1.13 Measurement of Distances

One of the most important activity in surveying is the measurement or computation of horizontal distance between two points. If the points are at different elevations, the distance measured is the slope distance, and a vertical angle of the line joining the point is also required to compute the horizontal distance. Depending on the accuracy desired in measurement, there are two broad methods of measuring the horizontal distances:

(a) Direct methods, and
(b) Indirect methods

The direct methods can be employed using either of the following equipment.

Pacing: A distance between two points can approximately be determined by counting the number of paces and multiplying it with the average length of the pace. When instruments are not there, this is the method to get an approximate distance.

Passometer and Pedometer: Passometer is a small instrument which counts the number of paces. Pedometer directly gives the distance by multiplying the number of paces with the average pace length of the person carrying the instrument.

Odometer: It is a simple device which can be attached to the wheel of any device, two-wheelers, three-wheelers or four-wheelers or any such devices. It measures the distance by counting the number of revolutions made by the wheel to which it is attached and multiplying this number with the perimeter of the wheel.

Survey Chains: Chains (Figure 1.8a) are used to measure distances when great precision is not needed. Metallic chains of fixed lengths, 50 feet or 100 feet, having indicators on every 10 feet may be used. These chains are also used along with Optical Square equipment for establishing the right angle to the chain line and measuring the distance. In India, old cadastral maps/property maps have been prepared using chain survey. The chains give errors in measurements for larger distances, due to sag and pull and other constraints. In addition, it is laborious to take measurements from chains as these are heavy and subject to wear & tear. In India link type surveying chains of 30 m lengths with 100 links are frequently used in land measurement. There are tallies fixed at every 3 m to facilitate convenience in reading. Along with chains, small accessories used are; (i) Arrows, (ii) Pegs, (iii) Ranging rods, (iv) Plumb bob, (v) Hammer, etc. Now-a-days chains

Tapes: Tapes (Figure 1.8b) are used to measure the distances much accurately than the chains. These tapes are available in different types and lengths. Some are described below:

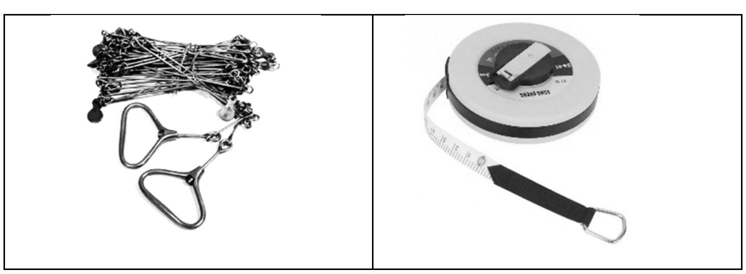


Figure 1.8 (a) Survey chain, and (b) Measuring tape

(i) Linen tapes**:** Linen tapes have painted strip of woven linen, attached to a spindle in a case. The tape is wound in leather, plastic or metal case when not in use. These tapes are light and handy but not very accurate for large distances as they are subject to serious variations in length.

(ii) Metallic tapes**:** These are ribbons of water proof fabric interwoven with thin brass or bronze wires to provide additional strength and to prevent stretching/breaking of tape. These tapes are available in 10, 20, 30 or 50 m length. Like linen tapes, these are also attached to a spindle in a leather, plastic or metal case. Non-metallic glass fibre tapes which are quite flexible, strong and non-conductive, are also available, and are used near power lines or electrical equipment.

(iii) Steel tapes: These tapes are superior to metal tape, and is more accurately graduated. It can't, however, withstand the rough usage. In case the tape gets wet, it is required to wipe it with a dry cloth immediately.

(iv) Invar tapes**:** For high precision distance measurements, such as base line measurements in triangulation/traverse survey, the tapes made of the alloy invar are used. Invar tape is made of 35% nickel and 65% steel. The tapes have a very low coefficient of thermal expansion, and hence are unaffected by temperature differences in the field.

