1.17 Plane Tabling

Plane Table is called the father of "Mapping". It is used to prepare various maps in the field. It is a graphical method, where observations, mapping and contouring, proceed simultaneously. It is a time-consuming and laborious process to create a map, but is a more accurate approach. The plane table consists of a wooden drawing board with arrangement of fixing it on a tripod. With the availability of Total Station, GPS, satellite images and LiDAR data, Plane tabling methods of surveying are almost obsolete now-a-days.

1.17.1 Advantages and disadvantages of plane table surveying

Advantages

(a) The map is prepared in the field; therefore, the office work is minimal.
(b) The observations and plotting are done simultaneously, and the surveyor can see the terrain before him/her, so chances of losing the details are rare.
(c) Errors in plotting the details on plane table can be checked by drawing the check lines using several methods.
(d) The angles and distance measurements can be obtained graphically, and hence there is no need to carry out measurements in the field.
(e) Many far-off objects/details can be plotted accurately using intersection method to prepare the map in shortest time.
(f) It is advantageous in magnetic areas where compass survey is not reliable.

Disadvantages

(a) Plane tabling work is dependent on weather conditions (e.g., rains, high winds).
(b) The plane table is not very much suitable in a dense forest area or urban area.
(c) If survey map is to be replotted at some different scale, entire work has to be re-done.
(d) Its accessories are heavy to carry in the field from one location to another.
(e) The paper maps are subject to shrinkage or expansion while working in the field for long time.
(f) It is laborious and time-consuming to prepare map of a large area
(g) It requires large manpower for doing various activities from observations to plotting.

1.17.2 Methods of plane tabling

There are three steps to work with plane table; (i) Levelling the plane table, (ii) Centering the plane table, and (iii) Orienting the plane table. Levelling is done using the sprit bubble tube. Centering is done with the help of plumb bob. Orientation is done either with a magnetic compass or with a back ray method.

The equipment required for plane table surveying are shown in Figure 1.38:

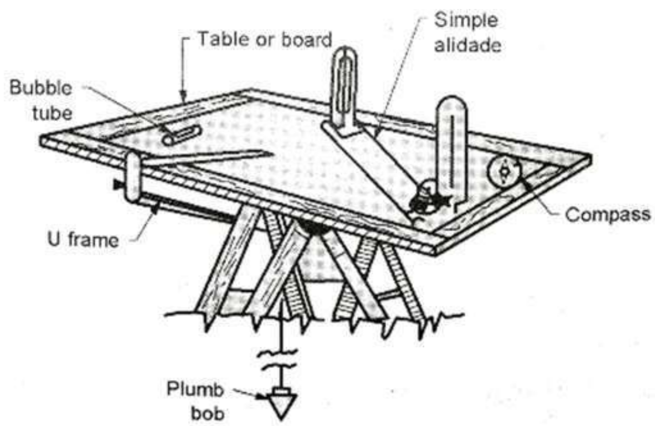

Figure 1.38 Accessories of plane table survey

There are four methods of plane table surveying:
(i) Radiation,
(ii) Intersection,
(iii) Traversing and
(iv) Resection.

The radiation method uses of a distance and a direction to locate the object on the map. The plane table is set up at a station and various points in the vicinity are located on the map by measuring the distances to the different stations using a tape (or tacheometry), and subsequently radiating (drawing) the rays from the instrument station to those points which are to be located on the map. The intersection method is used extensively to locate an object by two directions from two stations at the end of a base line of known length. The method is widely used for plotting the far-off details on the maps. From the first station of a base line, directions are drawn to the various stations, and the same is done by shifting the plane table at other end of base line. The intersections of these two directions of the same object will give the location on the map. The traversing method is used in areas where visibility is obstructed by high-rise building/forest or topography. Plane table occupies each traverse station and details are plotted either by radiation method or intersection method. The resection method is used to accurately locate the position of ground station (unknown point) on the map, occupied by plane table. It is done by drawing the rays from two or three already known and plotted point on the map. Once the position of ground station is plotted on the plane table, any of the method for plotting the details could be used. For resection methods, two-point problem or three-point problem may be used.

Now-a-days, plane tabling is considered as obsolete, and therefore is not carried out in the field. The field data is directly collected and stored using either Digital Levels, GPS or Total Station, and mapping is carried out using the capabilities of the software in a computer. Alternatively, photogrammetry and remote sensing images are used to create various types of maps required in various civil engineering projects.

