but in broken and mountainous region the contour interval should be large otherwise the contours will come too close to each other.
- **The Purpose and extent of the survey:** Contour interval is small if the area to be surveyed is small and the maps are required to be used for the design work or for determining the quantities of earth work etc. while wider interval shall have to be kept for large areas and comparatively less important works.
- **The Scale of the Map:** The contour interval should be in the inverse ratio to the scale of the map i.e. the smaller the scale, the greater is the contour interval.
- **Time and Expense of Field and Office work:** The smaller the interval, the greater is the amount of field-work and plotting work.

Common Values of the Contour - Interval

- For large scale maps of flat country, for building sites, for detailed design work and for calculation of quantities of earth work; 0.2 to 0.5 m.

- For reservoirs and town planning schemes; 0.5 to 2m.

- For location surveys. 2 to 3m.

- For small scale maps of broken country and general topographic work; 3m,5m,10m,or 25m.

Characteristics of Contours

i. All points in a contour line have the same elevation.

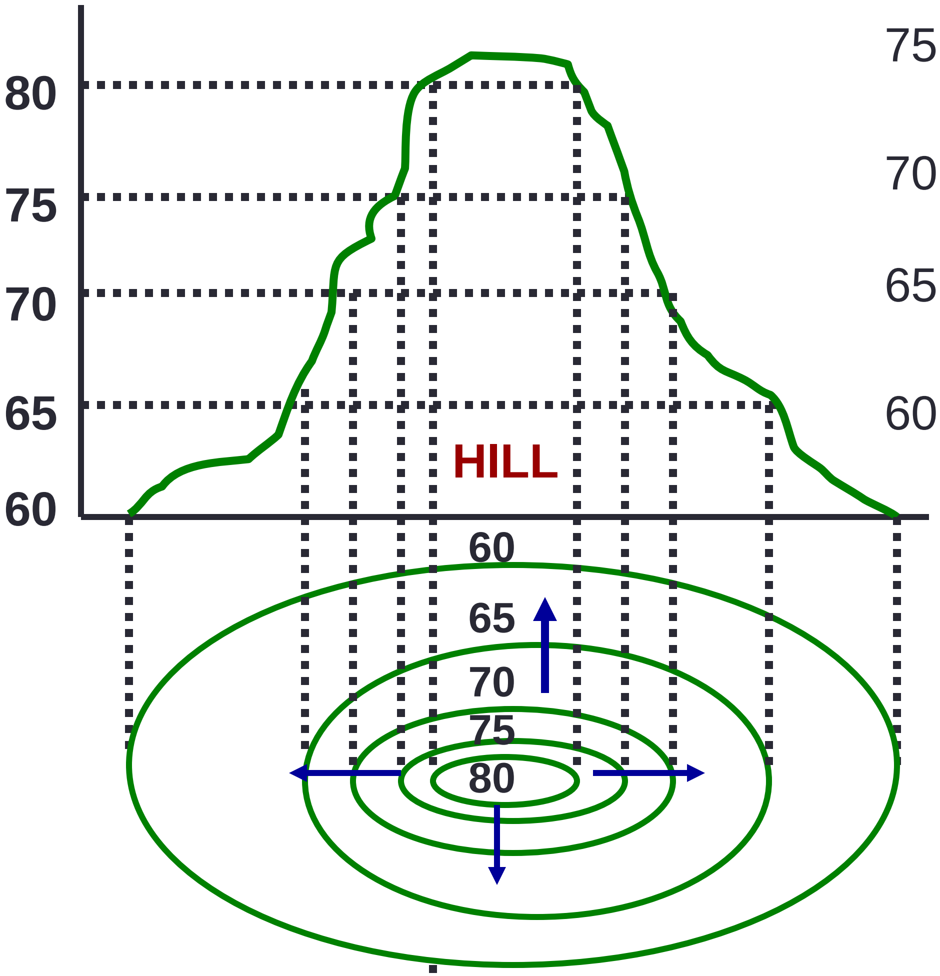
ii. Flat ground is indicated where the contours are widely separated and steep- slope where they run close together.

iii. A uniform slope is indicated when the contour lines are uniformly spaced and