1.13.1 Measurement of distance by chain or tape

The distance could be measured on level ground or sloping ground with a chain or a tape in a similar manner. On the ground, the line to be measured is marked at both ends and also at intermediate points, wherever necessary, in the same alignment direction. The chain or tape is laid on the ground in the alignment direction, and a peg is inserted at the other end. The chain or tape is again brought where the peg was inserted and full chain/tape length is again measured and another peg is inserted. The process continues till end point of the line is reached. The total distance is thus computed by adding up all the distances.

On uneven or sloping ground, the distance is directly measured in small stretches by keeping the chain/tape horizontal (by eye judgement only). This distance is measured and the chain/tape point at other end is projected on the ground with the help of a plumb bob, and marked with a peg. The starting end of chain/tape is brought to this peg and again a small horizontal distance is measured by keeping the chain/tape horizontal. Again, the chain/tape point is transferred on the ground with the help of a plumb bob, and peg inserted. This process is repeated till end point of the line is reached. The total distance is thus computed by adding up all the distances. Since, this approach provides rough measurements, now-a-days this method is not used on sloping ground.

If the length to be measured is very large, the direction of measurement is determined by a process, called *ranging* so that all the measurements fall in a straight line. However, in modern surveying, the EDM device and Total Station are used for measurement of long distances. These equipment have the advantages as these can provide measurement of longer distances in one single step, electronically. The details of EDM and Total Station are given in Unit 3 as well as Garg (2021).

1.13.2 Ranging of survey lines

Ranging is a process to establish intermediate points between these two stations in the same line so that the measurements are made along a straight line, following the principle of short distance, and not in a zig-zag manner. To measure the long distance between two stations on the ground, ranging rods (survey flags) are used (Figure 1.9) so that the movement is along a straight line. The ranging is carried out as (a) Direct ranging, and (b) Indirect ranging.

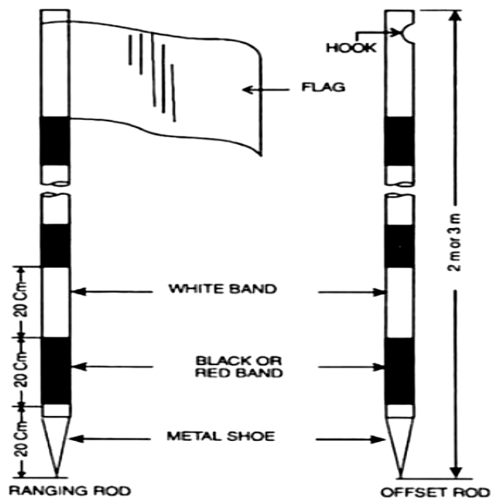


Figure 1.9 Specifications of a ranging rod

(a) Direct Ranging

It is also called ranging by eye estimation method. Suppose ranging is to be carried between two stations A and B (Figure 1.10), the process involved is-

1. Firstly, a ranging rod (rod-1) or survey flag is established at a known station (point) A and fix on the ground firmly till the completion of work.
2. Second ranging rod (rod-2) is established at the farthest station (point) B and fix it firmly on the ground till the completion of work.
3. Third ranging rod (rod-3) is established by eye judgement at any convenient point P such that A, P, B stations are in one straight line and AP survey line could easily be measured with a tape. The position of observer's eye must be before point A, at least more than a meter away to help establishing the point P. Distance AP is now measured.
4. Fourth ranging rod (rod-4) is established at another convenient point Q such that P, Q, B stations are in one straight line and PQ survey line could easily be measured with a tape. Here, the position of observer's eye must be before point P, at least more than a meter away to help establishing point Q. Distance PQ is now measured.
6. In this way, process may be repeated for longer distances till you reach close to last station B. The corresponding distances and the last distance to station B are measured.