1.18 Theodolite Surveys

Theodolite is the most versatile instrument used in survey work. It is a multi-purpose equipment which can be used for measuring the angles, prolongation of a straight line, determination of levels and determination of distances. In general, it is used for measuring the vertical and horizontal angles of given objects. Inception of a theodolite was done basically for providing the horizontal and vertical controls in survey work, i.e., the coordinates. For mapping a larger area, locations of ground controls are essentially required which can be determined using angles and other observation.

1.18.1 Various types of theodolites

There are various models of theodolites, such as:

(a) Vernier theodolite
(b) Optical theodolite
(c) Electronic theodolite (or Total Station)

Vernier theodolite is a commonly used instrument for measuring the horizontal and vertical angles. It can also be used for prolonging a line, levelling work, determining the indirect distances (through Techeometry), determining the elevations of distance objects (Trigonometrical levelling). In a vernier theodolite, readings for vertical and horizontal angles can be read through main scale and vernier scale. It has two verniers for horizontal readings and another two verniers for vertical readings, and using these verniers, both the angles can be read accurately up to 20".

Precise theodolites use optical principle for more accurate results. In optical theodolites, vertical and horizontal circles are made of glass, and the lowest readings are read through a micrometer. Least count ranges from 0.2 to 10 seconds. Now-a-days electronic theodolites (or Total Stations) are used which read and display the angles and other measurements. The electronic theodolite has an opto-electronic system. The encoders count the pulse of the movement and displays the measurements digitally, with the least count from 0.1" to 5". The electronic device of digital display provides less fatigue with less chances of reading errors. Details of Total Stations are given in Module 3.

1.18.2 Various parts of a vernier theodolite

Figure 1.39 shows a sectional view of a typical vernier theodolite. The main parts of a vernier theodolite are:

(a)Telescope: A telescope, which is mounted on a horizontal axis (trunnion axis), can rotate in the vertical plane. Its function is to provide a line of sight for measuring angles.
(b) Upper plate and Lower plate: There are two horizontal circular plates in vernier theodolite (Figure 1.39). On lower side, the upper plate is attached to an inner spindle which rotates in the outer spindle of lower plate. Using upper clamping screw, upper plate can be clamped to lower plate. Using slow motion tangent screw, slight relative motion between the two plates can be given, even after clamping the plate. Two diametrically opposite verniers, A and B, are fixed to upper plate. These are provided with magnifying glasses, and used in reading horizontal circle readings with an accuracy of up to 20". The lower plate, attached to the outer spindle carries a graduated circle from 0 to 360^0. Graduations

are up to an accuracy of 20′. It can be clamped at any desired position using lower clamp screw. If upper clamp is locked and the lower one is loosened, the two plates will rotate together. But, if the upper clamp is loosened and lower clamp is locked, upper plate alone will rotate. This arrangement is utilised in measuring the horizontal angle as well as setting up the initial reading as 00^0 00’ 00”.

(c) Vertical circle: A vertical circle, graduated up to an accuracy of 20’, is rigidly connected to the telescope, and hence it moves along with the rotation of the telescope in vertical plane. It is used to read vertical angles. The graduations on vertical circle are in quadrantal system, 0^0 line being horizontal.

(d) Plate bubble tube: The plate bubble tube is mounted on the upper plate. It helps in making the vertical axis of the instrument truly vertical.

(e) Vernier frame: It is a T-shaped frame, and is also known as T-frame or Index frame. It consists of a vertical arm of T-shape and a horizontal arm, supporting telescope. With the help of the clamping screw the vertical frame and hence the telescope can be clamped at an angle. The vertical arm it carries verniers C and D to read the graduations on vertical circle. Verniers C and D are provided with glass magnifiers to read angles with magnified view. The A-shape frame supports the telescope, and it allows telescope to rotate on its trunnion axis in vertical plane. The T-frame and the clamps are also fixed to this frame.

(f) Altitude bubble: An altitude bubble tube is fitted over the horizontal arm. The bubble is brought to center with the help of a screw, before taking each reading of vertical angle.

(g) Levelling head: It consists of two parallel triangular plates known as *tribrach plates*. The entire instrument rests on these plates. The upper tribrach plate is provided with three levelling screws. By operating these screws, levelling of the theodolite can be done. The lower tribrach can be fitted into a tripod head.