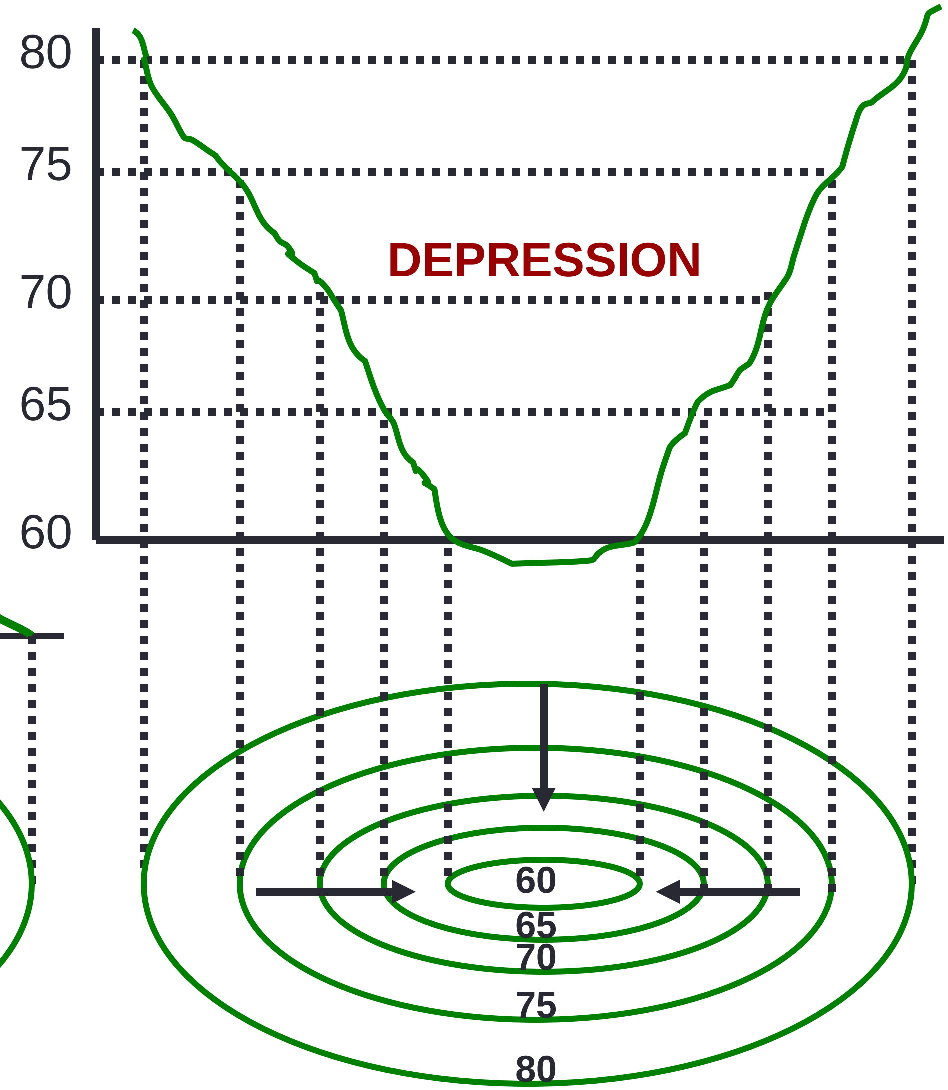
iv. A plane surface when they are straight, parallel and equally spaced.

v. A series of closed contour lines on the map represent a hill , if the higher values are inside

vi. A series of closed contour lines on the map indicate a depression if the higher values are outside

