Introduction to Surveying

Surveying is *the art of making measurements of objects on, above or beneath the ground to show their relative positions on paper.* The relative position required is either horizontal, or vertical, or both.

Less precisely the term **Surveying** is used to the *measurement of objects in their horizontal positions. Measurements to deteremine their relative vertical positions is known as* **levelling**.

11.1 OBJECT AND USES OF SURVEYING

As stated in the definition, object of surveying is to show relative positions of various objects of an area on paper and produce plan or map of that area. Various uses of surveying are listed below:

(*i*) Plans prepared to record property lines of private, public and government lands help in avoiding unnecessary controversies.

(*ii*) Maps prepared for marking boundaries of countries, states, districts etc., avoid disputes.

(*iii*) Locality plans help in identifying location of houses and offices in the area.

(*iv*) Road maps help travellers and tourist.

(*v*) Topographic maps showing natural features like rivers, streams, hills, forests help in planning irrigation projects and flood control measures.

(*vi*) For planning and estimating project works like roads, bridges, railways, airports, water supply and waste water disposal surveying is required.

(*vii*) Marine and hydrographic survey helps in planning navigation routes and harbours.

(*viii*) Military survey is required for strategic planning.

(*ix*) Mine surveys are required for exploring minearl wealth.

(*x*) Geological surveys are necessary for determining different strata in the earth crust so that proper location is found for reservoirs.

(*xi*) Archeological surveys are useful for unearthing relics of antiquity.

(*xii*) Astronomical survey helps in the study of movements of planets and for calculating local and standard times.

11.2 PRIMARY DIVISIONS IN SURVEYING

The earth is an oblate spheroid, length of equatorial axis being 12756.75 km and polar axis being 12713.80 km. Since the difference between these two axes and irregularities on the earth surface are very small (Note. Height of Mount Everest is 8.79 km) compared to these two axes, the earth may be treated as a sphere. Figure 11.1 shows a circular plane passing through a point *A* on the earth surface. The gravitational force is always directed towards the centre of the earth.

Hence, the plumb-line shown in Fig. 11.1 is a *vertical line*. Line perpendicular to vertical line (tangential to earth surface) is known as *horizontal line*. In surveying all measurement at any point are in the direction of these two lines.

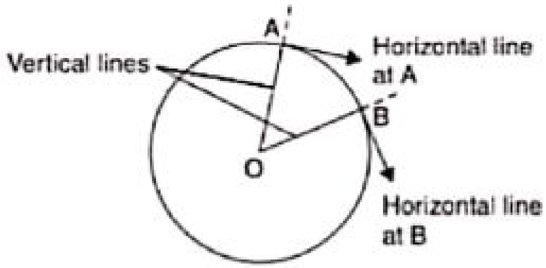


Fig. 11.1. Vertical and horizontal lines

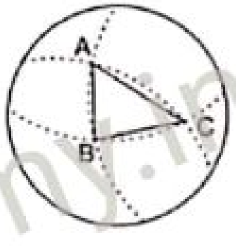


Fig. 11.2. Plane and spherical triangles

Obviously, the vertical and horizontal lines at another point *B* are not parallel to the respective lines at *A*. It should be noted that all lines lying on the earth's surface are curved lines and all triangles are spherical triangles as shown in Fig. 11.2. Hence, surveying involves spherical trigonometry.

If the area to be surveyed is small, the curvature of the earth may be neglected and all plumb lines treated as the same vertical. Hence, the lines normal to plumb line at any point in the area are treated as the same horizontal. All triangles in the area may be treated as plane triangles.

The survey in which earth curvature is neglected is called *Plane Surveying* and the survey in which earth's curvature is considered is known as *Geodetic Surveying*.

No definite value can be assigned to the area up to which a survey may be treated as plane, since the degree of accuracy required forms the controlling factor. However, the following points should be noted:

(*i*) The length of an arc of 1.2 km on earth's mean surface is only 1 mm more than the straight line connecting those two points.

(*ii*) The sum of the interior angles of a geometrical figure laid on the surface of the earth differs from that of the corresponding figure only to the extent of one second for about 200 square kilometres of area.

Hence, in most of engineering projects plane surveying is used. The geodetic surveying is used to determine the precise positions of control stations on the surface of the earth to which plane survey details are connected in works of larger magnitude like preparing maps of countries. Thus, in surveying there are two primary divisions *viz*. *Geodetic Surveying* and *Plane Surveying*.

11.3 FUNDAMENTAL PRINCIPLES OF SURVEYING

To get accurate results in surveying one should follow the following fundamental principles:

(*i*) Work from whole to part

(*ii*) Take extra care in fixing new control points.

11.3.1 Work from Whole to Part

In surveying large areas, a system of control points are identified and they are located with high precision. Then secondary control points are located using lesser precise methods. The details of the localised areas are measured and plotted with respect to the secondary control points. This is called working from whole to part. This principle in surveying helps in localising the errors. If the surveying is carried out by adding localised areas errors accumulated and may become unacceptable when large area is covered.

11.3.2 Extra Care in Fixing New Control Points

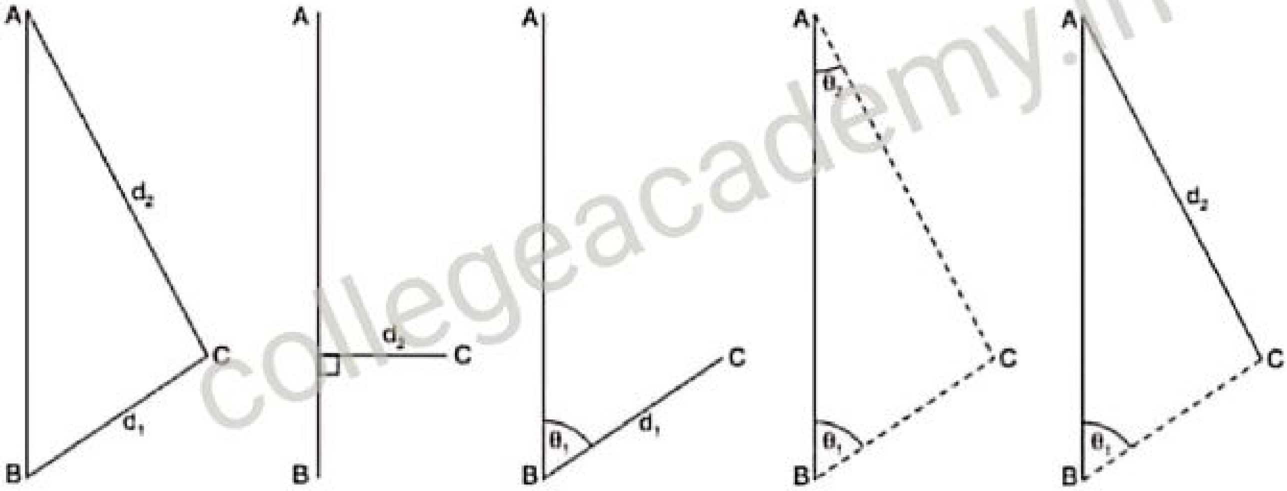


Fig. 11.3. Locating point C w.r.t. points A and B

Figure 11.3 shows the various methods of fixing point *C* with respect to already fixed points *A* and *B* by measuring sides, angles or setting perpendiculars. For fixing new control points (stations) with respect to already fixed points at least two independent process should be followed. If *A* and *B* are already located control points and with respect to them new control point *C* is to be located, apart from the minimum measurements required as shown in Fig. 11.3, one more measurement should be taken. Measuring the lengths of check lines and tie lines will also serve this purpose (Ref. Fig. 11.4).

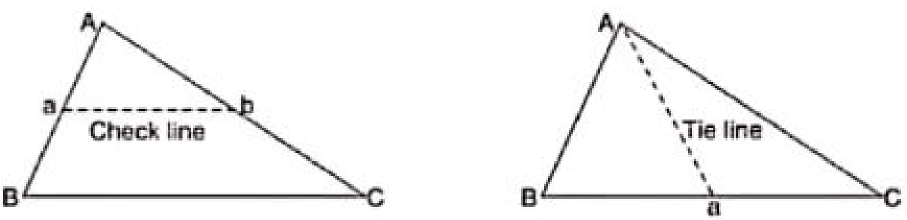


Fig. 11.4. Check line and tie line

11.4 CLASSIFICATION OF SURVEYING

Surveying may be classified on the following basis:

(*i*) Nature of the survey field

(*ii*) Object of survey

(*iii*) Instruments used and

(*iv*) The methods employed.

11.4.1 Classification Based on Nature of Survey Field

On this basis survey may be classified as land survey, marine or hydraulic survey and astronomical survey.

Land Survey. It involves measurement of various objects on land. This type of survey may be further classified as given below:

(*a*) *Topographic Survey:* It is meant for plotting natural features like rivers, lakes, forests and hills as well as man made features like roads, railways, towns, villages and canals.

(*b*) *Cadestal Survey:* It is for marking the boundaries of municipalities, villages, talukas, districts, states etc. The survey made to mark properties of individuals also come under this category.

(*c*) *City Survey:* The survey made in connection with the construction of streets, water supply and sewage lines fall under this category.

Marine or Hydrographic Survey. Survey conducted to find depth of water at various points in bodies of water like sea, river and lakes fall under this category. Finding depth of water at specified points is known as sounding.

Astronomical Survey. Observations made to heavenly bodies like sun, stars etc., to locate absolute positions of points on the earth and for the purpose of calculating local time is known as astronomical survey.

11.4.2 Classification Based on Object of Survey

On the basis of object of survey the classification can be as engineering survey, military survey, mines survey, geological survey and archeological survey.

(*a*) *Engineering Survey:* The objective of this type of survey is to collect data for designing civil engineering projects like roads, railways, irrigation, water supply and sewage disposals. These surveys are further sub-divided into:

Reconnaissance Survey for determining feasibility and estimation of the scheme.

Preliminary Survey for collecting more information to estimate the cost of the project, and

Location Survey to set the work on the ground.

(*b*) *Military Survey:* This survey is meant for working out plans of strategic importance.

(*c*) *Mines Survey:* This is used for exploring mineral wealth.

(*d*) *Geological Survey:* This survey is for finding different strata in the earth's crust.

(*e*) *Archeological Survey:* This survey is for unearthing relics of antiquity.

11.4.3 Classification Based on Instruments Used

Based on the instruments used, surveying may be classified as:

(*i*) Chain survey

(*ii*) Compass survey

(*iii*) Plane table survey

(*iv*) Theodolite survey

(*v*) Tacheometric survey

(*vi*) Modern survey using electronic distance meters and total station

(*vii*) Photographic and Aerial survey

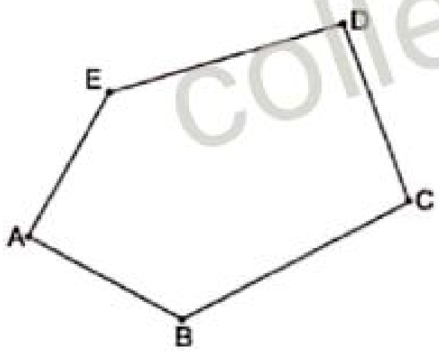
The survey is taught to students mainly based on this classification.

11.4.4 Classification Based on Methods Employed

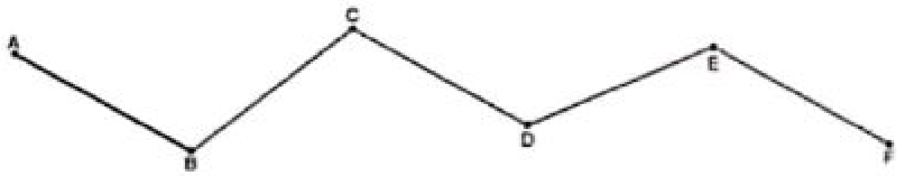
On this basis surveying is classified as triangulation and traversing.

(*i*) *Triangulation:* In this method control points are established through a network of triangles.

(*ii*) *Traversing:* In this scheme of establishing control points consists of a series of connected points established through linear and angular measurements. If the last line meets the starting point it is called as closed traverse. If it does not meet, it is known as open traverse [Ref. Fig. 11.5].



(a) Closed traverse



(b) Open traverse

Fig. 11.5. Traversing

11.5 PLANS AND MAPS

As stated in the definition of surveying the objective of measurements is to show relative positions of various objects on paper. Such representations on paper is called plan or map. *A plan may be defined as the graphical representation of the features on, near or below the surface of the earth as projected on a horizontal plane to a suitable scale.*

However, since the surface of the earth is curved and that of the paper is plane, no part of the earth can be represented on such maps without distortion. If the area to be represented is small, the distortion is less and large scale can be used. Such representations are called plans. If the area to be represented is large, small, scales are to be used and distortion is large. Representation of larger areas are called maps. Representation of a particular locality in a municipal area is a plan while representation of a state/country is a map. There is no exact demarcation between a plan and map.

11.6 SCALES

It is not possible and also not desirable to make maps to one to one scale. While making maps all distances are reduced by a fixed proportion. That fixed proportion is called scale of the map. Thus, if 1 mm on the paper represents 1 metre on the ground, then the scale of the map is 1 mm = 1 m or 1 mm = 1000 mm or 1 : 1000. To make scale independent of the units it is preferable to use representative factor which may be defined as the ratio of one unit on paper to the number of units it represent on the ground. Thus 1 mm = 1 m is equivalent to

$$RF = \frac{1}{1000}$$

Apart from writing scale on map, it is desirable to show it graphically on it. The reason is, over the time, the paper may shrink and the scaling down the distances from map may mislead. The graphical scale should be sufficiently long (180 mm to 270 mm) and the main scale divisions should represent one, ten or hundred units so that it can be easily read.

The scale of a map is considered as

(*i*) large if it is greater than 1 cm = 10 m *i.e.*,

$$RF > \frac{1}{1000}$$

(*ii*) intermediate if it is between

$$RF = \frac{1}{1000} \quad \text{and} \quad \frac{1}{10,000}$$

(*iii*) small if $RF < \frac{1}{10,000}$

In general, scale selected should be as large as possible, since it is not possible for human eye to distinguish between two point if distance between them is less than 0.25 mm. The recommended scales for various types of surveys are as shown in Table 11.1.

Linear Measurements and Chain Surveying

All the distances required for making a plan are the horizontal distances. Hence in the field horizontal distances are measured or sufficient readings are taken to calculate horizontal distances. In this chapter the methods used for linear measurements are explained. Method of preparing a plan using only linear measurements is by conducting chain surveying. This method is also explained in this chapter and Indian Standard Conventions for showing objects on the map are presented at the end of the chapter.

12.1 METHODS OF LINEAR MEASUREMENTS

Various methods used for linear measurements may be grouped as:

(*i*) Approximate

(*ii*) Using chain or tape

(*iii*) By optical means and

(*iv*) Using electromagnetic distance measurement instruments.

12.1.1 Approximates Methods of Linear Measurements

These methods are used in reconnaissance survey or to detect major mistakes committed while measuring with better methods. On smooth roads they can give results within 1 per cent error. These approximate measurements may be by:

(*i*) pacing

(*ii*) using passometer

(*iii*) using pedometer

(*iv*) using odometer or by

(*v*) using speedometer.

(*i*) **Pacing:** In this method surveyor walks along the line to be measured and counts the number of steps. Then the distance measured is equal to number of steps × average length of a step. Average length of a step can be found by walking along a known length. A normal man takes a step of length 0.75 m to 0.8 m.

(*ii*) **Using Passometer:** A passometer is a watch-like instrument which is carried vertically in the pocket of shirt or tied to a leg. It records number of steps taken. Thus the problem of counting number of steps is eliminated in this approximate method of linear measurement.

(*iii*) **Using Pedometer:** This instrument is similar to passometer but it can record the distance instead of number of steps. In this, zero setting and setting of step length is made before walking.

(*iv*) **Odometer:** This instrument is attached to the wheel of a cycle or other vehicle. It records the number of revolutions made by the wheel. Knowing the circumference of the wheel, the distance travelled may be found.

(*v*) **Speedometer:** Odometer calibrated to give distance directly is called speedometer. This is to be used for particular vehicle only. All automobiles are provided with speedometers. By running the vehicle along the line to be measured distance can be found.

12.1.2 Measurement with Chains or Tapes

Measurement of distances using chain or tape is termed as chaining. This is the accurate and commonly employed method in surveying: These instruments can be classified as (*i*) chain (*ii*) steel band and (*iii*) tapes.

(*i*) **Chains:** The chains are composed of 100 pieces of 4 mm diameter galvanised mild steel wires bent into rings at the end and joined to each other by three circular or oval shaped rings. These rings give flexibility to the chain. The ends of chains are provided with swivel joints (Ref. Fig. 12.1(*a*)).