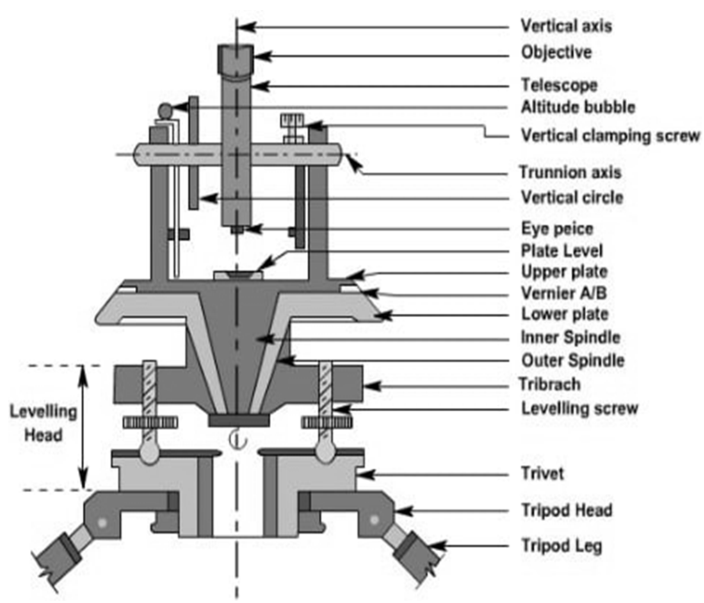

Figure 1.39 Various part of a vernier theodolite (Dangi, 2020)

(h) Shifting head: It is provided below the lower plate, and used to slide one plate over another over a small area of about 10 mm radius. The two plates can be tightened in the desired position. It facilitates the exact centering of the instrument.

(i) Tripod: It is just like any other tripod used for fixing the instrument. Theodolite is always mounted on a tripod before its use. At the lower end, the tripod legs are provided with steel shoes to get a good grip with the ground. The top of tripod is provided with external screw to which the lower tribrach plate can be clamped. When not in use, the tripod head is protected with a steel cap provided for this purpose.
(j) Plumb bob: A plumb bob is a triangular metallic weight which is suspended with a thread and hook with the lower base of the equipment. The pointed tip of the plumb bob indicates facilitates exact centering of the theodolite at a station.

1.18.3 Technical terms

(a) **Centering:** It involves setting up the theodolite exactly over an instrument station so that its vertical axis lies immediately above the station mark. It can be done by means of plumb bob suspended from a small hook attached to the vertical axis of the theodolite. Some instruments having shifting arrangement of centre facility can provide easy and rapid centering of equipment.

(b) **Line of collimation:** It is also known as the *line of sight*. It is the imaginary line joining the intersection of the cross-hairs of the diaphragm to the optical centre of the object-glass and in its continuation.

(c) **Axis of the telescope:** It is also an imaginary line joining the optical centre of object-glass to centre of the eye-piece.

(d) **Vertical axis:** It is the axis about which the telescope can be rotated in the horizontal plane (Figure 1.39).

(e) **Horizontal axis.** It is also called the *trunnion axis* or the *transverse axis.* It is the axis about which the telescope can be revolved in the vertical plane (Figure 1.39).

(f) **Transiting:** It is also known as *plunging* or *reversing.* It is the process of turning the telescope about its horizontal axis through 180^0 in the vertical plane, thus bringing it upside down and making it point exactly in opposite direction.

(g) **Swinging:** It involves turning the telescope about its vertical axis in the horizontal plane. A swing is called *right swing* if the telescope is rotated clockwise, whereas the *left swing* of the telescope involves the rotation in anticlockwise direction.

(h) **Face left:** If the vertical circle of the instrument is on the left of the observer while taking a reading, the position is called *face left* and the observations taken on horizontal or vertical circle are known as *face left observations*.

(i) **Face right:** If the vertical circle of the instrument is on the right of the observer while talking a reading, the position is called *face right,* and the observations taken on horizontal or vertical circle are known as *face right observations.*

(j) **Changing face:** It is the operation of changing the vertical circle from left to the right of observer, and vice-versa. It is done in two steps: transit the telescope and then swing it. Firstly, the telescope is revolved through 180^0 in a vertical plane and then rotated through 180^0 in the horizontal plane.

(k) **One set of observations:** The combined observations taken on face left as well as face right make one set of observations.

