Chapter 2
SURVEYING

2.1 INTRODUCTION [Nov, Dec 2010, 2011]

Surveying is the art of determining the relative positions of distinctive features on the earth's surface. This is achieved by the measurement of distances, directions and elevations.

In general, surveying is limited to operations concerned with the representation of ground features in plan. A branch of surveying which deals with the measurement of the relative heights of the features is known as levelling.

2.2 IMPORTANCE OF SURVEYING

The knowledge of surveying is advantageous in many phases of engineering. Every engineering project such as water supply and irrigation schemes, rail roads and transmission lines, mines bridges and buildings etc require surveys. Before plans and estimates are prepared, boundaries should be determined and the topography of the site should be ascertained. After the plans are made, the structures must be stated out on the ground. As the work progresses, lines and grades must be given.

2.3 OBJECTIVES OF SURVEYING

The main object of any survey is the preparation of a plan or a map showing all the features of the area under consideration. A plan may be defined as a projection of the ground and the features upon it on a horizontal plane. So, a plan is the representation to some scale of the area and the objects contained in it. The representation is called a map if the scale adopted is small, while it is called a plan if the scale is large. For example, a map of India, a plan of a building.

2.4 TYPES OF SURVEYING [Nov, Dec 2010]

The surveying may be primarily divided into two types: plane surveying and geodetic surveying.

2.4.1 Plane Surveying [May, June 2009; Nov, Dec 2010]

The surveying in which earth surface is assumed as a plane and the curvature of the earth is ignored is known as *plane surveying*. As the plane survey extends only over small areas, the line connecting two points on the earth is considered as a straight line and the angle between any two lines is considered as plane angle.

Surveys covering an area up to 260 km^2 may be treated as plane surveys. Such plane surveys are carried out for engineering projects and for geographical, geological, navigational and military purposes.

Plane surveys are used for the layout of highways, railways, canals, construction of bridges, dams, buildings, etc. The scope and use of plane surveying is wide. In order to have proper, economical and accurate planning of projects plane surveys are basically needed.

2.4.2 Geodetic Surveying [Nov, Dec 2010]

The surface of the earth is not plane but spheroidal. Therefore, the line connecting any two points on the earth's surface is not a straight line but a curve.

The surveying in which curvature of the earth is taken into account for all measurements is known as *geodetic surveying*.

The result obtained from the above surveying will possess a high degree of accuracy as it considers the effect of curvature of the earth also. This surveying extends over large areas and so any line connecting two points on the earth's surface is considered as an arc. The angle between any two such arcs is treated as a spherical angle. To undertake this method of surveying, a through knowledge in spherical trigonometry is required.

Geodetic surveys need sophisticated instruments and accurate methods of observations. In order to eliminate the errors in observations due to atmospheric refraction, angular observations are generally taken only in nights and arc lamps are used as signals on survey stations.

In India, geodetic surveys are carried out by the Department of the Survey of India under the direction of the Surveyor General of India.

2.5 CLASSIFICATION OF SURVEYS

Depending on the use and the purpose of the finished work, surveys are classified under the following heads:

1. Classification Based Upon the Nature of the Field

(a) Land surveying

(i) Topographical surveys To locate horizontal and vertical points by linear and angular measurements. For determining the natural features of a country such as streams, lakes, forests etc., and artificial features such as roads, railways, canals, towns & villages etc.

(ii) Cadastral surveys Cadastral surveys are made incident to the fixing of property lines, the calculation of land area, or the transfer of land property from one owner to another. It is also done to fix the boundaries of municipalities and of state & federal jurisdictions.

(iii) City surveying City surveying is done in connection with the construction of streets, water supply systems, sewers and other works.

(b) Marine (or) hydrographic surveys It deals with the bodies of water for purpose of navigation, water supply, harbour works or for the determination of mean sea level. The work consist in measurement of discharge of streams, making topography survey of shores and banks, taking and locating soundings to determine the depth of water and observing the fluctuations of the ocean tide.

(c) Astronomical survey It offers the surveyor means of determining the absolute locations of any point or the absolute location and direction of any line on the surface of the earth. This consists of observation of heavenly bodies such as sun or any fixed star.

2. Classification Based Upon the Objective of Survey **[Nov, Dec 2010]**

(a) Engineering surveys These are carried out for the determination of quantities which will be useful for the designing of engineering works.

(b) Military or defence surveys These are carried out for the preparation of maps of important military areas.

(c) Geological surveys These are carried out to ascertain the composition of the earth's crust.

(d) Mine surveys These are conducted for exploring the mineral wealth below the earth surface.

(e) Archaeological surveys These are executed to prepare maps of ancient cultures.

3. Classification Based Upon Methods Employed

(a) Triangulation surveys

(b) Traverse surveys

The framework in traverse survey consists of series of connected lines. The lengths and directions of these lines are measured with a chain or tape and with an angular measurement respectively.

A traverse is divided into two categories: *closed traverse normal open traverse.* A description of the two types of traverse is provided in this section.

1. Closed Traverse A traverse is said to be closed if a complete circuit is made, i.e. the origin and end point are one and the same thereby the circuit forms a closed polygon. This is particularly suitable for locating a building, boundaries of lakes, wooded lands, etc. A closed traverse is shown in Fig. 2.1.

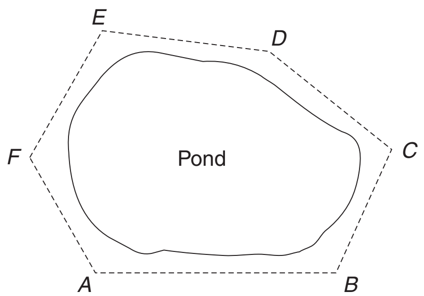


Fig. 2.1 *Closed traverse*

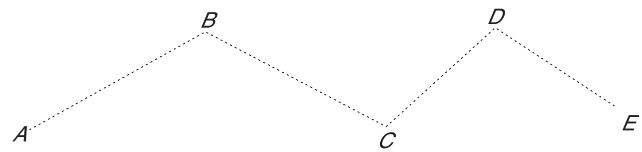


Fig. 2.2 *Open traverse*

2. Open Traverse A traverse is said to be open if it does not form a closed polygon. It consists of a series of survey lines extending in one general direction but never returning to the starting point as shown in Fig. 2.2.

4. Classification Based Upon the Instruments Used **[May, June 2009, 2011; Nov, Dec 2012]**

(a) Chain surveying
(b) Compass surveying
(c) Plane table surveying
(d) Theodolite surveying
(e) Tacheometric surveying
(f) Aerial surveying
(g) Photographic surveying

2.6 PRINCIPLES OF SURVEYING **[May, June 2009, 2010; Nov, Dec 2009; Apr, May 2015]**

The two main principles of surveying are (i) working from the whole to the part, and (ii) fixing new points by at least two independent processes.

1. Working from the whole to the part Whether it is a plane surveyor or a geodetic survey, the main principle adopted is to work from the whole to the part. In the case of surveying of extensive areas, such as a town or a big estate, the survey is started by establishing a system of control points with high precision. The line joining these points will form the boundary lines of the area, otherwise, this is the main skeleton of the survey. The above control points may be established by triangulation or by running a traverse surrounding the area. The main triangles and traverses are then broken into smaller ones and measured using less laborious methods. The main reason to work from the whole to the part is to avoid the accumulation of errors and to control any localised errors. If, on the other hand, the survey is carried out from the part to the whole, the errors will be magnified in each and every step and will become uncontrollable at the end. The above principle is also fit to the levelling also.

2. Fixing new points by at least two independent processes The use of two independent processes to fix a new point, helps in taking one set of measurements from one process and the same may be checked by another set of measurements. The above is explained by the following two techniques as indicated in Fig. 2.3 (a) and Fig. 2.3 (b).

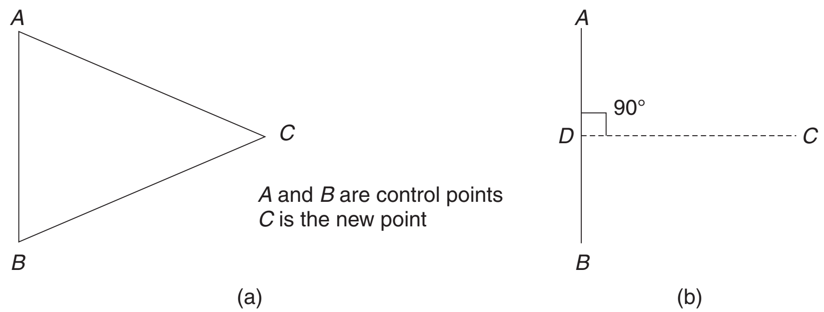


Fig. 2.3 *Fixing of points*

Let A and B the two given control points established by triangulation. Then, to fix the position of the point C,

(a) the distance AC and BC may be measured and the position of C may be fixed by drawing the arcs; or

(b) by dropping a perpendicular from C to the base line AB. Here, the distance CD and 90° angle of intersection are the two different measurements made to locate C.

2.7 MEASUREMENT OF DISTANCES

The two main methods of determining the distances between two points on the surface of the earth are the direct method and the computative method. In the case of the direct method, distances are measured using tapes, chains, etc. In the latter case, distances are obtained by calculation using tacheometry, triangulation, etc.