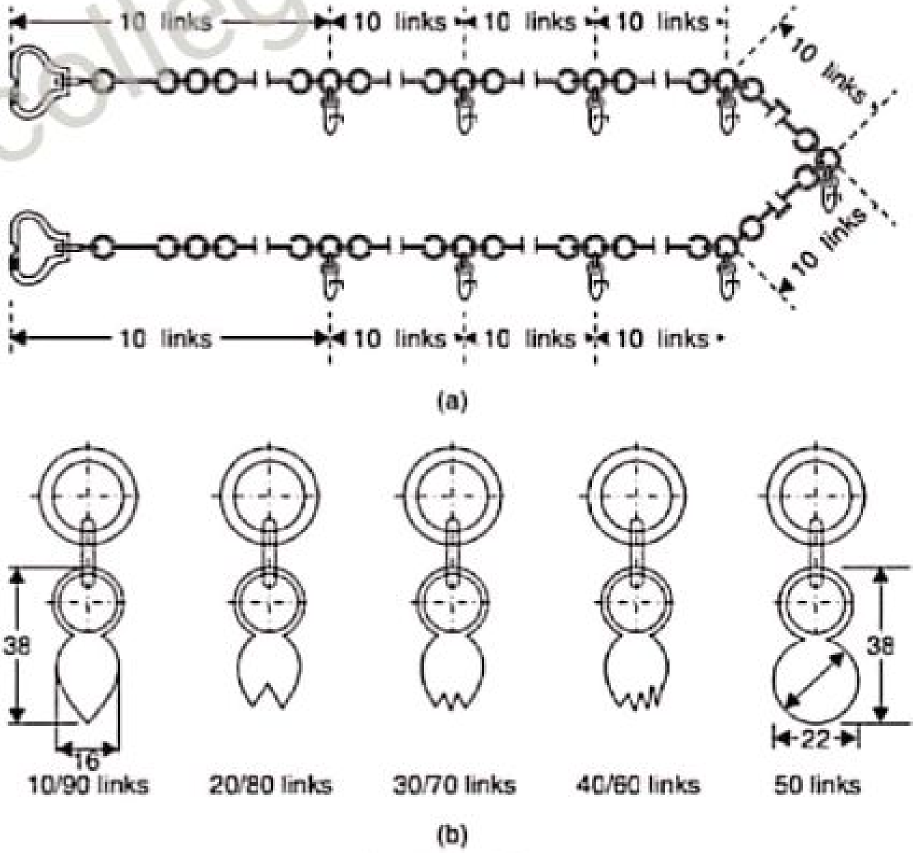


Fig. 12.1. Chain

so that the chain can be turned without twisting. To facilitate easy reading of the chain, brass tallies are provided. End of 10th link from each end is provided with a talley of one tooth, 20th link is provided with a talley of two teeth; 30th link with a talley of three teeth; 40th link with a talley of 4 teeth and the middle of chain is provided with a talley of circular shape [Ref. Fig. 12.1(*b*)].

It is to be noted that

(*i*) length of a link is the distance between centres of two consecutive middle rings.

(*ii*) the length of the chain is from outside of one handle to the outside of the other handle.

Commonly used metric chains are of 20 m length. They have 100 links with talleys at every 2 m. Each link is of 0.2 m length. Simple rings are provided at every one metre length except wherever tallies are provided. The total length of chain is marked on the brass handle.

However 30 m chains are also in use. Length of each link is 0.3 m. It is not so convenient as 20 m chain to read, since no rings can be provided at one metre distance and each link needs multiplication with 0.3 to arrive at metre units. However as a result the influence of using 100 ft chain in olden days, this type of chain are also in market.

Steel Band: It is also known as band chain. It consists of steel of 12 to 16 mm width and 0.3 to 0.6 mm thickness. The steel ribbon is wound around an open steel cross or in a metal reel (Ref. Plate 12.1). Metric steel bands are available in lengths of 20 m and 30 m. Any one of the following two methods of markings are used:

(*i*) Providing brass studs at every 0.2 m and numbering at every metre. Last links from either end are subdivided in cm and mm.

(*ii*) Etching graduations as meters, decimeters and centimeters on one side of the band and 0.2 m links on the other side.

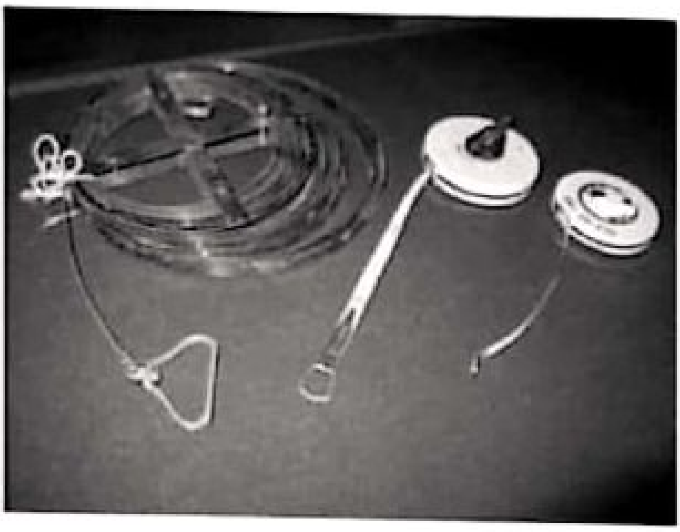


Plate 12.1

Tapes: Depending upon the materials used, they are classified as:

(*i*) cloth or linen tape

(*ii*) metallic tape

(*iii*) steel tape and

(*iv*) invar tape.

12.2 INSTRUMENTS USED IN CHAINING

The following instruments are required for measurements with chain and tape:

(*i*) Arrows

(*ii*) Pegs

(*iii*) Ranging rods and ranging poles

(*iv*) Offset rods

(*v*) Laths

(*vi*) Whites

(*vii*) Plumb bobs and

(*viii*) Line ranger.

12.2.1 Arrows

When the length of the line to be measured is more than a chain length, there is need to mark the end of the chain length. Arrows are used for this purpose. A typical arrow is shown in Fig. 12.5. Arrows are made up of 4 mm diametered steel wire with one end sharpened and other end bent into a loop. Length of an arrow is approximately 400 mm.

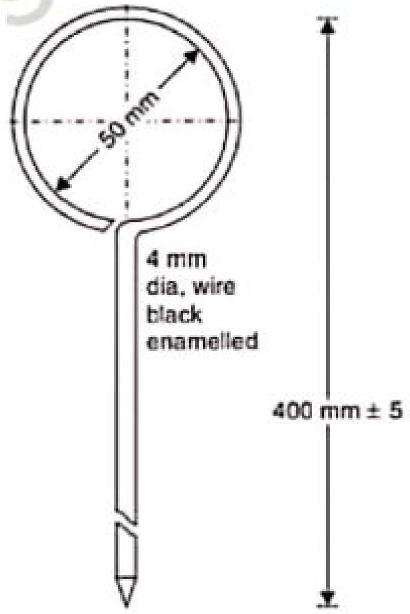


Fig. 12.5. Arrows

12.2.2 Pegs

Wooden pegs are used in measuring a length of a line to mark the end points of the line. The pegs are made of hard wood of 25 mm × 25 mm section, 150 mm long with one end tapered as shown in Fig. 12.6. When driven in ground to mark station points they project about 40 mm.

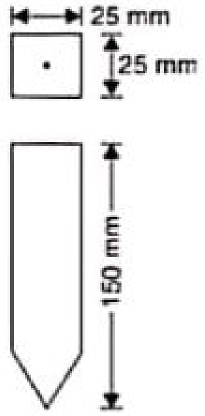


Fig. 12.6. Pegs

12.2.3 Ranging Rods and Ranging Poles

For ranging intermediate points along the line to be measured, ranging rods and ranging poles are used. Ranging rods are 2 to 3 m long and are made of hard wood. They are provided with iron shoe at one end as shown in Fig. 12.7.

They are usually circular in section with 30 mm diameter and are painted with 200 mm colour bands of red and white or with black and white. If distance is more than 200 m, for clear visibility they may be provided with multicoloured flags at their top. The ranging rods are occasionally used to measure short distances since they are painted with alternate colour of band 200 mm.

Ranging poles are similar to ranging rods except that they are longer. Their length varies from 4 m to 8 m and diameter from 60 mm to 100 mm. They are made of hard wood or steel. They are fixed in the ground by making 0.5 m holes and then packed to keep them vertical.

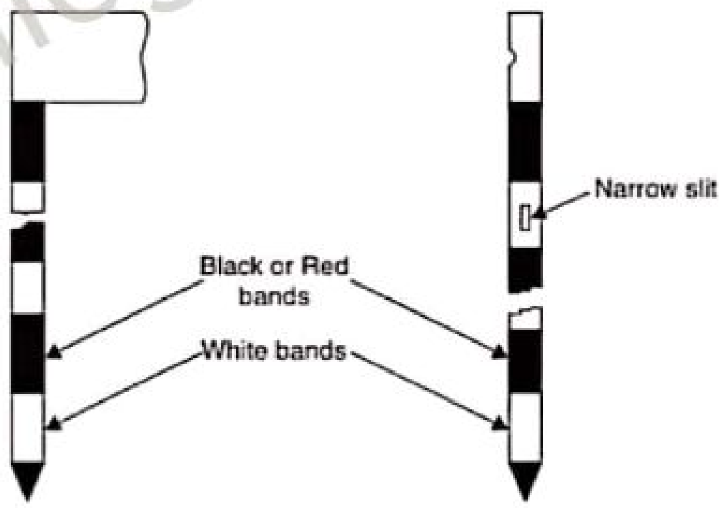


Fig. 12.7 Ranging rod

Fig. 12.8. Offset rod

12.2.4 Offset Rods

These rods are also similar to ranging rods and they are 3 m long. They are made up of hard wood and are provided with iron shoe at one end. A hook or a notch is provided at other end. At height of eye, two narrow slits at right angles to each other are also provided for using it for setting right angles. A typical offset rod is shown in Fig. 12.8.

12.2.5 Laths

Laths are 0.5 to 1.0 m long sticks of soft wood. They are sharpened at one end and are painted with white or light colours. They are used as intermediate points while ranging or while crossing depressions.

12.2.6 Whites

Whites are the pieces of sharpened thick sticks cut from the nearest place in the field. One end of the stick is sharpened and the other end is split. White papers are inserted in the split to improve the visibility. Whites are also used for the same purpose as laths.

12.2.7 Plumb Bob

A typical plumb bob is shown in Fig. 12.9. In measuring horizontal distances along sloping ground plumb bobs are used to transfer the position to ground. They are also used to check the verticality of ranging poles.

Fig. 12.9. Plumb bob

12.2.8 Line Ranger

It is an optical instrument used for locating a point on a line and hence useful for ranging. It consists of two isosceless prisms placed one over the other and fixed in an instrument with handle. The diagonals of the prisms are silvered so as to reflect the rays.

To locate point C on line AB (ref. Fig. 12.10) the surveyor holds the instrument in hand and stands near the approximate position of C. If he is not exactly on line AB, the ranging rods at A and B appear separated as shown in Fig. 12.10 (*b*). The surveyor moves to and fro at right angles to the line AB till the images of ranging rods at A and B appear in a single line as shown in Fig. 12.10 (*c*). It happens only when the optical square is exactly on line AB. Thus the desired point C is located on the line AB.

Its advantage is it needs only one person to range. The instrument should be occasionally tested by marking three points in a line and standing on middle point observing the coincidence of the ranging rods. If the images of the two ranging rods do not appear in the same line, one of the prism is adjusted by operating the screw provided for it.

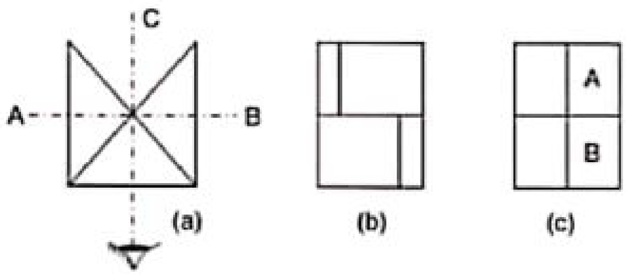


Fig. 12.10. Line ranger

12.3 CHAIN SURVEYING

Chain survey is suitable in the following cases:

(*i*) Area to be surveyed is comparatively small

(ii) Ground is fairly level

(iii) Area is open and

(iv) Details to be filled up are simple and less.

In chain surveying only linear measurements are made *i.e.* no angular measurements are made. Since triangle is the only figure that can be plotted with measurement of sides only, in chain surveying the area to be surveyed should be covered with a network of triangles. Figure 12.11 shows a typical scheme of covering an area with a network of triangles. No angle of the network triangles should be less than 30° to precisely get plotted position of a station with respect to already plotted positions of other station. As far as possible angles should be close to 60°. However, the arrangements of triangles to be adopted depends on the shape, topography, natural and artificial obstacles in the field.

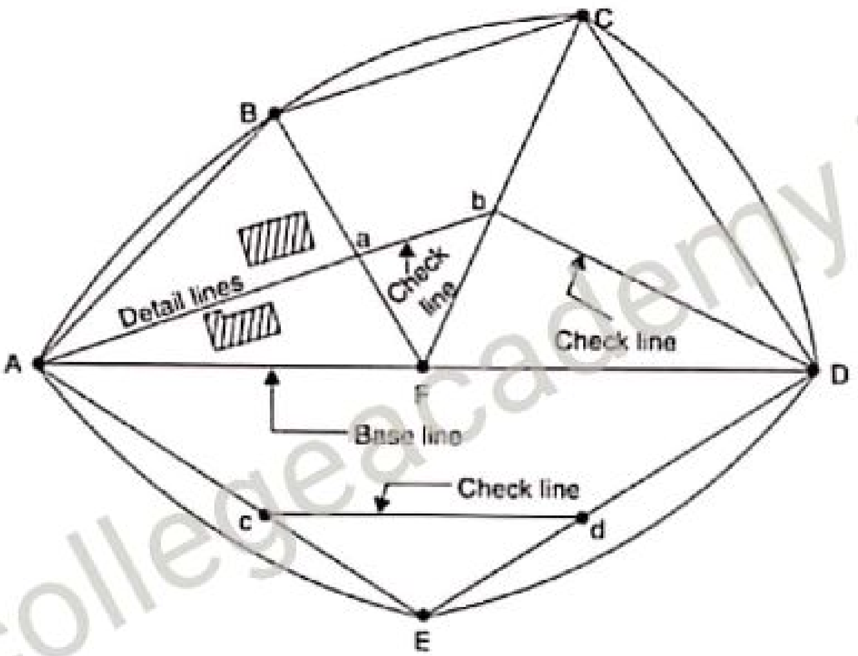


Fig. 12.11. Network of triangles

12.3.1 Technical Terms

Various technical terms used in connection with the network of the triangles in surveying are explained below:

Station: Station is a point of importance at the beginning or at the end of a survey line.

Main station: These are the stations at the beginning or at the end of lines forming main skeleton. They are denoted as A, B, C etc.

Subsidiary or tie stations: These are the stations selected on main lines to run auxiliary/secondary lines for the purpose of locating interior details. These stations are denoted as *a, b, c,* ....., etc., or as 1, 2, 3, ... etc.

Base line: It is the most important line and is the longest. Usually it is the line plotted first and then frame work of triangles are built on it.

Detail lines: If the important objects are far away from the main lines, the offsets are too long, resulting into inaccuracies and taking more time for the measurements. In such cases the secondary lines are run by selecting secondary stations on main lines. Such lines are called detail lines.

Check lines: These are the lines connecting main station and a substation on opposite side or the lines connecting to substations on the sides of main lines. The purpose of measuring such lines is to check the accuracy with which main stations are located.

12.3.2 Selection of Stations

The following points should be considered in selecting station points:

(*i*) It should be visible from at least two or more stations.

(*ii*) As far as possible main lines should run on level ground.

(*iii*) All triangles should be well conditioned (No angle less than 30°).

(*iv*) Main network should have as few lines as possible.

(*v*) Each main triangle should have at least one check line.

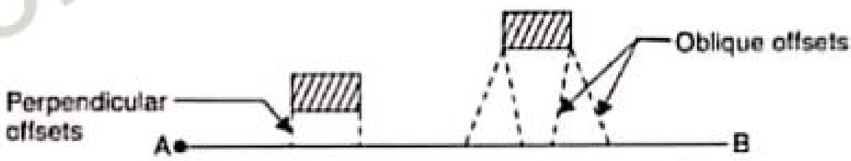
(*vi*) Obstacles to ranging and chaining should be avoided.

(*vii*) Sides of the larger triangles should pass as close to boundary lines as possible.

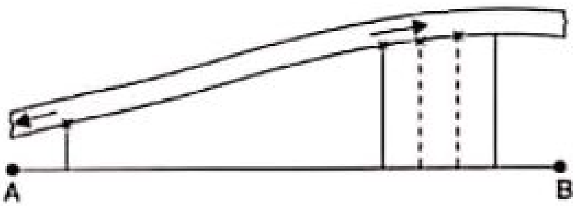
(*viii*) Tresspassing and frequent crossing of the roads should be avoided.

12.3.3 Offsets

Lateral measurements to chain lines for locating ground features are known as offsets. For this purpose perpendicular or oblique offsets may be taken (Ref. Fig. 12.12). If the object to be located (say road) is curved more number of offsets should be taken. For measuring offsets tapes are commonly used.



(a)



(b)

Fig. 12.12. Offsets

For setting perpendicular offsets any one of the following methods are used:

(*i*) Swinging

(*ii*) Using cross staffs

(*iii*) Using optical or prism square.

Perpendicular Offset by Swinging

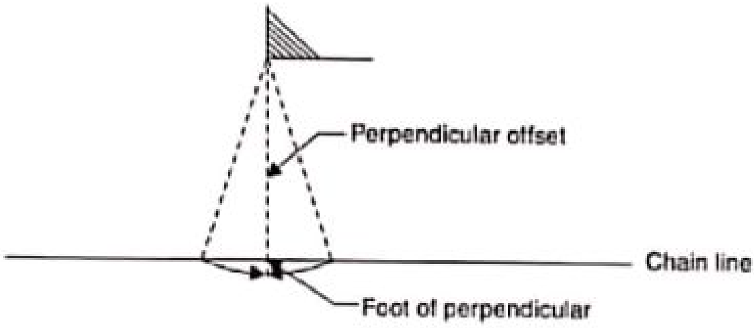


Fig. 12.13

Chain is stretched along the survey line. An assistant holds the end of tape on the object. Surveyor swings the tape on chain line and selects the point on chain where offset distance is the least (Fig. 12.13) and notes chain reading as well as offset reading in a field book on a neat sketch of the object.