(l) **Fundamental axes**: There are three fundamental axes of a theodolite; the vertical axis, the axis of telescope or line of collimation, and the horizontal axis or trunnion axis. In an adjusted theodolite, all the above three axes are mutually perpendicular to each other.

1.18.4 Measurement of horizontal angles

Theodolite is generally used for accurately measuring the horizontal and vertical angles. For this, the theodolite is centered on the desired station point, levelled and telescope is focused. This process of centering, levelling and focusing is called *temporary adjustment of the instrument*, and it is similar to any optical telescope, such as levels. Now the object is bisected at the intersection of cross-hairs so that both the horizontal and vertical angle readings are taken. The reading is read from the main scale as well as vernier scale, and both are added together to get final reading. The vernier scale is a small scale used for determining the fractional parts of the smallest division of the main scale more accurately than it can be done by simply estimating with eye. The vernier scale carries an index mark (arrow) which represents the zero of the vernier divisions.

There are two methods of measuring the horizontal angles:
(a) Reiteration method, and
(b) Repetition method

(a) Reiteration method

Reiteration method is generally preferred for measuring several horizontal angles around the instrument station. It measures several angles in continuation, and finally closes the horizon at the starting point. These angles are measured on both left face and right face. The final readings of the verniers should be almost same as their initial readings. If error is observed, it is equally distributed among all the measured angles.

Suppose it is required to measure the angles AOB, BOC and COD by reiteration method, as shown in Figure 1.40a. The steps involved are:

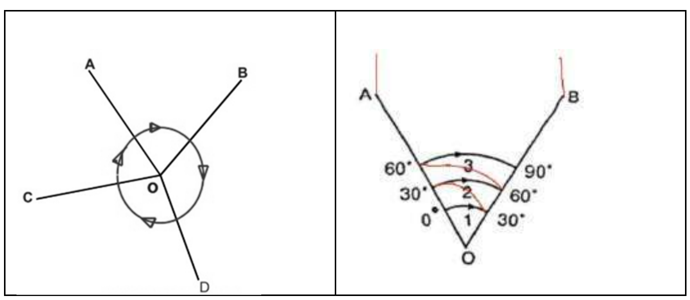

Figure 1.40 (a) Reiteration method (b) Repetition method

(i) Set up the instrument over station O and centre it and level it accurately.
(ii) Make sure that the instrument face is left face.
(iii) Set the vernier A to 0^0 by using the upper clamp and its tangent screw.
(iv) Direct the telescope to object A, and bisect it accurately by using the lower clamp and its tangent screw. Ensure that the reading at vernier A is still 0^0. Note down the reading in vernier B also.
(v) Loosen the upper clamp and turn the telescope clockwise until the point B is exactly bisected by using the upper tangent screw. Read both the verniers. The mean of the two vernier readings (after deducting 180^0 from the reading at vernier B) will give the value of the horizontal angle AOB.

(vi) Similarly, bisect objects C and D successively, read both the verniers at each bisection, and find the value of horizontal angles BOC and COD.
(vii) Finally, close the horizon by sighting towards point A.
(viii) The vernier A should have the same reading as the starting reading, but generally it is observed that there is a small error. This error is either equally distributed in all the angles or distributed in individual angle in proportion to its magnitude. If the error is very large, all the readings are discarded and a new set of readings is taken.
(ix) Change the face of the instrument from left to right.
(x) Again measure the horizontal angles in the same manner (as with face left) by turning the telescope in anticlockwise direction.
(xi) Find the closing error, and apply the necessary correction to all the horizontal angles in face right.
(xii) The mean of the two results for each angle (face left and face right) is taken as its true value.

The observation table is shown in Table 1.6.

