Catalog

2.1 THEODOLITE

A theodolite is essentially a transit of high precision. Theodolites come in different sizes and weights and from different manufacturers. Although theodolites may differ in appearance, they are basically alike in their essential parts and operation. Some of the models currently available for use in the military are WILD (Herrbrugg), BRUNSON, K&E, (Keuffel & Esser), and PATH theodolites.

To give you an idea of how a theodolite differs from a transit, we will discuss some of the most commonly used theodolites in the U.S. Armed Forces.

One-Minute Theodolite

The 1-min directional theodolite is essentially a directional type of instrument. This type of instrument can be used, however, to observe horizontal and vertical angles, as a transit does.

The theodolite shown in figure 11-12 is a compact, lightweight, dustproof, optical reading instrument. The scales read directly to the nearest minute or 0.2 mil and are illuminated by either natural or artificial light. The main or essential parts of this type of theodolite are discussed in the next several paragraphs.

HORIZONTAL MOTION

Located on the lower portion of the alidade, and adjacent to each other, are the horizontal motion clamp and tangent screw used for moving the theodolite in azimuth. Located on the horizontal circle casting is a horizontal circle clamp that fastens the circle to the alidade. When this horizontal (repeating) circle clamp is in the lever-down position, the horizontal circle turns with the telescope. With the circle clamp in the lever-up position, the circle is unclamped and the telescope turns independently. This combination permits use of the theodolite as a REPEATING INSTRUMENT. To use the theodolite as a DIRECTIONAL TYPE OF INSTRUMENT, you should use the circle clamp only to set the initial reading. You should set an initial reading of 0 º 30' on the plates when a direct and reverse (D/R) pointing is required. This will minimize the possibility of ending the D/R pointing with a negative value.

VERTICAL MOTION

Located on the standard opposite the vertical circle are the vertical motion clamp and tangent screw. The tangent screw is located on the lower left and at right angles to the clamp. The telescope can be rotated in the vertical plane completely around the axis (360^o)

LEVELS.-

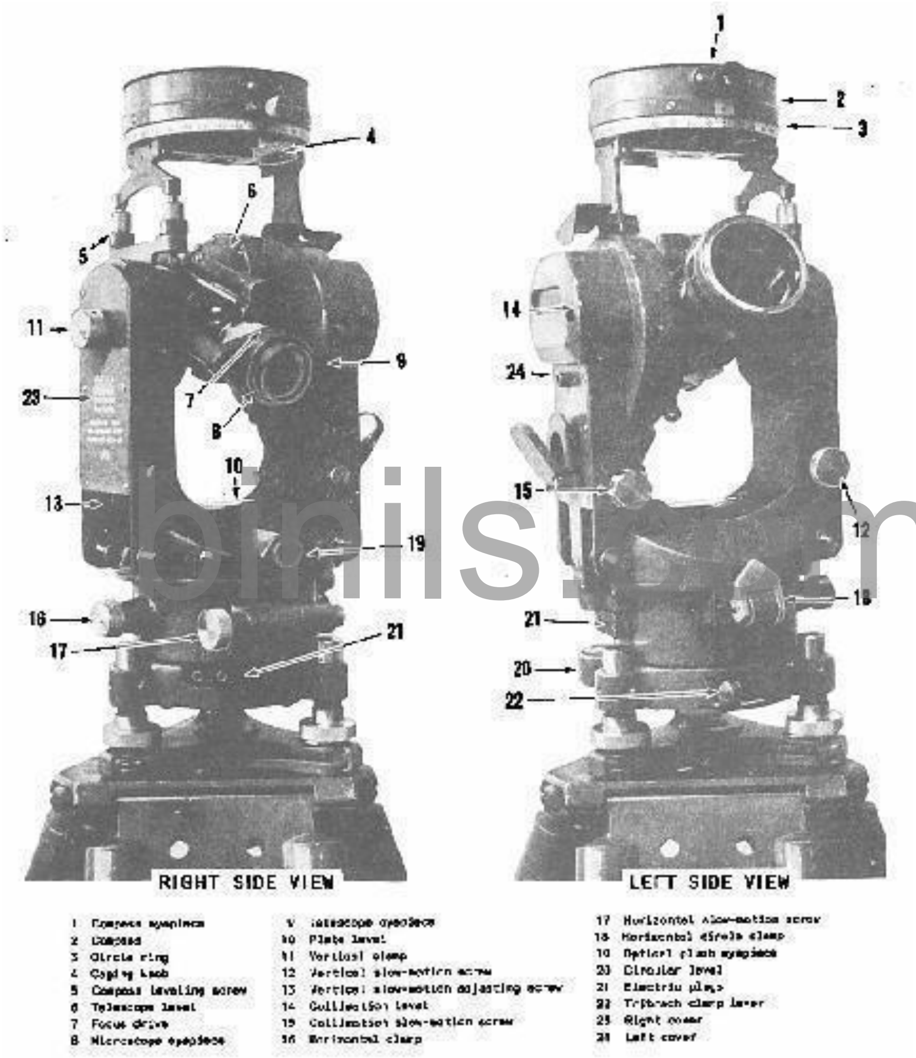
The level vials on a theodolite are the circular, the plate, the vertical circle, and the telescope level. The CIRCULAR LEVEL is located on the tribrach of the instrument and is used to roughly level the instrument. The PLATE LEVEL, located between the two standards, is used for leveling the instrument in the horizontal plane. The VERTICAL CIRCLE LEVEL (vertical collimation) vial is often referred to as a split bubble. This level vial is completely built in, adjacent to the vertical circle, and viewed through a prism and 45^0 mirror system from the eyepiece end of the telescope. This results in the viewing of one- half of each end of the bubble at the same time. Leveling consists of bringing the two halves together into exact coincidence, as Shown in figure 11-13. The TELESCOPE LEVEL, mounted below the telescope, uses a prism system and a 45^0 mirror for leveling operations. When the telescope is plunged to the reverse position, the level assembly is brought to the top

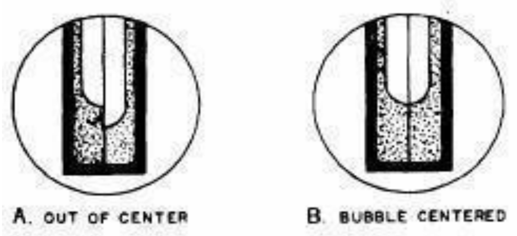
Figure 11-13.-Coincidence- type level.

(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

TELESCOPE.-

The telescope of a theodolite can be rotated around the horizontal axis for direct and reverse readings. It is a 28-power instrument with the shortest focusing distance of





about 1.4 meters. The cross wires are focused by turning the eyepiece; the image, by turning the focusing ring. The reticle (fig. 11-14) has horizontal and vertical cross wires, a set of vertical and horizontal ticks (at a stadia ratio of 1:100), and a solar circle on the reticle for making solar observations. This circle covers 31 min of arc and can be imposed on the sun's image (32 min of arc) to make the pointing refer to the sun's center. One-half of the vertical line is split for finer centering on small distant objects.

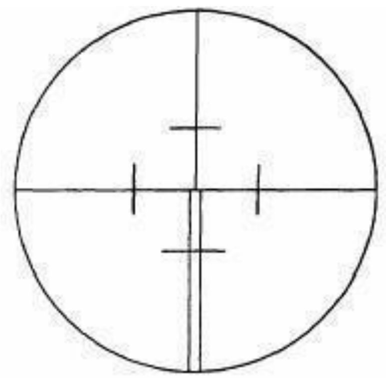


Figure 11-14.-Theodolite reticle.
(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

The telescope of the theodolite is an inverted image type. Its cross wires can be illuminated by either sunlight reflected by mirrors or by battery source. The amount of illumination for the telescope can be adjusted by changing the position of the illumination mirror.

TRIBRACH. -

The tribrach assembly (fig. 11-15), found on most makes and models, is a detachable part of the theodolite that contains the leveling screw, the circular level, and the optical plumbing device. A locking device holds the alidade and the tribrach together and permits interchanging of instruments without moving the tripod. In a "leapfrog" method, the instrument (alidade) is detached after observations are completed. It is then moved to the next station and another tribrach. This procedure reduces the amount of instrument setup time by half.

CIRCLES. -

The theodolite circles are read through an optical microscope. The eyepiece is located to the right of the telescope in the direct position, and to the left, in the reverse. The microscope consists of a series of lenses and prisms that bring both the horizontal and the vertical circle images into a single field of view. In the DEGREE-GRADUATED SCALES (fig. 11-16), the images of both circles are shown as they would appear through the microscope of the 1-min theodolite. Both circles are graduated from 0 ° to 360 ° with an index graduation for each degree on the main scales. This scale's graduation appears to be superimposed over an auxiliary that is graduated in minutes to cover a span of 60 min (1 °). The position of the degree mark on the auxiliary scale is used as an index to get a direct reading in degrees and minutes. If necessary, these scales can be interpolated to the nearest 0.2 min of arc. The vertical circle reads 0 ° when the theodolite's telescope is pointed at the zenith, and 180 ° when it is pointed straight down

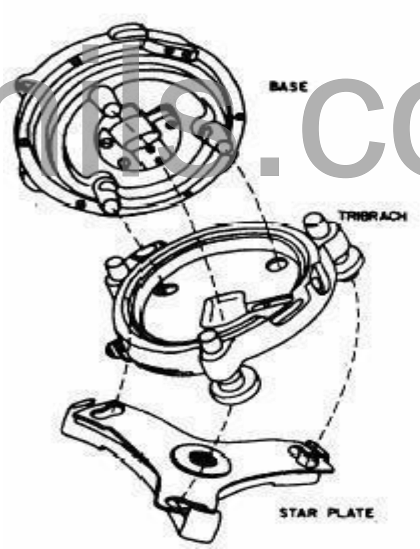


Figure 11-15.-Three-screw leveling head.

(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

A level line reads 90 o in the direct position and 270° in the reverse. The values read from the vertical circle are referred to as ZENITH DISTANCES and not vertical angles. Figure 11-17 shows how these zenith distances can be converted into vertical angles.

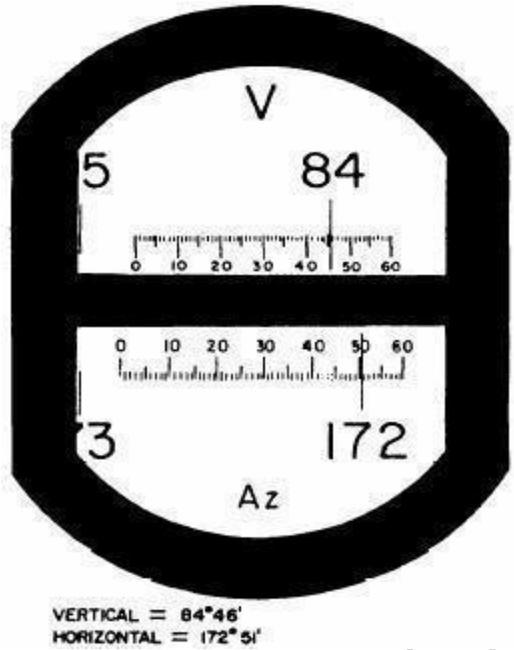


Figure 11-16.-Degree-graduated scales.
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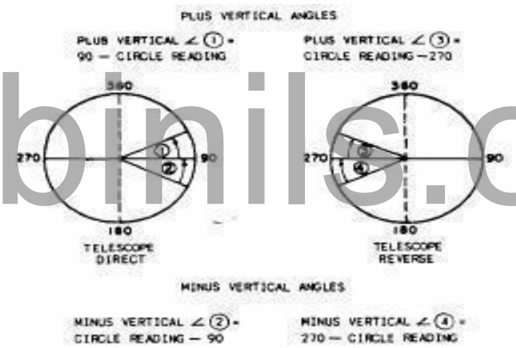

Figure 11-17.-Converting zenith distances into vertical angles (degrees).
(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

In the MIL-GRADUATED SCALES (fig. 11-18), the images of both circles are shown as they would appear through the reading micro-scope of the 0.2-mil theodolite. Both circles are graduated from 0 to 6,400 mils. The main scales are marked and numbered every 10 mils, with the last zero dropped. The auxiliary scales are graduated from 0 to 10 roils in 0.2-mil increments. Readings on the auxiliary scale can be interpolated to 0.1 mil. The vertical circle reads 0 mil when the telescope is pointed at the zenith, and 3,200 mils when it is pointed straight down. A level line reads 1,600 roils in the direct position and 4,800 roils in the reverse. The values read are zenith distances. These zenith distances can be converted into vertical angles as shown in figure 11-1 The excavation of material in underwater areas is called dredging, and a dredge is an excavator afloat on a barge. A dredge may get itself into position by cross bearings, taken from the dredge on objects of known location on the beach, or by some other piloting method.