Perpendicular Offsets Using Cross Staffs

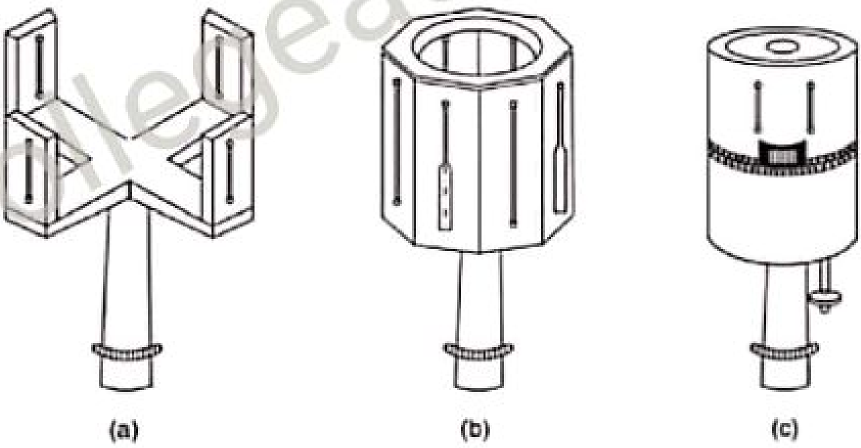


Fig. 12.14. Cross staff

Figure 12.14 shows three different types of cross staffs used for setting perpendicular offsets. All cross staffs are having two perpendicular lines of sights. The cross staffs are mounted on stand. First line of sight is set along the chain line and without disturbing setting right angle line of sight is checked to locate the object. With open cross staff (Fig. 12.14 (*a*)) it is possible to set perpendicular only, while with french cross staff (Fig. 12.14 (*b*)), even 45° angle can be set. Adjustable cross staff can be used to set any angle also, since there are graduations and upper drum can be rotated over lower drum.

Perpendicular Offsets Using Optical Square and Prism Square

These instruments are based on the optical principle that if two mirrors are at angle 'θ' to each other, they reflect a ray at angle '2θ'. Figure 12.15 shows a typical optical square.

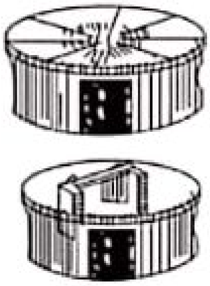
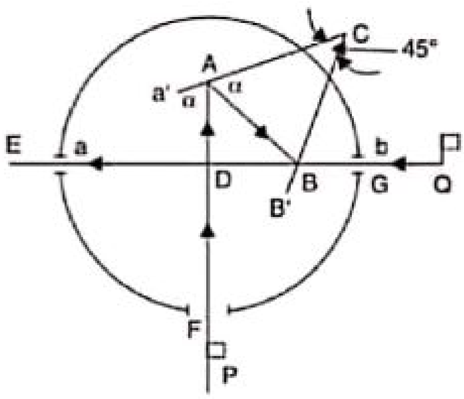



Fig. 12.15. Optical square

Optical square consists of a metal box about 50 mm in diameter and 125 mm deep. In the rim of the box there are three openings:

(*i*) a pin hole at E

(*ii*) a small rectangular slot at G, and

(*iii*) a large rectangular slot at F.

A and B are the two mirrors placed at 45° to each other. Hence the image of an object at F which falls on A gets reflected and emerge at E which is at right angles to the line FA. The mirror A which is opposite to the opening at F is fully silvered. It is fitted to a frame which is attached to the bottom plate. If necessary this mirror can be adjusted by inserting a key on the top of the cover. The mirror B which is in the line with EG is silvered in the top half and plain in the bottom half. It is firmly attached to the bottom plate of the box.

The ranging rod at Q is directly sighted by eye at E in the bottom half of the B which is a plain glass. At the same time in the top half of B, the reflected ray of the object at P is sighted. When the image of P is in the same vertical line as the object at Q, then the lines PA is at right angles to the line EB.

This instrument can be used for finding foot of the perpendicular or to set a right angle.

In prism square, instead of two mirrors at 45° to each other a prism which has two faces at 45° to each other is used [Fig. 12.16.]. Its advantage is it will not go out of adjustment even after long usage.

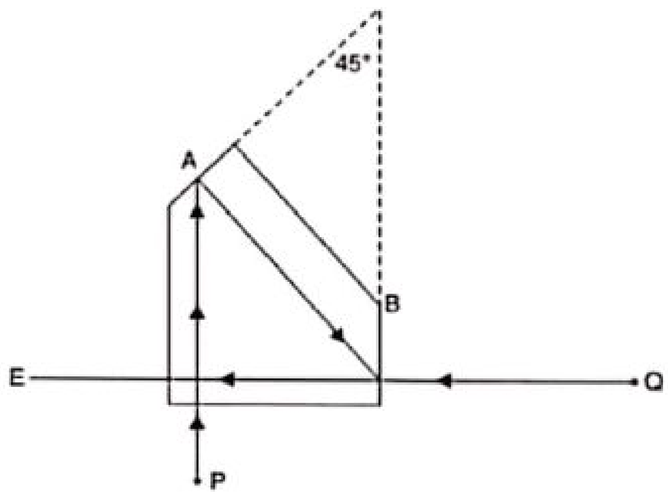


Fig. 12.16. Prism square

12.6 ERRORS IN CHAINING

Errors in chaining may be classified as:

(*i*) Personal errors

(*ii*) Compensating errors, and

(*iii*) Cumulating errors.

12.6.1 Personal Errors

Wrong reading, wrong recording, reading from wrong end of chain etc., are personal errors. These errors are serious errors and cannot be detected easily. Care should be taken to avoid such errors.

12.6.2 Compensating Errors

These errors may be sometimes positive and sometimes negative. Hence they are likely to get compensated when large number of readings are taken. The magnitude of such errors can be estimated by theory of **probability**. The following are the examples of such errors:

(*i*) Incorrect marking of the end of a chain.

(*ii*) Fractional part of chain may not be correct though total length is corrected.

(*iii*) Graduations in tape may not be exactly same throughout.

(*iv*) In the method of stepping while measuring sloping ground, plumbing may be crude.

12.6.3 Cumulative Errors

The errors, that occur always in the same direction are called cumulative errors. In each reading the error may be small, but when large number of measurements are made they may be considerable, since the error is always on one side. Examples of such errors are:

(*i*) Bad ranging

(*ii*) Bad straightening

(*iii*) Erroneous length of chain

(*iv*) Temperature variation

(*v*) Variation in applied pull

(*vi*) Non-horizontality

(*vii*) Sag in the chain, if suspended for measuring horizontal distance on a sloping ground.

Errors (*i*), (*ii*), (*vi*) and (*vii*) are always +ve since they make measured length more than actual. Errors (*iii*), (*iv*) and (*v*) may be +ve or –ve.

12.8 CONVENTIONAL SYMBOLS

IS 962—1989, 'code of practice for architectural and building drawings' has specified standard symbols for various objects as shown in Table 12.1 on next page.

If coloured plans are to be made, the code recommends light washes of the following shades:

For roads – Burnt sienna

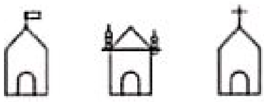
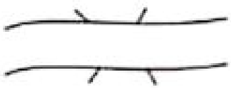
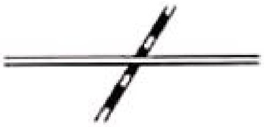
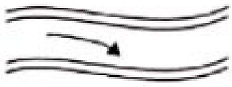
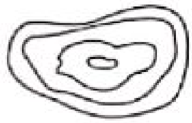
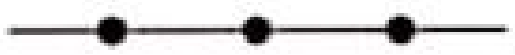
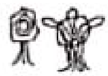
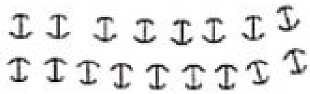
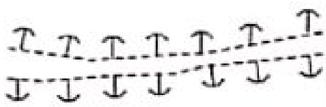
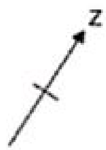
For buildings – Light grey

For compound walls – Indigo

For water – Borders edged with Prussian blue

For trees – Green.

Table 12.1

Chain line	
Triangulation station	
Traverse station	
Building	
Shed with open side	
Shed with closed side	
Temple, mosque and church	
Path	
Unfenced road	
Fenced road	
Railway line: Single	
Railway line: Double	
Road bridge	
Level crossing	
Road over railway	
Road under railway	
Boundaries without pillars	
Boundaries with pillars	
Township or taluka boundaries	
River	
Pond	
Electric line	
Tree	
Orchard	
Woods	
Grass	
Cutting	
Embankment	
North line	

Plane Table Surveying

In this method of surveying a table top, similar to drawing board fitted on to a tripod is the main instrument. A drawing sheet is fixed on to the table top, the observations are made to the objects, distances are scaled down and the objects are plotted in the field itself. Since the plotting is made in the field itself, there is no chance of omitting any necessary measurement in this surveying. However the accuracy achieved in this type of surveying is less. Hence this type of surveying is used for filling up details between the survey stations previously fixed by other methods.

In this chapter, accessories required, working operations and methods of plane table surveying are explained. At the end advantages and limitations of this method are listed.

14.1 PLANE TABLE AND ITS ACCESSORIES

The most commonly used plane table is shown in Fig. 14.1. It consists of a well seasoned wooden table top mounted on a tripod. The table top can rotate about vertical axis freely. Whenever necessary table can be clamped in the desired orientation. The table can be levelled by adjusting tripod legs.

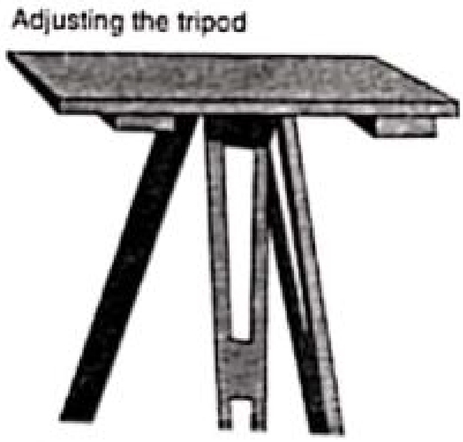


Fig. 14.1. Plane table with stand

The following accessories are required to carry out plane table survey:

1. Alidade
2. Plumbing fork with plumb bob.

3. Spirit level
4. Trough compass
5. Drawing sheets and accessories for drawing.

14.1.1 Alidade

It is a straight edge ruler having some form of sighting device. One edge of the ruler is bevelled and is graduated. Always this edge is used for drawing line of sight. Depending on the type of line of sight there are two types of alidade:

(*a*) Plain alidade (*b*) Telescopic alidade

Plain Alidade: Figure 14.2 shows a typical plain adidate. A sight vane is provided at each end of the ruler. The vane with narrow slit serves as eye vane and the other with wide slit and having a thin wire at its centre serves as object vane. The two vanes are provided with hinges at the ends of ruler so that when not in use they can be folded on the ruler. Plain alidade is not suitable in surveying hilly areas as the inclination of line of sight in this case is limited.

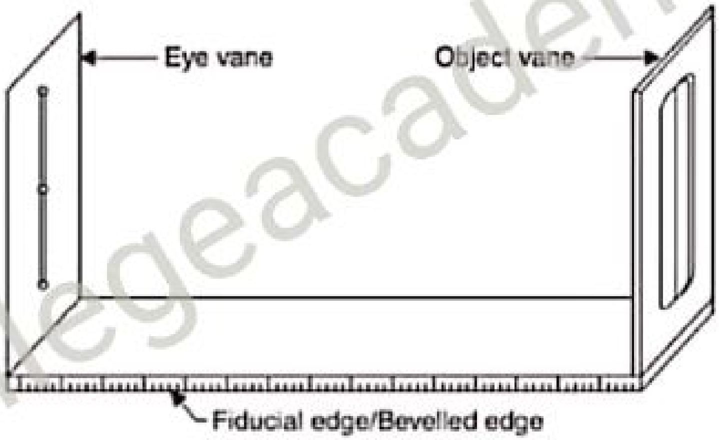


Fig. 14.2. Plane alidade

Telescopic Alidade: It consists of a telescope mounted on a column fixed to the ruler [Fig. 14.3]. The line of sight through the telescope is kept parallel to the bevelled edge of the ruler. The telescope is provided with a level tube and vertical graduation arc. If horizontal sight is required bubble in the level tube is kept at the centre. If inclined sights are required vertical graduation helps in noting the inclination of the line of sight. By providing telescope the range and the accuracy of line of sight is increased.

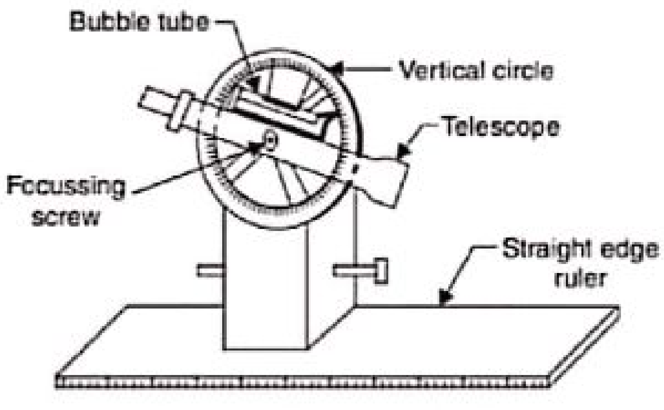


Fig. 14.3. Telescopic alidade

14.1.2 Plumbing Fork and Plumb Bob

Figure 14.4 shows a typical plumbing fork with a plum bob. Plumbing fork is a U-shaped metal frame with a upper horizontal arm and a lower inclined arm. The upper arm is provided with a pointer at the end while the lower arm is provided with a hook to suspend plumb bob. When the plumbing fork is kept on the plane table the vertical line (line of plumb bob) passes through the pointed edge of upper arm. The plumb bob helps in transferring the ground point to the drawing sheet and vice versa also.

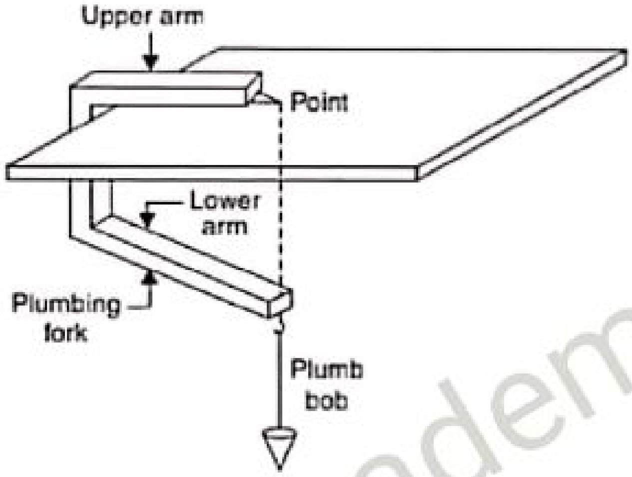


Fig. 14.4. Plumbing fork and plumb bob.

14.1.3 Spirit Level

A flat based spirit level is used to level the plane table during surveying (Fig. 14.5). To get perfect level, spirit level should show central position for bubble tube when checked with its positions in any two mutually perpendicular direction.

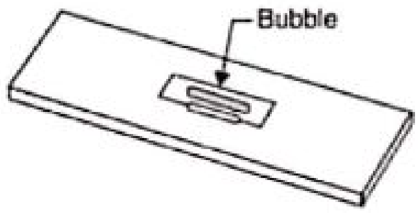


Fig. 14.5. Spirit level

14.1.4 Trough Compass

It consists of a 80 to 150 mm long and 30 mm wide box carrying a freely suspended needle at its centre (Ref. Fig. 14.6). At the ends of the needle graduations are marked on the box to indicate zero to five degrees on either side of the centre. The box is provided with glass top to prevent oscillation of the needle by wind. When needle is centred (reading 0–0), the line of needle is parallel to the edge of the box. Hence marking on the edges in this state indicates magnetic north–south direction.

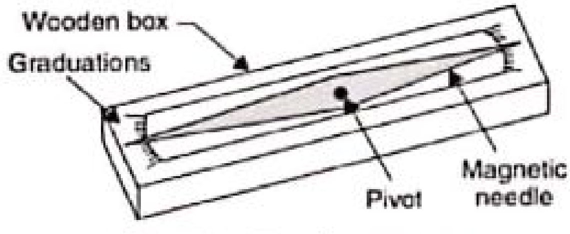


Fig. 14.6. Trough compass

14.1.5 Drawing Sheet and Accessories for Drawing

A good quality, seasoned drawing sheet should be used for plane table surveying. The drawing sheet may be rolled when not in use, but should never is folded. For important works fibre glass sheets or paper backed with thin aluminium sheets are used.

Clips clamps, adhesive tapes may be used for fixing drawing sheet to the plane table. Sharp hard pencil, good quality eraser, pencil cutter and sand paper to keep pencil point sharp are other accessories required for the drawing work. If necessary, plastic sheet should be carried to cover the drawing sheet from rain and dust.

14.2 WORKING OPERATIONS

After fixing the table top to the stand and drawing sheet to the table, the following operations are to be carried out before map making:

1. Centering
2. Levelling
3. Orientation.

14.2.1 Centering

Centering is the process of setting the plane table on the point so that its plotted position is exactly over the position on the ground. This is achieved by moving the legs of the tripod and checking the position of the point on the ground and on the paper with the help of plumbing fork and plumb bob.