7. Finally, all the distances are added together (In this case, AP+PQ+QR) to get distance AB.

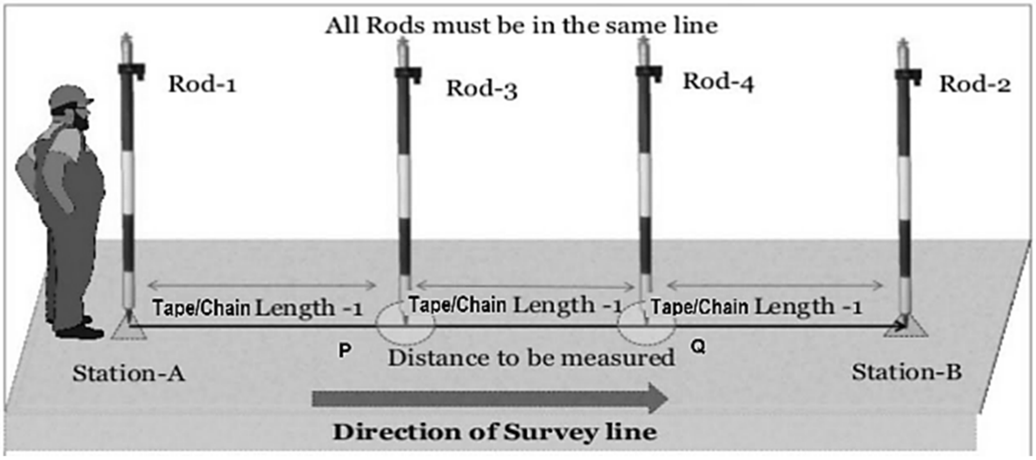


Figure 1.10 Direct ranging (https://dreamcivil.com/ranging-in-surveying/)

(b) Indirect or reciprocal ranging

Due to intervening ground, if stations A and B are not intervisible, reciprocal ranging is used. Figure 1.11 shows this scheme of ranging. It finally establishes two intermediate points M and N indirectly in between the line AB. It involves two persons to occupy arbitrarily M_1 and N_1 points by each. Point M_1 and point N_1 are selected such that both stations A and B are visible from these. In addition, one surveyor is needed at station A and another surveyor at station B. To start the process, one surveyor near station A ranges the survey flag (ranging rod) near M_1 to position M_2 such that AM_2N_1 are in a straight line. Then surveyor near station B directs the person at N_1 to move the ranging rod to N_2 such that BN_2M_2 are in a straight line. Again, surveyor at station A will range the ranging rod at M_2 to move it to M_3 till AM_3N_2 are in a straight line. The process is repeated till intermediate points M and N are finally established such that AMNB are in a line.

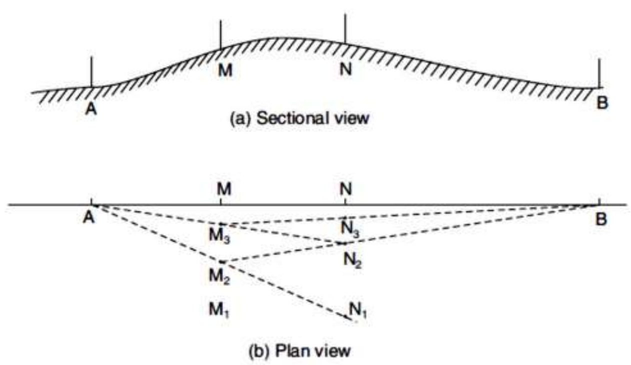


Fig. 1.11 Reciprocal ranging

1.14 Measurement of Bearings

Bearing is the direction of each survey line with respect to a reference meridian direction. Bearing of a line can be defined as the angle measured in clockwise direction from a given reference. Meridian direction can be divided into two main directions; (a) True meridian, and (b) Magnetic meridian.   Both are explained below.

(a) True meridian

The true or geographic meridian at a point is the line of intersection of plane passing through the north and south poles and the point with the surface of the Earth. Since the Earth represents approximately a spherical shape of the Earth, the meridians through different points are not parallel, and meet at the north and south poles. In case of small surveys, however, the meridians can be assumed to be parallel without making any significant error. The true meridian at a place can be established accurately through astronomical observations (Sun or Stars). Since, the direction of true meridian at a place remains unchanged, so bearing taken with respect to the true meridian does not change. True meridians are used from maps prepared by defence and army.