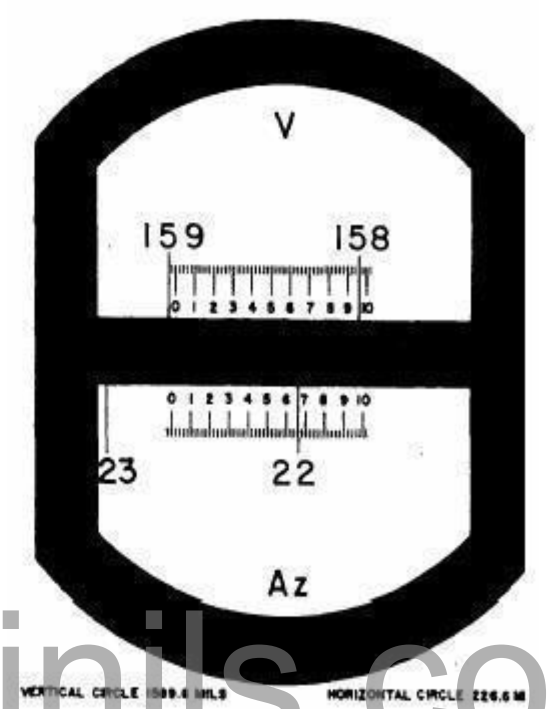

Figure 11-18.-Mil-graduated scales.

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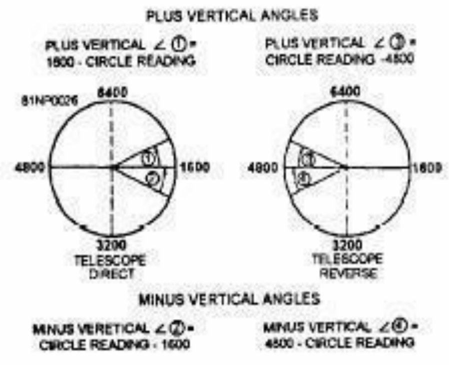

Figure 11-19.-Vertical angles from zenith distances (mils).
(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

Many times, however, dredges are positioned by survey triangulation. The method of determining direction angles from base line control points is the same as that just described.

LAND SURVEYING

Land surveying includes surveys for locating and manumitting the boundaries of a property; preparation of a legal description of the limits of a property and of the area included; preparation of a property map; resurveys to recover and remonument property corners; and surveys to subdivide property. It is sometimes necessary to retrace surveys of property lines, to reestablish lost or obliterated corners, and to make ties to property lines and corners; for example, a retracement survey of property lines may be required to assure that the military operation of quarry excavation does not encroach on adjacent property where excavation rights have not been obtained. Similarly, an access road from a public highway to the quarry site, if it crosses privately owned property, should be tied to the property lines that are crossed so that correctly executed easements can be obtained to cross the tracts of private property.

EAs may be required to accomplish property surveys at naval activities outside the continental limits of the United States for the construction of naval bases and the restoration of such properties to property owners. The essentials of land surveying as practiced in various countries are similar in principle. Although the principles pertaining to the surveys of public and private lands within the United States are not necessarily directly applicable to foreign countries, knowledge of these principles will enable the EA to conduct the survey in a manner required by the property laws of the nation concerned.

In the United States, land surveying is a survey conducted for the purpose of ascertaining the correct boundaries of real estate property for legal purposes. In accordance with federal and states laws, the right and/or title to landed property in the United States can be transferred from one person to another only by means of a written document, commonly called a deed. To constitute a valid transfer, a deed must meet a considerable number of legal requirements, some of which vary in different states. In all the states, however, a deed must contain an accurate description of the boundaries of the property.

A right in real property need not be complete, outright ownership (called fee simple). There are numerous lesser rights, such as leasehold (right to occupancy and use for a specified term) or easement (right to make certain specified use of property belonging to someone else). But in any case, a valid transfer of any type of right in real property usually involves an accurate description of the boundaries of the property.

As mentioned previously, the EA may be required to perform various land surveys. As a survey team or crew leader, you should have a knowledge of the principles of land surveys in order to plan your work accordingly.

PROPERTY BOUNDARY DESCRIPTION

A parcel of land may be described by metes and bounds, by giving the coordinates of the property corners with reference to the plane coordinates system, by a deed reference to a description in a previously recorded deed, or by References to block and individual property numbers appearing on a recorded map.

By Metes and Bounds

When a tract of land is defined by giving the bearings and lengths of all boundaries, it is said to be described by metes and bounds. This is an age-old method of describing land that still forms the basis for the majority of deed descriptions in the eastern states of the United States and in many foreign lands. A good metes-and-bounds description starts at a point of beginning that should be monument and referenced by ties or distances from well- established monuments or other reference points. The bearing and length of each side is given, in turn, around the tract to close back on the point of beginning. Bearing may be true or magnetic grid, preferably the former. When magnetic bearings are read, the declination of the needle and the date of the survey should be stated. The stakes or monuments placed at each corner should be described to aid in their recovery in the future. Ties from corner monuments to witness points (trees, poles, boulders, ledges, or other semi-permanent or permanent objects) are always helpful in relocating corners, particularly where the corner markers themselves lack permanence. In timbered country, blazes on trees on or adjacent to a boundary line are most useful in reestablishing the line at a future date. It is also advisable to state the names of abutting property owners along the several sides of the tract being described. Many metes-and-bounds descriptions fail to include all of these particulars and are frequently very difficult to retrace or locate in relation to adjoining ownerships.

One of the reasons why the determination of boundaries in the United States is often difficult is that early surveyors often confined themselves to minimal description; that is, to a bare statement of the metes metes Today, good practice requires that a land surveyor include all relevant information in his description.

In preparing the description of a property, the surveyor should bear in mind that the description must clearly identify the location of the property and must give all necessary data from which the boundaries can be reestablished at any future date. The written description contains the greater part of the information shown on the plan. Usually both a description and a plan are prepared and, when the property is transferred, are recorded according to the laws of the county concerned. The metes-and-bounds description of the property shown in figure 10-34 is given below.

"All that certain tract or parcel of land and premises, hereinafter particularly described, situate, lying and being in the Township of Maplewood in the County of Essex and State of New Jersey and constituting lot 2 shown on the revised map of the Taylor property in said township as filed in the Essex County Hall of Records on March 18, 1944.

"Beginning at an iron pipe in the northwesterly line of Maplewood Avenue therein distant along same line four hundred and thirty-one feet and seventy- one-hundredths of a foot north-easterly from a stone monument at the northerly corner of Beach Place and Maplewood Avenue; thence running (1) North forty-four degrees thirty-one and one-half minutes West along land of. . ."

Another form of a lot description maybe presented as follows:

"Beginning at the northeasterly corner of the tract herein described; said corner being the intersection of the southerly line of Trenton Street and the westerly line of Ives Street; thence running S 6°29'54" E bounded easterly by said Ives Street, a distance of two hundred and twenty-seven one hundredths (200.27) feet to the northerly line of Wickenden Street; thence turning an interior angle of 89 ° 59'16" and running S 83°39'50" W bonded southerly by said Wickenden Street, a distance of one hundred and no one-hundredths (100.00) feet to a corner; thence turning an interior angle of " You will notice that in the above example, interior angles were added to the bearings of the boundary lines. This will be another help in retracing lines

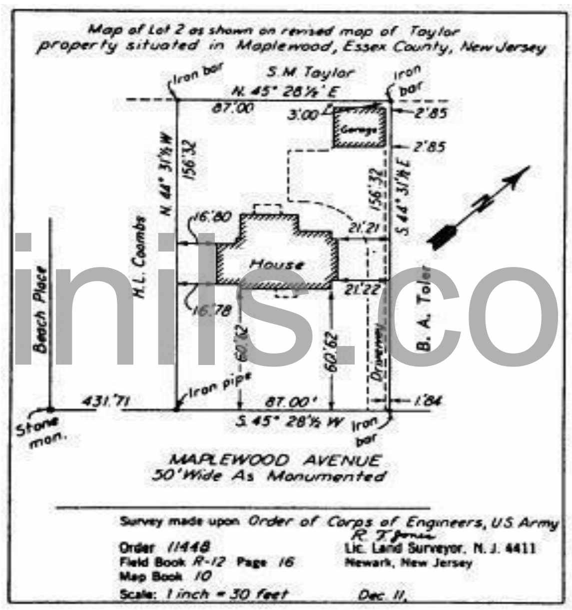

Figure 10-34.-Lot plan by metes and bounds.
(https://www.brainkart.com/article/Theodolite-Surveying_4609/)

INTRO TO ANTIQUE SURVEY INSTRUMENTS

First, some basics about their composition and finish... most instruments were made of wood, brass, or aluminum, although you will find whole instruments or instrument parts made of iron, steel, ebony, ivory, celluloid, and plastic. It is important to remember that many surveying instruments were "needle" instruments and their magnetic needles would not seek north properly if there were local sources of interference, such as iron. The United States General Land Office issued instructions requiring brass Gunter's chains to be used in close proximity to the magnetic needle. (They soon changed that requirement to steel brazed link chains; the brass chain could not stand up to the type of wear and tear a chain received.

In American surveying instruments, wood was common until about 1800; brass instruments were made approximately 1775 to 1975, and aluminum instruments from 1885 to the present.

The finish of instruments has changed. Early wooden instruments were generally unfinished and were usually made of tight grained woods which resisted water well. Early brass instruments were usually unfinished or polished and lacquered to retain the shine. In the mid-1800s American instrument makers began finishing brass instruments with dark finishes for two reasons: first, that the dark finish reduced glare and as a result reduced eyestrain, and secondly, that the dark finish helped to even out the heating of an instrument in the sunlight and as a result reduced collimation problems caused by the heating. Beware of being taken in by polished and lacquered brass instruments; prior to 1900 that may have been the original finish for the instrument, but after 1900, bright brass finishes are usually not original finishes.

There are three kinds of surveying instruments that are rather unique to North American surveying. They are the compass, the chain and the transit. In addition, the engineer's or surveyor's level contributed very strongly to making the United States the leading industrial nation in the world by virtue of the highly efficient railroad systems it helped design in the mid 1800's. I take a great deal of satisfaction in pointing out that in this country it was the compass and chain that won the west, not the six-shooter!

The following is a list of antique surveying instruments and tools with a brief and basic description of how they were used.

ABNEY HAND LEVEL - Measures vertical angles.

ALIDADE - Used on a Plane Table to measure vertical and horizontal angles & distances.

ALTAAZIMUTH INSTRUMENT - Measures horizontal and vertical angles; for position "fixing".

ASTRONOMIC TRANSITS - Measures vertical angles of heavenly bodies; for determining geographic position.

BAROMETER, ANEROID - Measures elevations; used to determine vertical distance.
BASE-LINE BAR - Measures horizontal distances in triangulation and trilateration surveys.
BOX SEXTANT - Measures vertical angles to heavenly bodies. CHRONOGRAPH - Measures time.
CHRONOMETER - Measures time.
CIRCUMFERENTER - Measures horizontal directions and angles. CLINOMETER - Measures vertical angles.

COLLIMATOR - For adjusting and calibrating instruments.

COMPASSES - Determines magnetic directions; there are many kinds, including plane, vernier, solar, telescopic, box, trough, wet, dry, mariners, prismatic, pocket, etc.

CROSS, SURVEYORS - For laying out 90 and 45 degree angles. CURRENT METER - Measures rate of water flow in streams and rivers.
DIAL, MINER'S - A theodolite adapted for underground surveying; measures directions as well as horizontal and vertical angles.

GONIOMETER - Measures horizontal and vertical angles.

GRADIOMETER - Also known as Gradiometer level, it measures slight inclines and level lines- of-sight.
HELIOGRAPH - Signaling device used in triangulation surveys.

ELIOSTAT - Also known as a heliotrope, it was used to make survey points visible at long distances, particularly in triangulation surveys.

HORIZON, ARTIFICIAL - Assists in establishing a level line of sight, or "horizon".

HYPSOMETER - Used to estimate elevations in mountainous areas by measuring the boiling points of liquids. This name was also given to an instrument which determined the heights of trees.

INCLINOMETER - Measures slopes and/or vertical angles.