Table 1.6 Reiteration method of recording observations

		Face left								Swing Right			Face right								Swing left			Average horizontal angle		
Inst. at	Sighted to	A			B		Mean			Horizontal angles			A			B		Mean			Horizontal angles					
		°	'	"	'	"	°	'	"	°	'	"	°	'	"	'	"	°	'	"	°	'	"	°	'	"
O	P	00	00	00	00	00	00	00	00	43	53	10	00	00	00	00	00	00	00	00	43	53	10	43	53	10
	Q	43	53	10	53	10	43	53	10	54	30	50	43	53	00	53	00	43	53	10	54	30	50	54	30	50
	R	98	24	00	24	00	98	24	00	126	47	20	98	24	00	24	00	98	24	00	126	47	20	126	47	20
	S	225	11	20	11	20	225	11	20	134	46	40	225	11	20	11	20	225	11	20	134	48	40	134	48	40
	P	360	00	00	00	00	360	00	00				360	00	00	00	00	360	00	00						

(b) Repetition method

This method is used to determine very accurate horizontal angle. It is preferred when only one or two angles are to be measured around the instrument station. Here, the same angle is measured several times and the correct value of the angle is obtained by dividing the accumulated reading with the number of repetitions. The minimum number of repetitions made is usually three, individually on face left and face right. This way, horizontal angle can be measured to a finer degree of accuracy than the least count of the vernier.

Suppose a horizontal angle AOB is to be measured by repetition method (Figure 1.40b):

(i) Set up the theodolite at station-point O and centre it and level it accurately.
(ii) Make sure that the face of the instrument is left face.
(iii) Set the vernier A to 0^0 by using the upper clamp and its tangent screw. Then loosen the lower clamp, direct the telescope to bisect object A by using the lower clamp and its tangent screw. Ensure that the reading of vernier A has not changed. Note down the reading in vernier B also.

(iv) Loosen the upper clamp, bisect the object B by clockwise movement of telescope and using the upper clamp and its tangent screw.

(v) Read both the verniers, and take the mean value.

(vi) Loosen the lower clamp and turn the telescope anitclockwise until the object A is bisected again. Check the vernier readings which must be the same as at point B.

(vii) Loosen the upper clamp, turn the telescope clockwise and again bisect B using the upper tangent screw. The verniers will now read nearly twice the value of previous angle.

(viii) Repeat the processes (vi and vii) until the angle is measured with 3 repetitions. Read both verniers, and determine the average value of angle AOB by dividing final value with the number of repetitions (in this case 3).

(ix) Change the face of the instrument to right face. Repeat steps (iii to viii) and determine one more value of angle AOB.

(x) The average of the two values of the angle (one on face left and another on face right) will give the precise value of angle AOB.

The observations are recorded in the tabular from as given in Table 1.7.

Table 1.7 Repetition method of recording observations

		Face left									Swing Right			Face right									Swing left			Average horizontal angle		
Inst. at	Sighted to	A			B		Mean			No. of repetition	Horizontal angles			A			B		Mean			No. of repetition	Horizontal angles					
		°	'	"	'	"	°	'	"		°	'	"	°	'	"	'	"	°	'	"		°	'	"	°	'	"
O	P	00	00	00	00	00	00	00	00					00	00	00	00	00	00	00	00							
	Q	58	43	20	43	20	58	43	20	1	58	43	20	58	43	40	43	40	58	43	40	1	58	43	40			
	Q	168	19	40	19	40	168	19	40	3	58	43	33	168	19	20	19	20	168	19	20	3	58	43	27	58	43	30

1.18.5 Measurement of vertical angles

A vertical angle is an angle between the inclined line of sight and the horizontal. It may be an angle of elevation or depression, according as the object is above or below the horizontal plane. In both the methods of measuring horizontal angles, if the object is bisected at the intersection of cross hairs (centre), vertical angles can also be read at the same time on verniers C and D. The average of both the verniers readings are taken. It is important that the altitude bubble is in the centre for each reading of vertical angle. After taking vertical angles at face left and face right, mean value is adopted. The observations of vertical angles are also recorded in the same manner as the horizontal angles readings.

To measure the vertical angle of an object A at a station O (Figure 1.41a), the following steps are followed:

(i) Set up the theodolite at ground point O and centre it and level it accurately. The instrument should be on face left.

(ii) Set the zero reading at verniers of vertical circle by using the vertical clamp and tangent screw. The line of sight is thus made horizontal.

(iii) Loosen the vertical circle clamp screw and bisect object A exactly by using the vertical circle tangent screw. Bring the bubble in the altitude level in centre position by using the screw.
(iv) Read both the verniers C and D on the vertical circle. The mean of the two vernier readings gives the value of the required vertical angle AOA' directly.
(v) Change the face of the instrument from left to right and repeat the process at (iii) and (iv) above. Thus, one more value of vertical angle AOA' on face right.
(vi) The average of the two values of the angle is taken which is the required value of vertical angle. The vertical angle could be angle of elevation (+ive) of angle of depression (-ive), as shown in Figure 1.41b.