(b) Magnetic meridian

The magnetic meridian through a point on the ground is the direction taken by a freely suspended magnetic needle at the point. The magnetic needle indicates the direction of magnetic north and south poles, and is not the same as true meridian. Since the magnetic meridian is observed with a magnetic needle, the magnetic meridian can be affected by magnetic substances if these are present near the area. A magnetic compass is used to measure the magnetic bearing of a line.

1.14.1 Types of bearings

Bearings are measured in two ways:

1. Whole circle bearing (WCB)
2. Reduced bearing (RB) or Quadrantal bearing (QB)

The *whole circle bearing* (WCB) of a survey line is the angle made by a survey line with the magnetic north direction, always measured in clock-wise direction, as shown in Figure 1.12. It can have a value between 0^0 and 360^0. Since for trigonometrical calculations, we need RB angles, the whole circle bearing is reduced (converted) to RB. Figure 1.13 shows the relationship between the WCB of four lines with their corresponding RB in all the four quadrants (NE, SE, SW, and NW).

The *reduced bearing* (RB) or *quadrantal bearing* (QB) of a line is the angle made by the line with the either magnetic north or south direction, whichever is a smaller angle. The north-south direction and the east-west direction divide the horizontal plane into four quadrants, and any point on the ground will lie in one of the quadrants. Figure 1.13 shows these four quadrants. Thus, in quadrants I and IV, the reference direction is north and the angle is measured either to the east or west. In quadrants II and III, the angle is measured from the south, either to the west or east. Since the angle is observed from north or south towards the east or west, it is always less than 90°, as shown in Figure 1.13. RB is designated with the letters N (north) or S (south) and the direction in which the angle is measured; toward the east (E) or west (W). For example, the RB can be designated as N 30^0 15’E; S 47^0 45’E; S 40^0 23’W; and N 57^0 44’W.

Quadrant in which bearing lies	*Conversion relation*
NE	$\alpha = \theta$
SE	$\alpha = 180° - \theta$
SW	$\alpha = \theta - 180°$
NW	$\alpha = 360° - \theta$

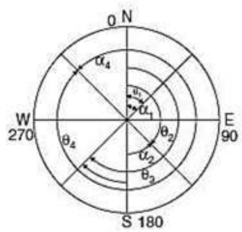


Figure 1.12 Representation of whole circle bearing

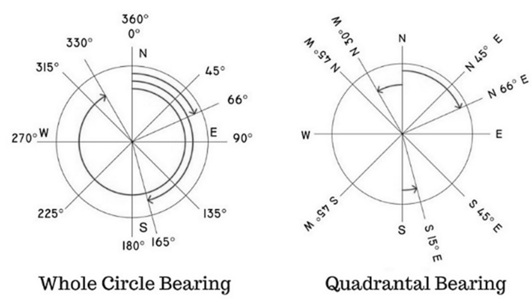


Figure 1.13 Representation of whole circle bearing into reduced bearing

1.14.2 Magnetic compasses

The magnetic compasses used in surveying may be classified as:

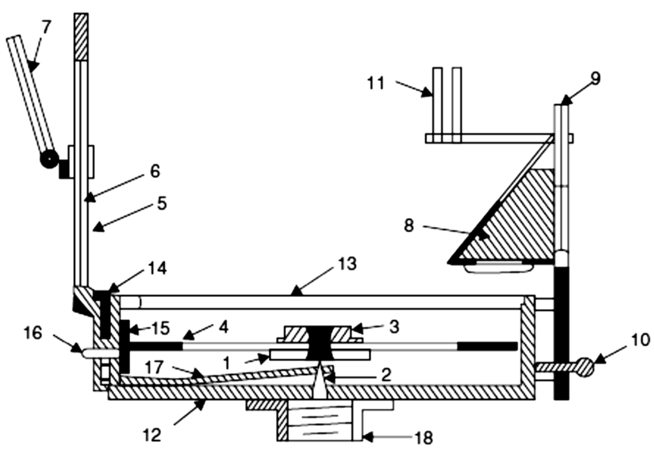
1. Prismatic Compass
2. Surveyor's Compass
3. Trough Compass
4. Tubular Compass

The compass works on the principle that a freely suspended magnetic needle takes the direction of the magnetic force at a place. It provides a reference direction with respect to which all angles can be measured. A magnetic needle is generally made perfectly symmetrical and is supported on a hard, pointed pivot so that it rotates freely. The north pole of a magnetic needle freely suspended gives the direction of the magnetic lines of force, and is used as a reference direction in compass surveying.