2.7.1 Different Methods of Direct Measurements

Following are the methods of measuring the distances directly:

(a) pacing
(b) measurement with passometer
(c) measurement with pedometer
(d) measurement by odometer and speedometer
(e) chaining

Pacing

Measurements of distances by pacing are chiefly confined to the preliminary surveys and explorations where a surveyor is called upon to make a rough survey as quickly as possible. This method consists in of counting the number of paces between the two points of a line. A length of pace more nearly to that of ones natural step is preferable.

Passometer

It is an instrument, shaped like a watch and is carried in pocket or attached to one leg. The mechanism of the instrument is operated by motion of the body and it automatically registers the number of paces. Then it can be multiplied by the average length of the pace to get the distance.

Pedometer

It is similar to the passometer except that it, is adjusted to the length of the pace of the person carrying it. It registers the total distance covered by any number of paces.

Odometer and Speedometer

Odometer is an instrument for registering the number of revolutions of a wheel. The odometer is fitted to a wheel which is rolled along the line whose length is required. The number of revolutions registered by the odometer can be multiplied by the circumference of the wheel to get the distance.

Chaining **[May, June 2012]**

Chaining is a term which is used to denote measuring distance either with the help of a chain or a tape and is the most accurate method of making direct measurements.

2.7.2 Chain **[May, June 2012, 2013]**

The chain is generally composed of 100 or 150 links. The links are formed by pieces of galvanised loops and connected together by means of three oval-shaped rings. The oval-shaped rings afford flexibility to the chain. In good-quality chains, the joints of links are welded so that change in length will be reduced considerably due to stretching. The ends of the chain are provided with brass handles with swivel joints so that the chain can be turned round without twisting. The outside of the handle is the zero point or the end of the chain. The length of a link is the distance between the centres of the two consecutive middle rings. The end links also include the handles. Metallic tags of different patterns called tallies are fixed at specific points of a chain, for quick and easy reading of the distance. For every five metres, there will be a tally. On tallies, the letter M will be engraved so as to distinguish a metric chain from a nonmetric chain. The length of the chain will be available in standard length of 20 or 30 m on the handle for easy identification. The details of a metric chain is shown in Fig. 2.4.

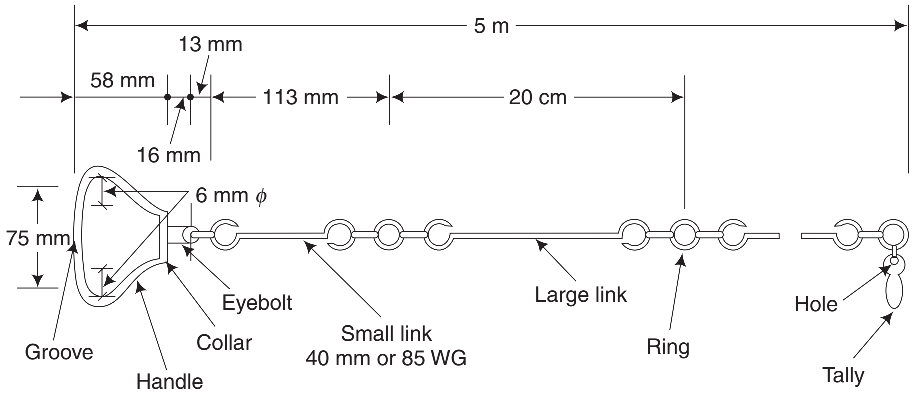


Fig. 2.4 *Details of a metric chain*

2.7.3 Steel Band

A steel band consists of a ribbon of steel with a brass swivel handle at each end. The width of the band is 16 mm and the length may be 20 or 30 m. The graduations in it are marked in two ways:

1. The band is divided by brass studs at every 0.2 m and numbered at every one metre. The first and last links are subdivided into centimetres and millimetres.
2. The graduations are etched as metres, decimetres, centimetres on one side and 0.2 m links on the other side. The band is wound on an open steel cross or in a metal steel case.

Advantages

1. Measurements using steel bands are more accurate than chaining.
2. It is lighter and easier to handle.
3. The length is not altered due to usage as compared to a chain.

Disadvantages

1. It cannot be so easily read.
2. Frequent cleaning is essential to avoid rust formation.
3. It needs proper care while handling as it breaks easily.
4. It cannot be repaired in case if it is broken.

2.7.4 Principle of Chain Surveying

The principle of chain surveying is to divide the area into a number of triangles of suitable sides. A network of triangles is preferred here as triangle is the simple plane geometrical figure which can be plotted with the lengths of its sides alone. Chain surveying is the simplest kind of surveying. In this case, there is no need for measuring angles.

2.7.5 Suitability of Chain Surveying

1. It is suitable when the ground is fairly level and open with simple details.
2. When large scale plans are needed, this type is suitable.
3. It is suitable when the area to be surveyed is comparatively small in extent.
4. It is suitable for ordinary works as its length alters due to continued use.
5. Sagging of chain due to its heavy weight reduces the accuracy of measurements.
6. It can be read easily and repaired in the field itself.
7. It is suitable for rough usage.

2.7.6 Unsuitability of Chain Surveying

1. It is unsuitable for large areas crowded with many details.
2. It is unsuitable for wooded areas and undulating areas.

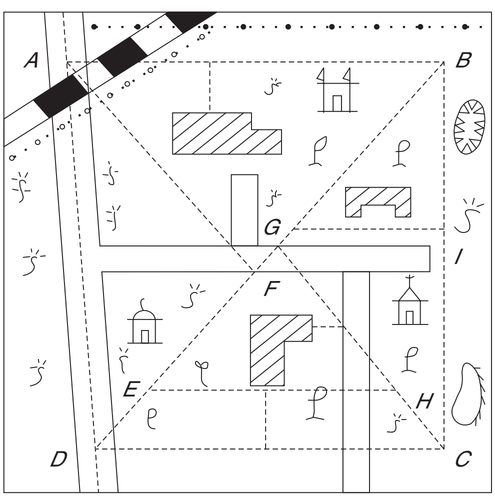
2.7.7 Technical Terms in Chain Surveying

These terms are explained below with reference to Fig. 2.5.

1. Main Survey Station It is the point where two sides of a main triangle meet.

2. Tie Stations These are the stations selected on the main survey lines for running auxiliary lines. These are otherwise called as subsidiary stations.

3. Base Line It is the longest of the main survey lines. This line is the main reference line for fixing the positions of various stations and also to fix the direction of other lines. This should be carefully measured and laid as the accuracy of entire triangulation critically depends on this measurement.



1. Main survey stations — A, B, C, D
2. Main survey lines—AB, BC, CD, DA, BD
3. Box line—BD
4. Subsidiary stations—FG
5. Subsidiary or tielines—AF, GC
6. Check line — EH, GI

Fig. 2.5 *Layout of a chain survey*

4. Check Line A check line is used in the field in order to check the accuracy of the measurements made.

5. Tie Line The chain line joining the tie stations and subsidiary stations is called so.

6. Offset While survey is carried out, important details such as boundaries, fences, buildings and towers are located with respect to main chain lines by means of lateral measurements. The two types of offsets shown in Fig. 2.6 are the perpendicular offset and the oblique offset.

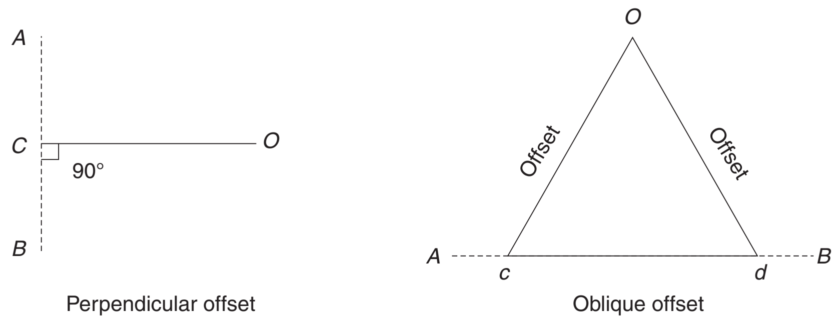


Fig. 2.6 *Offset*

2.7.8 Electronic Methods of Measuring Distance

In the electronic methods, distances are measured with the instruments that rely on propagation, reflection and subsequent reception of either radio or light waves.

Various instruments that are used under electronic methods

(i) Geodimeter
(ii) Tellurometer
(iii) Decca navigator
(iv) Lambda position fixing systems

Geodimeter is based on the propagation of modulated light waves. Other three instruments are based on radio waves for distance measurements. Geodimeter and Tellurometer are chiefly employed for measurement of distance on land. Decca navigator and lambda position of fixing system are used at sea.

2.8 MEASUREMENT OF ANGLES

The instruments commonly used for measurement of angles are the compass and the theodolite. Sometimes, a box sextant is also used.