14.2.2 Levelling

The level of the plane table should be ensured in two positions of spirit level which are at right angles to each other. The legs of tripod are moved radially or along the circumference to adjust the plane table and get levelled surface.

14.2.3 Orientation

Orientation is the process of setting plane table over a station such that all the lines already plotted are parallel to corresponding lines on the ground. Accuracy of plane table survey mainly depends upon the accuracy of orientation of plane table at each station point. It can be achieved by any one of the following methods:

(*a*) using trough compass

(*b*) by back sighting

(*c*) by solving two point or three point problems.

The first two methods are commonly used while the third method is used occationally. The third method is explained under the article methods of plane tabling by resection.

(*a*) *Orientation Using Trough Compass:* When the survey work starts, the plane table is set on first station and the table is oriented by rough judgement such that the plotted position of the area falls in the middle portion of the paper. Then the table is clamped and the north direction is marked on right hand side top corner of drawing sheet. Trough compass is used to identify north direction. This orientation is to be maintained at all subsequent stations. After centering and levelling the table trough compass is kept along the marked north direction and the table is rotated to get freely suspended magnetic needle centred. After achieving it the table is clamped.

This method of orientation is considered rough, since the local attraction to magnetic needle affects the orientation. This method is used as preliminary orientation and finer tuning is made by observing the already plotted points.

(*b*) *Orientation by Back Sighting:* It is the commonly used method in plane table surveying. After completing surveying from plane table set at A, if table is to be shifted to next station B, a line is drawn from the plotted position of station A towards station B. Then distance AB is measured, scaled down and plotted position of station B is obtained. Then table is shifted to station B, centred, levelled. Then keeping alidade along BA, station A is sighted and the table is clamped. Thus the orientation of the table is achieved by back sighting. Orientation may be checked by observing already plotted objects.

14.3 METHODS OF PLANE TABLING

The following four methods are available for carrying out plane table survey:

1. Radiation
2. Intersection
3. Traversing
4. Resection.

The first two methods are employed for locating details while the other two methods are used for locating position of plane table station on drawing sheet.

14.3.1 Radiation

After setting the plane table on a station, say O, it is required to find the plotted position of various objects A, B, C, D .... To get these positions, the rays OA, OB, OC ..... are drawn with soft pencil (Ref. Fig. 14.7). Then the distances OA, OB, OC ......, are measured scaled down and the positions of A, B, C ....., are found on the drawing sheets.

This method is suitable for surveying small areas and is convenient if the distances to be measured are small. For larger areas this method has wider scope, if telescopic alidade is used, in which the distances are measured technometrically.

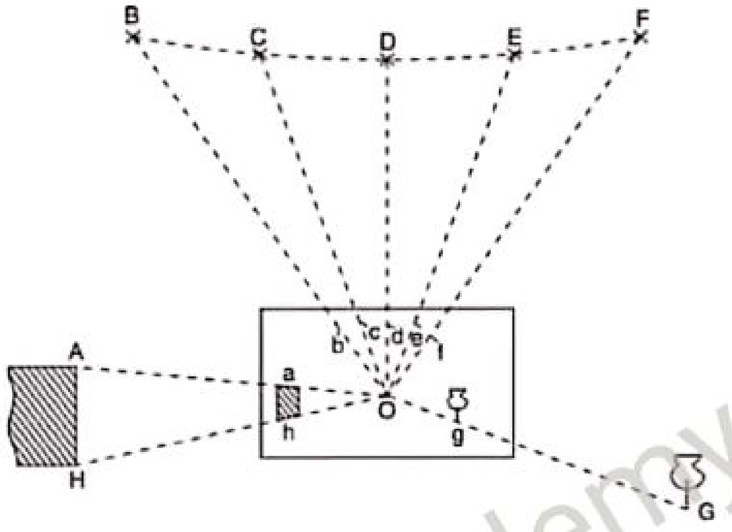


Fig. 14.7. Radiation method of plane tabling

14.3.2 Intersection

In this method the plotted position of an object is obtained by plotting rays to the object from two stations. The intersection gives the plotted position. Thus it needs the linear measurements only between the station points and do not need the measurements to the objects. Figure 14.8 shows the method for locating objects A and B from plane table positions O_1 and O_2.

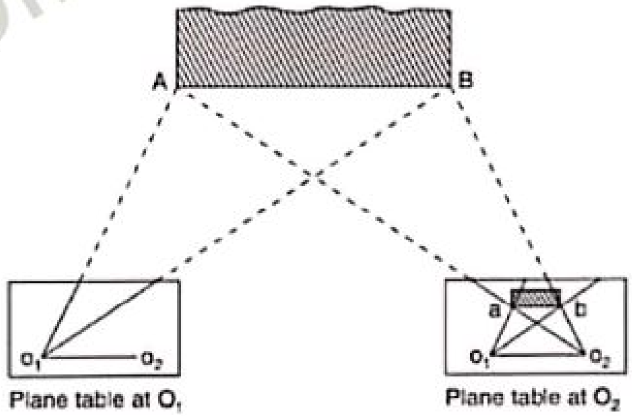


Fig. 14.8. Intersection method of plane tabling

This method is commonly employed for locating:

(*a*) details

(*b*) the distant and inaccessible points

(*c*) the stations which may be used latter.

14.3.3 Traversing

This is the method used for locating plane table survey stations. In this method, ray is drawn to next station before shifting the table and distance between the stations measured. The distance is scaled down and next station is located. After setting the plane table at new station orientation is achieved by back sighting. To ensure additional checks, rays are taken to other stations also, whenever it is possible. Figure 14.9 shows a scheme of plane table survey of closed area. This method can be used for open traverses also.

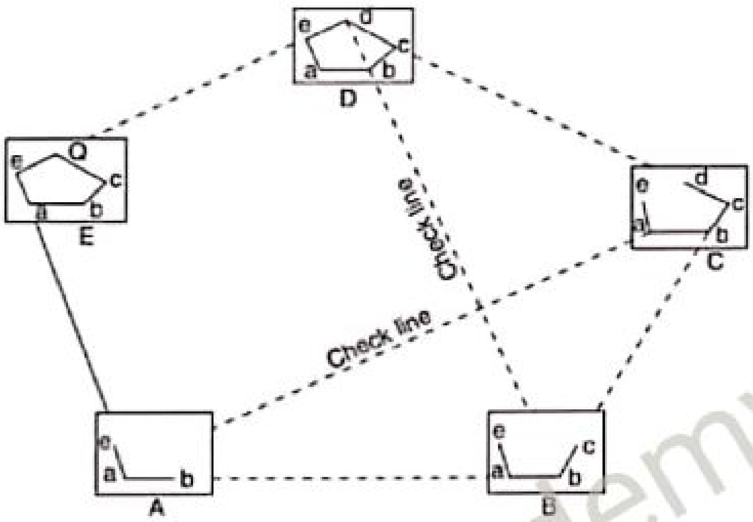


Fig. 14.9. Plane table traversing

14.3.4 Resection

This method is just opposite to the method of intersection. In the method of intersection, the plotted position of stations are known and the plotted position of objects are obtained by intersection. In this method the plotted position of objects are known and the plotted position of station is obtained. If a, *b* and *c* are the plotted positions of objects A, B and C respectively, to locate instrument station P on the paper, the orientation of table is achieved with the help of *a*, *b*, *c* and then resectors Aa, Bb, Cc are drawn to get the '*p*', the plotted position of P. Hence in the resection method major work is to ensure suitable orientation by any one of the methods. The following methods are employed in the method of resection:

(*a*) by compass

(*b*) by back sighting

(*c*) by solving two point problem

(*d*) by solving three point problem.

(*a*) *Resection after Orientation by Compass:* Let *a* and *b* be the plotted positions of A and B of two well defined points in the field. Keeping the through compass along north direction marked on the drawing sheet table is oriented on station P, the position of which is to be found on paper. The resectors Aa and Bb [Fig. 14.10] are drawn to locate '*p*' the plotted position of station point P.

This method gives satisfactory results, if the area is not influenced by local attractions. It is used for small scale mapping only.

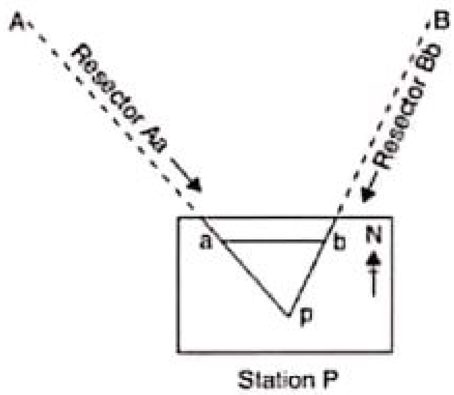


Fig. 14.10. Resection after orientation with compass

(b) *Resection after Orientation by Back Sighting:* Figure 14.11 shows the scheme of resection after orientation by back sighting. From station A, the position of B is plotted as '*b*' and ray has been taken to station P as *ap′*. Then plane table is set at P and oriented by back sighting A, line AP is not measured but the position of P is obtained on the paper by taking resection Bb.

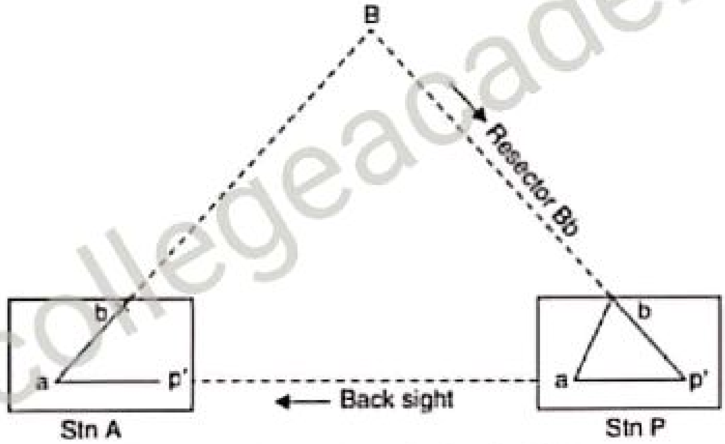


Fig. 14.11. Resection after back sighting

(c) *Resection after Solving Two Point Problem:* The problem of finding plotted position of the station point occupied by the plane table with the help of plotted positions of two well defined points is known as solving two point problem. Figure 14.12 shows the scheme of solving this.

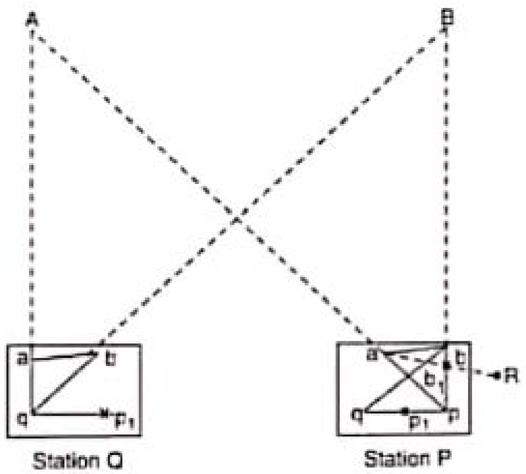


Fig. 14.12. Two-point problem

Let A and B be two well defined points like lightening conductor or spire of church, the plotted positions a and b already known. Now the problem is to orient the table at P so that by resection its plotted position p can be obtained. The following steps may be followed to solve this problems:

(*i*) Select a suitable point Q near P such that the angles PAQ and PBQ are not accute.

(*ii*) Roughly orient the table at Q and draw the resectors Aa and Bb to get the point 'q'.

(*iii*) Draw the ray qp and locate p_1 with estimated distance QP.

(*iv*) Shift the plane table to P and orient the table by back sighting to Q.

(*v*) Draw the resector Aa to get 'p'.

(*vi*) Draw the ray pB. Let it intersect line bq at b_1.

(*vii*) The points b and b_1 are not coinciding due to the angular error in the orientation of table. The angle bab_1 is the angular error in orientation. To correct it,

* Fix a ranging rod at R along ab,
* Unclamp the table and rotate it till line ab sights ranging rod at R. Then clamp the table. This gives the correct orientation of the table which was used in plotting the points A and B.

(*viii*) The resectors Aa and Bb are drawn to get the correct plotted position 'p' of the station P.

(*d*) *Resection after Solving Three Point Problem:* Locating the plotted position of a station point using observations to three well defined points whose plotted positions are known, is called solving three point problem.

Let A, B, C be three well defined objects on the field whose plotted positions a, b and c are known. Now the problem is to locate plotted position of the station point P. Any one of the following methods can be used.

(*i*) Mechanical (Tracing paper) method,

(*ii*) Graphical method, or

(*iii*) Trial and error method (Lehman's method).

(*i*) *Mechanical Method:* This method is known as tracing paper method since it needs a tracing paper. The method involved the following steps [Ref. Fig. 14.13.]

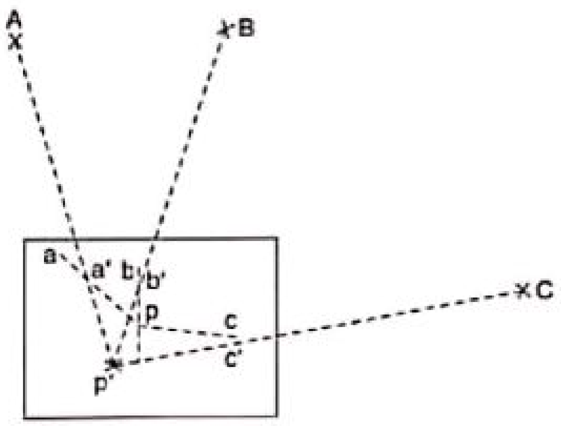


Fig. 14.13

* Set the table over station P and by observation approximately orient the table.
* Fix the tracing paper on the plane table and select P approximately, say as p'. From p', draw p' A, p' B and p' C. These lines may not pass through the plotted positions *a*, *b* and *c* since the orientation is not exact.
* Loosen the tracing paper and rotate it so that the rays pass through respective points *a*, *b* and *c*. Now prick the point p' to get the plotted position '*p*' of the station P.
* Keep the alidade along *pa* and sight A. Then clamp the table. This is correct orientation. Check the orientation by observing along *pb* and *pc*.

(*ii*) *Graphical Method:* The following two graphical methods are available to solve three point problem:

* Bessel's solution
* Method of perpendiculars.

Bessels Solution: It involves the following steps:

1. Keep the bevelled edge of alidade along *ba* and sight object at A. Clamp the table and draw bc' along the line *bc* [Fig. 14.14 (*a*)].
2. Keep bevelled edge of alidade along *ab*, unclamp the table and sight B. Clamp the table. Draw line *ac* intersecting bc' at *d* [Fig. 14.14(*b*)].
3. Keep the alidade along *dc* and bisect C. Clamp the table [Fig. 14.14(*c*)]. This gives the correct orientation.
4. Draw resectors to get '*p*'.

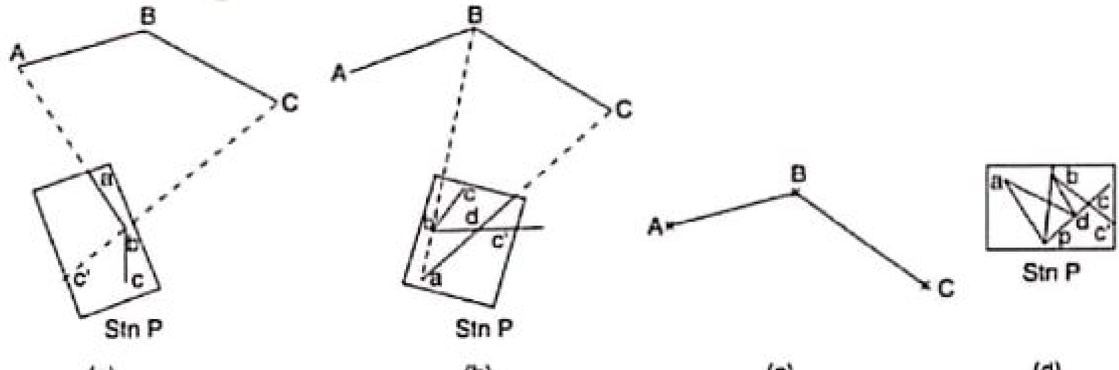


Fig. 14.14. Graphical solution (Bessel's method)

ethod of Perpendiculars

is is another graphical method. It involves the following steps [Ref. Fig. 14.15].

1. Draw line *ae* perpendicular to *ab*. Keep alidade along *ea* and turn the table till A is sighted. Clamp the table and draw the ray Bb to intersect the ray A*ac* at *e* [Fig. 14.15(*a*)].
2. Draw *cf* perpendicular to *bc* and clamp the table when *fc*C are in a line. Draw Bb to intersect C*cf* at F [Fig. 14.15(*b*)].