LEVEL - Measures vertical distances (elevations). There are many kinds, including Cooke's, Cushing's, Gravatt. dumpy, hand or pocket, wye, architect's, builder's, combination, water, engineer's, etc.

LEVELLING ROD - A tool used in conjunction with a levelling instrument. LEVELLING STAVES - Used in measuring vertical distances. MINER'S COMPASS - Determines magnetic direction; also locates ore. MINER'S PLUMMET - A "lighted" plumb bob, used in undergroundsurveying.
MINING SURVEY LAMP - Used in underground surveying for vertical and horizontal alignment.

OCTANT - For measuring the angular relationship between two objects. PEDOMETER - Measures paces for estimating distances.
PERAMBULATOR - A wheel for measuring horizontal distances.

PHOTO-THEODOLITE - Determines horizontal and vertical positions through the use of "controlled" photographs.

PLANE TABLE - A survey drafting board for map-making with an alidade. PLUMB BOB - For alignment; hundreds of varieties and sizes.
PLUMMETS - Same as plumb bob.

QUADRANT - For measuring the angular relationship between two objects. RANGE POLES - For vertical alignment and extending straight lines.

SEMICIRCUMFERENTER - Measures magnetic directions and horizontalangles.

SEXTANTS - Measures vertical angles; there are many kinds, including box, continuous arc, sounding, surveying, etc.

SIGNAL MIRRORS - For communicating over long distances; used in triangulation surveys.

STADIA BOARDS - For measuring distances; also known as stadia rods. STADIMETER or STADIOMETER - For measuring distances.

TACHEOMETER - A form of theodolite that measures horizontal and vertical angles, as well as distances.

TAPES - For measuring distances; made of many materials, including steel, invar, linen, etc. Also made in many styles, varieties, lengths, and increments.

THEODOLITE - Measures horizontal and vertical angles. Its name is one of the most misused in surveying instrument nomenclature, and is used on instruments that not only measure angles, but also directions and distances. There are many kinds, including transit, direction, optical, solar, astronomic, etc.

TRANSIT - For measuring straight lines. Like the theodolite, the transit's name is often misused in defining surveying instruments. Most transits were made to measure horizontal and vertical angles and magnetic and true directions. There are many kinds, including astronomic, solar, optical,vernier, compass, etc.

WAYWISER - A wheel for measuring distances

Traverse (surveying)

Traverse is a method in the field of surveying to establish control networks. It is also used in geodetic work. Traverse networks involved placing the survey stations along a line or path of travel, and then using the previously surveyed points as a base for observing the next point. Traverse networks have many advantages of other systems, including:

- Less reconnaissance and organization needed;

- While in of the polygon shape, the traverse can change to any shape and thus can accommodate a great deal of different terrains;

- Only a few observations need to be taken at each station, whereas in other survey networks a great deal of angular and linear observations need to be made and considered;

- Traverse networks are free of the strength of figure considerations that happen in triangular systems;

- Scale error does not add up as the traverse is performed. Azimuth swing errors can also be reduced by increasing the distance between stations.

The traverse is more accurate than triangulation (a combined function of the triangulation and trilateration practice).

Types

Frequently in surveying engineering and geodetic science, control points (CP) are setting/observing distance and direction (bearings, angles, azimuths, and elevation). The CP throughout the control network may consist of monuments, benchmarks, vertical control, etc.

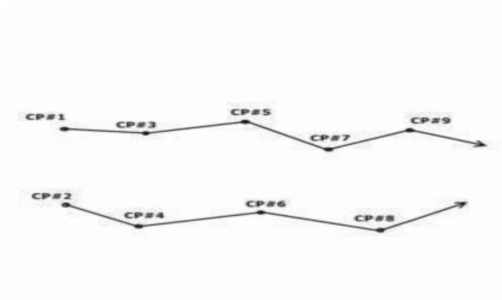

Fig-Diagram of an open traverse

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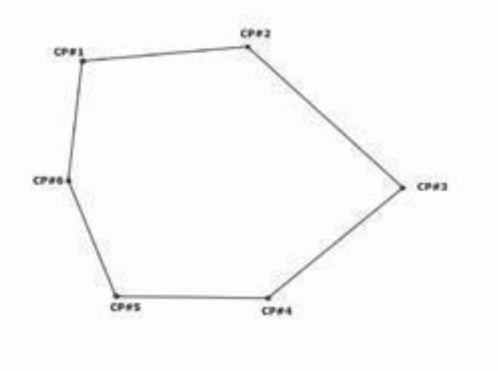

Fig- Diagram of a closed traverse

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Open/Free

An open, or free traverse (link traverse) consist of known points plotted in any corresponding linear direction, but do not return to the starting point or close upon a point of equal or greater order accuracy. It allows geodetic triangulation for sub-closure of three known points; known as the "Bowditch rule" or "compass rule" in geodetic science and surveying, which is the principle that the linear error is proportional to the length of the side in relationto the perimeter of the traverse

- Open survey is utilized in plotting a strip of land which can then be used to plan a route in road construction. The terminal (ending) point is always listed as *unknown* from the observation point.

Closed

A closed traverse (polygonal, or loop traverse) is a practice of traversing when the terminal point closes at the starting point. The control points may envelop, or are set within the boundaries, of the control network. It allows geodetic triangulation for sub-closure of all known observed points.

- Closed traverse is useful in marking the boundaries of wood or lakes. Construction and civil engineers utilize this practice for preliminary surveys of proposed projects in a particular designated area. The terminal(ending) point closes at the starting point.

- **Control point -** the primary/base control used for preliminary measurements; it May consist of any known point capable of establishing accurate control of distance and direction (i.e. coordinates, elevation, bearings, etc.)

1. ***Starting*** -It is the initial starting control point of the traverse.

2. ***Observation*** -All known control points that are settled or observedwithin the traverse.

3. ***Terminal*** -It is the initial ending control point of the traverse; its coordinates are *unknown*

Earthwork Computations

Computing earthwork volumes is a necessary activity for nearly all construction projects and is often accomplished as a part of route surveying, especially for roads and highways. Suppose, for example, that a volume of cut must be removed between two adjacent stations along a highway route. If the area of the cross section at each station is known, you can compute the average-end area (the average of the two cross-sectional areas) and then multiply that average end area by the known horizontal distance between the stations to determine the volume of cut.

To determine the area of a cross section easily, you can run a planimeter around the plotted outline of the section. Counting the squares, explained in chapter 7 of this traman, is another way to determine the area of a cross section. Three other methods are explained below.

AREA BY RESOLUTION. - Any regular or irregular polygon can be resolved into easily calculable geometric figures, such as triangles and *ABH* and DFE, *and* two trapezoids, *BCGH* and *CGFD.* For each of these figures, the approximate dimensions have been determined by the scale of the plot. From your knowledge of mathematics, you know that the area of each trianglecan be determined using the following formula:

$$A [s(s-a) (s-b) (s-c)]^{1/2}$$

s = one half of the perimeter of the triangle, and that for each trapezoid, you can calculate the area using the formula:

Where:

$$A = \quad (b1+b2)\ h$$

When the above formulas are applied and the sum of the results are determined, you find that the total area of the cross section at station 305 is
509.9 square feet.

AREA BY FORMULA. - A regular section area for a three-level section can be more exactly determined by applying the following formula:

determine the area of sections of this kind, you should use a method of determining area by coordinates. For explanation purpose, let's consider station 305 (fig. 10-6). First, consider the point where the center line intersects the grade line as the point of origin for the coordinates. Vertical distances above the grade line are positive *Y* coordinates; vertical distances below the grade line are negative *Y* coordinates. A point on the grade line itself has a *Y* coordinate of 0. Similarly, horizontal distances to the right of the center line are positive *X* coordinates; distances to the left of the center line are negative *X* coordinates; and any point on the center line itself has an *X*coordinate of 0.

Plot the cross section, as shown in figure 10-7, and be sure that the *X* and *Y* coordinates have their proper signs. Then, starting at a particular point and going successively in a clockwise direction, write down the coordinates, as shown in figure 10-8.

After writing down the coordinates, you then multiply each **upper** term by the **algebraic** difference of the **following** lower term and the **preceding** lower term, as indicated by the direction of the arrows (fig. 10-8). The algebraic sum of the resulting products is the **double** area of the cross section. Proceed with the computation as follows:

Figure 10-4.-A cross section plotted on cross-section paper.

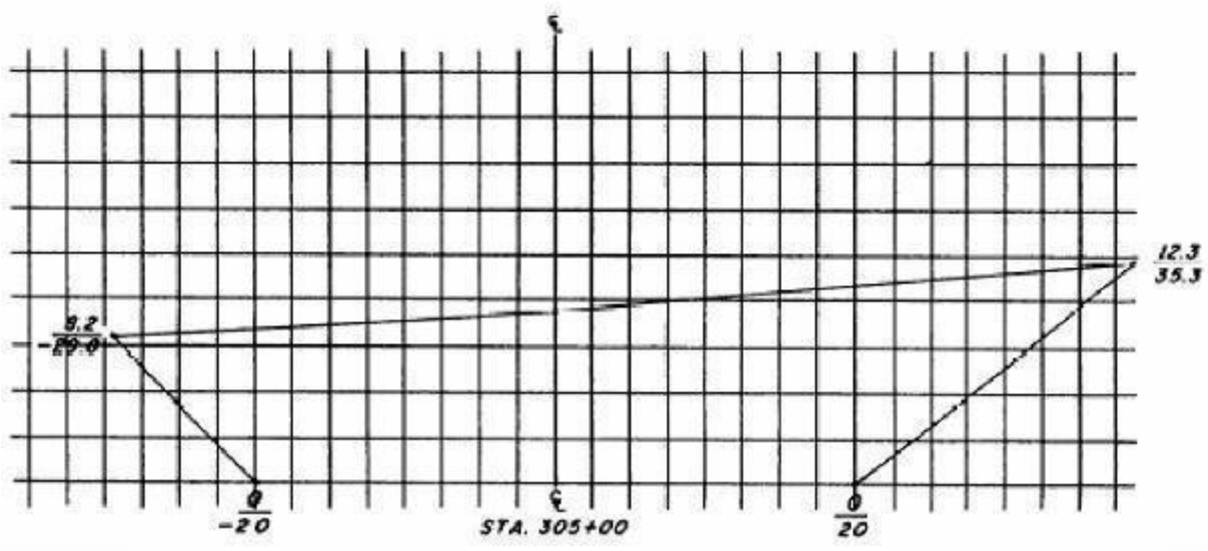


Figure10-6 for irregular sections (https://www.brainkart.com/article/Traverse-(surveying)-and-Types-Of-Traverse_4614/)

Figure 10-5.-Cross section resolved into triangles and trapezoids.

$$A = w/4.\ (h_1+h_2) + C/2.\ (d_1+d_2)$$

the formula for station 305 + 00 (fig. 10-4), you get the following results:

A = ***(40/4) (8.2+ 12.3) + (9.3/2) (29.8+ 35.3) = 507.71*** square feet.

AREA OF FIVE-LEVEL OR IRREGULAR SECTION. –

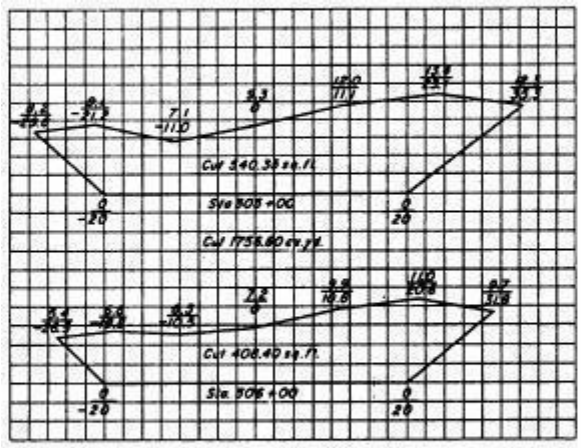


Fig- Irregular Section

(https://www.brainkart.com/article/Traverse-(surveying)-and-Types-Of-Traverse_4614/)

Figures 10-6 and 10-7 are The field notes and plotted cross sections for two irregular sections. To determine the area of sections of this kind, you should use a method of determining area by coordinates. For explanation purpose, let's consider station 305 (fig. 10-6). First, consider the point where the center line intersects the grade line as the point of origin for the coordinates. Vertical distances above the grade line are positive *Y* coordinates; vertical distances below the grade line are negative *Y* coordinates. A point on the grade line itself has a *Y* coordinate of 0. Similarly, horizontal distances to the right of the center line are positive *X* coordinates; distances to the left of the center line are negative *X* coordinates; and any point on the center line itself has an *X* coordinate of 0. Plot the cross section, as shown in figure 10-7, and be sure that the *X* and *Y* coordinates have their proper signs. Then, starting at a particular point and going successively in a clockwise direction, write down the coordinates, as shown in figure 10-8.