2.8.1 Method of Measurement of Angles

The horizontal angles may be measured in two ways:

1. Included angles, as indicated in Fig. 2.7 (a).

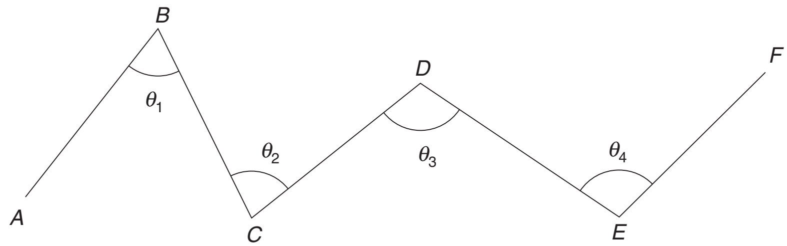


Fig. 2.7 (a) *Included angles*

2. Deflection angles between successive lines, as shown in Fig. 2.7 (b).

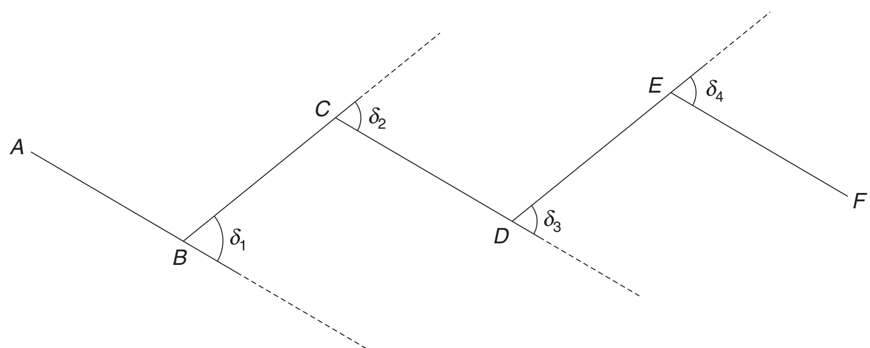


Fig. 2.7 (b) *Deflection angles*

2.8.2 Compass **[May, June 2012, 2013, 2014]**

This instrument essentially consists of a freely suspended magnetic needle on a pivot, which can move over a graduated scale. In addition to the above, it has an object vane and an eye vane which will be useful to get the line of sight. This instrument will be supported by a tripod stand while taking observations.

The two types of compass are the prismatic compass and the surveyor's compass.

1. Prismatic Compass It is the most suitable type of rough surveys where speed is very important rather than accuracy. It is commonly used for the preliminary survey for a road, railway, military purposes, a rough traverse, etc. The result from compass observations may be unrealistic in places where there is more local attraction due to magnetic rock or iron ore deposits. Figure 2.8 shows the different parts of a prismatic compass.

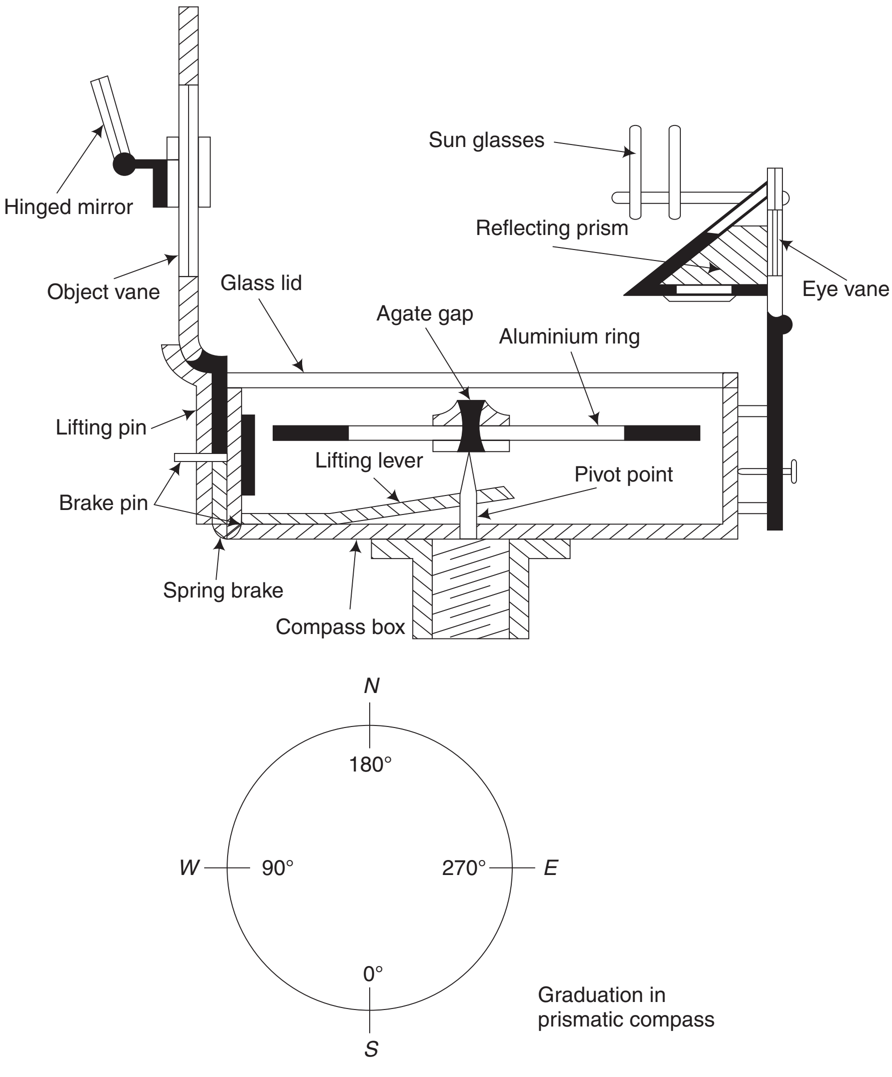


Fig. 2.8 *Prismatic compass*

2. Surveyor's Compass This type is not often used now for land surveying. In general, it is similar to a prismatic compass except that it has another plain sight having a narrow vertical slit in place of the prism as detailed in Fig. 2.9.

2.8.3 Bearing

Bearing is the horizontal angle between the reference meridian and the survey line. It is measured in the clockwise direction. Bearings are classified into different types and each of the type is described in this section.

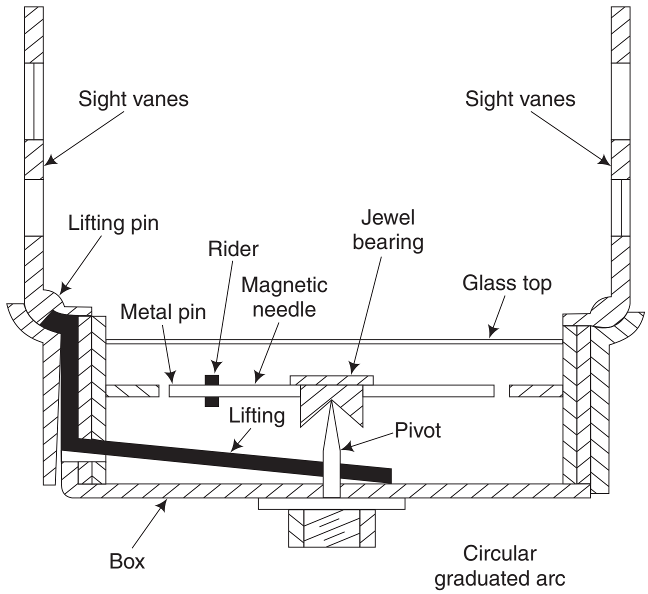


Fig. 2.9 *Surveyor's compass*

1. True Bearing True bearing of a line is the angle which a line makes with the true north or geographical north, measured always in the clockwise direction. The range of measurement is from 0°–360°.

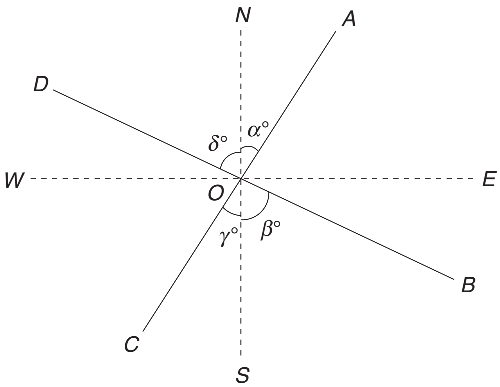
2. Magnetic Bearing It is the angle which a line makes with the magnetic north measured always in the clockwise direction. The measuring range is from 0°–360°.

3. Whole Circle Bearing (WCB) Since the range of 0° to 360° completes a circle, any angle measured in between 0° to 360° directly is called a whole circle bearing. The magnetic and true bearing are just whole circle bearings. **[Nov, Dec 2009]**

4. Reduced Bearing (RB) This is based on quadrantal system wherein any angle is measured with respect to the north–south line, towards east or west as shown in Fig. 2.10. **[Nov, Dec 2009]**

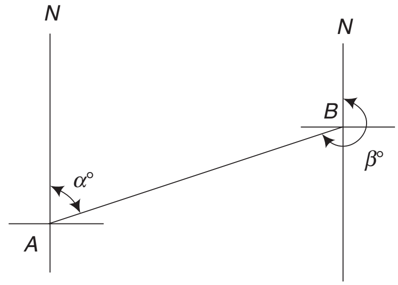
5. Fore Bearing (FB) The angle measured from a survey station to the other station, in the direction in which survey is conducted, is called the fore bearing. In Fig. 2.11, the bearing of line *A* to *B* is the fore bearing.

6. Back Bearing (BB) It is the bearing taken from the next station to its preceding station from which the fore bearing was taken. Referring to Fig. 2.11, the bearing taken from station *B* towards station *A* is the back bearing of the line *AB*. In WCB system, BB = FB ± 180° using +ve sign if the FB is less than 180° and –ve sign if the FB is greater than 180°. In RB system, to convert FB into BB or vice versa, N is replaced by S, S by N, E by *W* and *W* by *E* without changing the numerical value of its bearing.