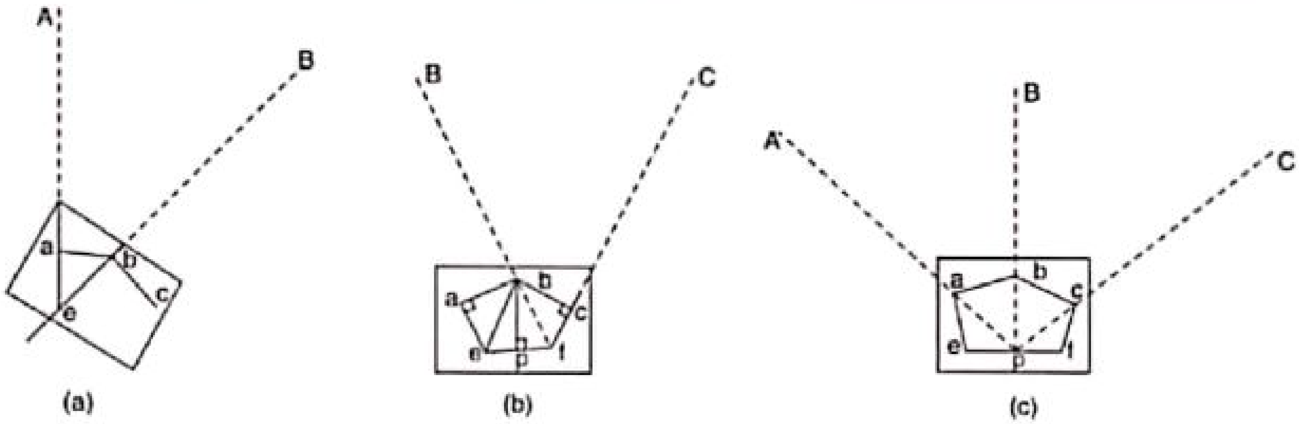


Fig. 14.15. Method of perpendiculars of solve three point problem

3. Join *cf* drop *bp* perpendicular to *ef* to get the plotted position '*p*'.
4. Orient the table such that *pb*B are in a line. Clamp the table to place it in correct orientation. Resections A*a* and C*c* may be used to check the orientation.

Trial and Error Method

This method is also known as '*triangle of error method*' and '*Lehman's Method*'. It involves the following steps:

1. Set the table over point P and orient the table approximately, just by observation.
2. Draw the rays *a*A, *b*B and *c*C [Fig. 14.16]. If the orientation was perfect, the three rays would have intersected at a single point, *i.e.* at point '*p*'. Otherwise a triangle of error is formed.
3. To eliminate the triangle of error an approximate position, ray *p'*, is selected near the triangle of error. Then keeping alidade along *p'a* object A is sighted and the table is clamped. Draw the resectors *c*C and *b*B to check the orientation.
4. Above step is repeated till triangle of error is eliminated.

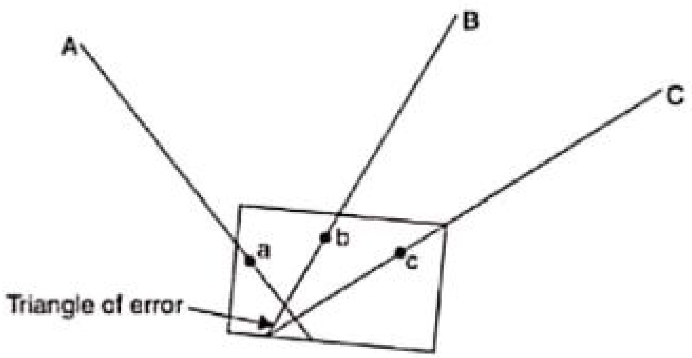


Fig. 14.16

Lehman presented the following guidelines to select '*p'*' so that triangle of error is eliminated quickly.

Rule 1: The distance of point sought '*p*' is in the same proportion from the corresponding rays as the distance of those from the plane table station.

Rule 2: The point sought 'p' is on the same side of all the three resectors.

Defining the triangle ABC on the field as great triangle and the circle passing through them as great circle, from the above two rules of Lehman, the following sub-rules may be drawn [Ref. Fig. 14.17].

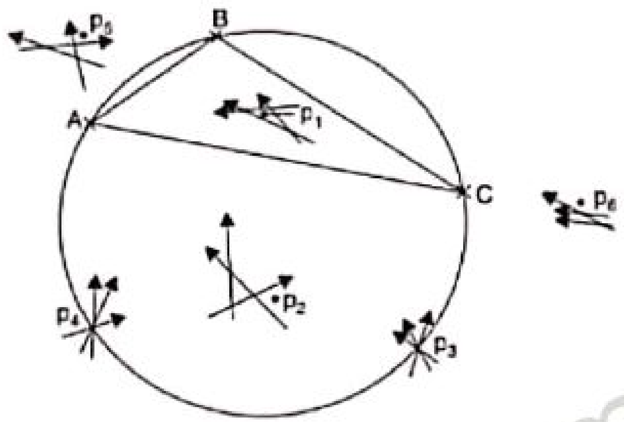


Fig. 14.17

- If 'P' lies within the great triangle, the point 'p' is within the triangle of error (p_1 in the Fig. 14.17).
- If the plane table station P lies outside the great triangle the point sought 'p' is outside the triangle of errors (p_2).
- If the 'P' is on the great circle, the correct solution is impossible (p_3 and p_4).
- If 'P' is outside the great circle, 'p' is nearer to the intersection of rays to the nearest two points (P_5).
- If point P is outside the great circle and the two rays drawn are parallel to each other the point sought is outside the parallel lines and on the same side of the three rays (P_6).

14.4 ERRORS IN PLANE TABLE SURVEYING

The errors may be grouped into the instrumental and personal errors.

14.4.1 Instrumental Errors

1. The surface of plane table not perfectly plane.
2. Bevelled edge of alidade not straight.
3. Sight vanes of alidade not perfectly perpendicular to the base.
4. Plane table clamp being loose.
5. Magnetic compass being sluggish.
6. Drawing sheet being of poor quality.

14.4.2 Personal Errors

1. Centering errors
2. Levelling errors
3. Orientation errors
4. Sighting errors
5. Errors in measurement
6. Plotting errors
7. Errors due to instability of tripod.

14.5 ADVANTAGES AND LIMITATIONS OF PLANE TABLE SURVEY

Advantages are

1. Possibility of omitting measurement is eliminated.
2. The surveyor can compare the plotted work in the field then and there only.
3. Irregular objects are plotted more accurately, since they are seen while plotting.
4. Booking errors are eliminated.
5. Local attractions do not influence the plotting.
6. No great skill is required to produce satisfactory maps.
7. Method is fast.
8. No costly instruments are required.

Limitations are

1. Survey cannot be conducted in wet weather and rainy days.
2. Plane table is cumbersome and heavy to carry.
3. It needs many accessories.
4. It is less accurate.
5. Reproduction of map to different scale is difficult.

Level and Levelling

Elevation measurements involve measurements in vertical plane. It is also known as levelling. It may be *defined as the art of determining the elevations of given points above or below a datum line or establishing given points of required heights above or below the datum line.*

15.1 OBJECT AND USES OF LEVELLING

As stated in the definition of levelling, the object is

(*i*) to determine the elevations of given points with respect to a datum

(*ii*) to establish the points of required height above or below the datum line.

Uses of levelling are

(*i*) to determine or to set the plinth level of a building.

(*ii*) to decide or set the road, railway, canal or sewage line alignment.

(*iii*) to determine or to set various levels of dams, towers, etc.

(*iv*) to determine the capacity of a reservoir.

15.2 TERMS USED IN LEVELLING

Before studying the art of levelling, it is necessary to clearly understand the following terms used in levelling:

1. **Level Surface:** A surface parallel to the mean spheroid of the earth is called a level surface and the line drawn on the level surface is known as a level line. Hence all points lying on a level surface are equidistant from the centre of the earth. Figure 15.1 shows a typical level surface.

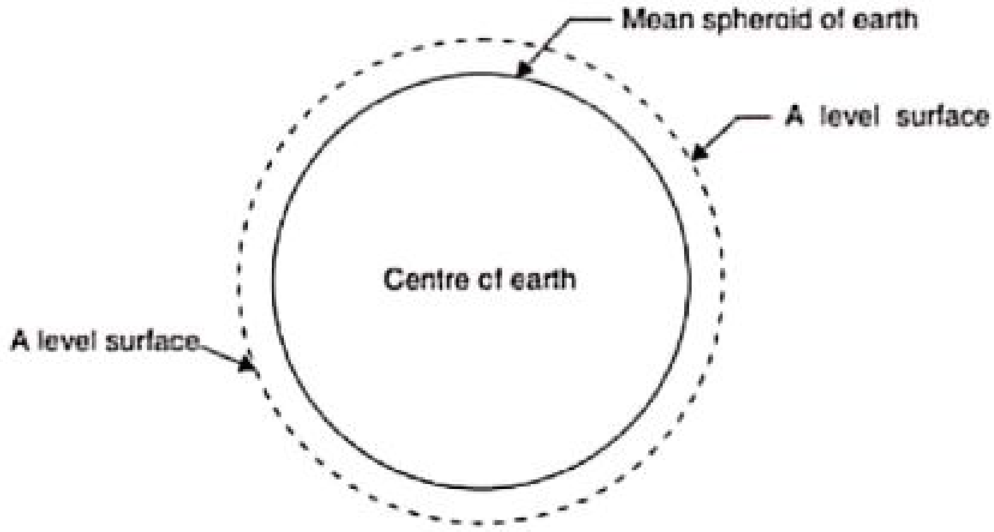


Fig. 15.1. A level surface

2. **Horizontal Surface:** A surface tangential to level surface at a given point is called horizontal surface at that point. Hence a horizontal line is at right angles to the plumb line at that point [Ref. Fig. 15.2].

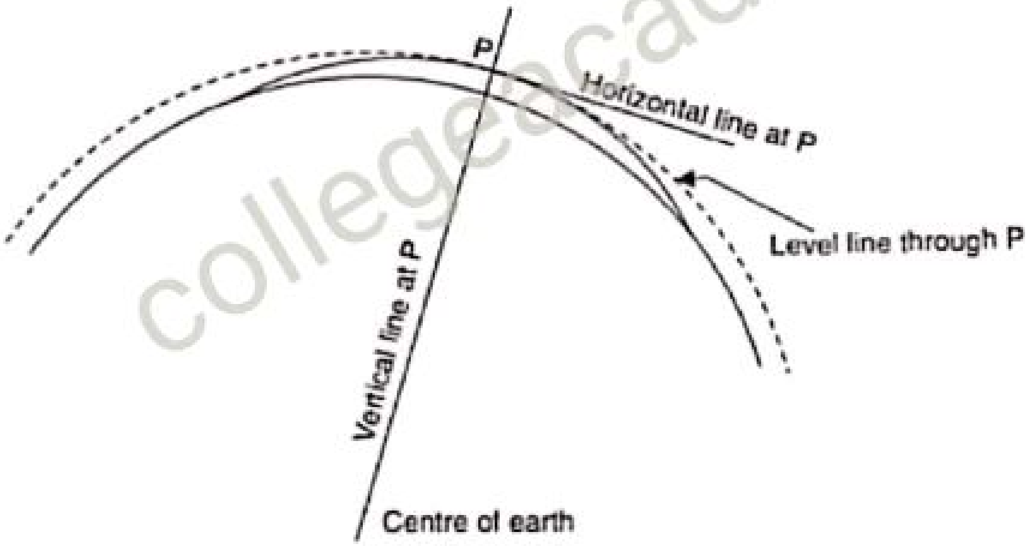


Fig. 15.2. Vertical and horizontal lines

3. **Vertical Line:** A vertical line at a point is the line connecting the point to the centre of the earth. It is the plumb line at that point. Vertical and horizontal lines at a point are at right angles to each other [Fig. 15.2].

4. **Datum:** The level of a point or the surface with respect to which levels of other points or planes are calculated, is called a datum or datum surface.

5. **Mean Sea Level (MSL):** MSL is the average height of the sea for all stages of the tides. At any particular place MSL is established by finding the mean sea level (free of tides) after averaging tide heights over a long period of at least 19 years. In India MSL used is that established at Karachi, presently, in Pakistan. In all important surveys this is used as datum.

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

7. **Benchmarks:** A benchmark is a relatively permanent reference point, the elevation of which is known (assumed or known w.r.t. MSL). It is used as a starting point for levelling or as a point upon which to close for a check. The following are the different types of benchmarks used in surveying:

(*a*) GTS benchmarks (*b*) Permanent benchmarks

(*c*) Arbitrary benchmarks and (*d*) Temporary benchmarks.

(*a*) **GTS Benchmark:** The long form of GTS benchmark is Great Trigonometrical Survey benchmark. These benchmarks are established by national agency. In India, the department of Survey of India is entrusted with such works. GTS benchmarks are established all over the country with highest precision survey, the datum being mean sea level. A bronze plate provided on the top of a concrete pedastal with elevation engraved on it serves as benchmark. It is well protected with masonry structure built around it so that its position is not disturbed by animals or by any unauthorised person. The position of GTS benchmarks are shown in the topo sheets published.

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

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

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

15.3 LEVELLING INSTRUMENTS

A level is an instrument giving horizontal line of sight and magnifying the reading at a far away distance. It consists of the following parts:

(*i*) A telescope to provide a line of sight

(*ii*) A level tube to make the line of sight horizontal and

(*iii*) A levelling head to level the instrument.

The following types of levels are available:

(*i*) Dumpy level (*ii*) Wye (or, *Y*) level

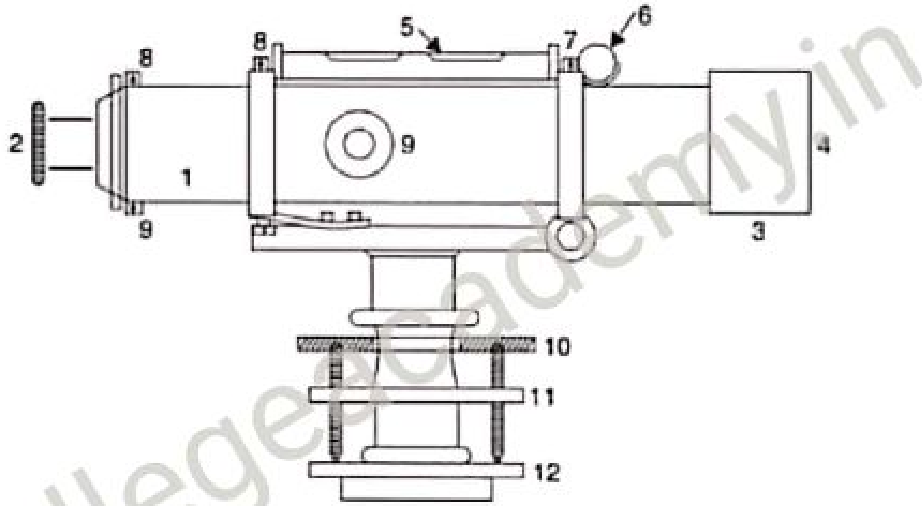
(*iii*) Cooke's reversible level (*iv*) Cushing's level

(*v*) Tilting level and (*vi*) Auto level.

15.3.1 Dumpy Level

It is a short and stout instrument with telescope tube rigidly connected to the vertical spindle. Hence the level tube cannot move in vertical plane. It cannot be removed from its support. Hence it is named as dumpy level. The telescope rotates in horizontal plane in the socket of the levelling head. A bubble tube is attached to the top of the telescope. Figure 15.3 shows a typical dumpy level. Plate 15.1 shows its photograph.

Plate 15.1 Dumpy level



1. Telescope
2. Eyepiece
3. Shade
4. Objective end
5. Longitudinal bubble tube
6. Transverse bubble tube
7. Bubble tube adjusting screws
8. Diaphragm adjusting screws
9. Focusing screws
10. Foot screws
11. Upper parallel plate (tribrach)
12. Foot plate (Trivet stage)

Fig. 15.3. Dumpy level

Telescope is a tube with object glass and eyepiece. Object glass can be adjusted using the focussing screw before sighting the graduated staff held on the object. Eyepiece can be adjusted by rotating it to see that parallel is removed and cross hairs appears distinctly. Eyepiece once adjusted needs no change as long as the same person takes the readings.

Level tube is a glass tube with slightly curved shape provided over the level tube. The tube is filled with ether or alcohol leaving a little air gap, which takes the shape of a bubble. The air bubble is always at the highest point. The level tube is fixed with its axis parallel to telescope tube, so that when bubble is centred, the telescope is horizontal. The tube is graduated on either side of its centre to estimate how much the bubble is out of centre. The glass tube is placed inside a brass tube which is open from top and on lower side it is fixed to telescope tube by means of capston headed nuts. The bubble tube is adjusted with these nuts, if it is out of order.

Levelling head consists of two parallel plates with three foot screws. The upper plate is known as tribratch plate and the lower one as the trivet. The lower plate can be screwed on to the tripod stand. By adjusting the screws the instrument can be levelled to get perfect horizontal line of sight.

Dumpy level is to be fitted to a tripod stand to use it in the field. The tripod stand consists of three legs connected to a head to which the lower plate of level can be fitted. The lower side of the legs are provided with metal shoes to get good grip with ground. Plate 15.2 shows typical level stands.

Plate 15.2 Levelling stands (adjustable and non-adjustable)

15.3.2 Wye or Y-Level

In this type of level, the telescope is supported in two Y-shaped supports and can be fixed with the help of curved clips. Clips can be opened and telescope can be reversed end to end and fitted. The advantage of this level is some of the errors eliminated, if the readings are taken in both the direction of telescope.

15.3.3 Cooke's Reversible Level

In this instrument the telescope is supported by two rigid sockets into which telescope can be introduced from either end and then screwed. For taking the readings in the reversed position of telescope, the screw is slackened and then the telescope is taken out and reversed end for end. Thus it combines the rigidity of dumpy level and reversibility of Y-level.

15.3.4 Cushings Level

In this reversing of telescope end for end is achieved by interchanging the eyepiece and the objective piece since both collars are exactly the same.

15.3.5 Tilting Level

In this, telescope can be tilted through about four degrees with the help of a tilting screw. Hence bubble can be easily centered. But it needs centering of the bubble before taking every reading. Hence it is useful, if at every setting of the instrument number of readings to be taken are few.