The Prismatic compass is very popular for survey work, and the Surveyor’s compass is rarely used. However, the principle of operation of both the compasses is the same, but they are made differently. In Surveyor's compass, the graduations are done in quadrantal system, there is no prism attachment and the reading are taken with respect to north end. Trough and tubular compasses are used as add-ons to other instruments. They are not complete surveying instruments by themselves but are used only to indicate magnetic meridian direction to set the instrument in order to derive the magnetic bearing of the lines. A trough compass is generally used as an accessory to a plane table or theodolite, while a tubular compass is used only with a theodolite.

(a) Prismatic compass

A prismatic compass is shown in Figure 1.14. The prismatic compass consists of an eye vane from where sighting is done is to the other station. An object vane is attached to metal frame, diametrically opposite to the eye vane. It is hinged at the bottom for folding over the glass cover when the compass is not in use. A fine silk thread or hair is fitted vertically in the centre of object vane frame, which is used to bisect the other objects/points. It has a perfectly symmetrical magnetic needle, balanced on a hard, steel pivot. When not in use, the needle can be lifted off the pivot, by folding the objective vane. It ensures that the magnetic needle is not rotating all the time on pivot, and pivot tip is not subject to undue wear. The needle is sensitive and takes up the north-south directly rapidly. A metal circular box supports an aluminum graduated ring, and is covered with glass so as to provide protection to aluminum ring with dust and moisture. The aluminum ring, graduated from 0^0 to 360^0, is attached to the needle on its top a diametrical arm of the ring. Aluminum, being a non-magnetic substance, is used to ensure that the ring does not affect the rotation of needle. The graduations are done in a clockwise direction with $0^0/360^0$ marked on the south end of the needle, 90^0 marked on the west, 180^0 on the north, and 270^0 on the east directions. It is clear from the graduations that the prismatic compass gives the whole circle bearings of the lines. The graduations on the ring are inverted as they are to be read by a prism arrangement by creating an inverted image. The graduations are marked to half degrees (least count 30'), but reading can be taken to one-fourth of a degree by eye judgement.



1. Needle
2. Pivot
3. Agate cap
4. Graduated disc
5. Slit metal frame
6. Horse hair
7. Mirror
8. Reflecting prism with cap
9. Eye vane
10. Focussing stud
11. Dark sunglasses
12. Box
13. Glass cover
14. Lifting pin
15. Light spring
16. Brake pin or knob
17. Lifting lever
18. Support to fit on tripod

Figure 1.14 Cross-sectional diagram of a prismatic compass (Duggal, 2017)

To measure an angle, the line of sight from compass station is established. The eye vane is made up of a rectangular frame with holes in the centre along its length. One of these holes is used to view the other object/stations by keeping observer's eye near the hole. A right-angle prism is hinged at the bottom of eye vane. A narrow slit in the prism holder enables to read the angles at the graduated ring. The prism also provides magnified view of the graduations on the ring. A metal cover is used to cover the graduated circle and the prism. The prism can be raised or lowered on the metal frame with a screw, as per the vision of the observer. Two dark coloured glasses are also provided on the metal frame, which can be brought in the view of line of sight while sighting towards bright objects or sun in the background so as to reduce the incoming glare. The metal box through a ball and socket arrangement can be levelled before using the compass. The bottom of metal plate has a screwed end that can be used to attach the compass to a tripod.

Steps to use prismatic compass

The following steps are required to use the Prismatic compass.