Representation
Line $OA \rightarrow N\,\alpha°\,E$
Line $OB \rightarrow S\,\beta°\,E$
Line $OC \rightarrow S\,\gamma°\,W$
Line $OD \rightarrow N\,\delta°\,W$

Fig. 2.10 *Reduced bearing (or) quadrantal bearing*



NAB = $\alpha°$ = fore bearing
NBA = $\beta°$ = back bearing
∴ Fore bearing – back bearing = 180°

Fig. 2.11 *Fore and back bearing*

Table 2.1 *Comparison between prismatic compass and surveyor's compass*

	Prismatic compass	*Surveyor's compass*
1.	In the prismatic compass, the magnetic needle and the graduated dial are attached together while the prism and the box rotate.	In the surveyor's compass, the magnetic needle remains freely suspended and stationary while the dial is attached to the box.
2.	The graduations are provided in the clockwise direction.	In this case, the graduations are marked from 0° to 90° in all the four quadrants.
3.	Readings are observed by looking through the prism eye-piece from the south end of the compass.	Readings are taken by directly looking on the dial immediately below the north end of the needle.
4.	The zero of the reading is marked on the south end of the instrument.	Here, it is marked on the north and south end.
5.	A mirror is attached to the object vane for sighting objects at higher elevations or depression.	No such mirror is provided in the object vane.
6.	The position of east and west are in their correct positions.	The position of east and west are interchanged.
7.	By using this, one can obtain directly the whole circle bearings.	This is based on quadrantal system having 0° at north and 90° at east and west ends. With this, it is possible to read only the reduced bearings.
8.	The prismatic compass may be held in hand while taking observations.	The surveyor's compass needs a light tripod or a single pointed rod to support it.

Table 2.2 gives the rules to convert WCB to RB and the conversion is illustrated in Fig. 2.12.

Table 2.2 Conversion of WCB to RB

Case	*WCB between*	*Rule for RB*	*Quadrant*
I	0° and 90°	WEB	NE
II	90° and 180°	180° – WCB	SE
III	180° and 270°	WCB – 180°	SW
IV	270° and 360°	360° – WCB	NW

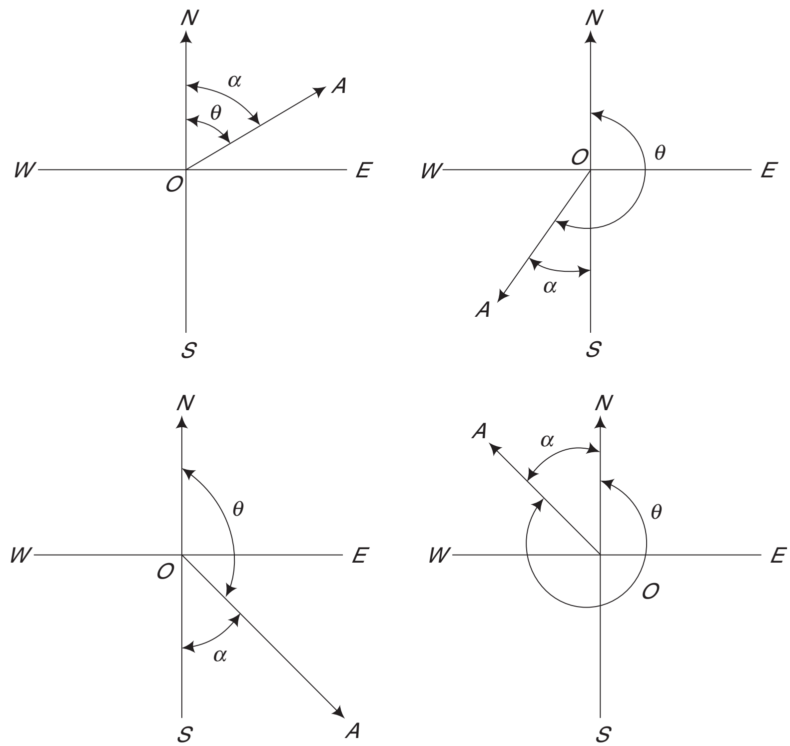


Fig. 2.12 *Conversion of WCB to RB*

When a line lies exactly along North, South, East or West, if

WCB of a line = 0°, then, RB is N

WCB of a line = 90°, then, RB is E 90°

WCB of a line = 180°, then, RB is S

WCB of a line = 270°, then, RB is W 90°

Table 2.3 presents the rules to convert RB to WCB

Table 2.3 Conversion of RB to WCB

Case	*RB Quadrant*	*Rule for WCB*	*WCB between*
I	NE	RB	0° and 90°
II	SE	180° – RB	90° and 180°
III	SW	180° + RB	180° and 270°
IV	NW	360° – RB	270° and 360°

2.8.4 Calculation of Angles from Bearings

Knowing the bearing of two lines, the angle between the two can very easily be calculated with the help of a diagram.

Ref., to Fig. 2.13(a), the included angle α between the lines AC and $AB = \theta_2 - \theta_1$ = FB of one line – FB of the other line, both bearings being measured from a common point A. Reference to Fig. 2.13(b), the angle $\alpha = (180° + \theta_1) - \theta_2$ = BB of previous line – FB of next line.

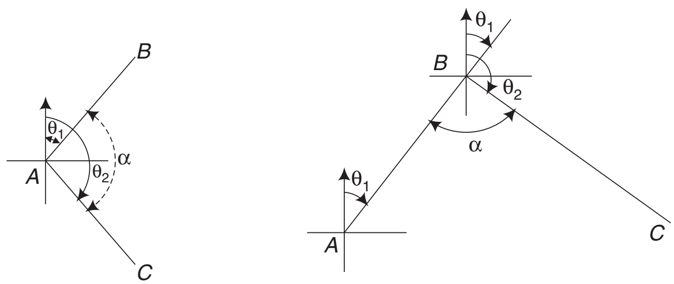


Fig. 2.13

Let us consider the quadrantal bearing, referring to Fig. 2.14(a) in which both the bearings have been measured to the same side of common meridian, the included angle $\alpha = \theta_2 - \theta_1$. In Fig. 2.14(b), both the bearings have been measured to the opposite sides of the common meridian, and included angle $\alpha = \theta_1 + \theta_2$. In Fig. 2.14(c) both the bearings have been measured to the same side of different meridians and the included angle $\alpha = 180° - (\theta_2 + \theta_1)$. In Fig. (d), both the bearings have been measured to the opposite sides of different meridians, and angle $\alpha = 180° - (\theta_1 - \theta_2)$.

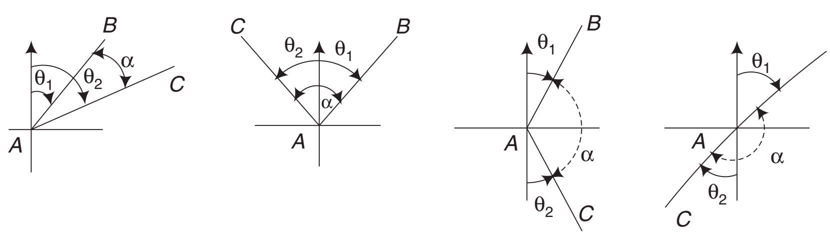


Fig. 2.14

Thus Fig 2.14 main advantage of the quadrantal bearings is that they never exceed 90° and the values of their trigonometrical functions can easily be extracted from the ordinary tables. They, however, possess the following disadvantages:

(i) It is necessary to put the appropriate cardinal points without which the bearings will have no significance.

(ii) The alternate clockwise and anti clockwise direction of increase of angle in the different quadrants is sometimes inconvenient and may very easily lead to mistakes being made.

(iii) The noting of the cardinal points may prove to be an extra unnecessary trouble.

The following at the advantages of this system:

(i) It is easy to calculate the included angle between two lines with the help of this system of bearings.

(ii) The convention of reckoning the bearing clockwise from the magnetic north is so simple that it is not necessary to remember whether the bearings are observed with reference to the north meridian or south meridian.

(iii) The plotting of traverse becomes easy because the bearings are to be measured only in the clockwise direction.

(iv) There is no botheration of putting the cardinal points.

The only drawback of this system is that when the bearings are to be used for computation and where the values of the trigonometrical functions are required, they are to be reduced to their equivalent values.

2.8.5 Local Attraction

If external magnetic influences are present in the place of observation using a compass, The needle will be seriously deflected from its normal position. Such disturbance due to the surrounding magnetic field is called local attraction.

The readings observed will be affected due to the presence of magnetic rocks or iron-ore deposits, steel structures, railways, iron lamp posts, electrical steel towers, etc. The actual bearing may be affected if we carelessly keep a bunch of iron keys, knife, iron buttons, steel-framed spectacles, the chain itself, arrows, etc. near the instrument. To detect its presence, one has to find the fore and back bearing of a line and obtain the difference between them. If the difference is not exactly equal to 180° then it indicates the presence of local attraction, provided there are no instrumental and observational errors.

2.8.6 Traversing with Compass and Chain

In compass traversing, the instrument is set at each station successively and the fore and back bearings of each line are noted in the field note book. The errors in this survey tend to compensate as each bearing is observed independently. Distances between the successive stations are measured using the chain. The offset points are located either by chaining or by angular measurements with compass.

2.9 LEVELLING [Nov, Dec 2010]

2.9.1 Definition

It is defined as the art of determining the relative heights of points on the earth's surface. This technique of surveying deals with measurements in vertical planes.