After writing down the coordinates, you then multiply each **upper term** by the **algebraic** difference of the **following** lower term and the **preceding** lower term, as indicated by the direction of the arrows (fig. 10-8). The algebraic sum of the resulting products is the **double** area of the cross section. Proceed with the computation as follows:

8.2[–21.2 – (–20.0)]	=		–9.8
9.1[–11.0 – (–29.8)]	=	+171.1	
7.1[0 – (–21.2)]	=	+150.5	
9.3[11.1 – (–11.0)]	=	+205.5	
12.0[23.1 – 0]	=	+277.2	
13.4[35.3 – 11.1]	=	+324.3	
12.3[20.0 – 23.1]	=		–38.1
		+1,128.6	–47.9
		– 47.9	
		1,080.7	

Since the result (1,080.70 square feet) represents the **double** area, the area of the cross section is one half of that amount, or 540.35 square feet. By similar method, the area of the cross section at station 306 (fig. 10-7) is 408.40 squarefeet.

EARTHWORK VOLUME. –

As discussed previously, when you know the area of two cross sections, you can multiply the average of those cross-sectional areas by the known distance between them to obtain the volume of earth to be cut or filled. Consider figure 10-9 that shows the plotted cross sections of two side hill sections. For this figure, when you multiply the average-end area (in fill) and the average- end area (in cut) by the distance between the two stations (100 feet), you obtain the estimated amount of cut and fill between the stations. In this case, the amount of space that requires filling is computed to be approximately 497 cubic yards and the amount of cut is about 77.40 cubic yards.

MASS DIAGRAMS. –

A concern of the highway designer is economy on earthwork. He wants to know exactly where, how far, and how much earth to move in a section of road. The ideal situation is to balance the cut and fill and limit the haul distance. A technique for balancing cut and fill and determining the

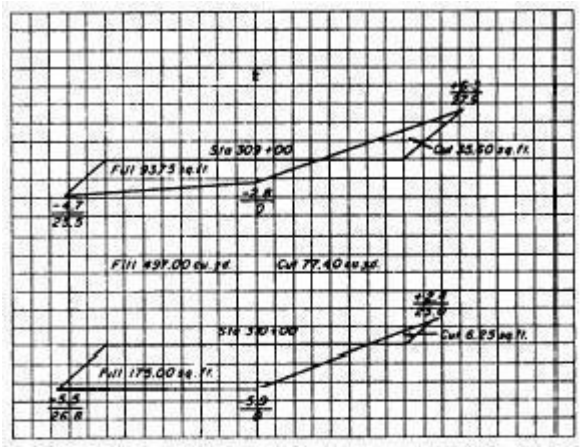
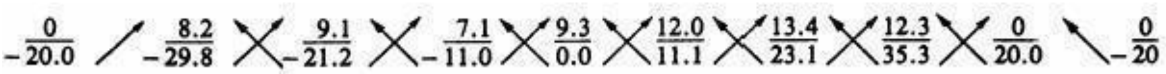


Figure 10-9.-Plots of two sidehill sections.

(https://www.brainkart.com/article/Traverse-(surveying)-and-Types-Of-Traverse_4614/)



A **mass diagram** is a graph or curve on which the algebraic sums of cuts and fills are plotted against linear distance. Before these cuts and fills are tabulated, the swells and compaction factors are considered in computing the yardage. Earthwork that is in place will yield more yardage when excavated and less yardage when being compacted. An example of this is sand: 100 cubic yards in place yields 111 cubic yards loose and only 95 cubic yards when compacted. Table 10-1 lists conversion factors for various types of soils. These factors should be used when you are preparing a table of cumulative yardage for a mass diagram. Cuts are indicated by a rise in the curve and are considered positive; fills are indicated by a drop in the curve and are considered negative. The yardage between any pair of stations can be determined by inspection. This feature makes the mass diagram a great help in the attempt to balance cuts and fills within the limits of economic haul.

The limit of economic haul is reached when the cost of haul and the cost of excavation become equal. Beyond that point it is cheaper to waste the cut from one place and to fill the adjacent hollow with material taken from a nearby borrow pit. The limit of economic haul will, of course, vary at different stations on the project, depending on the nature of the terrain, the availability of equipment, the type of material, accessibility, availability of manpower, and other considerations.

Components and their functions of Theodolite

A compass measures the direction by measuring the angle between the line and a reference direction, which is the magnetic meridian. A compass can measure angles up to an accuracy of 30" and by judgement up to an accuracy of 15'. The principle of working of the compass is based on the property of the magnetic needle, which when freely suspended, takes the north-south direction. Compass measurements are thus affected by external magnetic influences and therefore a compass is unsuitable in some areas. In this here, we will discuss another method of measuring directions of lines; a theodolite is very commonly used to measure angles in survey work

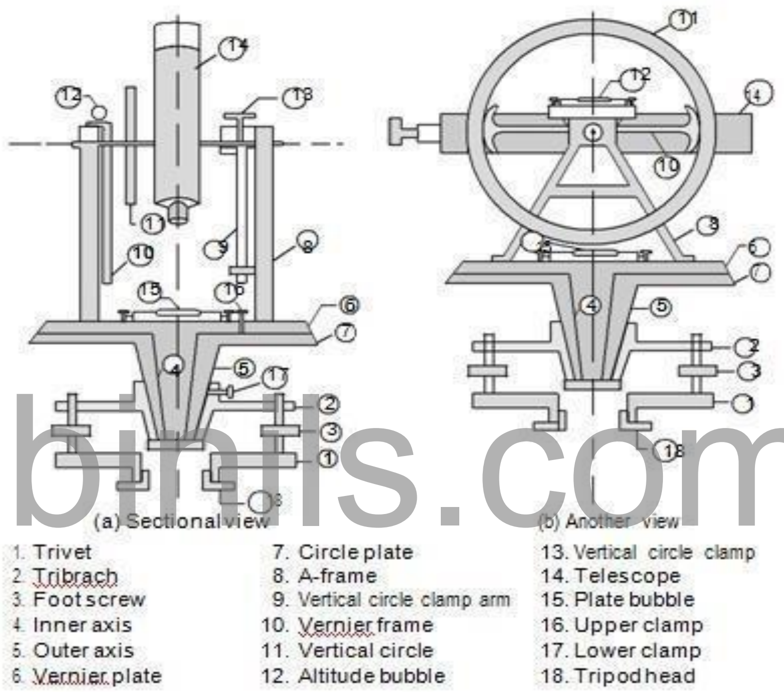
There are a variety of theodolites-vernier, optic, electronic, etc. The improvements (from one form to the other) have been made to ensure ease of operation, better accuracy, and speed. Electronic theodolites display and store angles at the press of a button. This data can also be transferred to a computer for further processing. We start our discussion with the simplest theodolite-the vernier theodolite.

The vernier theodolite is a simple and inexpensive instrumenting but very valuable in terms of measuring angles. The common vernier theodolite measures angles up to an accuracy of 20" in a compass, where the line of sight is simple, restricting its range, theodolites are provided with telescopes which provide for much greater range and better ac-curacy in sighting distant objects. It is, however, a delicate instrument and needs to be handled carefully. The theodolite measures the horizontal angles between lines and can also measure vertical angles. The horizontal angle measured can be the included angle, deflection angle or exterior angle in a traverse. The vertical angle is the angle in a vertical plane between the inclined line of sight of the instrument and the horizontal. In the following sections we will discuss the vernier theodolite as well as its applications in surveying.

Vernier Theodolite

The vernier theodolite is also known as a *transit*. In a transit theodolite or simply transit the telescope can be rotated in a vertical plane. Earlier versions of theodolites were of the non- transit type and are obsolete now. Only the transit theodolite will be discussed here.

Two different views of a vernier theodolite are shown in Figs 6.1(a) and following. The instrument details vary with different manufacturers but the essential parts remain the same. The main parts of a theodolite are the



(a) Sectional view *(b) Another view*

1. Trivet
13. Vertical circle clamp

2. Tribrach 8. A-frame 14. Telescope

3. Foot screw 9. Vertical circle clamp arm 15. Plate bubble

4. Inner axis 10. Vernier frame 16. Upper clamp

5. Outer axis 11. Vertical circle 17. Lower clamp

6. Vernier plate 12. Altitude bubble 18.Tripod head
7. Circle plate

Fig. 6.1 *Vernier theodolite*
(https://www.brainkart.com/article/Vernier-Theodolite_4632/)

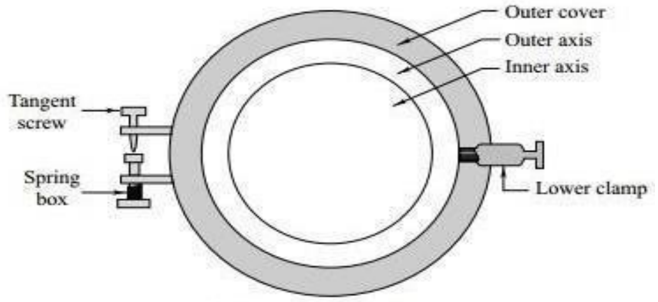
Levelling head, the levelling head is the base of the instrument. It has the provision to attach the instrument to a tripod stand while in use and attach a plumb bob along the vertical axis of the instrument. The levelling head essentially consists of two triangular plates kept a distance apart by levelling screws. The upper plate of the levelling head, also known as the *tribrach*, has three arms, each with a foot screw. Instruments with four foot screws for levelling are also available. In terms of wear and tear, the three-foot-screw instrument is preferable. The lower plate, also known as the *trivet*, has a central hole and a hook to which a plumb bob can be attached. In modern instruments, the base plate of the levelling head has two plates which can move relative to each other. This allows a slight movement of the level-ling head relative to the tripod. This is called a *shifting head* and helps in centering the instrument over the station quickly. The functions of the levelling head are to support the upper part of the instrument, attach the theodolite to a tripod, attach a plumb bob, and help in levelling the instrument with the foot screws.

Lower plate The lower plate, also known as the *circle plate*, is an annular, Horizontal plate with a beveled graduated edge fixed to the upper end of a hollow cylindrical part. The graduations are provided all around, from 0 ^{o} to 360 ^{o}, in the clockwise direction. The graduations are in degrees divided into three parts so that each division equals 20". An axis through the centre of the plate is known as the outer axis or the centre. Horizontal angles are measured with this plate. The diameter of the lower plate is sometimes used to indicate the size of or designate the instrument; for example, a 100-mm theodolite.

Upper plate The upper plate is also a horizontal plate of a smaller diameter attached to a solid, vertical spindle. The beveled edge of the horizontal part carries two verniers on diametrically opposite parts of its circumference. These verniers are generally designated A and B. They are used to read fractions of the horizontal circle plate graduations. The centre of the plate or the spindle is known as the inner axis or centre. The upper and lower plates are enclosed in a metal cover to prevent dust accumulation. The cover plate has two glass windows longer than the vernier length for the purpose of reading. Attached to the cover plate is a metal arm hinged to the centre carrying two magnifying glasses at its ends. The magnifying glasses are used to read the graduations clearly.

Two axes or centres The inner axis as mentioned earlier is the axis of the conical spindle attached to the upper or vernier plate. The outer axis is the centre of the hollow cylindrical part attached to the lower or circle plate. These two axes coincide and form the vertical axis of the instrument, which is one of the fundamental lines of the theodolite.

Clamps and tangent screws There are two clamps and associated tangent or slow-motion screws with the plates. The clamp screws facilitate the motion of the instrument in a horizontal plane. The lower clamp screw locks or releases the lower plate. When this screw is unlocked, the lower and upper plates move together. The associated lower tangent screw allows small motion of the plates in the locked position. The upper clamp screw locks or releases the upper vernier plate. When this clamp is released (with the lower clamp locked), the lower plate does not move but the vernier plate moves with the instrument. This causes a change in the reading. The upper tangent screw allows for a small motion of the vernier plate for fine adjustments. When both the clamps are locked, the instrument cannot move in the horizontal plane. The construction of the clamp and tangent screws is shown in Fig. 6.2.