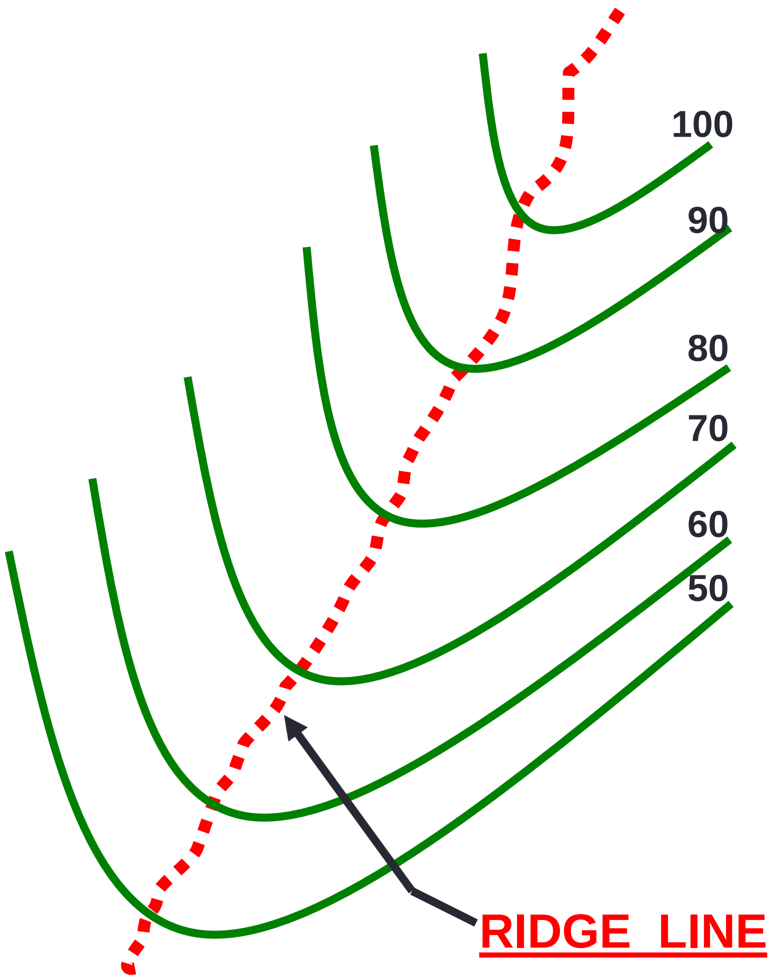


A HILL



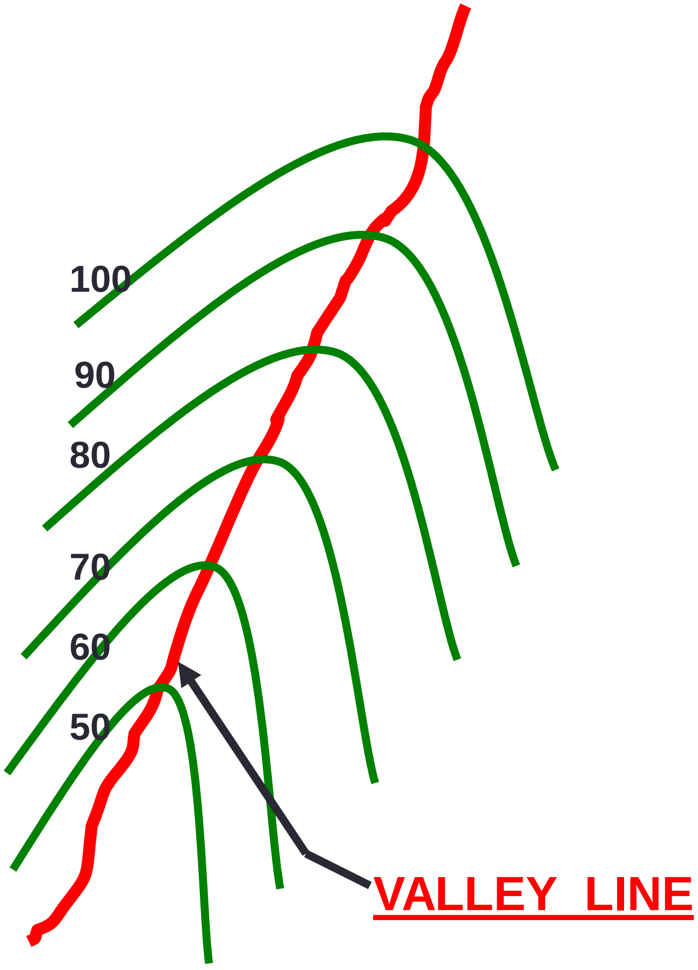
A DEPRESSION

vii) Contour line cross ridge or valley line at right angles.



If the higher values are inside the bend or loop in the contour, it indicates a Ridge.

vii) Contour line cross ridge or valley line at right angles.