2.9.2 Objectives

Levelling provides an accurate network of heights, covering the entire area of the project. For the execution of many engineering projects levelling becomes very essential. For instance, the construction of railways, highways, canals, dams, water supply, sanitary lines, etc. is done through the determination of elevations of different points along the alignment (alignment involves the fixing of the centre line of railway or highway as the case may be). Greater the accuracy in the observations, the greater will be the saving in expenditure during project execution. A good network of levels provides an excellent idea of the existing terrain for the engineer, who can then plan and design his project keeping in view the economy and safety.

2.9.3 Technical Terms used in Levelling

Level surface The surface which is normal to the direction of gravity at all points is called a level surface. Every point on the level surface will be equidistant from the centre of the earth. For example, the surface of a still lake forms a level surface.

Horizontal plane The plane tangential to the level surface at any point is known as a horizontal plane.

Vertical plane The plane which contains vertical line at a place is called a vertical plane. The vertical line at any point will be perpendicular to the level surface at that point.

Datum surface This is an arbitrary surface with reference to which the heights (elevations) of points are measured and compared.

Reduced level (RL) Reduced level of a point is its height above or below the datum.

Back sight (BS) It is the first staff reading taken after setting up the instrument in any position. This will always be a reading on a point of known height.

Fore sight (FS) This is the last staff reading taken on a point before shifting the instrument. This will always be a point whose height has to be determined.

Intermediate sight (IS) Intermediate sight refers to any staff reading taken on a point of unknown elevation after the back sight and before the fore sight. This is necessary if it is needed to take more than two readings from the same position of the instrument.

Change point (CP) A change point indicates the shifting of the instrument. Both the back sight and the fore sight are taken on a change point.

Benchmark (BM) A benchmark is a fixed point of reference of known elevation. The reduced level of the benchmark is used to determine the reduced levels of other points.

Benchmarks are classified into the following types:

(a) Great Trigonometrical Survey benchmarks (GTS bench marks)
(b) Permanent benchmarks
(c) Arbitrary benchmarks
(d) Temporary benchmarks

GTS bench marks are those established by the Survey of India Department. The notation of a Benchmark is shown in Fig. 2.15. In small levelling works, the reduced level of a well defined reference point is arbitrarily assumed and is called as an arbitrary benchmark. Temporary benchmarks are the reference points which are established when there is a break in the work.

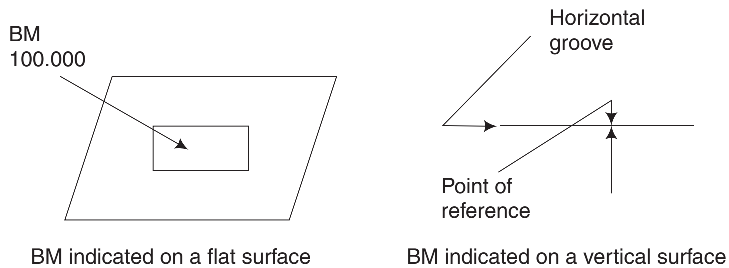


Fig. 2.15 *Notation of benchmark*

2.9.4 Principle of Levelling **[Apr, May 2015, Regulation 2008]**

Figure 2.16 illustrates the operations of levelling and Fig. 2.17 explains the principle of levelling. The principle of levelling lies in furnishing a horizontal line of sight and finding the vertical distances of the points above or below the line of sight. The line of sight is provided with a level. A graduated levelling staff is used to measure the height of the line of sight.

Let O represent the centre of the earth. A and A' are the points whose difference in elevation is required. C is the position of the instrument (level). The line CO is the direction of plumb line. BB' denotes the line of sight which is perpendicular to CO. AB and $A'B'$ are the readings on a staff vertically held at points A and A' respectively.

$$OA + AB = OA'' + A''A' + A'B'$$

or

$$AB - A'B' - AA' = dh$$

where dh is the difference in elevation between the points A and A'.

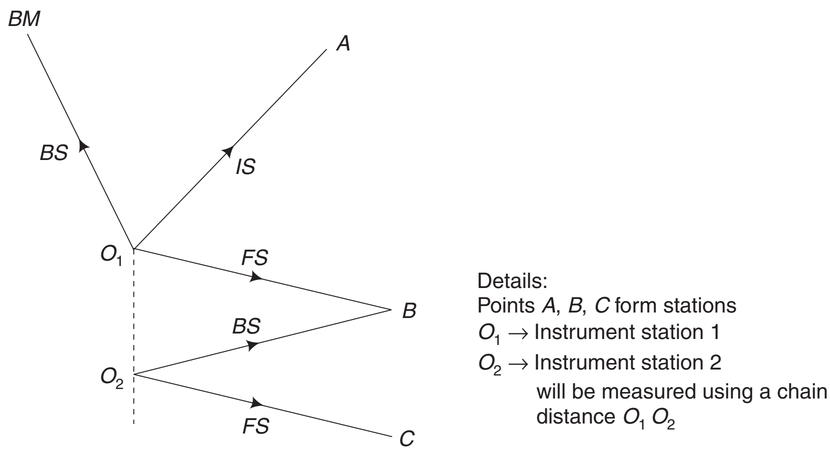


Fig. 2.16 *Explanatory figure of a levelling operation*

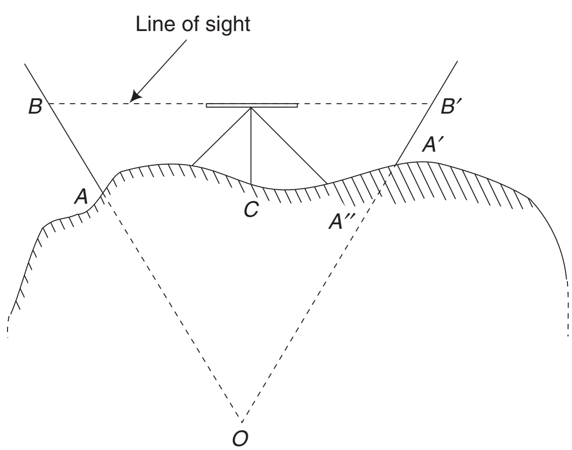


Fig. 2.17 *Principle of levelling*

In order to nullify the effect of curvature of earth's surface, the distances of both the staff positions from the instrument station *C* are kept equal.

2.9.5 Level

The instrument which is used for levelling is known as a level. It essentially consists of the following accessories:

1. A telescope to provide the line of sight.
2. A level tube to make the line of sight horizontal.

3. A levelling head to bring the bubble of the tube level at the centre of its run.
4. The tripod to support the above parts of the level.

In order to take readings of elevations, levelling staffs are used.

2.9.6 Instruments for Levelling [Nov, Dec 2009]

Instruments needed for levelling are the Dumpy levels and the levelling staff.

1. Dumpy Levels Figure 2.18 shows the different parts of a Dumpy level which was designed by Gravatt. This is also called the solid Dumpy level. In this, the telescope is rigidly fixed to the base so that the telescope can neither be rotated about its longitudinal axis nor it can be removed from the supports. This instrument consists of a long bubble tube attached to the fixed telescope. Dumpy literally means short and thick. This is more stable than the other types.

2. Levelling Staff A levelling staff is a straight rectangular wooden rod graduated in metres and smaller divisions. The bottom-most reading is zero and the reading given by the line of sight on the staff is the height of the point on which the staff is held.

The telescopic levelling staff shown in Fig. 2.19 is made of three pieces, the topmost and the central pieces are 1.25 m long, the bottom-most being 1.5 m long. The central and the bottom rods are hollow and the top one is solid. The top staff slides into the central piece telescopically so that the staff is compact when not used. The markings are same as that of the folding staff except the metre numerals are replaced by the alphabet *M* and the graduations marked erect so that when viewed through the telescope, it is inverted.