(a) Clamp and tangent screw

(b) Vertical circle graduations (20′ main scale)

(https://www.brainkart.com/article/Vernier-Theodolite_4632/)

Plate level The plate level is a spirit level with a bubble and graduations on the glass cover. A single level or two levels fixed in perpendicular directions may be provided. The spirit level can be adjusted with the foot screw of the levelling head. The bubble of the spirit level can be moved with the foot screws of the levelling head, which is a very fundamental adjustment required for using the theodolite. A small circular bubble may be provided for rough adjustment before levelling.

Index frame The index frame, also known as a T-frame or vernier frame, is a T-shaped metal frame. The horizontal arm carries at its ends two verniers, which remain fixed in front of the vertical circle. These verniers are generally designed C and D. The vertical leg of the T-frame, known as the clipping arm, has clipping screws with which the frame can be titled. The altitude level is generally fixed on top of this frame. When the telescope is rotated in a vertical plane, the vertical circle moves and vertical angles are measured on the vertical circle with the help of these verniers.

Standard or A-frame Two standards in the shape of the letter A are attached to the upper plate. The horizontal axis of the instrument is attached to these standards. The clipping arm of the index frame and the arm of the vertical circle clamp are also attached to the A-frame. The A-frame supports the telescope and the vertical circle.

Telescope The telescope is a vital part of the instrument. It enables one to see stations that are at great distances. The essential parts of a telescope are the eye-piece, diaphragm with cross hairs, object lens, and arrangements to focus the tele-scope. A focusing knob is provided on the side of the telescope. Earlier, external focusing telescopes were used. Today, only internal focusing telescopes are used in theodolites. These reduce the length of the telescope. The telescope may carry a spirit level on top in some instruments.

Vertical circle The vertical circle is a circular plate supported on the trunnion or horizontal axis of the instrument between the A-frames. The vertical circle has a beveled edge on which graduations are marked. The graduations are generally quadrantal, 0 º -90 º in the four quadrants as shown in Fig. 6.2. The full circle system of graduations can also be seen in some instruments. The vertical circle moves with the telescope when it is rotated in a vertical plane. A metal cover is provided to protect the circle and the verniers from dust. Two magnifying glasses on metal arms are provided to read the circle and verniers. The cover has glass or plastic windows on which the magnifiers can bemoved.

Vertical circle clamp and tangent screw The vertical circle is provided with a clamp and tangent screw as in the case of the horizontal plate, upon clamping the vertical circle, the telescope cannot be moved in a vertical plane. The tangent screw allows for a slow, small motion of the vertical circle. Altitude level is used for levelling, particularly when taking vertical angle observations. A circular or trough magnetic compass is generally fitted to theodolite for measuring the magnetic bearing of lines. It is fitted on the cover of the horizontal plates. Two plates with graduations are provided in the compass box for ensuring that the needle ends are centred. The needle can be locked or released by a pin. When released, the telescope can be turned in azimuth to make the north end of the needle point to the north by making it read zero.

Tripod One accessory essential with the theodolite is the tripod on which it is mounted when it has to be used. The tripod head is screwed onto the base or the lower part of the levelling head. Its legs should be spread out for stability. The legs of the tripod are also used for rough levelling.

Plumb bob A heavy plumb bob on a good string with a hook at the end is required for centering the theodolite over a station. The plumb bob is fixed to the hook or other device projecting from the centre of the instrument in a central opening in the levelling head.

Main circle and Vernier graduations in most of the instruments, the vernier enables readings up to 20? of the arc. This is made possible by marking the graduations on the circle and the vernier suitably as follows. As shown in Fig. 6.2(b), the main circle is graduated into degrees and each degree is divided into three parts. Each main scale division thus represents 2 . For the vernier, 59 main scale divisions are taken and divided into 60 parts. 59 main scale divisions form 59 20 . Therefore, each vernier scale division represents

59 � 20/60 minutes. As you would have studied earlier, least count of the vernier = difference between a main scale division and a vernier scale division

= main scale division - vernier scale division. Hence, in this case,

Least count = 20 - 59 20/60 = 1/3 = (1/3) 60? = 20? Thus the least count of the vernier in common theodolites is 20"

Terminology of Theodolite

It is important to clearly understand the terms associated with the theodolite and its use and meaning. The following are some important terms and their definitions.

Vertical axis It is a line passing through the centre of the horizontal circle and perpendicular to it. The vertical axis is perpendicular to the line of sight and the trunnion axis or the horizontal axis. The instrument is rotated about this axis for sighting different points.

Horizontal axis It is the axis about which the telescope rotates when rotated in a vertical plane. This axis is perpendicular to the line of collimation and the vertical axis.

Telescope axis It is the line joining the optical centre of the object glass to the centre of the eyepiece.

Line of collimation It is the line joining the intersection of the cross hairs to the optical centre of the object glass and its continuation. This is also called the line of sight.

Axis of the bubble tube It is the line tangential to the longitudinal curve of the bubble tube at its centre.

Centering: Centering the theodolite means setting up the theodolite exactly over the station mark. At this position the plumb bob attached to the base of the instrument lies exactly over the station mark.

Transiting It is the process of rotating the telescope about the horizontal axis through 180 ^{o} . The telescope points in the opposite direction after transiting. This process is also known as *plunging* or *reversing.*

Swinging It is the process of rotating the telescope about the vertical axis for the purpose of pointing the telescope in different directions. The right swing is a rotation in the clockwise direction and the left swing is a rotation in the counter-clockwise direction.

Face-left or normal position This is the position in which as the sighting is done, the vertical circle is to the left of the observer.

Face-right or inverted position This is the position in which as the sighting is done, the vertical circle is to the right of the observer.

Changing face, it is the operation of changing from face left to face right and vice versa. This is done by transiting the telescope and swinging it through180 ^{o} .

Face-left observation It is the reading taken when the instrument is in the normal or face-left position.

Face-right observation It is the reading taken when the instrument is in the inverted or face- right position.

2.2 Temporary Adjustments of Theodolite

Theodolite has two types of adjustments-temporary and permanent. Temporary adjustments are to be done at every station the instrument is set up. Permanent adjustments deal with the fundamental lines and their relationships and should be done once in a while to ensure that the instrument is properly adjusted. The fundamental lines and their desired relationships are explained later in this chapter and the permanent adjustments are explained in detail in Chapter 4. In this section we will discuss temporary adjustments.

The temporary adjustments are the following:

(a) setting up and centering,

(b) levelling,

(c) focusing the eyepiece, and

(d) focusing the objective.

Setting Up and Centering

The following procedure is adopted for this operation.

1. Remove the theodolite from its box carefully and fix it onto a tripod kept over the station where the instrument is to be set up. The tripod legs should be well apart and the telescope should be at a convenient height for sighting.

2. Tie a plumb bob onto the hook provided at the base. If there is no shifting head in the instrument, Centre it by adjusting the tripod legs and shifting the instruments as a whole to bring the plumb bob over the station mark.

3. To centre the plumb bob, shift the tripod legs radially as well as circumferentially. *Moving any leg radially shifts the plumb bob in the direction of the leg*. This does not affect the level status of the instrument. *Moving any leg circumferentially does not appreciably shift the plumb*. However, this movement tilts the instrument and affects the level of the plate bubbles. By moving the legs, the plumb bob is brought

over the station mark at the same time ensuring that the instrument is approximately level. This saves a lot of time for the next operation of levelling.

4. If the instrument has a shifting head with a clamp, first centre the instrument using legs. Make the final adjustment by loosening the clamp and shifting the head (or the instrument as a whole) to bring the plumb bob over the station mark. In all operations, the starting step should be to first bring the plumb bob very close to the mark and then make the final adjustment using the legsor the shifting head.

Levelling

After setting up and centering the instrument, levelling is done. Levelling has To be done at every station the instrument is set up. By levelling the instrument, it is ensured that as the instrument is swung about the vertical axis, the horizontal plate moves in a horizontal plane. The instrument may have a three-screw or a four-screw levelling head. The levelling operations differ slightly in these two cases as detailed in the following sections. Most instruments have only one bubble tube, but some instruments have two bubble tubes set at right angles over the plates.

Three-screw levelling head

When the theodolite has a three-screw levelling head, the following procedure is adopted.

1. Swing the theodolite and bring the plate bubble parallel to any two of the foot screws. Centre the bubble by rotating the foot screws. To do this, hold the foot screws by the unbind o reigned o each ch hand and *rotate both either inwards or outwards* [see Fig. 6.3(a)]. Also note that the bubble moves in the direction of movement of the left thumb during this operation.

2. Once the bubble traverses (or comes to the central position from the graduation of the tube), swing the instrument and bring the bubble over the third foot screw. In this position, the bubble tube is at right angles to the earlier position. Centre the bubble by rotating the third foot screw alone.

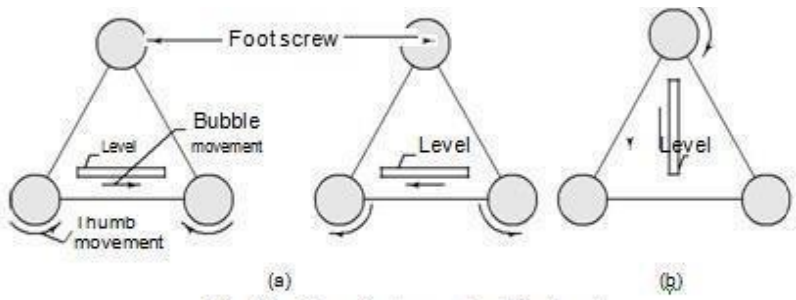


Fig. 6.3 Three-foot-screw levelling head

(*https://www.brainkart.com/article/Temporary-Adjustments-of-Theodolite_4634/*)

3. Bring the plate bubble to its previous position by swinging the instrument back. Check whether the bubble traverses. If it does not traverse, bring the bubble to the centre using the two foot screws as before.

4. Repeat the procedure till the bubble traverses in both these positions.

5. Swing the instrument through 180 o and check whether the bubble traverses. The bubble should traverse in all positions if the instrument has been properly adjusted.

If two plate bubbles are provided [see Fig. 6.3(b)], the procedure is the same except that swinging the instrument through 90 o is not required. When one plate level is kept parallel to a pair of foot screws, the other plate level is over the third foot screw (in a perpendicular direction). The third foot screw is adjusted alternately by the same process using the foot screws over which they are parallel.

Four-screw leveling head

When the theodolite has a four-screw levelling head, the following procedure is adopted.

1. After setting up and centering the theodolite, bring the plate level parallel to any one pair of diagonally opposite foot screws. Operate these foot screws to centre the bubble (Fig. 6.4).

2. Swing the instrument to bring the plate level parallel to the other pair of foot screws. Centre the bubble.

3. Swing it back to the previous position. Check whether the bubble traverses. If it does not, centre it with the foot screws to which the level is parallel.

4. Swing it back, check the position of the bubble, and repeat the procedure.

5. Once the bubble traverses in the two orthogonal positions, swing it through 180 °. The bubble should traverse in this position or in any other position.

If two plate levels are provided, the procedure is the same. Bring one plate level parallel to a pair of opposite foot screws. The other pair will be parallel to the remaining pair of foot screws. There is no need to swing the instrument. Bring the bubble to the central position alternately and check in the other positions.

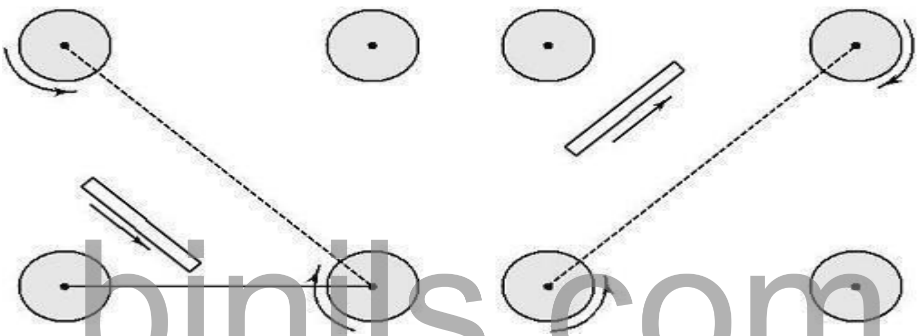


***Fig. 2.2.2** Four-foot-screw leveling head*

(*https://www.brainkart.com/article/Temporary-Adjustments-of-Theodolite_4634/*)

Focusing the Eyepiece

Focusing the eyepiece is the operation of bringing the cross hairs to focus. The focusing position varies with the eyesight of the observer. If the same observer is taking the readings, this has to be done only once. To focus the eyepiece, use the following procedure.