1. *Setting up and centering*: Fix the Prismatic compass on the tripod, and place the tripod over the station. Since, there is no centering device in the compass, it is centred over the station either with a plumb bob or by dropping a small piece of stone from the centre of the tripod. Tripod legs are moved to carry out proper centring over the station.
2. *Levelling*: Level the compass by approximation with the help of ball and socket arrangement so that the magnetic needle can move freely in a horizontal plane, after unfolding the objective vane and eye vane. There is no bubble tube attached to the compass for accurate levelling, hence it is carefully done with eye judgement only.
3. *Sighting the object:* Direct the object vane towards the object/station whose bearing is to be measured. Bisect the object/station with the vertical hair on object vane while looking through the hole of the eye vane. The metal circular plate of compass is rotated clockwise or anticlockwise so that the line of sight is passing through the object/station sighted and the cross hair of the object vane and also the view hole of eye vane.
4. *Taking readings*: The prism near the eye vane has to be adjusted with the help of a screw for a clear vision of the graduated ring readings. Once the magnetic needle comes to rest, record the reading at the point on the ring corresponding to the vertical hair seen directly through the slit in the prism holder. The prismatic compass will give the whole circle bearings of the lines. Disturb the line of sight, again align the line of slight on the same object/station, and take second reading. Repeat it at least one more time to take third reading. Take the average of at least three readings to improve the accuracy of observations.
5. Steps 1 to 4 are to be repeated at other compass stations.

1.14.3 Fore bearing and back bearing

Normally, bearings are used for traverse lines. Figure 1.15 illustrates how the bearing of a line is taken. Suppose fore bearing and back bearings of a line AB are to be measured. Set the compass at station A, bisect station B. The needle points to the north always and the reading is taken from the south end, in case of a Prismatic compass. The graduations made in the clockwise direction from the south end give the whole circle bearing of line AB, as can be seen from Figure 1.15. Measure the magnetic bearing towards B point (say 260^0). This is called *fore bearing* of line AB. Now set the compass at station B, bisect station A, and bearing of line BA is measured from point B towards point A (say 80^0) clockwise from magnetic north. This bearing is called *back bearing* of line AB or fore bearing of line BA. Both the bearings must differ by 180^0, which is clear from the Figure also. This difference can also be used as a check while taking the measurements.

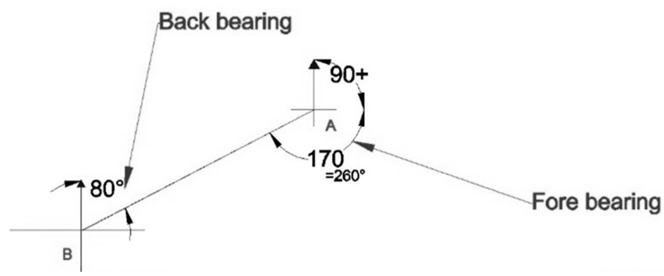


Figure 1.15 Fore bearing and back bearing

1.14.4 Magnetic declination

The magnetic meridian and the true meridian at any place are not same but different, the horizontal angle between these is known as *magnetic declination*. The magnetic north at a place may be either towards east or west of true north (Figure 1.16). If it is towards east, it is known as eastern or +ve declination, and if towards west, it is called as western declination or –ve declination. It means, eastern declination is to be added and western to be subtracted to the observed magnetic bearings to obtain true meridian. Magnetic declination varies from time to time and also from place to place

True bearing = magnetic bearing ± magnetic declination (E or W) (1.3)

To know the magnetic declination at a location, true meridian is established from astronomical observations (Sun or Stars) and magnetic meridian is determined by a compass. In other words, if we know the magnetic declination and magnetic bearing of laine, its true bearing can be computed. Engineering maps are made with respect to magnetic meridians, while maps used by army are made with respect to true meridian.