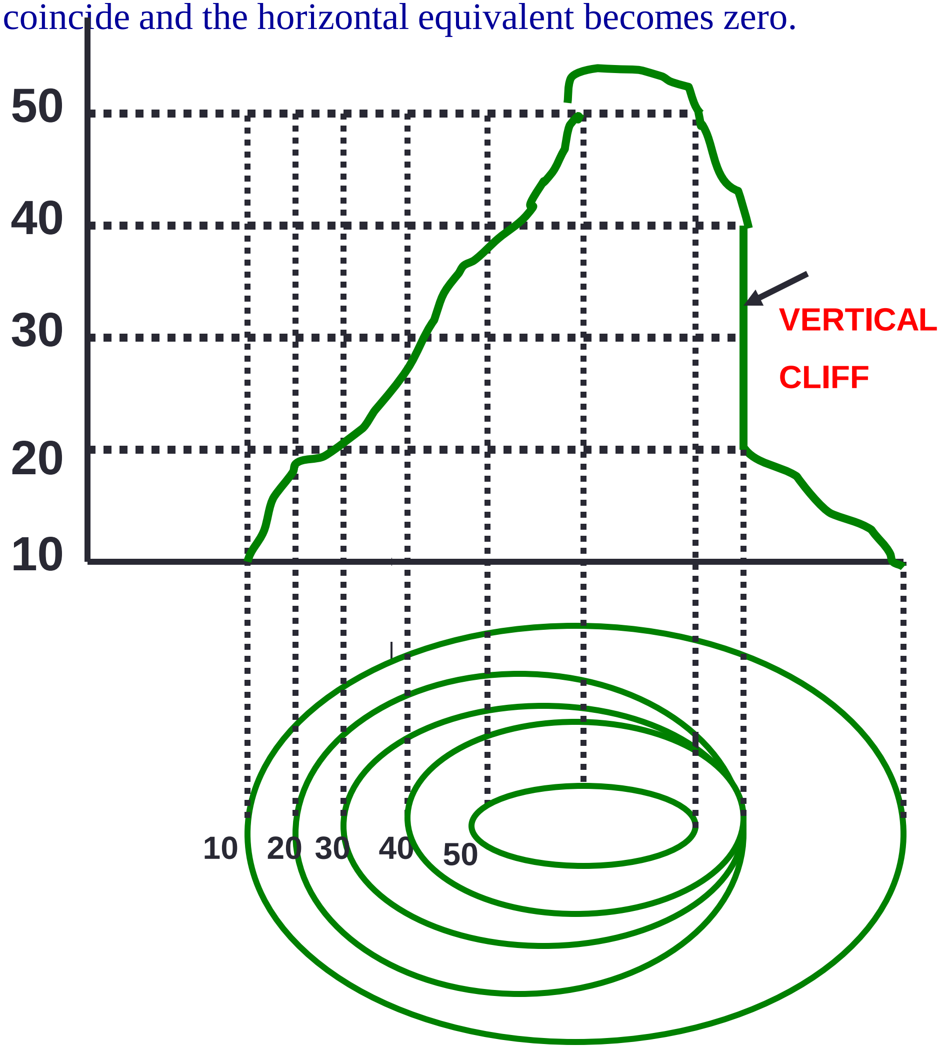


If the higher values are outside the bend, it represents a Valley

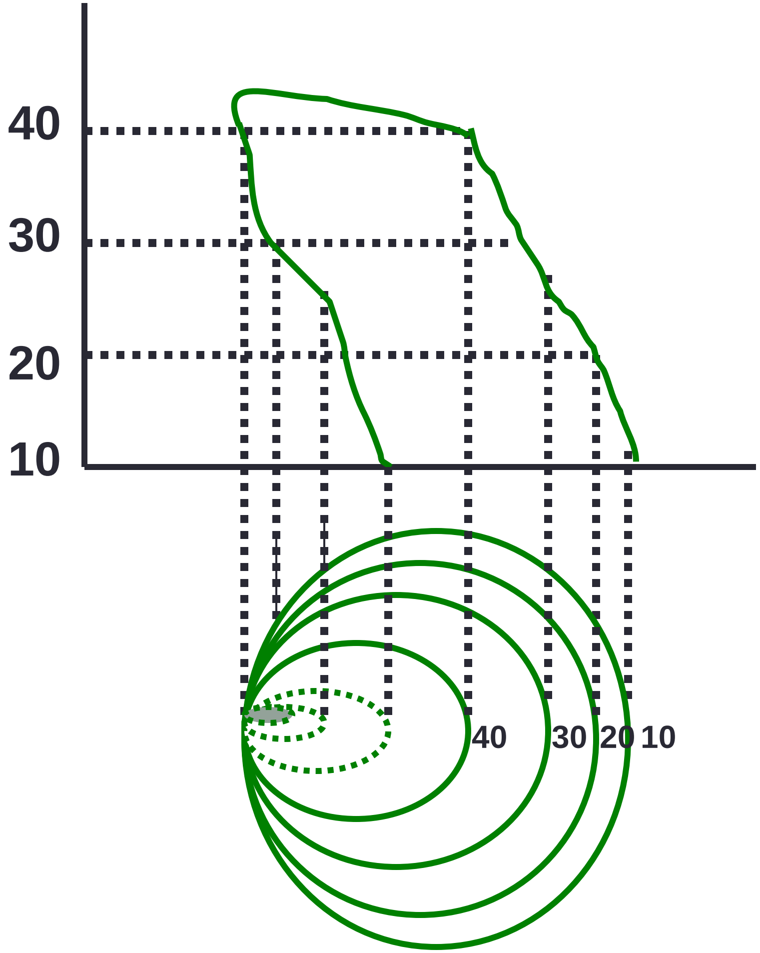
viii). Contours cannot end anywhere but close on themselves either within or outside the limits of the map.

ix). Contour lines cannot merge or cross one another on map except in the case of an overhanging cliff.

x) Contour lines never run into one another except in the case of a vertical cliff. In this case, several contours coincide and the horizontal equivalent becomes zero.