1. Keep a piece of white paper in front of the telescope or direct the telescope towards a clear portion of the sky.

2. Looking through the telescope, adjust the vision by rotating the eyepiece till the cross hairs come into sharp and clear view.

3. If the eyepiece has graduations, note the graduation at which you get a clear view of the cross hairs. This can help in later adjustment if required.

2.3 Measurement of Horizontal and Vertical Angles in Theodolite

The objective lens has to be focused whenever an object is sighted, as this depends upon the distance between the instrument and the object. A focusing screw on the side of the telescope is operated to focus the objective. This operation brings the image of the object in the plane of the cross hairs. This helps to exactly bisect the object, be it a ranging rod or an arrow. To focus the objective, swing the instrument to bring the object into view by looking over the telescope. Rotate the focusing knob till the object is in sharp view along with the cross hairs.

Using the Theodolite

The theodolite is mainly used to measure horizontal and vertical angles, even though many other operations can be done with the instrument. It is a delicate and sensitive instrument and needs to be handled carefully. The following points should be noted while using the instrument.

1. The theodolite should be set up and levelled at every station. This is a fundamental, necessary operation and should be carried out carefully.
2. In measuring horizontal angles, the inclination of the telescope is not significant The line of sight is arranged to bisect the object clearly.
3. The graduated circle plate gives the outer axis and the vernier plate provides the inner axis. Both the axes coincide if the instrument is properly adjusted and form the vertical axis.
4. There are three clamp screws each with its own tangent screw. The *lower clamp* screw releases the lower plate, the *upper clamp* screw releases the upper vernier plate, and the third vertical circular clamp releases the vertical circle. One should be familiar with the location of the clamp screws and the corresponding tangent screws.

5. Each clamp screw releases one plate. The lower plate is released by the lower clamp screw. When this plate is released, swinging the instrument or rotating it in a horizontal plane causes no change in the reading of the circle, as both the plates move together. This is used when an object has to be sighted with the zero setting of the circle or with any other reading without changing the reading.

6. Both the clamp screws should not be released together. When the lower clamp is tight and the upper clamp screw is released, the upper plate moves relative to the lower plate and the reading changes. This is done when one has to measure an angle.

7. The clamp screws should be tightened very near to their final position so that only a very small movement has to be effected by the tangent screw. For each clamp screw, the corresponding tangent screw should be for final adjustment.

8. To set the instrument to zero at the plate circle, release the upper clamp and rotate the instrument about the vertical axis. On the vernier A, make the zero of the circle coincide with the zero of the vernier. Tighten the upper clamp and using the upper tangent screw, make the zeros exactly coincide. This can be verified by looking through the magnifying glasses and seeing that the graduations on either side are symmetrical. Verify the condition on vernier B as well, where the 180 o graduation should coincide with the zero of the vernier.

9. While bisecting the signals or setting the zero reading, keep the line of sight in such a position that the tangent screw moves the sight in the same direction as the movement of the instrument. If the movement is clockwise, then the tangent screw is adjusted to move the cross hairs from left to right.

10. Operate a tangent screw only after clamping the corresponding clamp screw.

11. The magnifying glasses are so fixed that they can be moved along the circle. Read the circle by bringing the glass over the reading and looking directly over the reading to avoid any parallax error.

While bisecting stations with the theodolite, the station mark should be very clearand must be a point. Bisect either the cross marks on pegs at their inter-section or the ranging rod and arrow at their lowest pointed end.

12. Clamp screws and tangent screws need careful handling. Do not apply great force on these screws and handle them delicately during survey work.

Measuring Horizontal Angles

To measure the horizontal angle between two lines, the following procedure is adopted.

1. Referring to Fig. 6.5, the angle POQ is to be measured. Set up the theodolite at O.

2. Set the instrument to read 0 ° 00' 00''. This is not strictly required, as the angle can be determined as the defrauding's. However, it is convenient to make the initial reading zero. For this, release the upper clamp and O rotate the instrument to make the Q reading approximately zero. Clamp the upper plate and using the upper Fig. 6.5 Measuring a horizontal angle tangent screw, make the reading compass exactly zero. Vernier A reads zero and vernier B reads 180 ° 00' 00''

3. Release the lower plate and rotate the instrument to bisect the station P. After approximately bisecting it, clamp the lower plate and using the lower tangent screw, bisect the signal exactly. The readings on the plates do not change as both the plates move together in this operation. Check that the readings on vernier A and B are zero and 180°, respectively.

4. Release the upper plate by loosening the upper clamp. Rotate the instrument to screw, exactly bisect the signal at Q. Read both the verniers A and B. The reading at A will give the angle directly. The reading at B will be 180 ° + -POQ.

5. If there is any difference, take the average of the two values as the correct angle. Horizontal angles are measured this way for ordinary work. The accuracy can be improved by reading the angles with face-left and face-right observations and taking the average of the two. For more precise work, the angles are repeatedly measured with both the faces and the average taken. This method is known as the *repetition method* and is described below.

Method of Repetition in Theodolite

In the method of repetition, the horizontal angle is measured a number of times and the average value is taken. It is usual to limit the number of repetitions to three with each face except in the case of very precise work. With large number of repetitions, errors can also increase due to bisections, reading the Vernier's, etc. Very large number of repetitions necessarily do not lead to a more precise value of the angle. However, a number of errors are eliminated by the repetition method. The procedure is as follows (Fig. 6.6).

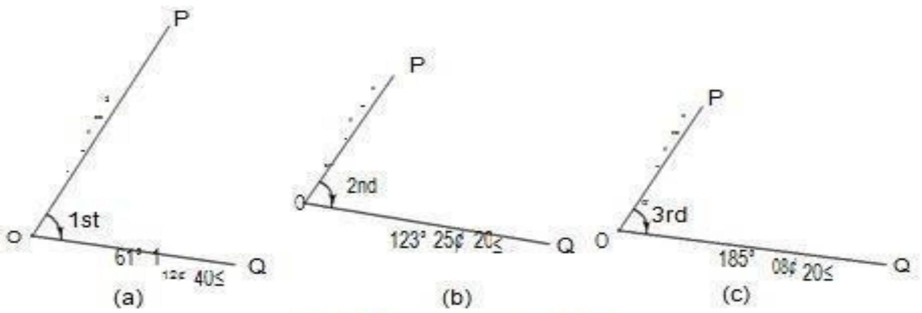


Fig. 6.6 Repetition method

(https://www.brainkart.com/article/Method-of-Reiteration-in-Theodolite_4637/)

1. Angle POQ is to be measured. Set up, centre, and level the theodolite at O. Ensure that the instrument is in the normal position, i.e., face left.

2. Set the instrument to read 0 ° 00' 00". For this release the upper clamp and bring the zero of the vernier (at vernier A) very close to the zero of the circle. Clamp the upper plate and using the upper tangent screw, coincide the two zeros exactly.

3. Loosen the lower clamp and rotate the instrument so that the left signal at P is approximately bisected. Tighten the lower clamp and using the lower tangent screw, bisect the signal at P exactly. Read the verniers at A and B. The reading should not change and they should read zero and 180 °

4. Loosen the upper clamp and rotate the instrument clockwise to bisect the right signal at Q. Using the upper tangent screw, bisects the signal at approximately Q exactly.

5. Read the verniers at A and B. The reading at A gives the value of the angle directly. The reading on the vernier at B will be 180 ° + the angle. Record both the readings.

6. Release the lower clamp and rotate the instrument clockwise to bisect the sig-mal at the left station P again. Using the lower tangent screw, bisect the signal

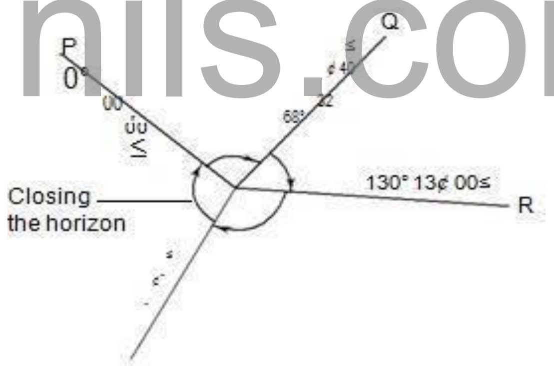


Fig- Reiteration method

(https://www.brainkart.com/article/Method-of-Reiteration-in-Theodolite_4638/)

The method of repetition helps to eliminate the following errors.

(a) Errors caused by the eccentricity of the centers and verniers, by reading both the verniers and averaging.

(b) Graduation errors by reading from different parts of the circle.

(c) Imperfect adjustment of the line of collimation and horizontal axis by face- left and face- right observations.

(d) Observational errors and other errors tend to be compensated by the large number of readings.

However, the errors due to levelling cannot be compensated. This has to be done by permanent adjustment. Also a large number of repetitions tend to increase the wear of clamp and tangent screws.

Therefore, from the two sets,

Mean value of the angle = (1/2)(61 ^{o} 42' 47"+ 61 ^{o} 42' 40") = 61 ^{o} 42' 44"

Method of Reiteration in Theodolite

The method of reiteration is another method of measuring horizontal angles. This method is useful when a number of angles are to be measured at one point. In Fig. 6.7, let O be the point where the instrument is set up and P, Q, R, and S be the stations. Angle POQ, QOR, and ROS are to be measured. In the reiteration method, each angle is measured in succession and finally the line of sight is brought back to P, i.e., the line of sight is made to close the horizon. The instrument is turned through 360 ^{o} . Obviously, the instrument should read, upon closing the horizon, the same reading set initially at P. The procedure is as follows.

1. Set up and level the theodolite at O. Keep the instrument in the normal position, i.e., face left. Set the vernier at A to read zero using the upper clamp and upper tangent screw. Check that the vernier at B reads 180 ^{o} .

2. Loosen the lower clamp and swing the instrument to bisect the station mark P Tighten the screw and using the lower tangent screw finally bisect the signal at P. Check that the verniers at A and B read zero and 180 ^{o} , respectively.

3. Release the upper plate with the upper clamp, swing the instrument clockwise to bisect the signal at Q. Tighten the clamp and using the upper tangent screw, bisect the mark at Q exactly.

4. Read the verniers at A and B and record both the readings.

5. Release the upper clamp screw, bisect the signal at R. Tighten the clamp and bisect the mark at R exactly with the upper tangent screw. Read the verniers at A and B and record the readings.

Continue the procedure with other stations.

-POQ = 68 º 32' 30" -QOR = 61 º 41' 10" -ROS = 102 º 54' 20".

Measuring Vertical Angles in Theodolite

A vertical angle is made by an inclined line of sight with the horizontal. The line of sight may be inclined upwards or downwards from the horizontal. Thus one may have an angle of elevation or depression. See Fig. 6.8. For measuring vertical angles, the theodolite is levelled with respect to the altitude bubble.

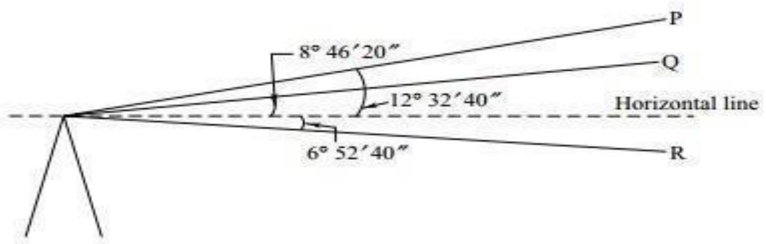


Fig. 6.8 Measuring vertical angles

(https://www.brainkart.com/article/Measuring-Vertical-Angles-in-Theodolite_4638/)

1. Set up the theodolite at the station from where the vertical angle is to be measured.Level the instrument with reference to the plate bubble.

2. Further level the instrument with respect to the altitude level fixed on the index rm. This bubble is generally more sensitive. The procedure for levelling is the same. Bring the altitude level parallel to two foot screws and level till the bubble traverses. Swing through 90º to centre the bubble again with the third foot screw. Repeat till the bubble traverses.

3. Swing the telescope to approximately direct the line of sight towards the signal at P. Loosen the vertical circle clamp screw and incline the line of sight to bisect P. Clamp the vertical circle and bisect the signal exactly with the horizontal cross hair.

4. Read the verniers C and D. The average of these readings gives the value of the angle.

This procedure assumes that the instrument is properly adjusted. If there is an index error, the instrument does not read zero when the bubble is in the centre and the line of sight is horizontal, the adjustment is done by the clip screw. There may be a small index error, which can be accounted for in the value of angle. The readings can be recorded as shown in Table 6.7.