15.3.6 Auto Level

The auto-level or the automatic-level is a self aligning level. Within a certain range of tilt automatic levelling is achieved by an inclination compensating device. The operational comfort, high speed and precision are the advantages of this instrument.

15.4 LEVELLING STAFF

Along with a level, a levelling staff is also required for levelling. The levelling staff is a rectangular rod having graduations. The staff is provided with a metal shoes at its bottom to resist wear and tear. The foot of the shoe represents zero reading. Levelling staff may be divided into two groups:

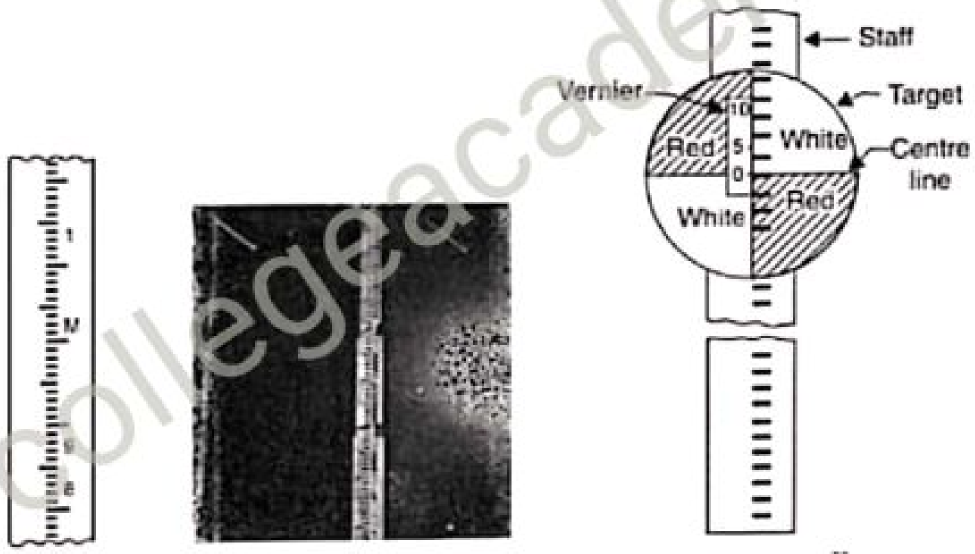
(*i*) Self reading staff (*ii*) Target staff.

(*i*) **Self reading staff:** This staff reading is directly read by the instrument man through telescope. In a metric system staff, one metre length is divided into 200 subdivisions, each of uniform thickness of 5 mm. All divisions are marked with black in a white background. Metres and decimetres are written in red colour [Fig 15.4 (*a*)]. The following three types of self reading staffs are available:

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

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

(*c*) *Telescopic staff:* A staff of 3 pieces with upper one solid and lower two hollow. The upper part can slide into the central one and the central part can go into the lower part. Each length can be pulled up and held in position by means of brass spring. The total length may be 4 m or 5 m [Fig. 15.4 (*b*)].



(a) Self-reading staff (b) Telescopic staff (c) Target staff

Fig. 15.4

(*ii*) **Target staff:** If the sighting distance is more, instrument man finds it difficult to read self reading staff. In such case a target staff shown in [Fig. 15.4 (*c*)] may be used. Target staff is similar to self reading staff, but provided with a movable target. Target is a circular or oval shape, painted red and white in alternate quadrant. It is fitted with a vernier at the centre.

The instrument man directs the person holding target staff to move the target, till its centre is in the horizontal line of sight. Then target man reads the target and is recorded.

15.5 METHODS OF LEVELLING

The following methods are used to determine the difference in elevation of various points:

(*i*) Barometric levelling (*ii*) Hypsometric levelling

(*iii*) Direct levelling and (*iv*) Indirect levelling.

15.5.1 Barometric Levelling

This method depends on the principle that atmospheric pressure depends upon the elevation of place. However it is Barometer is used to measure the atmospheric pressure and hence elevation is computed.

not accurate method since the atmospheric pressure depends upon season and temperature also. It may be used in exploratory surveys.

15.5.2 Hypsometric Levelling

This is based on the principle that boiling point of water decreases with the elevation of the place. Hence the elevation difference between two points may be found by noting the difference in boiling point of water in the two places. This method is also useful only for exploratory survey.

15.5.3 Direct Levelling

It is common form of levelling in all engineering projects. In this method horizontal sight is taken on a graduated staff and the difference in the elevation of line of sight and ground at which staff is held are found. Knowing the height of line of sight from the instrument station the difference in the elevations of instrument station and the ground on which staff is held can be found. This method is thoroughly explained in next article.

15.5.4 Indirect Methods

In this method instruments are used to measure the vertical angles. Distance between the instrument and staff is measured by various methods. Then using trigonometric relations, the difference in elevation can be computed. This is considered beyond the scope of this book. One can find details of such methods in books on surveying and levelling.

15.6 TERMS USED IN DIRECT METHOD OF LEVELLING

The following terms are used in direct method of levelling:

(*i*) **Plane of Collimation:** It is the reduced level of plane of sight with respect to the datum selected. It is also known as **'height of instrument'**. It should not be confused with the height of telescope from the ground where the instrument is set.

(*ii*) **Back Sight (BS):** It is the sight taken on a level staff held on the point of known elevation with an intension of determining the plane of collimation. It is always the first reading after the instrument is set in a place. It is also known as plus sight, since this reading is to be added to RL of the point (Benchmark or change point) to get plane of collimation.

(*iii*) **Intermediate Sight (IS):** Sights taken on staff after back sight (first sight) and before the last sight (fore sight) are known as intermediate sights. The intension of taking these readings is to find the reduced levels of the points where staff is held. These sights are known as 'minus sights' since the IS reading is to be subtracted from plane of collimation to get RL of the point where staff is held.

(*iv*) **Fore Sight (FS):** This is the last reading taken from the instrument station before shifting it or just before ending the work. This is also a minus sight.

(*v*) **Change Point (CP):** This is also known as turning point (TP). This is a point on which both fore sights and back sights are taken. After taking fore sight on this point instrument is set at some other convenient point and back sight is taken on the staff held at the same point. The two readings help in establishing the new plane of collimation with respect to the earlier datum. Since there is time gap between taking the two sights on the change point, it is advisable to select change point on a well defined point.

15.7 TEMPORARY ADJUSTMENTS OF A LEVEL

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

(*i*) Setting (*ii*) Levelling and

(*iii*) Focussing.

15.7.1 Setting

Tripod stand is set on the ground firmly so that its top is at a convenient height. Then the level is fixed on its top. By turning tripod legs radially or circumferentially, the instrument is approximately levelled. Some instruments are provided with a less sensitive circular bubble on tribrach for this purpose.

15.7.2 Levelling

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

(*i*) Loosen the clamp and turn the telescope until the bubble axis is parallel to the line joining any two screws [Ref. Fig. 15.5 (*a*)].

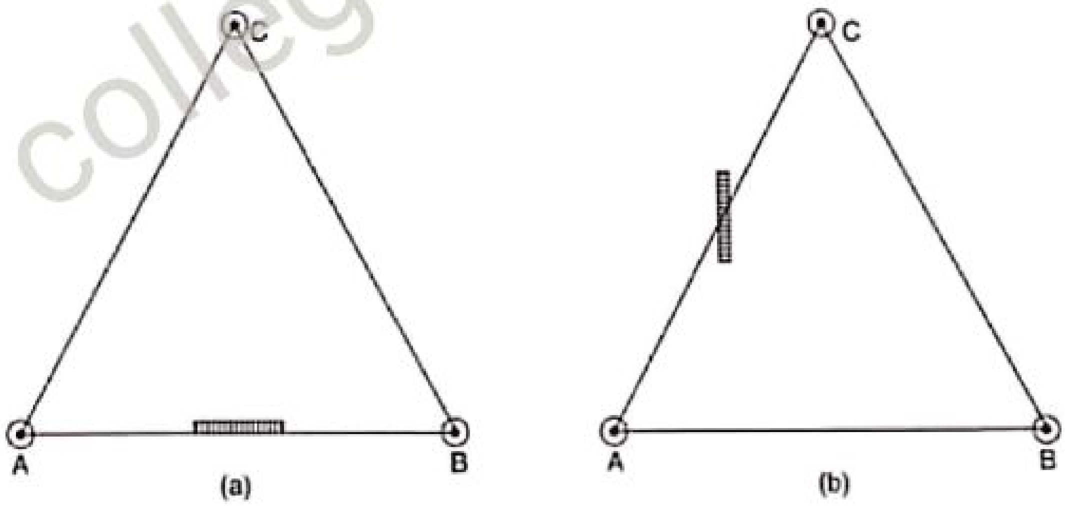


Fig. 15.5

(*ii*) Turn the two screws inward or outward equally and simultaneously till bubble is centred.

(*iii*) Turn the telescope by 90° so that it lies over the third screw [Fig. 15.4 (*b*)] and level the instrument by operating the third screw.

(*iv*) Turn back the telescope to its original position [Fig. 15.5 (*a*)] and check the bubble. Repeat steps (*ii*) to (*iv*) till bubble is centred for both positions of the telescope.

(*v*) Rotate the instrument by 180°. Check the levelling.

15.7.3 Focussing

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

(*i*) **Focussing the eyepiece:** For this, hold a sheet of white paper in front of telescope and rotate eyepiece in or out till the cross hairs are seen sharp and distinct.

(*ii*) **Focussing the objective:** For this telescope is directed towards the staff and the focussing screw is turned till the reading appears clear and sharp.

15.8 TYPES OF DIRECT LEVELLING

The following are the different types of direct levelling:

(*i*) Simple levelling
(*ii*) Differential levelling
(*iii*) Fly levelling
(*iv*) Profile levelling
(*v*) Cross sectioning and
(*vi*) Reciprocal levelling.

15.8.1 Simple Levelling

It is the method used for finding difference between the levels of two nearby points. Figure 15.6 shows one such case in which level of A is assumed, say 200.00 m. RL of B is required.

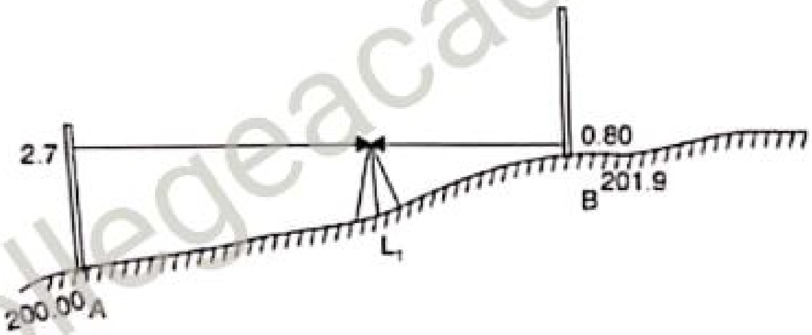


Fig. 15.6

RL of A = 200.00 m

Back sight on A = 2.7 m.

$\therefore$ Plane of collimation for setting at station = 200 + 2.7

= 202.7 m

Fore sight on B = 0.80 m

$\therefore$ RL of B = 202.7 – 0.80

= 201.9 m

It may be noted that the instrument station L_1 need not be along the line AB (in plan) and RL of L_1 do not appear in the calculations.

15.8.2 Differential Levelling

If the distance between two points A and B is large, it may not be possible to take the readings on A and B from a single setting.

In such situation differential levelling is used. In differential levelling the instrument is set at more than one position, each shifting facilitated by a change point. Figure 15.7 shows a scheme of such setting.

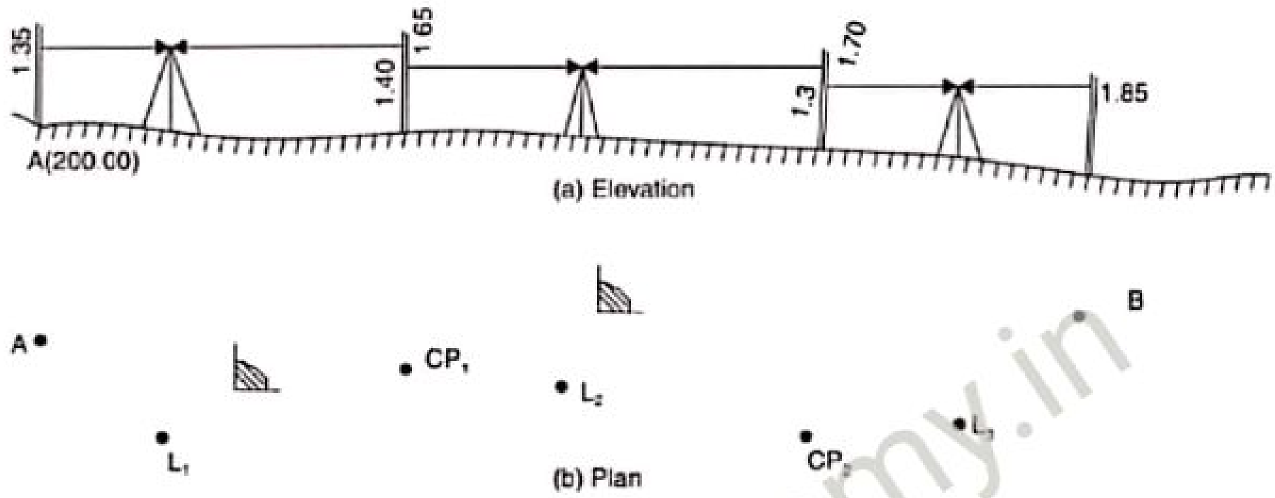


Fig. 15.7

RL of A is 200.00 m. Instrument is set up at L_1 and back sight on A is 1.35 m. The fore sight on change point CP_1 is 1.65 m. Then instrument is shifted to L_2 and back sight on CP_1 is 1.40 m. Fore sight on CP_2 is 1.70 m. After this instrument is shifted to L_3 and back sight on CP_2 is 1.3 m. The work ended with a fore sight of 1.85 m on B. The RL of B is to be found.

RL of A = 200.00 m

Back sight on A = 1.35 m

$\therefore$ Plane of collimation at L_1 = 200 + 1.35 = 201.35 m

Fore sight on CP_1 = 1.65 m

$\therefore$ RL of CP_1 = 201.35 – 1.65 = 199.70 m

Back sight to CP_1 from L_2 = 1.40

$\therefore$ Plane of collimation at L_2 = 199.70 + 1.40 = 201.10 m

Fore sight to CP_2 = 1.70 m

$\therefore$ RL of CP_2 = 201.10 – 1.70 = 199.40 m

Back sight to CP_2 from L_3 = 1.30 m

$\therefore$ Plane of collimation at L_3 = 199.40 + 1.30 = 200.70 m

Fore sight to B = 1.85 m

$\therefore$ **RL of B = 200.70 – 1.85 = 198.85 m Ans.**

If there are intermediate sight to the points E_1 and E_2, the RL of those points may be obtained by subtracting readings for E_1 and E_2 from the corresponding plane of collimations.

Booking and Reducing the Levels

The booking of readings and reducing the levels can be carried out systematically in the tabular form. There are two such methods:

(*i*) Plane of collimation method (*ii*) Rise and fall method.

For the above problem, with intermediate sights to E_1 = 0.80 m and E_2 = 0.70 m is illustrated below by the both methods.

Table 15.1. Booking and reducing levels by plane of collimation method

Station	BS	Reading IS	FS	Plane of Collimation	RL	Remarks
A	1.35			201.35	200.00	Benchmark
E_1		0.80			200.55	Plinth of building
CP_1	1.40		1.65	201.10	199.70	CP_1
E_2		0.70			200.40	Plinth of building
CP_2	1.30		1.70	200.70	199.40	CP_2
B			1.85		198.85	B
Check Σ BS = 4.05 Σ BS – Σ FS = – 1.15 (Fall)			Σ FS = 5.20		Diff in RL of A and B = 198.85 – 200.00 = –1.15	

In this method note the following:

1. Plane of collimation for first setting
   = RL of BM + BS
2. Subtract IS from plane of collimation to get RL of intermediate station and subtract FS from plane of collimation to get RL of change point.
3. Add back sight to RL of change point to get new plane of collimation.
4. Check: Σ BS – Σ FS = RL of Last point – RL of first point.

If it is –ve, it is fall and if +ve it is rise.

Table 15.2. Booking and reducing level by rise and fall method

Station	BS	IS	FS	Rise	Fall	RL	Remarks
A	1.35					200.00	Benchmark
		0.80		0.55		200.55	E_1
	1.40		1.65		0.85	199.70	CP_1
		0.70		0.70		200.40	E_2
	1.30		1.70		1.00	199.40	CP_2
			1.85		0.55	198.85	B
	Σ BS = 4.05		Σ FS = 5.20	Σ Rise = 1.25	Σ Fall = 2.40		
Check: Σ BS – Σ FS = –1.15			Σ Rise – Σ Fall = –1.15			RL of last point – RL of first point = –1.15	

Note the following:

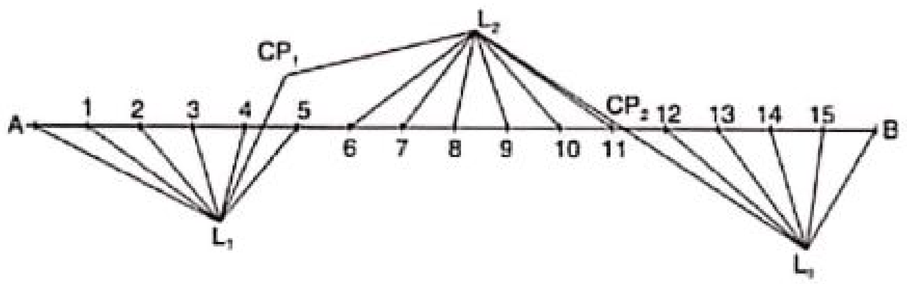
1. From A to E_1, difference = 1.35 – 0.80 = 0.55, rise
2. From E_1 to CP_1, difference = 0.80 – 1.65 = – 0.85, fall
3. From CP_1 to E_2, difference = 1.40 – 0.70 = 0.70, rise
4. From E_2 to CP_2, difference = 0.70 – 1.70 = –1.00, fall
5. From CP_2 to B, difference = 1.30 – 1.85 = – 0.55, fall.