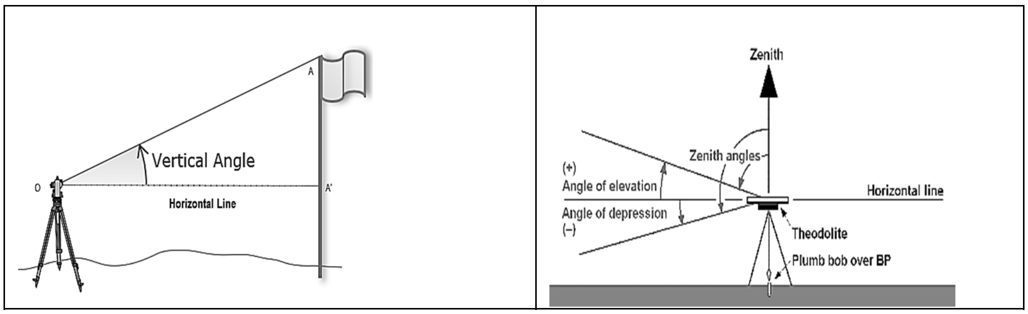

Figure 1.41 (a) Measurement of vertical angle AOA', and (b) Angle of elevation and angle of depression

1.18.6 Prolonging a straight line

Theodolite can be used to prolong a given line, such as in alignment surveys. The procedure to prolong a line AB up to Z (say) is given below (Figure 1.42).
(i) Set up the theodolite at A and centre it and level it accurately.
(ii) Bisect point B accurately by keeping a survey flag rod.
(iii) In the same line of sight, establish a point C at some convenient distance, away from B, as shown in Figure 1.42. Use theodolite to bisect so that vertical hair of the diaphragm overlaps with point B and point C.
(iv) Shift the theodolite at B, take a fore sight on C and establish another point D at some convenient distance in line beyond point C.
(v) Repeat the above processes until the last point (Z) is established.

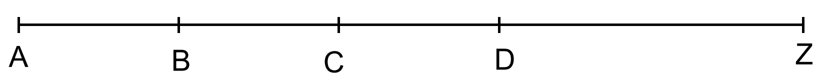

Fig. 1.42 Prolonging a line with a theodolite

1.18.7 Levelling with a theodolite

The theodolite can be used as a level, if the motion of the telescope in vertical plane is clamped such that the vertical circle verniers, C and D, read zero value. If the instrument is in perfect adjustment, the line of sight will be horizontal when the bubble is in its central position and vertical angle reading is zero. The instrument is now ready to be used as level, the level difference between two points can be determined by taking the levelling staff reading at both these points.

1.18.8 Traversing with a theodolite

Traversing is that type of survey in which a number of connected survey lines form the framework and the directions and lengths of the survey lines are measured with the help of an angle measuring and distance measuring instrument. There are two types of traverse surveying (Figure 1.43):

(a) **Closed traverse**: when the interconnected lines form a closed figure and the last line ends at the beginning of first line, it is known as a closed traverse. The closed traverse is generally used for locating the boundaries of area, lakes, forest, and survey of large areas.

(b) **Open traverse**: when the interconnected lines cover a large area along a corridor, and start point form and end point are different and they don't meet each other, it is said to be an open traverse. The open traverse is preferred for surveying a long narrow strip of land as required for alignment of a road, railway line, canal, etc.

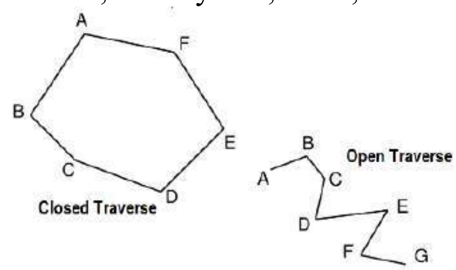

Figure 1.43 Closed traverse (left) and open traverse (right)

In theodolite traversing, the field work consists of (i) reconnaissance survey of area, (ii) selection of traverse stations, (iii) marking and locating the traverse stations, (iv) taking observations for traverse lines and angles, (v) adjusting the errors, (vi) computation of coordinates of traverse stations, (vii) plotting the coordinates of traverse stations, and (viii) take more observations of surrounding features to plot them on a map. A theodolite is normally used for determining the angles of the traverse lines, and an EDM or tacheometry is commonly used for taking the linear measurements of traverse lines.