Measuring Vertical Angle Between Two Points

The two points may be above the horizontal or below the horizontal or one may be above and the other below. In all cases, the vertical angles between the instrument and the points are measured. If the points lie on the same side of the horizontal, the vertical angle between the points is the difference between the measured angles. If they lie on either side of the horizontal through the instrument, the vertical angle between the points is the sum of the angles measured.

Table 6.7 Recording of observations Face left

(https://www.brainkart.com/article/Measuring-Vertical-Angles-in-Theodolite_4639/)

Instrument at	Sight to	Reading on vernier A	B				Angle	Horizontal angle		
		°	¢	≤	¢	≤		°	¢	≤
O	P	00	00	00	00	00				
	Q	62	43	40	43	40	POQ	62	43	40
	R	120	38	00	38	00	QOR	57	54	20
	S	192	53	40	53	40	ROS	72	15	40
	T	273	15	00	15	20	SOT	80	21	10
	P	359	59	40	59	40	TOP	86	44	50

Interconversion of Angles

The theodolite measures the whole circle bearings of lines. These can be converted to reduced bearings by the methods discussed in Chapter 3. Also, one can calculate included angles from bearings and vice versa. Included angles can also be calculated from deflection angles and vice versa.

The following relationships of the angles of a closed traverse are known from geometry:

(a) sum of the interior angles = (2*n* - 4) right angles

(b) sum of exterior angles = (2*n* + 4) right angles

(c) sum of the deflection angles = 4 right angles

It is desirable to draw a rough sketch of the traverse before attempting to solve problems. The following examples illustrate these principles.

Locating Landscape Details with the Theodolite

We have discussed so far methods to survey the main frame or the skeleton of the survey. In most surveys, it is necessary to locate details such as buildings, railway lines, canals, and other landmarks along with the survey. A transit with a steel tape is used to locate details, and many methods are available, as the transit is an angle-measuring instrument. The following methods can be used.

Angle and distance from a single station

A point can be located with an angle to the station along with the distance from that station as shown in Fig. 6.28(a). The angle is preferably measured from the same reference line to avoid confusion. A sketch with the line and the distance and angle measured will help in plotting later. A road can be located as shown in Fig. 6.28(b). Angles to a number of points are measured and with each angle two distances are measured to locate the road.

Angle from one station and distance from another

If for any reason, it is not possible to measure the angle and distance to an object from the same point, it may be possible to locate the point by measuring angles from one station and distances from the other. The recorded data should clearly indicate the stations from which the angle and distance are measured. Figure 6.28(c) shows this method of measuring. The angle is measured from station A to point P. When the instrument is shifted to B, the distance to point P is measured from B with a steel tape.

Angles from two stations

If for some reason, it is not possible to measure distances, then angles from two stations are enough to locate a point. As shown in Fig. 6.28(d), the point P is located by measuring angles to point P from stations A and B.

The following are the fundamental lines.

1. The vertical axis
2. The horizontal or trunnion axis
3. The line of collimation or line of sight
4. Axis of altitude level
5. Axis of plate level

The meaning of these terms has been discussed earlier. The axes are shown in Fig. 6.29. When the instrument is properly adjusted, the relationships between these axes are the following.

(a) The horizontal axis must be perpendicular to the vertical axis.

(b) The axis of the plate level must be perpendicular to the vertical axis.

(c) The line of collimation must be at right angles to the horizontal axis.

(d) The axis of the altitude level (and telescope level) must be parallel to the line of collimation.

(e) The vertical circle vernier must read zero when the line of sight is horizontal.

Each one of these relations gives conditions for accurate measurement.

(a) When the horizontal axis is perpendicular to the vertical axis, the line of sight generates a vertical plane when transited.

(b) When the axis of the plate level is perpendicular to the vertical axis, the vertical axis will be truly vertical when the bubble traverses.

(c) When the line of collimation is at right angles to the horizontal axis, the telescope when rotated about the horizontal axis will move in a vertical plane.

(d) When the line of collimation and the axis of altitude level are parallel, the vertical angles will be measured without any index error.

(e) The index error due to the displacement of the vernier is eliminated when the vernier reads zero with the line of collimation truly horizontal.

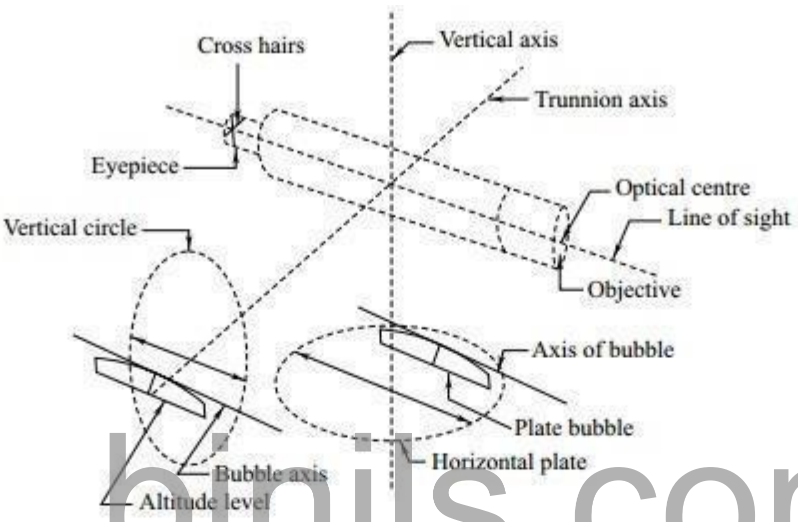


Fig. 6.29 Fundamental lines of a theodolite

(https://www.brainkart.com/article/Measuring-Vertical-Angles-in-Theodolite_4639/)

2.4 Tacheometric Surveying

Tacheometric is a branch of surveying in which horizontal and vertical distances are determined by taking angular observation with an instrument known as a tachometer. Tacheometric surveying is adopted in rough in rough and difficult terrain where direct leveling and chaining are either not possible or very tedious. The accuracy attained is such that under favorable conditions the error will not exceed 1/100. and if the purpose of a survey does not require accuracy, the method is unexcelled. Tacheometric survey also can be used for Railways, Roadways, and reservoirs etc. Though not very accurate. Tachometric surveying is very rapid, and a reasonable contour map can be prepared for investigation works within a short time on the basis of such survey. Uses of Tachometry Tachometry is used for preparation of topographic map where both horizontal and vertical distances are required to be measured; survey work in difficult terrain where direct methods of measurements are inconvenient; reconnaissance survey for highways and railways etc; Establishment of secondary control points. Instruments used in tachometric surveying an ordinary transits theodolite fitted with a stadia diaphragm is generally used for tacheometric surveying.

The stadia diaphragm essentially consists of one stadia hair above and the other an equal distance below the horizontal cross hair, the stadia hair being mounted in the same ring and in the same vertical plane as the horizontal and vertical cross-hair. The telescope used in stadia surveying are three kinds,

i).The Simple external focusing telescope.

ii).The external focusing anal lactic telescope (porro's telescope).

iii).The internal focusing telescope.

The first type is known as stadia theodolite, while the second type is known as tacheometer. The tacheometer has the advantage over the first and third type due to fact that the additive constant of the instrument is zero. The instruments employed in tachometry are the engineer's transit and the leveling rod or stadia rod, the theodolite and the subtense bar, the self-reducing theodolite and the leveling rod, the distance wedge and the horizontal distance rod, and the reduction tacheometer and the horizontal distance rod. Features of tacheometer or Characteristic of tacheometer The multiple constant (f/i) should have a normal value of 100 and the error contained in this value should not exceed 1 in 1000. The axial horizontal lines should be exactly midway between the other two lines. The telescope should be fitted with an anallatic lens to make the additive constant (f + d) exactly to zero. The telescope should be truly analectic. The telescope should be powerful having a magnification of 20 to 30 diameters. The Aperture of the object should be 35 to 45 mm in diameter. Levelling and Stadia Staff Rod For short distances, ordinary leveling staves are used. The leveling staff normally 4m long, and it can be folded with here parts. The graduations are so marked that a minimum reading of 0.005 or 0.001m can be taken. Different systems of Tacheometric Measurement The various systems of tacheometric survey may be classified as follows, The Stadia Method

i. Fixed Hair Method and

ii. Movable Hair Method

The Tangential System Measurements by means of special instruments. The principle is common to all system is to calculate the horizontal distance between two points A and B their deference in elevation, by observing 1) the angle at the instrument at A subtended by known short distance a long a staff kept at B and 2) the vertical angle to B from A Stadia systems In this systems staff intercepts, at a pair of stadia hairs present at diaphragm, are considered. The stadia system consists of two methods: a) Fixed-hair method and b) Movable-hair method Fixed-hair method In this method, stadia hairs are kept at fixed interval and the staff interval or intercept (corresponding to the stadia hairs) on the leveling staff varies. Staff intercept depends upon the distance between the instrument station and the staff. Movable- hair method In this method, the staff interval is kept constant by changing the distance between the stadia hairs. Targets on the staff are fixed at a known interval and the stadia hairs are adjusted to bisect the upper target at the upper hair and the lower target at the lower hair. Instruments used in this method are required to have provision for the measurement of the variable interval between the stadia hairs. As it is inconvenient to measure the stadia interval accurately, the movable hair method is rarely used. Non-stadia systems

This method of surveying is primarily based on principles of trigonometry and thus telescopes without stadia diaphragm are used. This system comprises of two methods:

(i) Tangential method and

(ii) (ii) Subtense bar method.

Fixed Hair Method

Case : 1 (When the line of sight is horizontal and staff is held Vertical)

Horizontal distance

D=KS +C

Here

D = Horizontal Distance

S=Staff intercept

K = Multiplying Constant

C=Additive constant

Example:1

The Following Reading were taken with a tacheometer on to a vertical staff, Calculate tacheometric constant

Horizontal Distance	**Stadia Reading(m)**		
45	**0.885**	**1.110**	**1.335**
60	**1.860**	**2.160**	**2.460**

D_1=KS_1+C--- (1)

D_2=KS_2+C---- (2)

D_1=KS_1+C

45=K(1.335 –0.885)+C

45=K(0.45)+C ---------- (3)

D_2=KS_2+C

60=K(2.460 –1.860)+C

60=K(0.6)+C

C=60-K(0.6) ------- (4)

Now put the value of eq 4 in eq 3,

45=K(0.45)+C (3)

45=K(0.45)+60 -K(0.60)

45–60=-0.15 K

-15=-0.15 K

K=100

Put the value of K in Eq no 3

45=K(0.45)+C

45=100 (0.45)+C

C=0

Example2

The stadia reading with horizontal sight at a vertical staff held 50 m away from the tacheometer were 1.385 and 2.380. the focal length of the object glass was 25cm. The distance between the object glass and trunion axis of a tacheometer was 15 cm. Calculate the stadia interval

D=KS+C

D=(f/i)S+(f+d) (1)

Here D=50m

S= 2.380–1.385= 0.995m

f = 25cm = 0.25m

d=15cm=0.15m

Put the all value in equation no1

50=((0.25x0.995)/i)+(0.25+ 0.15)

i=0.005m

i=5mm

Example 3

A staff held vertically at a distance of 50 m and100mfrom the centre of the theodolite with a stadia hair, the staff intercept with the telescope is 0.500 and 1.000 respectively. The instrument was then setup over a station P of RL 1850.95 m and the total height of instrument was 1.475m. The hair reading on a staff held vertically at station Q were 1.050, 1.900 and 2.750 with the line of sight horizontal. Calculate the horizontal distance of PQ and RL of Q point. Calculation of tacheometric constant

D=KS+C

50=K(0.005)+C------- (1)

100=K(1.000)+C ----(2)

50=K(0.005)+C--------- (1)

C=50–0.005K---------- (3)

Put the value of C in Eq 2

100=K(1.000)+C (2)

100=1.000K+50–0.005K

K=100

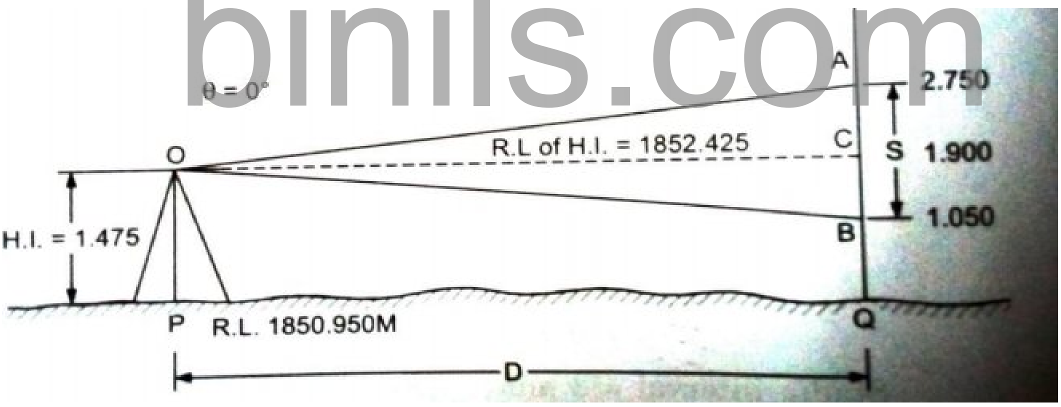
Now put the value of K in eq 3C=50 –0.005K (3