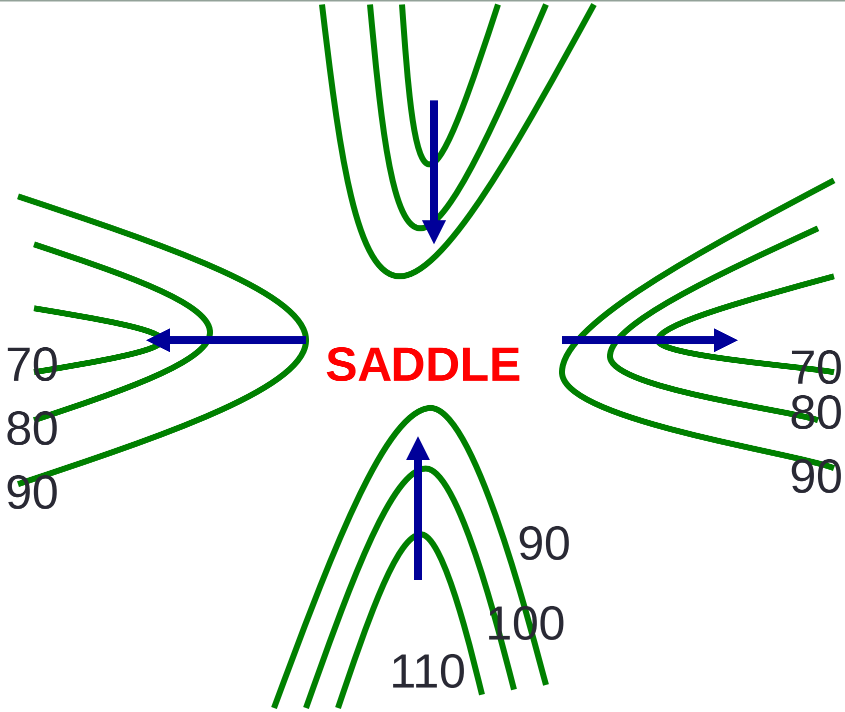


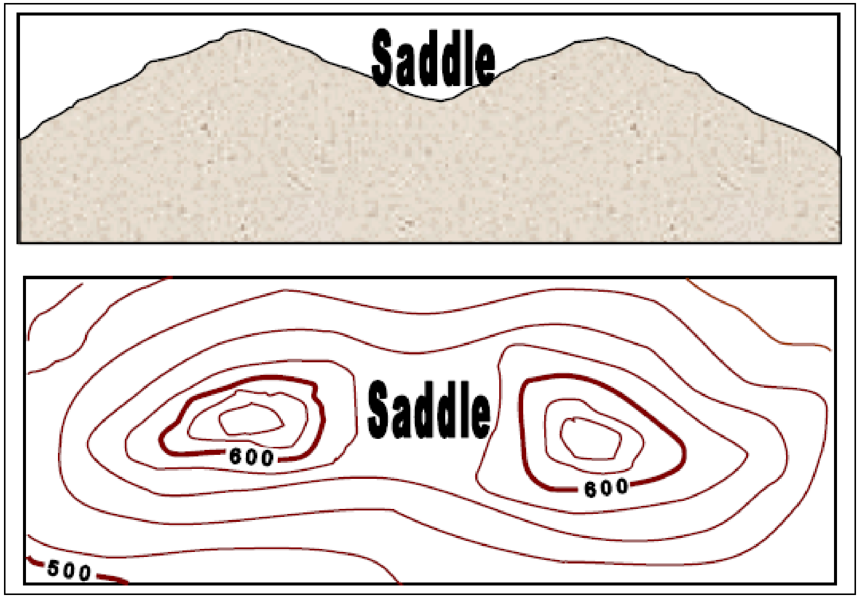
OVERHANGING CLIFF



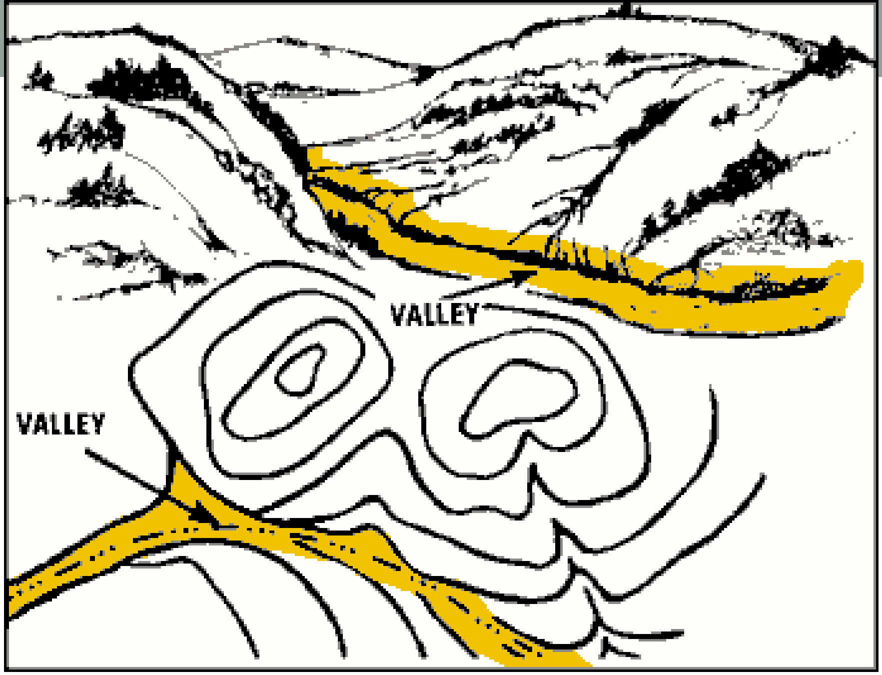
OVERHANGING CLIFF

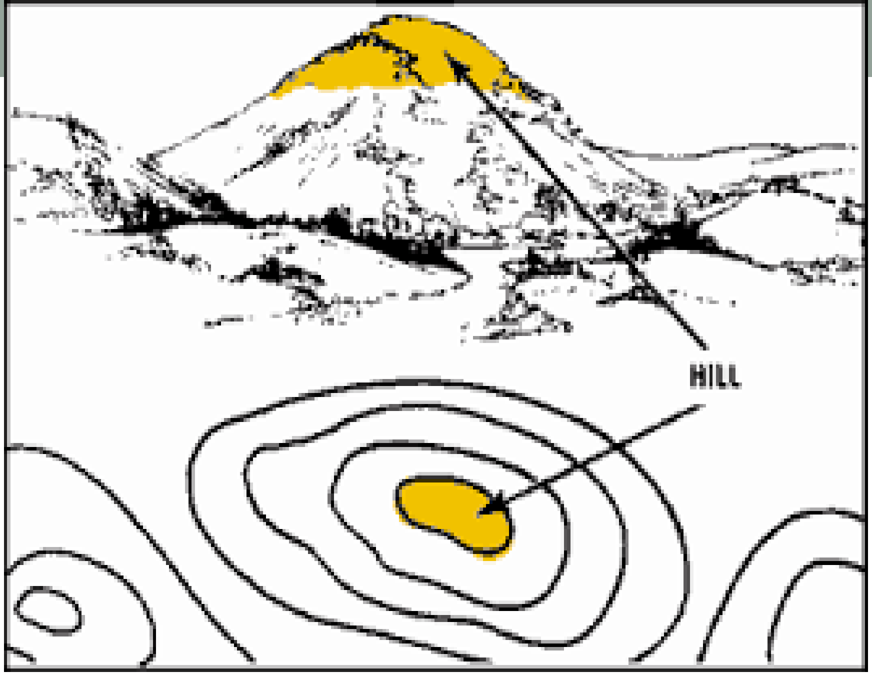
X) Depressions between summits is called a saddle. It is represented by four sets of contours as shown. It represents a dip in a ridge or the junction of two ridges. And in the case of a mountain range, it takes the form of a pass .