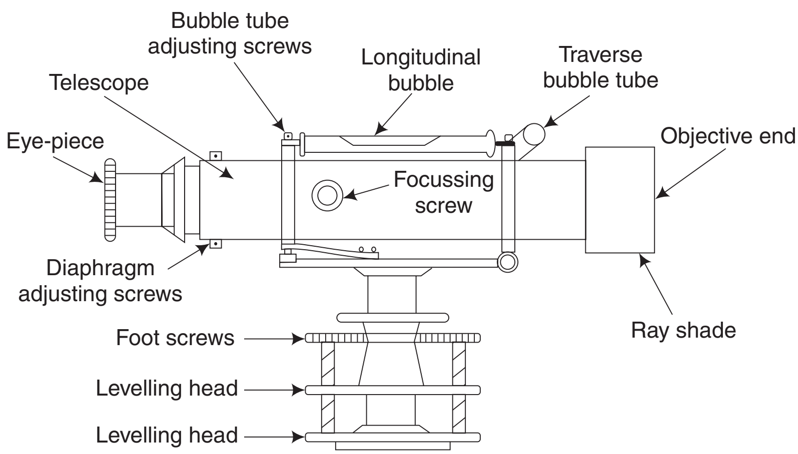


Fig. 2.18 *Dumpy level*

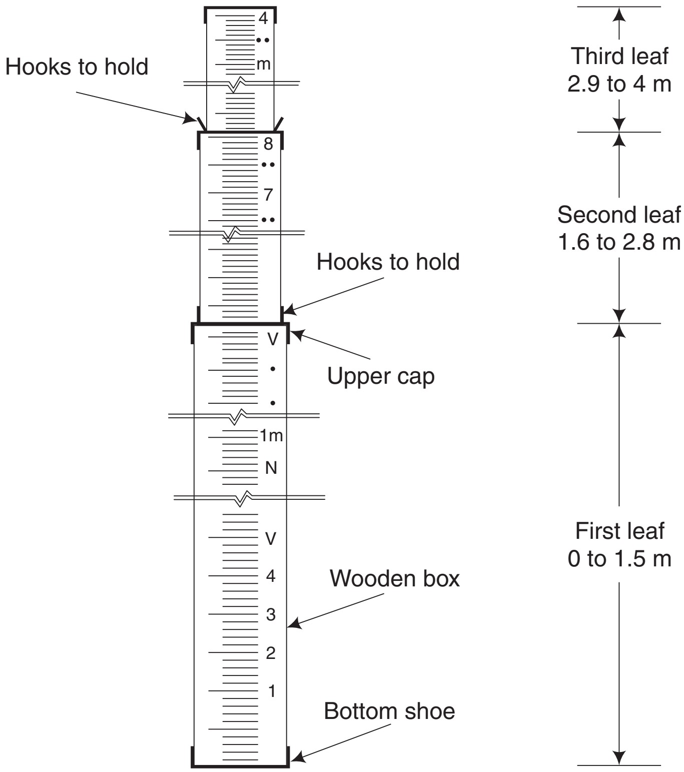


Fig. 2.19 *4 m telescopic levelling staff*

2.9.7 Classification of Levelling [Nov, Dec 2009; May, June 2011]

Levelling may be classified as simple levelling and differential levelling.

1. Simple Levelling Figure 2.20 illustrates simple levelling. Simple leveling is the easiest way adopted to find the difference in level between any two points. Let A and B are the two points and O be the station point placed approximately midway between A and B. Station O need not lie on the line joining A and B. The reading of the staff at A is first taken. Let this be h_1. Then, the reading of the staff h_2 at B is noted after adjusting the bubble to be at the centre. The difference between the two readings, i.e, $h_1 - h_2$ gives the difference in level between A and B.

If reduced level of A is 100, then, RL of B can be found as follows:

Height of instrument at $O = 100 + h_1$

RL of B $= 100 + h_1 - h_2$

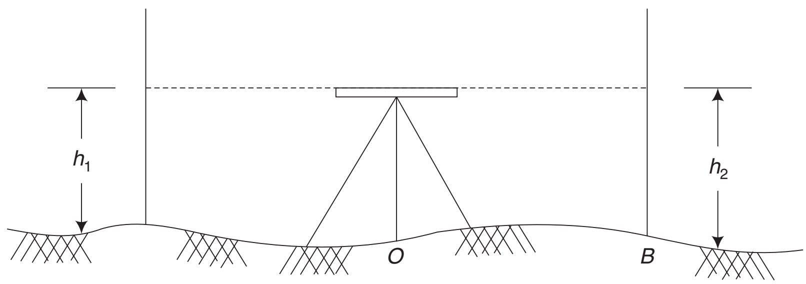


Fig. 2.20 *Simple levelling*

2. Differential Levelling Differential levelling is illustrated in Fig. 2.21. If it is necessary to find the difference in elevation between two points which are too far apart or if there are any obstacles between them or if the difference in elevation is high then differential levelling is adopted. This is a simple levelling adopted in successive stages. Hence, it is also known as compound or continuous levelling.

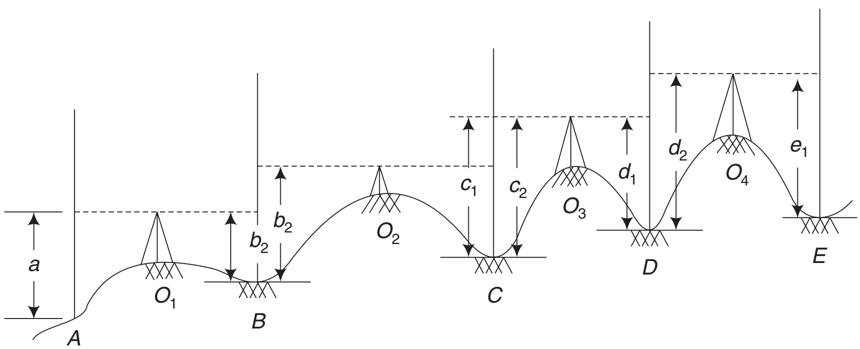


Fig. 2.21 *Differential levelling* **[May, June 2011]**

Let A and E be two points whose difference in elevation is necessary. The staff reading at A is noted as a from station point O_1. After adjusting the bubble, the staff reading at a firm point B is noted from O_1 as b_1. The staff reading a is the back sight and b, is the foresight. B is selected such that AO_I is approximately equal to O_1B. Now, the instrument is shifted to O_2 and the staff reading at B, from O_2 is taken and noted as b_2. Another firm point C is selected and the procedure is repeated till the point E is reached. The difference in level between A and B is $(a - b_1)$. The difference in level between B and C is $(b_2 - c_1)$ and so on. The difference in level between A and E are the algebraic sum of these differences.

3. Reciprocal Levelling This is a method of finding the difference in elevation between two points by making reciprocal observations when the site conditions do not allow to set up the level between the two stations.

On occasions, we come across a need to run a line of levels across a wide gap like a river or a deep valley or ravine. The site conditions do not allow to place the level anywhere so that the Foresight and the Back sight distances are even approximately equal. The site conditions also do not permit to set up the instrument exactly midway between stations on either side of the gap. In view of the large sight lengths the errors due to curvature and refraction and non adjustment of the instrument become important.

In such situation reciprocal levelling can be performed by which correct difference of levels can be determined taking into account the error due to curvature and refraction as well as collimation error.

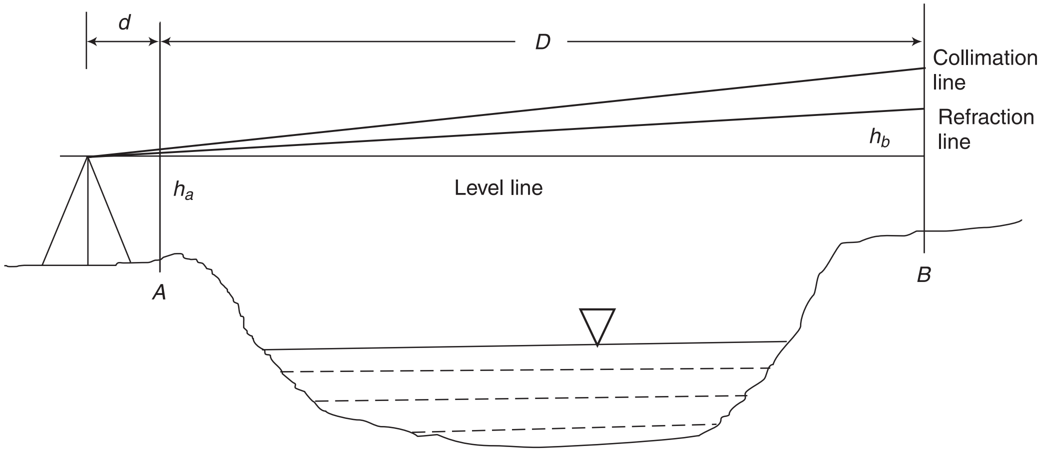


Fig. 2.22

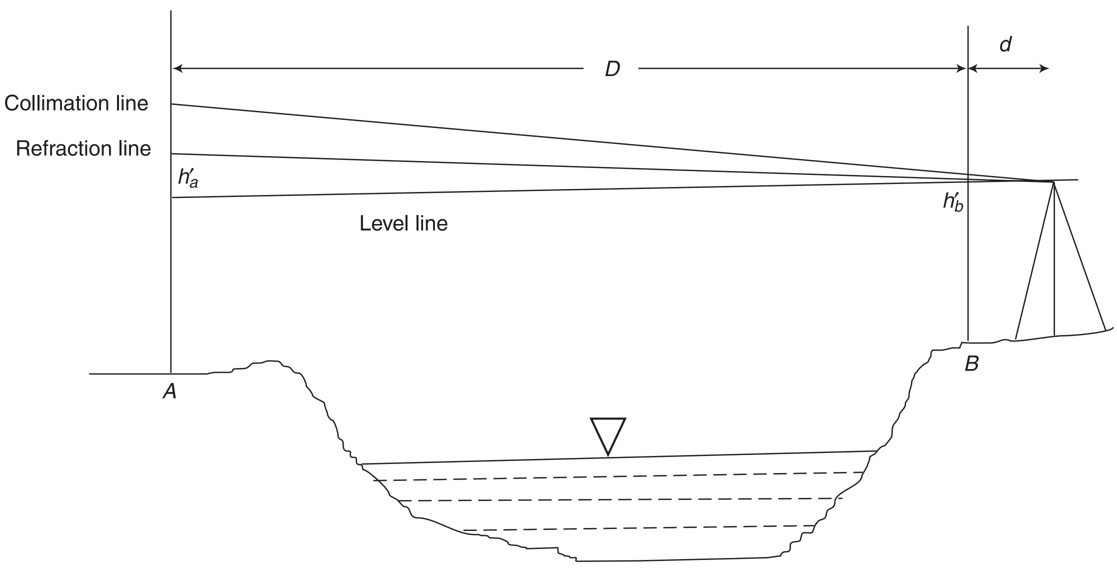


Fig. 2.23

Let A and B be two stations on opposite banks of a river or stream. Let A be at a higher level than B. Let D be the horizontal distance between A and B. Suppose the line of collimation of the instrument is elevated. Refer Fig. 2.23.