15.8.3 Fly Levelling

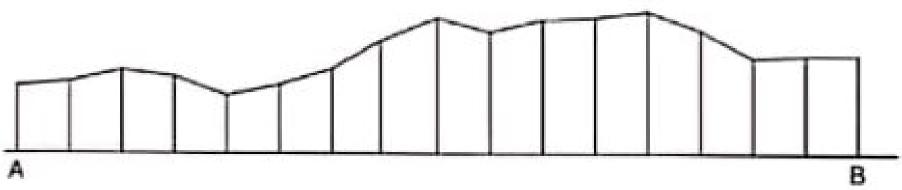
If the work site is away from the benchmark, surveyor starts the work with a back sight on the benchmark by setting instrument at a convenient point. Then he proceeds towards the site by taking fore sights and back sights on a number of change points till he establishes a temporary benchmark in the site. Rest of the levelling work is carried out in the site. At the end of the work again levelling is carried out by taking a set of convenient change points till the bench work is reached. This type of levelling in which only back sight and fore sights are taken, is called fly levelling, the purpose being to connect a benchmark with a temporary benchmark or vice versa. Thus the difference between fly levelling and differential levelling is only in the purpose of levelling.

15.8.4 Profile Levelling

This type of levelling is known as longitudinal sectioning. In high way, railway, canal or sewage line projects profile of the ground along selected routes are required. In such cases, along the route, at regular interval readings are taken and RL of various points are found. Then the section of the route is drawn to get the profile. Figure 15.8 (*a*) shows the plan view of the scheme of levelling and Fig. 15.8 (*b*) shows the profile of the route. For drawing profile of the route, vertical scale is usually larger compared to scale for horizontal distances. It gives clear picture of the profile of the route.



(a)



(b)

Fig. 15.8

The typical page of field book for this work will be having an additional column to note distances as shown in Table 15.3.

Table 15.3. Page of level book for profile levelling

Station	*Distance*	*BS*	*IS*	*FS*	*Plane of Collimation*	*RL*	*Remark*

15.8.5 Cross-Sectioning

In many engineering projects, not only longitudinal profile but also the profile of cross-sections at regular intervals are required. These profiles help in calculating the earth works involved in the projects. Figure 15.9 shows the scheme of such work in which longitudinal profile is found by taking readings at 20 m interval along chain lines AB, BC and readings are taken at an interval of 3 m on either side. The distances on the cross-sections are treated as left or right of the lines as they are found while facing the forward station of survey. The cross-sectional length depends upon the nature of the project.

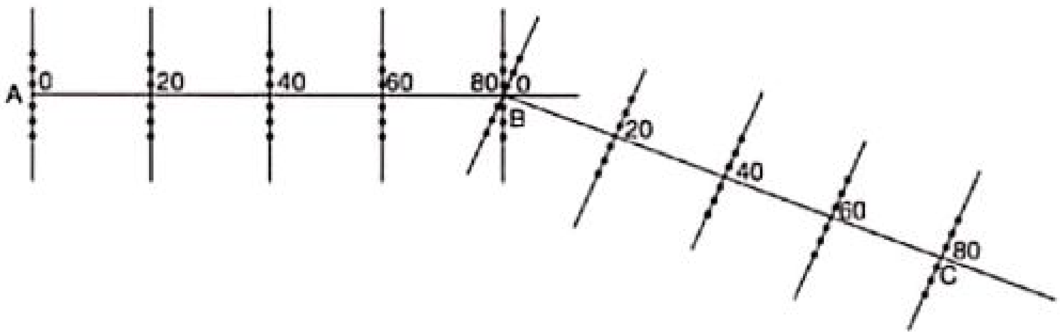


Fig. 15.9

Table 15.4 shows a page of level book required for this type of levelling.

Table 15.4. A typical page book for cross-section levelling

Station	*Distance in m*			*Readings*			*Plane of Collimation*	*RL*	*Remarks*
	L	*C*	*R*	*BS*	*IS*	*FS*			
BM									
		0							
L_1	3								
L_2	6								
L_3	9								
R_1			3						
R_2			6						

R_3			9						
		20							
L_1	3								
L_2	6								
L_3	9								
R_1			3						
R_2			6						
R_3			9						
									Checked.

15.8.6 Reciprocal Levelling

In levelling, it is better to keep distance of back sight and fore sight equal. By doing so the following errors are eliminated:

(*i*) Error due to non-parallelism of line of collimation and axis of bubble tube.

(*ii*) Errors due to curvature and refraction.

But in levelling across obstacles like river and ravine, it is not possible to maintain equal distances for fore sight and back sight. In such situations reciprocal levelling as described below is used:

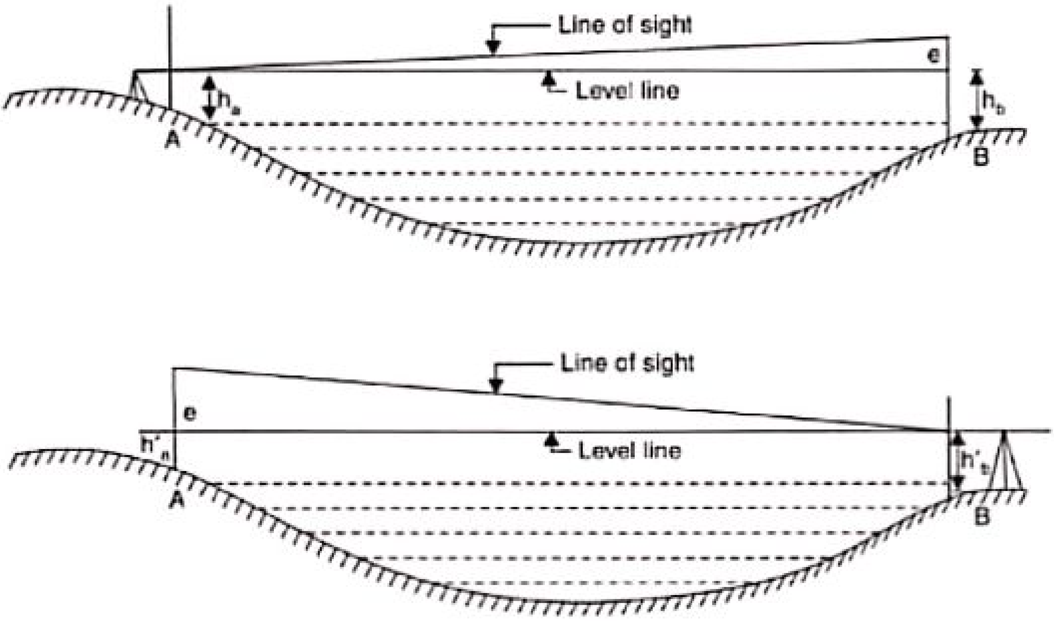


Fig. 15.10

(*i*) Referring to Fig. 15.10 (*a*).

Since A is very close, error in reading at A is negligible. Hence h_a is correct reading.

Let error in h_b be 'e'.

Then correct reading at B = $h_b - e$

$\therefore$ Difference in elevations = $H = h_a - (h_b - e)$ ... (*i*)

(*ii*) Referring to Fig. 15.10 (*b*), since B is very close to instrument, h_b' can be taken as correct reading.

Correct reading at A = $h_a' - e$

Difference in elevations $H = (h_a' - e) - h_b'$ ... (*ii*)

From equations (*i*) and (*ii*) we get,

$$2H = h_a - (h_b - e) + (h_a' - e) - h_b'$$

$$= (h_a + h_a') - (h_b + h_b')$$

$$\therefore \quad H = \frac{(h_a + h_a') - (h_b + h_b')}{2} \qquad \text{... (15.1)}$$

Thus, the true difference in the elevations of the two points is equal to the mean of the two apparent differences in the elevations.

■ **Example 15.1:** *The following staff readings were observed successively with a level. The instrument has been shifted after the second and fifth reading: 0.675, 1.230, 0.750, 2.565, 2.225, 1.935, 1.835, 3.220. The first reading was with staff held on benchmark of RL 100.000 m. Enter the readings in a page of level book and calculate the RL of all points. Apply arithmetic checks. Use plane of collimation method.*

Solution: It is carried out as shown in Table 15.5.

Table 15.5

Station	*BS*	*IS*	*FS*	*Plane of Collimation*	*RL*	*Remarks*
	0.675			100.675	100.00	BM of RL = 100.00
	0.750		1.230	100.195	99.445	CP_1
		2.565			97.630	
	1.935		2.225	99.905	97.970	CP_2
		1.835			98.070	
			3.220		96.685	Last Point
	Σ BS = 3.360		Σ FS = 6.675		Last RL – first RL	
	Σ BS – Σ FS = – 3.315 (Fall)				= – 3.315 (Fall)	Checked

■ **Example 15.2:** *Reduce the levels in example 15.1 by rise and fall method.*

Solution: It is carried out as shown in Table 15.6 below:

Modern Tools of Surveying

Theodolite is an instrument which replaced compass and level. It can measure both horizontal and vertical angles. If telescope is kept at zero reading of vertical angle it serves as an ordinary level. In this modern era of electronics equipments have come up to measure the distances to relieve surveyor from chaining long lines. Total station is another modern survey equipment which combines the features of theodolite and electromagnetic distance measurement (EDM) instruments. Global positioning system is an instrument, which establishes global position of the station making use at least 4 satellite stations. In this chapter all these modern tools of surveying are briefly explained.

16.1 THEODOLITE

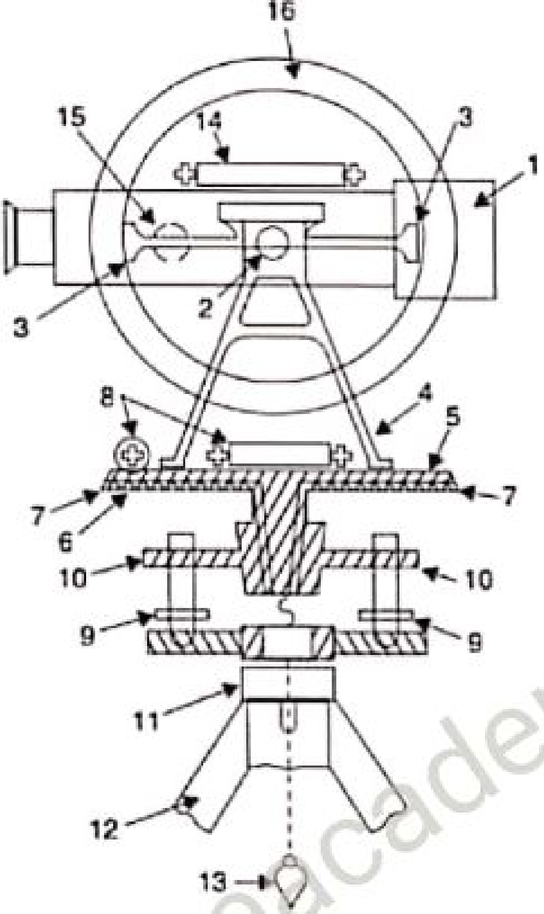
It is a commonly used instrument for measuring horizontal and vertical angles. It is used for prolonging a line, levelling and even for measuring the distances indirectly (techeometry). Using verniers angles can be read accurately up to 20". Precise theodolites are available which can read angles up to even 1" accuracy. They use optical principle for more accurate instruments. Now a days electronic theodolites are also available which display the angles.

In this article construction and use of vernier theodolite is explained.

16.1.1 Parts of a Vernier Theodolite

Figure 16.1 shows a sectional view of a typical vernier theodolite and plate 16.1 shows photograph of such theodolite. Main parts of such a theodolite are:

1. **Telescope:** A telescope is mounted on a horizontal axis (trunnian axis) hence it can rotate in vertical plane. Its length varies from 100 mm 175 mm and its diameter is 38 mm at objective end. Its functions is to provide a line of sight.



1. Telescope
2. Trunnian axis
3. Vernier frame
4. Standards or A-Frame
5. Upper plate
6. Lower plate
7. Vernier
8. Plate level
9. Foot crews
10. Levelling head
11. Tripod head
12. Tripod
13. Plumb bob
14. Altitude level
15. Focussing screw
16. Vertical circle

Fig. 16.1. Sectional view of a transit theodolite

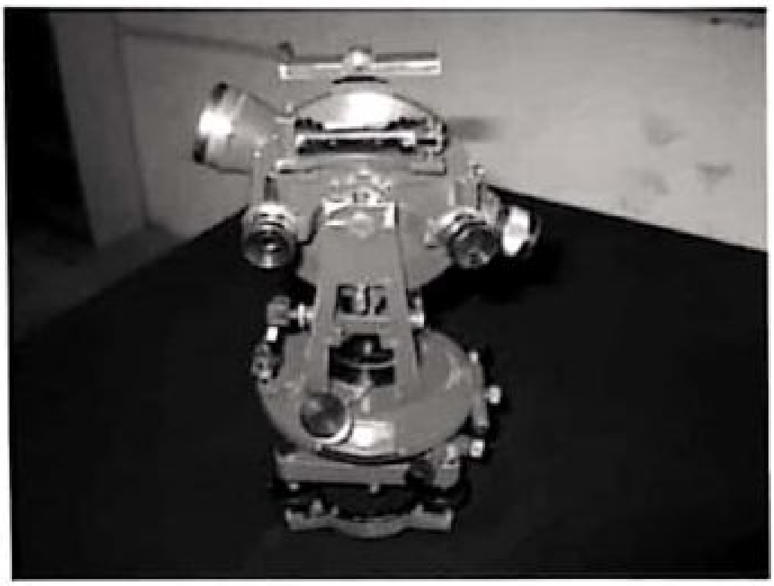


Plate 16.1 Theodolite

2. **Vertical Circle:** A vertical circle graduated up to an accuracy of 20′ is rigidly connected to the telescope and hence moves with it when the telescope is rotated in vertical plane.

The graduations are in quadrantal system, 0-0 line being horizontal (Ref. Fig. 16.2).

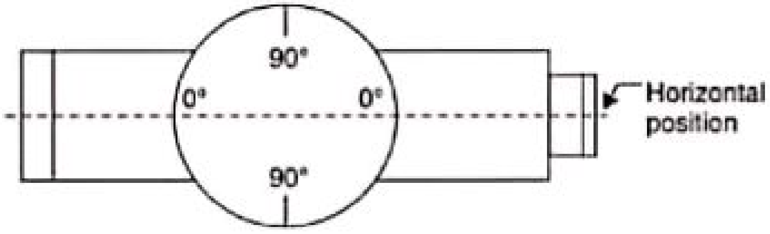


Fig. 16.2

3. **Vernier Frame:** It is a T-shaped frame (Fig. 16.3) consisting of a vertical arm and a horizontal arm. With the help of the climping screws the vertical frame and hence the telescope can be clamped at desired angle. Vertical frame is also known as **T-frame** or **index frame.**

The vernier arm is known as index arm. At the ends it carries verniers C and D so as to read graduations on vertical circle. They are provided with glass magnifiers. Altitude bubble tube is fitted over the horizontal arm.

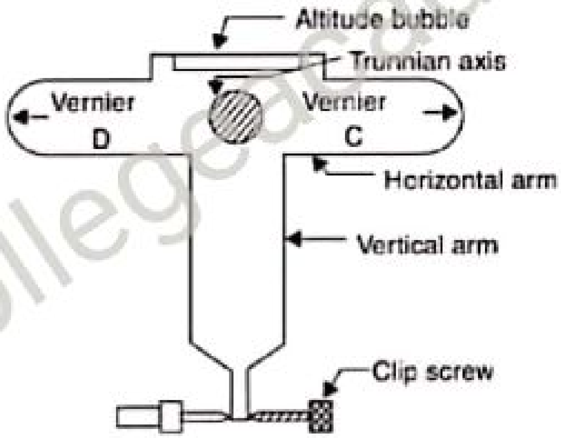


Fig. 16.3

4. **Standards or A-Frame:** The frames supporting telescope are in the form of English letter 'A'. This frame allows telescope to rotate on its trunnian axis in vertical frame. The T-frame and the clamps are also fixed to this frame.

5. **Upper Plate [Fig. 16.4]:** Upper plate supports standards on its top surface. On lower side it is attached to a inner spindle which rotates in the outer spindle of lower plate. Using upper clamp, upper plate can be clamped to lower plate. Using tangent screws, it is possible to give slight relative motion between the two plates, even after clamping. Two diametrically opposite verniers A and B fixed to upper plate help in reading horizontal circle graduations. They are provided with magnifying glasses.