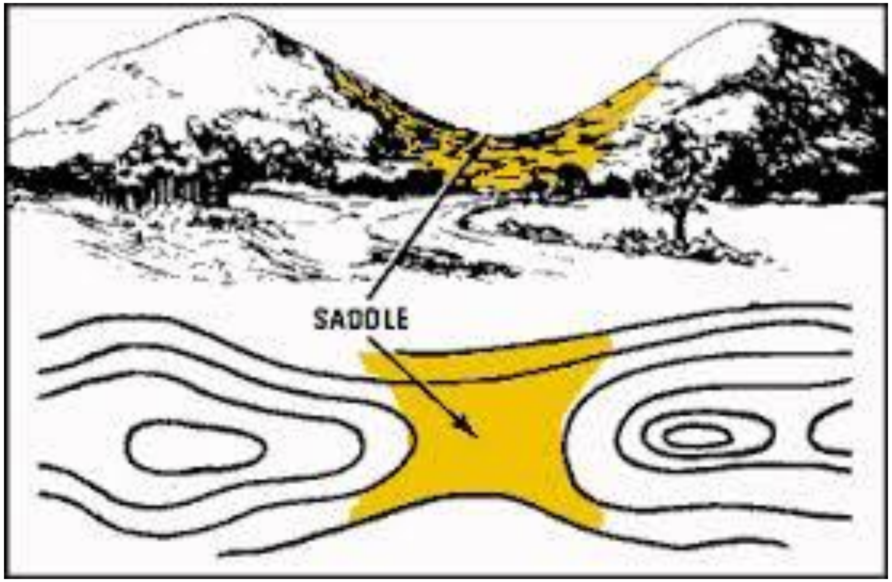


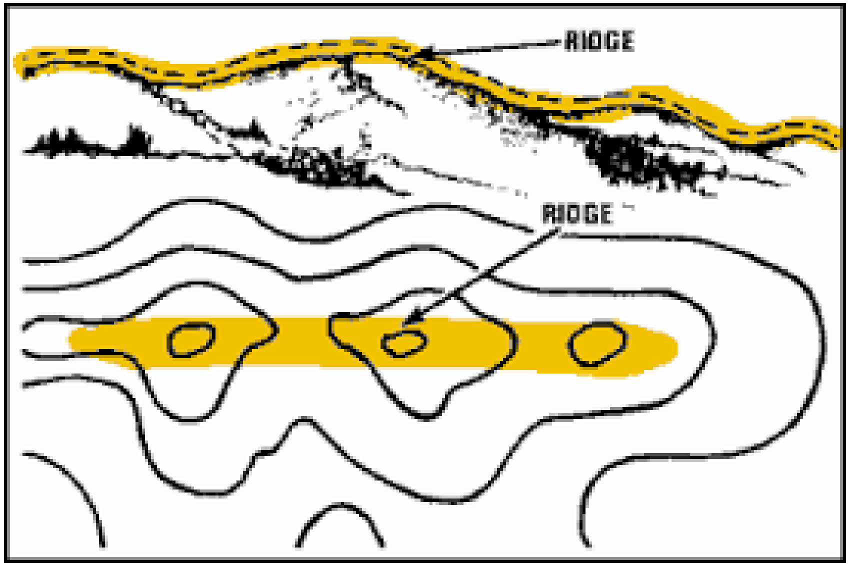


Line passing through the saddles and summits gives water shed line.


VALLEY
VALLEY


HILL


SADDLE


RIDGE
RIDGE

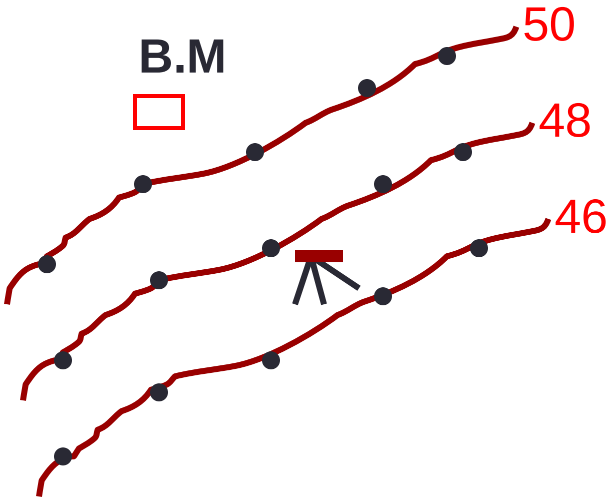
Methods of Contouring

There are mainly two methods of locating contours:-

(1)Direct Method and (2) Indirect Method.

Direct Method:

In this method, the contours to be located are directly traced out in the field by locating and marking a number of points on each contour. These points are then surveyed and plotted on plan and the contours drawn through them.



DIRECT METHOD OF CONTOURING

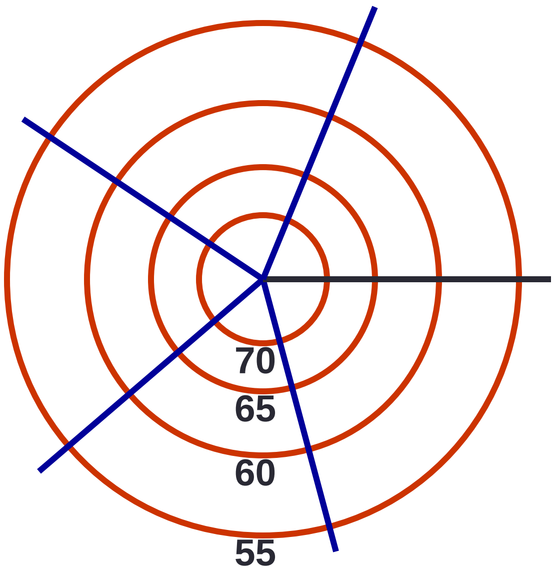
Direct Method:

- This method is most accurate but very slow and tedious as *a lot of time is wasted* in searching points of the same elevation for a contour.
- This is suitable for small area and where great accuracy is required

- **Procedure**: **To start with, a temporary B.M is established near the area to be surveyed with reference to a permanent B.M by *fly leveling*. The level is then set up in such a position so that the maximum number of points can be commanded from the instrument station. The height of instrument is determined by taking a back sight on the B.M. and adding it to the R.L. of bench mark. The staff reading required to fix points on the various contours is determined by subtracting the R.L. of each of the contours from the height of instrument.**

Direct Method By Radial Lines

- This method is suitable for small areas, where a single point in the center can command the whole area. Radial lines are laid out from the common center by theodolite or compass and their positions are fixed up by horizontal angles and bearings.
- Temporary bench marks are first established at the center and near the ends of the radial lines .The contour points are then located and marked on these lines and their positions are determined by measuring their distances along the radial lines. They are then plotted on the plan and the contours drawn by joining all the corresponding points with the help of a plane table instrument.