The instrument is set up on the left side of A in line with AB at a distance d from A. Let h_a and h_b be the staff reading obtained over A and B respectively. Refer Fig. 2.22.

Correct staff reading at $A = h_a - K_1 d - K_2 d^2$

Correct staff reading at $B = h_b - K_1(D + d) - K_2(D + d)^2$

where K_1 = Coefficient to correct for collimation error

K_2 = Coefficient to correct for curvature and refraction

$$\text{True Difference of Level} = h = [h_b - K_1(D + d) - K_2(D + d)^2] - [h_a - K_1 d - K_2 d^2]$$

Now the instrument is set up on the other bank on the right side of B in line with BA at a distance d from B. Refer Fig. 2.23.

$$\text{Correct staff reading at } A = h'_a - K_1(D + d) - K_2(D + d)^2$$

$$\text{Correct staff reading at } B = h'_b - K_1 d - K_2 d^2$$

$$\text{True Difference of Level} = h = [h'_b - K_1 d - K_2 d^2] - [h'_a - K_1(D + d) - K_2(D + d)^2]$$

Adding above equations of true differences of level, we get

$$2h = [h_b - h_a] + [h'_b - h'_a]$$

$$\text{True difference of level} = h = \{[h_b - h_a] + [h'_b - h'_a]\}/2$$

2.9.8 Reduction of Levels

There are two methods for calculating the reduced levels of points, the height of collimation or height of instrument method and the rise and fall method. In this section, these methods are discussed.

1. The Height of Collimation or Height of Instrument Method In this method, the height of instrument (HI) is calculated for each setting by adding the back sight (BS) to the elevation of BM. The reduced level of the first station or of the intermediate station can be obtained by subtracting the foresight at the first station or the intermediate sight at the intermediate station.

For the second setting HI is calculated by adding the back sight taken on the second point to its reduced level. The reduced level of the last point is obtained by subtracting the foresight of the last point from the HI at the last setting. Arithmetic check can be done in the following manner.

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

This method is simple, easy and rapid.

Table 2.4 Comparison of Height of Collimation Method with the Rise and Fall Method

	Height of collimation method	*Rise and fall method*
1.	It is more rapid and saves time and labour.	It is laborious as the staffreading of each station is compared to get a rise or fall.
2.	It is adopted for reduction of levels for longitudinal or cross sectional levelling works.	This is adopted for determining the difference in levels of two points where precision is required.
3.	There is no check on the RL of intermediate stations.	There is a complete check on the RLs of intermediate stations.
4.	There are only two arithmetic checks, i.e. Σ BS – Σ FS = Last RL – First RL	There are three arithmetic checks, i.e. Σ BS – Σ FS = Last RL – First RL = Σ Rise – Σ Fall
5.	Errors in any of the intermediate sights are not noticed.	Errors in the intermediate sights are noticed as these are used for finding out the rises and falls.

2. Rise and Fall Method In this method, the difference of level between two consecutive points for each setting of the instrument is obtained by comparing their staff readings. A rise is indicated if the back sight reading is greater than the foresight and a fall is shown if it is less than the foresight reading. The rise and fall worked out for all the points give the level difference of each point with respect to the preceding one. If the RL of the back staff point is known, the RL of the following point can be obtained by subtracting its fall from the RL of the preceding point or by adding its rise to the RL of the preceding point. Arithmetic check is done as explained below:

$$\Sigma \text{ BS} - \Sigma \text{ FS} = \Sigma \text{ Rise} - \Sigma \text{ Fall} = \text{Last RL} - \text{First RL}$$ **[Apr, May 2014]**

2.10 DETERMINATION OF AREAS

The primary object of land surveying is to determine the area of the tract surveyed. Area is defined as the area of a tract of land as projected upon a horizontal plane and not the actual area of the surface of the land. The units of area in metric system commonly used are square metres or hectares.

2.10.1 Computation of Areas by Direct Field Measurements **[May, June 2011]**

The area to be measured may not always be a regular polygon. In this case, the region is divided into a regular polygon and the portion between the irregular boundary and regular polygon. The area can be found by dividing the regular polygon into triangles.

1. By Dividing the Area into Number of Triangles In this method illustrated in Fig. 2.24, the area is divided into a number of triangles and the area of each triangle is calculated by measuring their sides and included angles. Then, the total area of the land will be equal to the sum of areas of individual triangles.

If two sides and one included angle of a triangle is known then area

$$= \frac{1}{2} ab \sin \theta$$

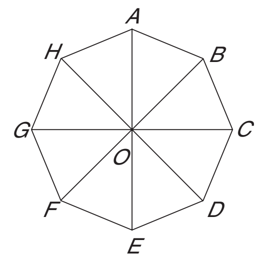


Fig. 2.24

When the lengths of the three sides of a triangle are measured, then,

$$\text{Area} = \sqrt{S(S-a)(S-b)(S-c)}$$

where $S = \frac{1}{2}(a + b + c)$ and a, b, c are sides of the triangle.

2. Areas between the survey lines and boundaries In this method illustrated in Fig. 2.25, a number of offsets are measured from the survey line to the boundary one at regular intervals. Then, the area between survey line and boundary line can be measured by the following rules.

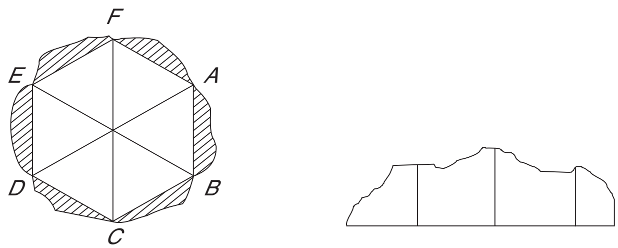


Fig. 2.25

(a) Trapezoidal rule This is based on the assumption that the figures are trapezoids. The base line AB is divided into equal parts. The ordinates are measured and their lengths are scaled off. This procedure is explained in Fig. 2.26. **[May, June 2011]**

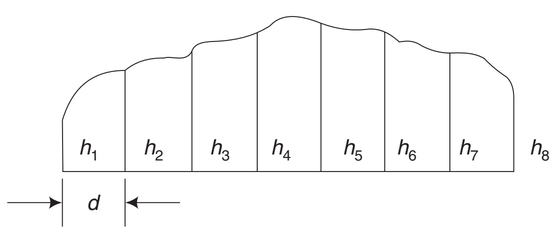


Fig. 2.26

$h_1, h_2, \ldots, h$ – length of ordinates at equal intervals
n – number of divisions

L – length of the base line
d – distance between adjacent ordinates

Note: If h_1 or h_n is equal to zero, that is also included in the formula.

$$\text{Total area, } A = \frac{d}{2}(h_1 + 2h_2 + 2h_3 + \ldots + 2h_{n-1} + h_n)$$

$$= \frac{d}{2}[\text{first ordinate} + 2\ (\text{sum of intermediate ordinates}) + \text{last ordinate}]$$

(b) Simpson's rule As illustrated in Fig. 2.27, in this rule, the terms and procedures are same as that of the above rule. But total area is given by:

$$A = \frac{d}{3}[h_1 + h_n + 2\ (h_3 + h_5 + h_7 + \ldots + h_{n-2}) + 4\ (h_2 + h_4 + \ldots + h_{n-1})]$$

i.e.,

$$A = \frac{d}{3}[\text{First ordinate} + \text{Last ordinate} + 2\ (\text{sum of odd ordinates})$$
$$+ 4\ (\text{sum of remaining even ordinates})]$$

[May, June 2011]

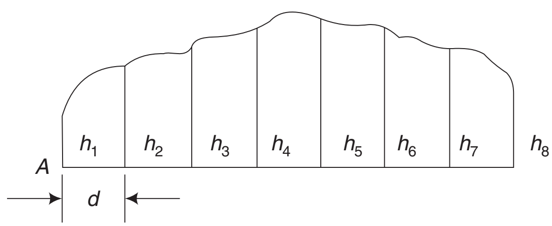


Fig. 2.27

Note:

(i) This rule is applicable only if the number of ordinates is odd. If the number of ordinates is even, the area of the last trapezoid is calculated separately and added to the result.

From Fig. 2.27,

Number of ordinates = 8.

The area for first seven ordinates can be obtained by applying Simpson's rule,

$$A_1 = \frac{d}{3}[h_1 + 2(h_3 + h_5) + 4(h_2 + h_4 + h_6) + h_7]$$

$$A_2 = \frac{1}{2}(h_7 + h_8) \times d$$

Then, total area $A = A_1 + A_2$.