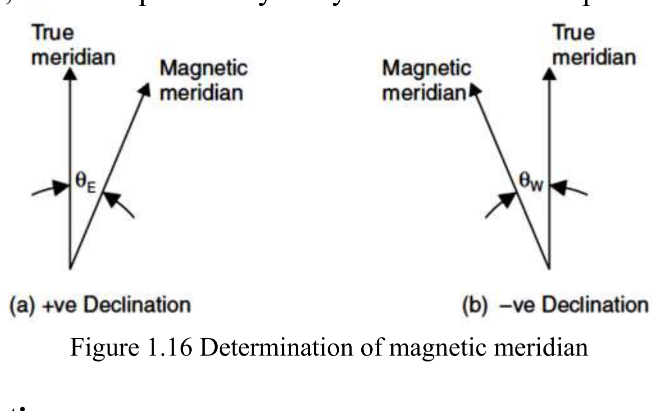


Figure 1.16 Determination of magnetic meridian

1.14.5 Local attraction

A properly balanced and freely suspended magnetic needle is expected to show the direction of magnetic meridian. However, many-times the local objects, like electric wires, magnetic ore, iron pipe line, and metallic buttons can attract magnetic needle towards themselves, and can give erroneous results. This deviation in reading is called *local attraction*. The materials/objects which can cause error due to local attraction could be magnetic rock or iron ore, steel structures, iron poles, rails, pipe-lines, electric poles and wires, key bunch, ring, knife, iron buttons, steel framed spectacles, and survey chain, arrows, hammer, clearing axe, etc. Special care is required to be taken to avoid error due to local attraction. However, in many circumstances, it is neither possible to remove the metallic objects from the survey field, nor changing the station of magnetic compass observations. In such cases, the fore bearing and back bearing of the line is taken, and those stations are considered unaffected by local attraction if the difference of fore bearing and back bearing of the lines is exactly 180°. The difference in value is the error. Using this approach, the stations affected or unaffected by local attraction. The error due to local attraction is distributed at the affected stations, such that now all the lines will satisfy the check, i.e.,

Difference in fore bearing and back bearing of a line = 180^0 (1.4)

1.14.6 Computation of included angles from bearings

In a closed traverse, bearings of lines may be calculated if bearing of one of the line and the included horizontal angles between various lines are known, using the relationship:

Bearing of a line= given bearing + included horizontal angle (1.5)

Figure 1.17 illustrates the computation of horizontal angles from bearings. If at any point, bearings of any two lines are known, the included angle between these two lines can easily be found by drawing a sketch, and then taking the difference of angles. The examples are given below.

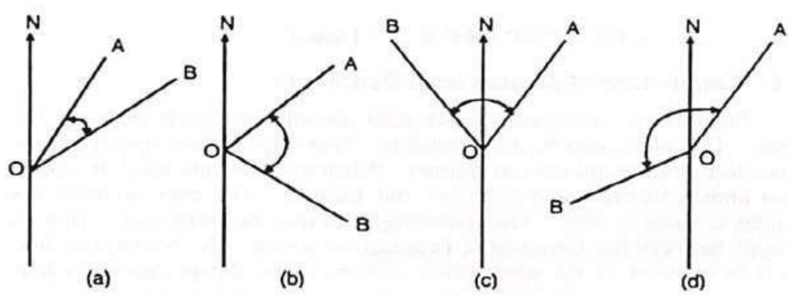


Figure 1.17 Relationship between horizontal angles and bearings

If the lines are on the same side of the meridian and in same quadrant (Figure 1.17a) the included angle ∠AOB= the difference of the reduced bearings of OA and OB. If the lines are on the same side of the meridian but in different quadrants (Figure 1.17b), the included angle ∠AOB= 180°– sum of the reduced bearings of OA and OB. If the lines are not on the same side of the meridian but they are in the adjacent quadrants (Figure 1.17c), the included angle ∠AOB= sum of the reduced bearings of OA and OB. If the lines are not on the same side of the meridian and also not in the opposite quadrants (Figure 1.17d) the included angle ∠AOB= 360°– difference of the whole circle bearings of OA and OB.

The above relationship can also be used to compute the bearings of lines, if all included angles and one bearing of a line is known. Due to local attraction problem, sometimes the bearings of all the lines are not measured for all the traverse lines, but angles can be measured with greater accuracy, in such cases, bearing of reaming lines in a traverse can be determined, and subsequent check applied for bearings.