RADIAL LINES METHOD OF CONTOURING

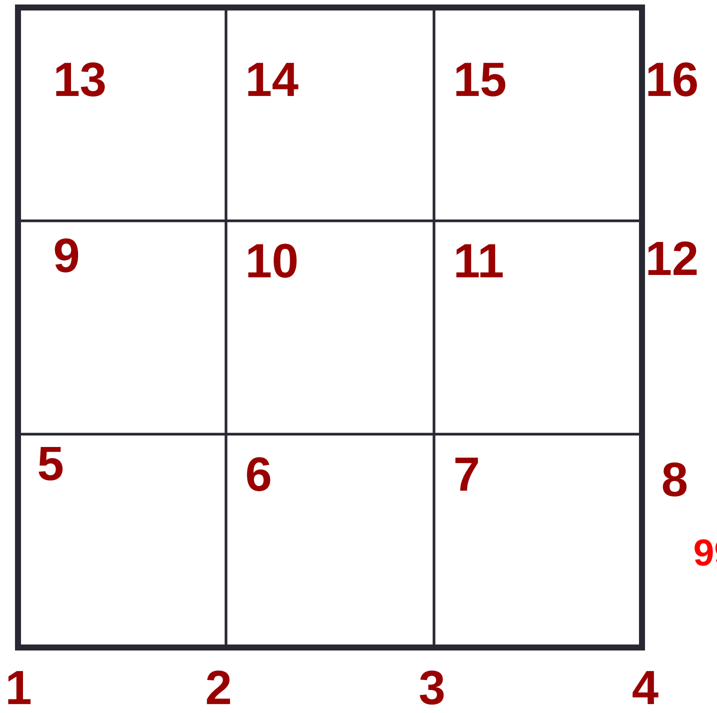
2. Indirect Method:

- In this method the points located and surveyed are not necessarily on the contour lines but the spot levels are taken along the series of lines laid out over the area. The spot levels of the several representative points representing hills, depressions, ridge and valley lines and the changes in the slope all over the area to be contoured are also observed. Their positions are then plotted on the plan and the contours drawn by interpolation. This method of contouring is also known as contouring by spot levels.
- This method is commonly employed in all kinds of surveys as this is cheaper, quicker and less tedious as compared to direct method. There are mainly three method of contouring in indirect method:
  - **Square Method**
  - **By Cross sections**
  - **By Tachometric Method**

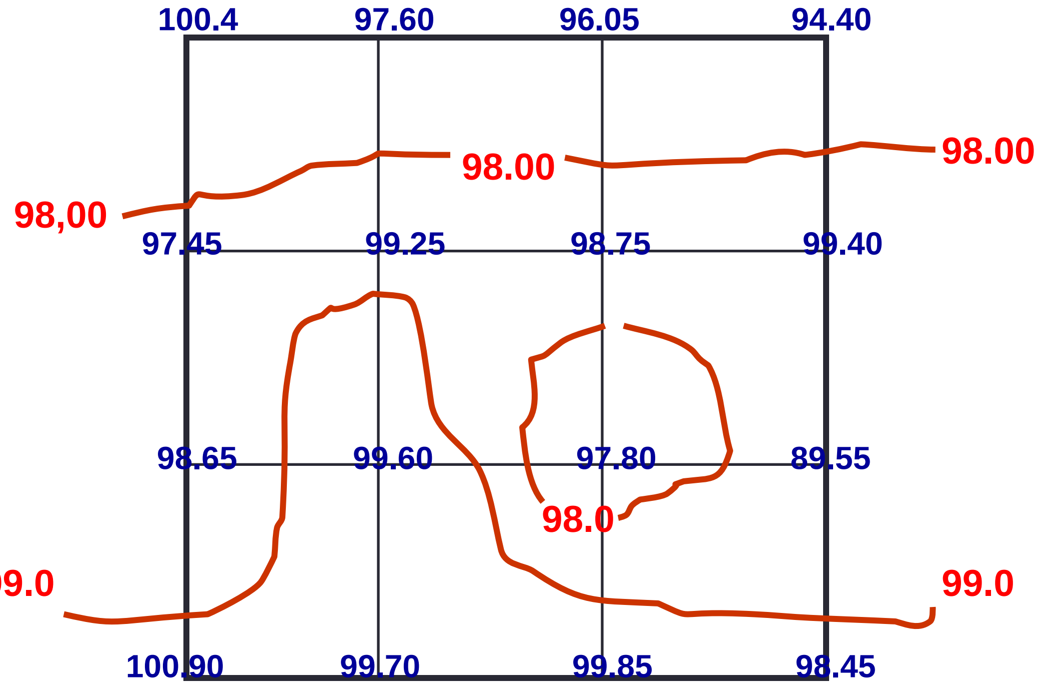
By Squares

- In this method, the whole area is divided into number of squares, the side of which may vary from 5m to 30m depending upon the nature of the ground and the contour interval. The square need not be of the same size throughout.
- The corners of the squares are pegged out and the reduced levels of these points are determined with a level.
- The important points within the squares may be taken when required and located by measurements from the corners. The squares are plotted and the reduced levels of the corners are written on the plan.