1.18.9 Methods of theodolite traversing

The measurement of angles between two successive lines is generally carried out for large traverses where the high degree of accuracy is required. In this method, the angles between the successive lines are measured, and the bearing of a line is observed. The bearings of the remaining lines can be computed from the observed bearing and angles. In a closed traverse, the angles measured are either exterior or interior, accordingly the traverse is run in a clockwise direction or in anti-clockwise direction (Figure 1.44). The sum of the two angles (exterior and interior) at a traverse station is 360^0. The angles can be measured by the method of repetition for greater precision. The distance between traverse sides is determined either by tacheometry (if it is short) or EDM/Total Station (if it is long). The closed traverse is preferably run in anti-clockwise direction.

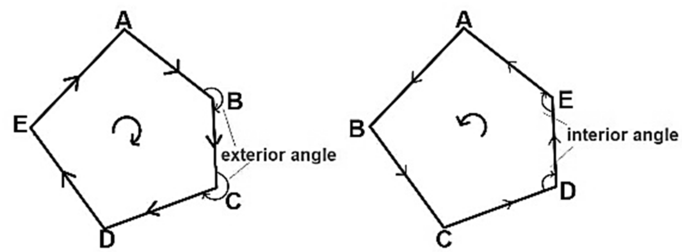

Figure 1.44 Exterior angles (clockwise traverse) and interior angles (anti-clockwise traverse)

In running the closed traverse ABCDEA, set up the theodolite at station A and measure the angle BAE. Distance AB is also computed by tacheometry or EDM. Also observe the bearing of line AB using magnetic compass. Shift the theodolite at B and measure the angle ABC and side BC. This way, visit all the traverse stations to measure the angles and sides.

In case of an open traverses, deflection angle is measured. Deflection angle is the angle made by a traverse line with the extended preceding traverse line. It can be deflection angle to the right or deflection angle to the left, depending on the direction (anticlockwise or clockwise) of angle measurement, respectively, as shown in Figure 1.45. Angle α_1 is the deflection angle to the right and α_2 is the deflection angle to the left. This is much suitable when the survey lines make small deflection angles with each other as in the case of surveys for roads, railways, pipe lines etc. In running a traverse as in the Figure, set up the theodolite at the starting station A and observe the bearing of line AB. Shift the instrument to station B, set the vernier A reading to zero and take a back sight reading on A. Then transit the telescope, loosen the upper clamp, turn the telescope clockwise and take a fore sight on C. Read both the verniers, the mean of these readings is the required deflection angle α_1 of BC from extended line AB. Also note down the direction of angle measurement (right in this case). Now shift the theodoilte, and set up at C station, and take the observations in the same way as before to measure angle α_2 (direction will be right here). Likewise, the deflection angle along with its direction (left or right) at each station is measured till the last station is covered.

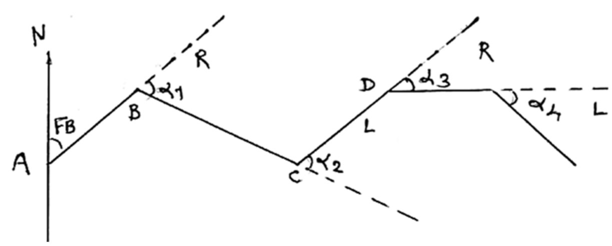

Figure 1.45 Deflection angle measurement in open traverse

1.18.10 Errors in theodolite observations

No observation is free from error. There are errors in theodolite observations also, which are to be minimized and removed. Some errors can be minimized by taking certain precautions while using the instrument and method of observation, while the errors, once they are present, can be adjusted in the observations before using them for any computational work.

(i) Errors eliminated by changing the face the theodolite:

(a) Error due to the line of collimation not being perpendicular to the horizontal axis of the telescope.
(b) Error due to the horizontal axis of the telescope not being perpendicular to the vertical axis.
(c) Error due to the line of collimation not coinciding with the axis of the telescope.

(*ii*) *Errors eliminated by reading both verniers and averaging the readings:*
(a) Error due to the axis of the vernier-plate not coinciding with the axis of the main scale plate.
(b) Error due to the unequal graduations.

(*iii*) *Error eliminated by measuring the angle on different parts of the horizontal circle:*
(a) Error due to the unequal graduations