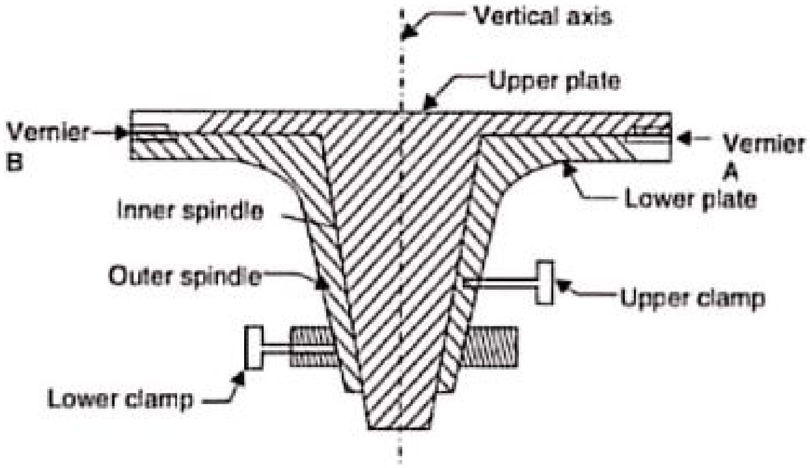


Fig. 16.4

6. **Lower Plate:** The lower plate, attached to the outer spindle carries a graduated circle at its bevelled edge. Graduations are up to an accuracy of 20′. It can be clamped at any desired position using lower clamps. If upper clamp is locked and the lower one is loosened the two plates rotate together. If the upper clamp is loosened and lower clamp locked, upper plate alone rotates. This mechanism is utilised in measuring horizontal angle.
7. **Plate Level:** One or two plate level tubes are mounted on the upper plate. If the two level tubes are provided they will be at right angles to each other one of them being parallel to trunnion axis. These levels help in making the vertical axis of the instrument truely vertical.
8. **Levelling Head:** It consists of two parallel triangular plates known as ***tribratch plates***. The upper tribratch plate is provided with three levelling screws—each one carried by a arm of tribratch plate. By operating screws the levelling of upper plate and hence telescope can be ensured. The lower tribratch can be fitted into a tripod head.
9. **Tripod:** Theodolite is always used by mounting it on a tripod. The legs of tripod may be solid or framed. At the lower end the legs are provided with steel shoes to get good grip with the ground. The top of tripod is provided with external screw to which the lower tribratch plate can be screwed. When not in use tripod head may be protected with a steel cap, provided for this purpose.
10. **Plumb Bob:** A hook is provided at the middle of lower tribratch plate from which a plumb bob can be suspended. It facilitates exact centering of the theodolite on a station.
11. **Shifting Head:** It is provided below the lower plate. In this, one plate slides over another over a small area of about 10 mm radius. The two plates can be tightened in the desired position. It facilitates exact centering of the instruments.
12. **Magnetic Compass:** In some theodolites a magnetic compass is fixed on one of the strands. It is useful if readings are to be recorded with magnetic north as meridian.

16.1.2 Use of Theodolite

Theodolite is used for measuring horizontal and vertical angles. For this the theodolite should be centered on the desired station point, levelled and telescope is focussed. This process of centering, levelling and focussing is called temporary adjustment of the instrument.

Measurement of Horizontal Angle

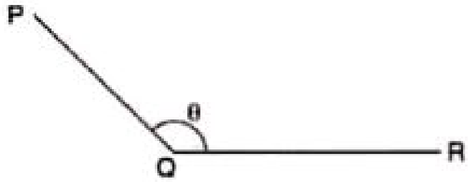


Fig. 16.5

The procedure is explained for measuring horizontal angle θ = PQR at station Q (Ref. Fig. 16.5)

1. Set the theodolite at Q with vertical circle to the left of the line of sight and complete all temporary adjustments.
2. Release both upper and lower clamps and turn upper plate to get 0° on the main scale. Then clamp main screw and using tangent screw get exactly zero reading. At this stage vernier A reads 0° and vernier B reads 180°.
3. Through telescope take line of sight to signal at P and lock the lower clamp. Use tangent screw for exact bisection.
4. Release the upper clamp and swing telescope to bisect signal at R. Lock upper clamp and use tangent screen to get exact bisection of R.
5. Read verniers A and B. The reading of vernier A gives desired angle PQR directly, while 180° is to be subtracted from the reading of vernier B to get the angle PQR.
6. Transit (move by 180° in vertical plane) the telescope to make vertical circle to the right of telescope. Repeat steps 2 to 5 to get two more values for the angle.
7. The average of 4 values found for θ, give the horizontal angle. Two values obtained with face left and two obtained with face right position of vertical circle are called one set of readings.
8. If more precision is required the angle may be measured **repeatedly.** *i.e.*, after step 5, release lower clamp, sight signal at P, then lock lower clamp, release upper clamp and swing the telescope to signal at Q. The reading of vernier A doubles. The angle measured by vernier B is also doubled. Any number of repetitions may be made and average taken. Similar readings are then taken with face right also. Finally average angle is found and is taken as desired angle 'Q'. This is called **method of repetition.**
9. There is another method of getting precise horizontal angles. It is called **method of reiteration.** If a number of angles are to be measured from a station this technique is used (Fig. 16.6). With zero reading of vernier A signal at P is sighted exactly and lower clamp and its tangent screw are locked. Then θ_1 is measured by sighting Q and noted. Then θ_2, θ_3 and θ_4 are measured by unlocking upper clamp and bisecting signals at R, S and P. The angles are calculated and checked to see that sum is 360°. In each case both verniers are read and similar process is carried out by changing the face (face left and face right).

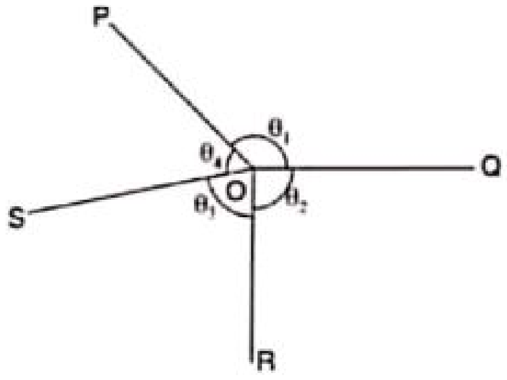


Fig. 16.6

Measurement of Vertical Angle

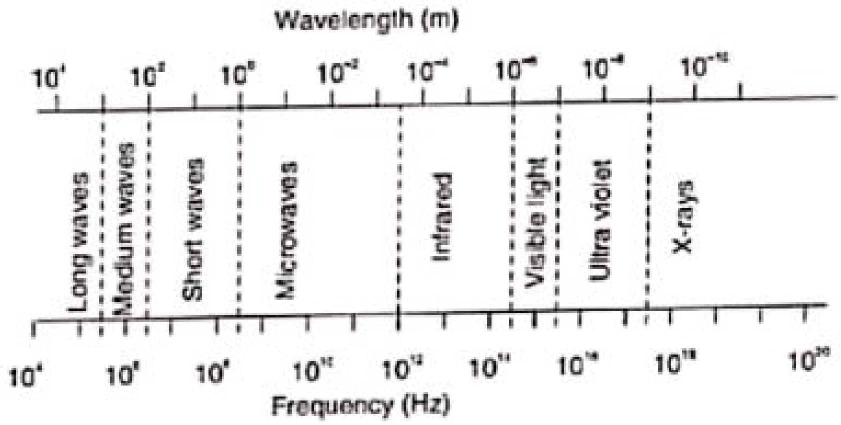
Horizontal sight is taken as zero vertical angle. Angle of elevations are noted as +ve angles and angle of depression as –ve angles.

To measure vertical angle the following procedure may be followed:

1. Complete all temporary adjustment at the required station.
2. Take up levelling of the instrument with respect to altitude level provided on the A – frame. This levelling process is similar to that used for levelling dumpy level *i.e.*, first altitude level is kept parallel to any two levelling screws and operating those two screws bubble is brought to centre. Then by rotating telescope, level tube is brought at right angles to the original position and is levelled with the third screw. The procedure is repeated till bubble is centred in both positions.
3. Then loosen the vertical circle clamp, bisect P and lock the clamp. Read verniers C and D to get vertical angle. Take the average as the actual vertical angle.

16.2 ELECTROMAGNETIC DISTANCE MEASURING INSTRUMENTS

Sun light or artificially generated electromagnetic waves consists of waves of different lengths. The spectrum of an electromagnetic wave is as shown below:



Among these waves microwaves, infrared waves and visible light waves are useful for the distance measurement. In EDM instruments these waves are generated, modulated and then propagated. They are reflected at the point up to which distance is to be measured from the instrument station and again received by the instrument. The time taken by the wave to travel this $2x$ distance may be measured and knowing the velocity of wave, the distance may be calculated. However time is too short, measuring the time taken is difficult. The improved techniques use phase difference method in which the number of completed wave and incomplete wave is measured. Knowing the length of wave, distances are calculated. Built up microprocessors provided in the instrument calculate the distances and display it by liquid crystal display (LCD).

EDM instruments may be classified into the following three types:

1. Micro wave instruments
2. Infrared wave instruments
3. Light wave instruments.

16.2.1 Micro Wave Instruments

These instruments make use of micro waves. Such instruments were invented as early as 1950 in South Africa by Dr. T.L. Wadley and named them as Tellurometers. The instrument needs only 12 to 24 V batteries. Hence they are light and highly portable. Tellurometers can be used in day as well as in night. The range of these instrument is up to 100 km. It consists of two identical units. One unit is used as master unit and the other as remote unit. Just by pressing a button, a master unit can be converted into a remote unit and a remote unit into a master unit. It needs two skilled persons to operate. A speech facility is provided to each operator to interact during measurements.

16.2.2 Infrared Wave Instruments

In these instrument amplitude modulated infrared waves are used. Prism reflectors are used at the end of line to be measured. These instruments are light and economical and can be mounted on theodolite. With these instruments accuracy achieved is ± 10 mm. The range of these instruments is up to 3 km. These instruments are useful for most of the civil engineering works. These instruments are available in the trade names DISTOMAT DI 1000 and DISTOMAT DI 55.

16.2.3 Light Wave Instruments

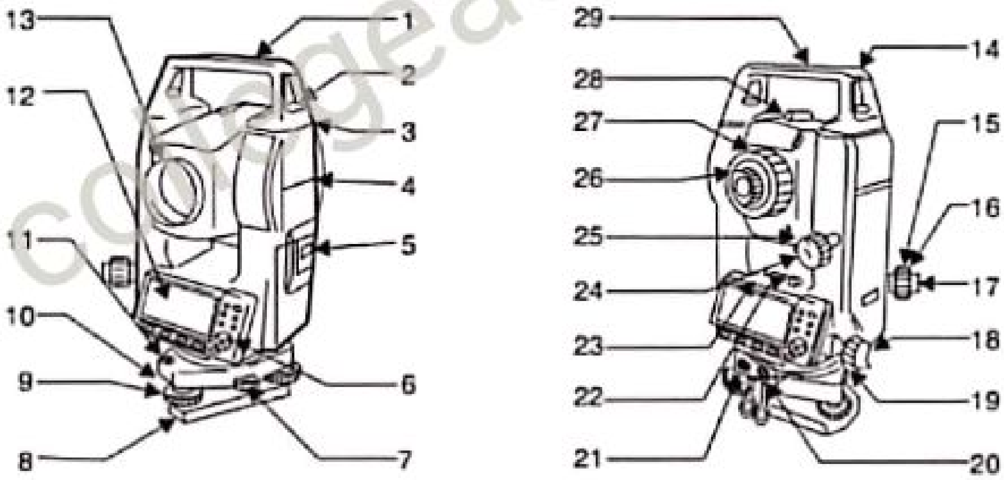
These instruments rely on propagation of modulated light waves. This type of instrument was first developed in Sweden and was namad as Geodimeter. During night its range is up to 2.5 km while in day its range is up to 3 km. Accuracy of these instruments varies from 0.5 mm to 5 mm/km distance. These instruments are also very useful for civil engineering projects.

The advantage of using EDM instruments is the speed and accuracy in measurement. Several obstacles to chaining are automatically overcome when these instruments are used.

It is combination of EDM instrument and electronic theodolite. It is also integrated with microprocessor, electronic data collector and storage system. The instrument can be used to measure horizontal and vertical angles as well as sloping distance of object to the instrument. Microprocessor unit processes the data collected to compute:

1. average of multiple angles measured
2. average of multiple distance measured
3. horizontal distance
4. distance between any two points
5. elevation of objects and
6. all the three coordinates of the observed points.

Data collected and processed may be down-loaded to computers for further processing. Total station is a compact instrument and weighs 50 to 55 N. A person can easily carry it to the field. Total stations with different accuracies, in angle measurement and different range of measurements are available in the market. Figure 16.7 shows one such instrument manufactured by SOKKIA Co. Ltd. Tokyo, Japan.



1. Handle
2. Handle securing screw
3. Data input/output terminal (Remove handle to view)
4. Instrument height mark
5. Battery cover
6. Operation panel
7. Tribrach clamp (SET300*S*/500*S*/600S: Shifting clamp)
8. Base plate
9. Levelling foot screw
10. Circular level adjusting screws
11. Circular level
12. Display
13. Objective lens
14. Tubular compass slot
15. Optical plummet focussing ring
16. Optical plummet reticle cover
17. Optical plummet eyepiece
18. Horizontal clamp
19. Horizontal fine motion screw
20. Data input/output connector (Besides the operation panel on SET600/600*S*)
21. External power source connector (Not included on SET600/600*S*)
22. Plate level
23. Plate level adjusting screw
24. Vertical clamp
25. Vertical fine motion screw
26. Telescope eyepiece
27. Telescope focussing ring
28. Peep sight
29. Instrument center mark

Fig. 16.7. Parts of total station

Brief Description of Important Operations

Distance Measurement: Electronic distance measuring (EDM) instrument is a major part of total station. Its range varies from 2.8 km to 4.2 km. The accuracy of measurement varies from 5 mm to 10 mm per km measurement. They are used with automatic target recognisers. The distance measured is always sloping distance from instrument to the object.

Angle Measurements: The electronic theodolite part of total station is used for measuring vertical and horizontal angle. For measurement of horizontal angles any convenient direction may be taken as reference direction. For vertical angle measurement vertical upward (zenith) direction is taken as reference direction. The accuracy of angle measurement varies from 2 to 6 seconds.

Data Processing : This instrument is provided with an inbuilt microprocessor. The microprocessor averages multiple observations. With the help of slope distance and vertical and horizontal angles measured, when height of axis of instrument and targets are supplied, the microprocessor computes the horizontal distance and X, Y, Z coordinates. The processor is capable of applying temperature and pressure corrections to the measurements, if atmospheric temperature and pressures are supplied.

Display: Electronic display unit is capable of displaying various values when respective keys are pressed. The system is capable of displaying horizontal distance, vertical distance, horizontal and vertical angles, difference in elevations of two observed points and all the three coordinates of the observed points.

Electronic Book: Each point data can be stored in an electronic note book (like compact disc). The capacity of electronic note book varies from 2000 points to 4000 points data. Surveyor can unload the data stored in note book to computer and reuse the note book.

Use of Total Station

The instrument is mounted on a tripod and is levelled by operating levelling screws. Within a small range instrument is capable of adjusting itself to the level position. Then vertical and horizontal reference directions are indexed using onboard keys. It is possible to set required units for distance, temperature and pressure (FPS or SI). Surveyor can select measurement mode like fine, coarse, single or repeated. When target is sighted, horizontal and vertical angles as well as sloping distances are measured and by pressing appropriate keys they are recorded along with point number. Heights of instrument and targets can be keyed in after measuring them with tapes. Then processor computes various information about the point and displays on screen. This information is also stored in the electronic note book. At the end of the day or whenever electronic note book is full, the information stored is downloaded to computers.

The point data downloaded to the computer can be used for further processing. There are software like auto civil and auto plotter clubbed with autocad which can be used for plotting contours at any specified interval and for plotting cross-section along any specified line.

Advantages of Using Total Stations

The following are some of the major advantages of using total station over the conventional surveying instruments:

1. Field work is carried out very fast.
2. Accuracy of measurement is high.
3. Manual errors involved in reading and recording are eliminated.
4. Calculation of coordinates is very fast and accurate. Even corrections for temperature and pressure are automatically made.
5. Computers can be employed for map making and plotting contour and cross-sections. Contour intervals and scales can be changed in no time.

However, surveyor should check the working condition of the instruments before using. For this standard points may be located near survey office and before taking out instrument for field work, its working is checked by observing those standard points from the specified instrument station.

16.4 GLOBAL POSITIONING SYSTEM

The station points used in surveying are to be identified before executing any project: For this purpose, surveyors used permanent objects as reference points and made reference sketches of station points. Navigators used sun and stars as references. Sometimes when the project is taken up the so called parmanent object (like building corner) may not exist when the execution of project work is taken up. For navigations weather conditions may obstruct the observations. Now a days this problem is over-come by using an instrument called Global Positioning System (GPS). This was developed by United States defence department and was called as Navigational System with Time and Ranging Global Positioning System (NAVSTAR) or which is now simply known as GPS.

There are 24 geostationary satellites positioned around the earth by US air force. These satellites are used as reference points to locate any point on the earth. These satellites are at an altitude of 20200 km above the earth. The 24 satellites are positioned such that from any point on the earth a minimum of 4 satellites are visible.

A user needs only GPS receiver. The receiver measures the travel time of the signals from satellites and calculate position (latitude and longitude) and the elevation altitude of the station with reference to a selected datum. The advantages of using GPS are:

1. Can be used in day as well as in night.
2. Intervisibility of the two stations on the earth is not a requirement.
3. Time required to establish the position of a point is much less.
4. Man power required is less.
5. Accuracy is high. Most expensive GPS provide accuracies within 10 mm.

Uses of GPS

GPS is very useful in

1. Marine navigation
2. Airborne aviation

3. Surveying of land.
4. Sports such as yatching, hiking.
5. The sophistication of GPS has improved so much that drivers of automobiles can get directions to their destinations easily on the screen.