SQUARE METHOD



SQURES LAID ON GROUND



CONTOURS INTERPOLATED

(ii) By Cross- Sections:

This method is most suitable for the survey of long narrow strips such as a road, railway or canal etc.

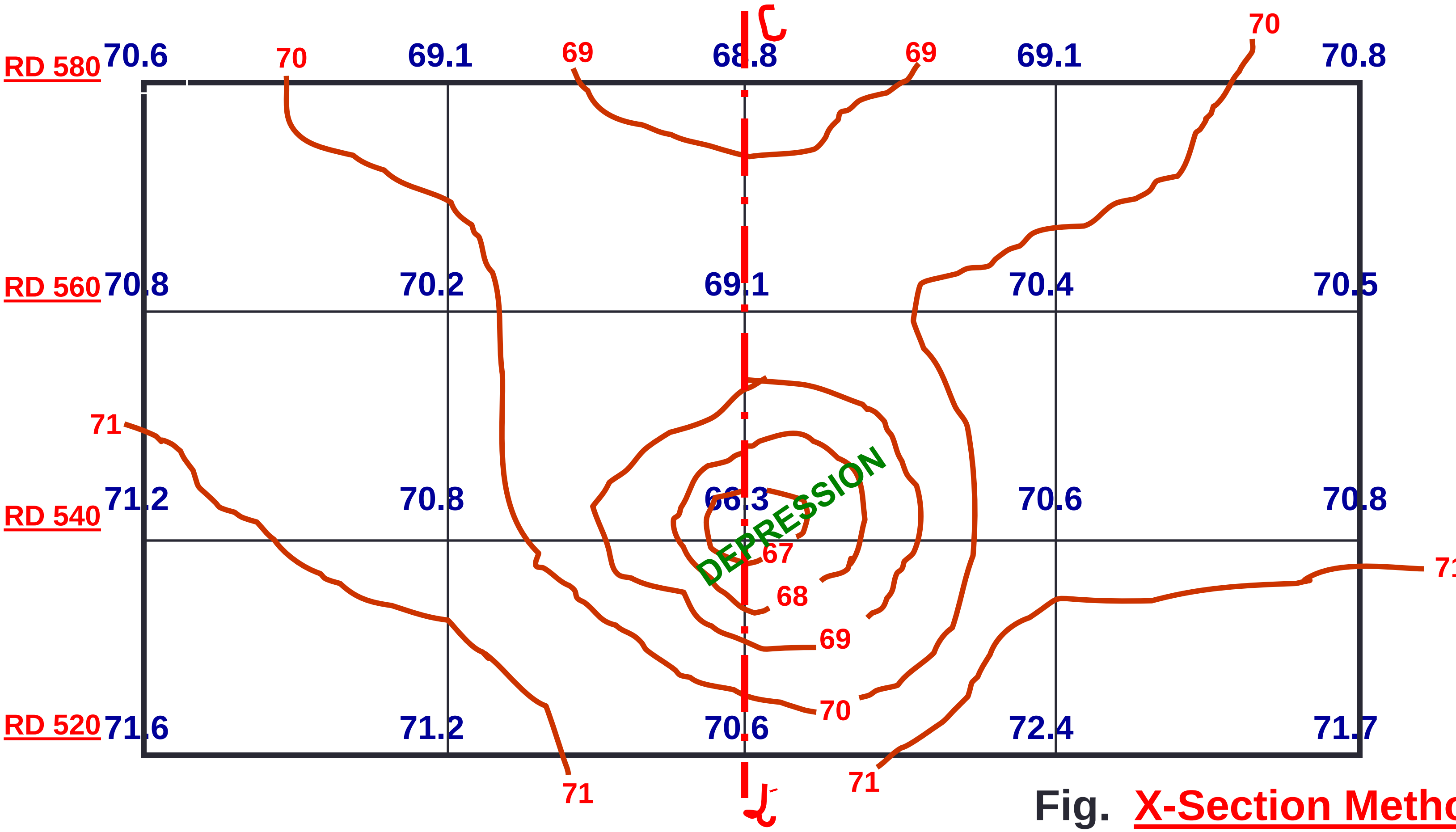


Fig. X-Section Method

(iii) By Tachometric method:

- A tachometer is a transit theodolite having a diaphragm fitted with two stadia wires, one above and other below the central wire. The horizontal distance between the instrument and staff station may be determined by multiplying the difference of the staff readings of the upper and lower stadia wires with the stadia constant of the instrument, which is usually 100.Thus the tachometer is used for both the vertical as well as horizontal measurements.

- This method is *most suitable in hilly areas* as the number of stations which can be commanded by a tachometer is far more than those by a level and thus the number of instrument settings are considerably reduced. A number of *radial lines* are *laid out* at a *known angular interval* and representative points are marked by pegs along these radial lines. Their *elevations and distances* are then *calculated and plotted* on the plan and the *contour lines* are then *interpolated.*

Drawing the Contour Lines

- Contour lines are drawn as fine and smooth free hand curved lines. Sometimes they are represented by broken lines. They are inked in either in black or brown color. A drawing pen gives a better line than a writing pen and French curves should be used as much as possible. Every fifth contour is made *thicker* than the rest.
- The elevation of contours must be written in a uniform manner, either on the higher side or in a gap left in the line .When the contour lines are *very long*, their *elevations are written at two* or *three places* along the contour. In the case of small scale maps, it is sufficient to figure every *fifth* contour.