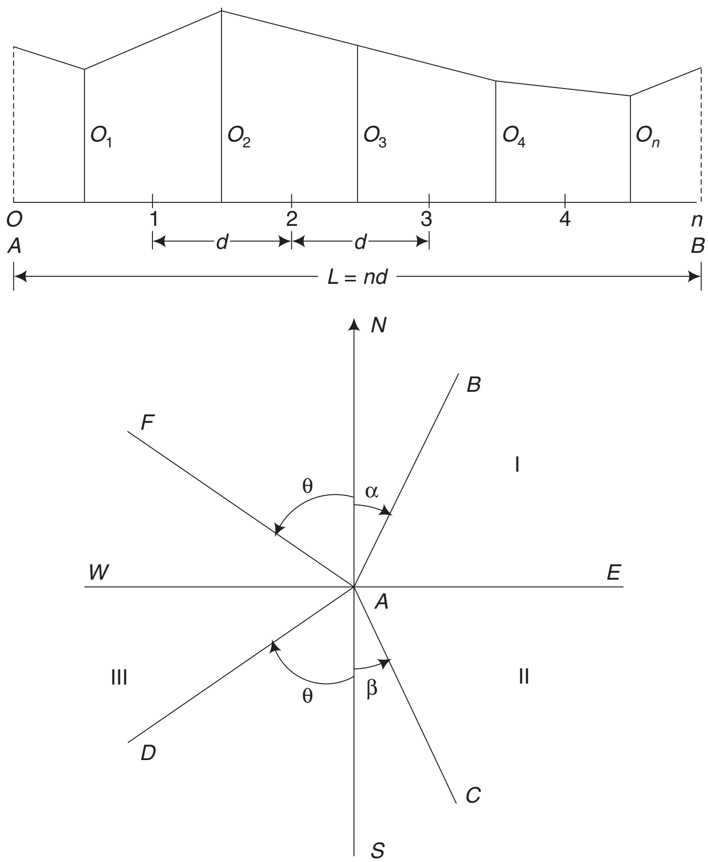


Fig. 2.28

(ii) If h_1 or h_n is zero that is also included in the rule.
The results obtained using the Simpson's rule are more accurate than those obtained by the Trapezoidal rule.

Comparison b/w Trapezoidal and Simpson's rule

The results obtained by the use of Simpson's rule are more accurate in all cases. The results obtained by using 'Simpson's rule are greater or smaller than those obtained by using the trapezoidal rule according as the curve of the boundary is concave of convex towards the base line. In dealing with irregularly shaped figures, the degree of precision of either method can be increased by increasing the number of ordinates.

Mid-ordinate rule

The method is used with the assumption that the boundaries between the extremities of the ordinates (or offsets) are straight line. The base line is divided in to a number of divisions and the ordinates are measured at the mid-points of each division, as illustrated in Fig. 2.28.

The average ordinate rule will not give correct results if the range of values of the ordinates is large. The trapezoidal rule and Simpson's rule are the most commonly used rules. Simpson's rule is considered generally more accurate, as the assumption of a curved boundary is more realistic compared to the assumption of a straight-line boundary between ordinates made in the trapezoidal rule. The method of coordinates and the trapezoidal rule give the same results, as both are based on the same assumption. If the boundary is concave towards the survey line, the Trapezoidal rule will calculate less area than the Simpson's rule, while if the boundary is convex towards the survey line, Simpson's rule will calculate a lower value.

2.11 CONTOURING

An imaginary line, on the ground, joining the points of equal elevation above the assumed datum is called a contour. Survey work, including office work in the preparation of a contour plan is known as contouring.

The vertical distance between any two consecutive contours is called *contour interval*.

The least horizontal distance between two consecutive contours is called *horizontal equivalent*.

To get a clear concept of contouring, let us consider the case of conducting the survey work on the boundary of still water in a pond. If the level of water surface is 100 m, then the periphery of water represents a contour of 100 m. Now, if the water level is lowered by 5 m, then the new boundary represents a contour of 95 m as shown in Fig. 2.29.

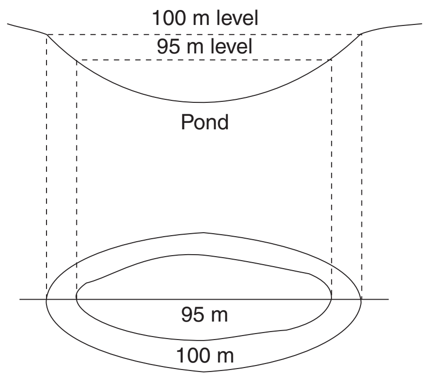


Fig. 2.29 *Contour in still water*

2.11.1 Characteristics of Contours

The characteristics of contour given below are useful in plotting and for interpreting a contour map correctly.

1. Contour which is equally spaced represents a uniform slope whereas one which is closely spaced represents a steep slope.

2. A series of straight, parallel, equally spaced contours represents an inclined plane surface.
3. Contour at any point is perpendicular to the line of the steepest slope at that point.
4. A series of closed contours with higher values on the inside, represents a hill and lower value on the inside indicates a pond or depression without an outlet as shown in Fig. 2.30.

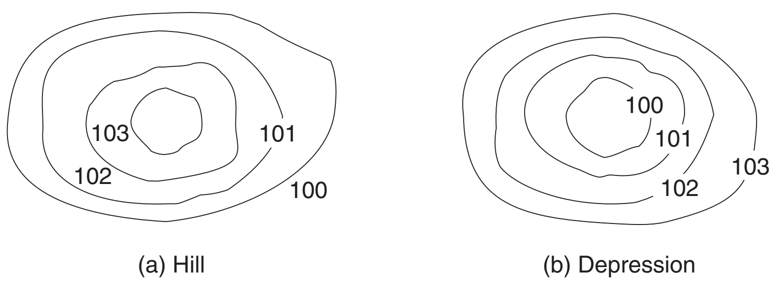


Fig. 2.30 *Contour for a hill and a depression*

5. Contour lines cross a ridge line at right angles, curving round it with the concave side towards higher ground. Whereas for valley line the convex side is towards the higher ground as shown in Fig. 2.31.

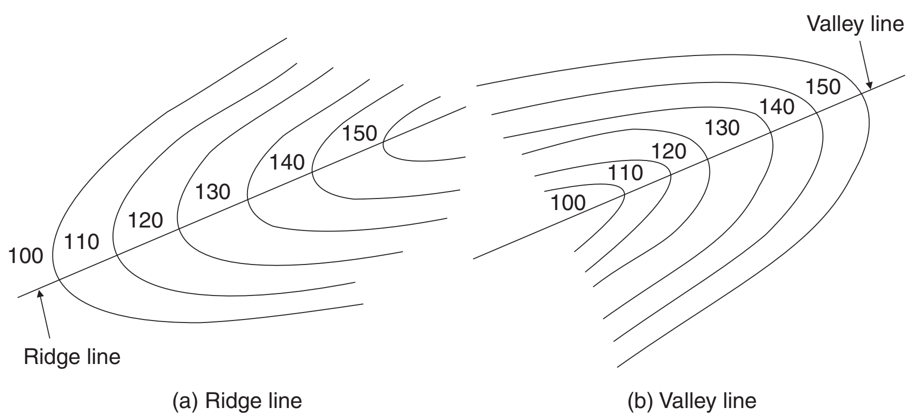


Fig. 2.31 *Contour for ridge and valley*

6. The same contour must appear on both sides of a ridge or a valley.
7. The contour cannot simply end anywhere, it must close on itself, though not necessarily within the limits of the map.

8. Contour lines of different elevations do not unite, except in the case of a vertical cliff as shown in Fig. 2.32.

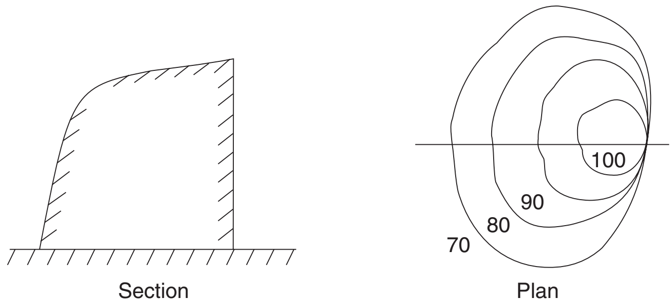


Fig. 2.32 *Contour for a vertical cliff*

9. Contour of different elevations can cross each other only in case of an overhanging cliff as shown in Fig. 2.33.

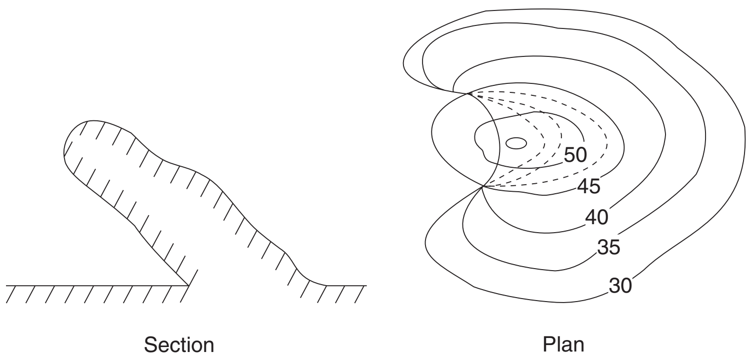


Fig. 2.33 *Contour for an overhanging cliff*

10. Contours do not have sharp turnings.

2.11.2 Uses of Contour Maps

Contour maps are used in many civil engineering works. Some of them are listed below.

1. To study the general topography of the country without doing any survey work.
2. For the site selection of various engineering works such as dams, canals, weirs, roads, railways, etc.
3. The section along any line can be drawn.
4. To determine the quantity of earthwork required for canals, roads, etc.
5. To determine the reservoir capacity.
6. To trace a contour gradient for road, canal and railway alignments.
7. To determine the intervisibility of points.