C=50–0.005(100)

C=0

Note: if K= 100 and C=0 means your instrument is perfect

Calculation of horizontal distance between PQ



D=KS+C (1)

Now

S=2.750–1.050=1.700m K=100

C=0

Put all thevalueinequationno1D=100 (1.700)+0

D=170m

Calculation of RL of Q point

RL of Q=1850.95+1.475–1.900

= 1850.525m

Fixed Hair Method

Case : 2 (When the line of sight is inclined and staff is held Vertical)

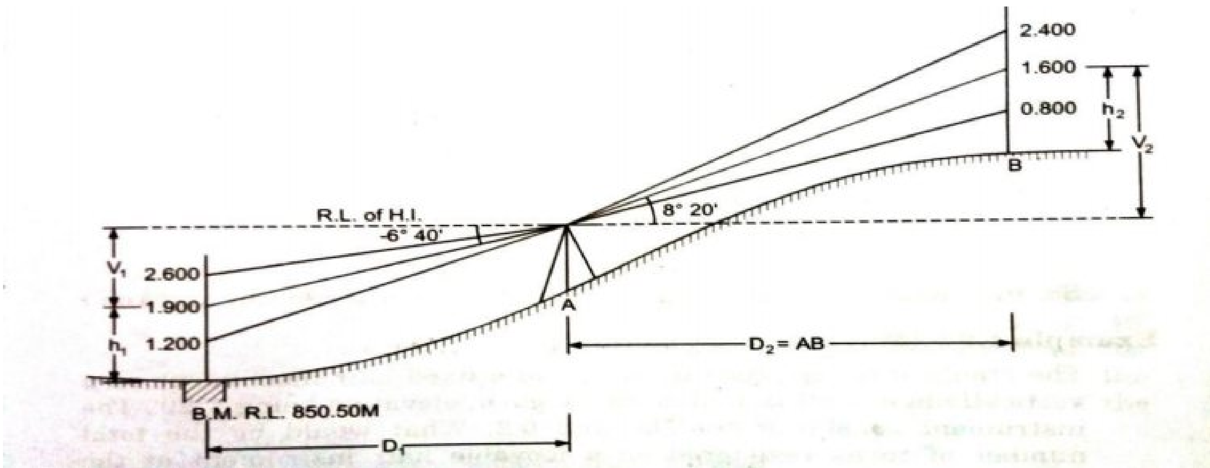
Horizontal distance $D = KS \cos^2 \theta + C \sin\theta$

Vertical Distance $V = KS \sin 2\theta/2 + C\sin\theta$

Example4

A tachometer was setup at a station A and the following readings were obtain on a staff held vertically, calculate the horizontal distance AB and RL of B, when the constant of instrument are 100 and 0.15

Inst. Station	Staff Station	Vertical angle	Hair Reading(m)			Remark
A	BM	$-6^0 40'$	1.200	1.900	2.600	RL of BM =850.50m
	B	$+8^0 20'$	0.800	1.600	2.400	



In the first observation

$S_1 = 2.600 - 1.200 = 1.400$m

$\Theta_1 = -6^o 40'$(Depression) K=100 and C=0.15

Vertical Distance $V_1 = KS \sin 2\theta/2 + C\sin\theta$

$= 100(1.400) \sin(2 \times 6^o 40')/2 + 0.15 \sin 6^o 40'$

=16.143 +0.0174

=16.160m

In the second observation

S_2 = 2.400 – 0.800 = 1.600Θ=+ 8 °20'(Elevation)

Vertical Distance V_2=KS Sin2θ/2+CSinθ

=100(1.600) sin(2x8 ° 20')/2 + 0.15Sin8 ° 20'

=22.944 +0.022

=22.966m

Horizontal distance D_2= KS Cos^2θ+ C Sinθ

= 100(1.600) $Cos^2$8 ° 20' + 0.15Sin8 ° 20'

=156.639+0.148

=156.787m

RL of Instrument Axis=RL of BM +h_1+V_1

=850.500+1.900+16.160

=868.560m

RL of B=RL of Inst.axis+V2–h2

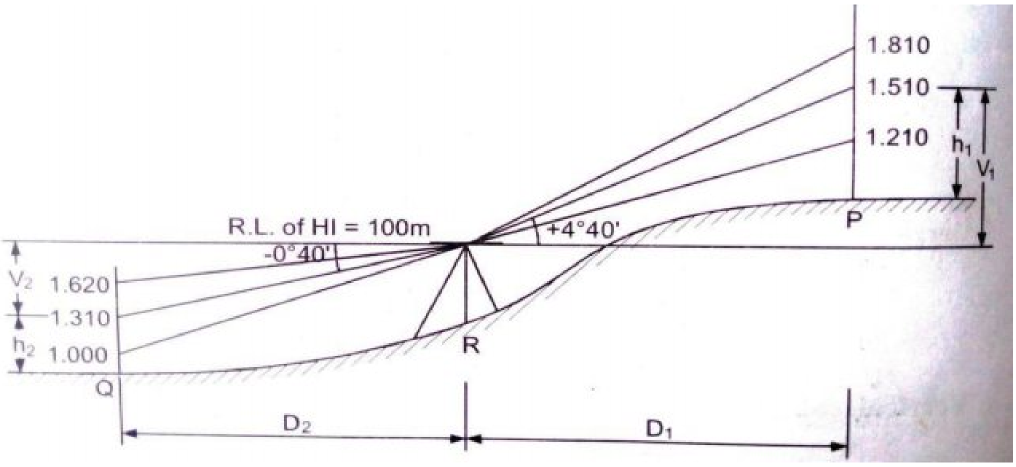
=868.560+22.966–1.600

RL of B =889.926m

Example5

To determine the gradient between w o point P and Q a tacheometer was set up at a R station and the following observation where taken keeping the staff held vertical, if the horizontal angle PRQ is 36 ° 20' determine the avg. Gradient between P and Q Point take K = 100 and C=0 and RL of H.I=100m

Staff station	**Vertical angle**	**Staff Reading**
P	$+4^0 40'$	1.210,1.510, 1.810
Q	$-0^0 40'$	1.000,1.310,1.620



In the first observation (From R to P)

S_1=1.810–1.210=0.6m

$\Theta_1 = +4^0 40'$

Horizontal distance

D=KS Cos²θ+ C Sinθ

=100x0.6 x $Cos^2 4^0 40'$ +0

=59.60m

Vertical Desistance

V=KSSin2θ/2+CSinθ

=100 x 0.6x Sin(2x$4^0$40')/2 +0

=4.865m

In the Second observation (From R to Q)

S_2=1.620–1.000=0.62m

$\Theta_2 = -0^0 40'$

Horizontal distance

D=KS Cos²θ +C Sinθ

=100x0.62 x $Cos^2 0^0 40'$ +0

=61.99m

Vertical Distance

V=KS Sin2θ/2+CSinθ

$= 100 \times 0.62 \times \sin(2\times 0^{0}\ 40')/2 \quad +0$

=0.721m

Avg. Gradient Between P and Q point

Difference of Elevation between P and Q

RL of P=RL of HI + $V_1 - h_1$

=100+4.865–1.510

=103.355m

RL of Q =RL of HI–$V_2 - h_2$

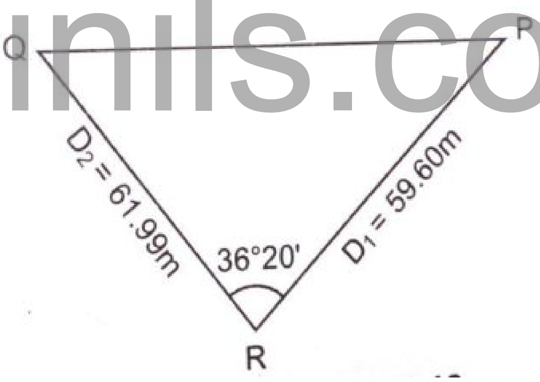
=100–0.721–1.310

=97.969m

Difference of RL of P& Q=103.355–97.969

=5.386

Average gradient between P and Q=Difference in RL between P&Q /Distance of P&Q



= 5.386/37.978

=1/7.051

Fixed Hair Method

Case : 3 (When the line of sight is inclined and staff is held Normal to the line of sign t)

If angle is +ve

Horizontal distance

D=KS Cosθ +C Cosθ +h Sinθ

Vertical Distance

V=KS Sinθ + C Sinθ

If angle is -ve

Horizontal distance

D=$KS\cos\theta + C\cos\theta - h\sin\theta$

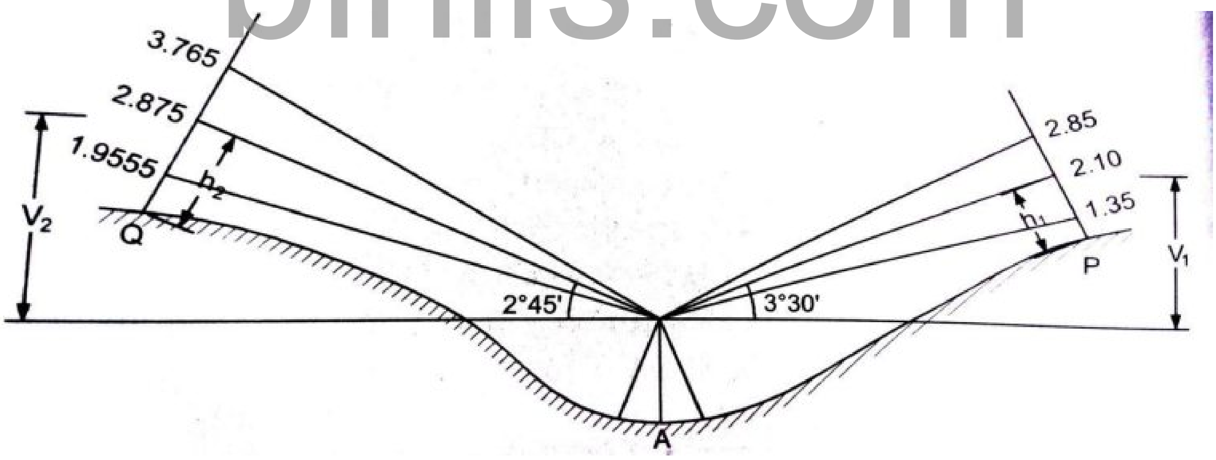
Vertical Distance

V=$KS\sin\theta + C\sin\theta$

Example 6

Find out the distance between P and Q by using the bellow data given in table, the staff held normal to the line of sight in both the cases value of the tacheometer constant is 100 and 0.3

Instrument	Staff at	Line	Bearing	Vertical angle	Hair Reading
A	P	AP	$84^0 36'$	$3^0 30'$	1.35,2.10, 2.85
A	Q	AQ	$142^0 24'$	$2^0 45'$	1.955,2.875,3.765



S_1=2.85–1.35=1.5m

S_2=3.765 – 1.955 =1.809m

Horizontal Distance

AP=D= $KS_1\cos\theta_1 + C\cos\theta_1 + h_1\sin\theta_1$

=100x1.5 xCos$3^0$30'+0.3 x Cos $3^0$30' +2.10xSin$3^0$30'

=149.72+ 0.299 +0.128

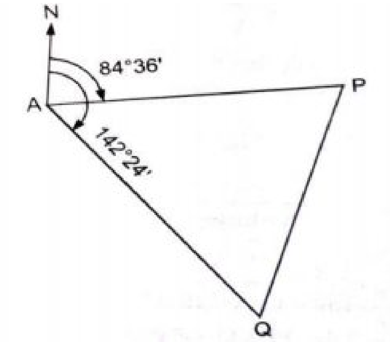
=150.147m

AQ=D=$KS_2Cos\theta_2+CCos\theta_2+h_2Sin\theta_2$

=100x1.809xCos2^{0}45’+0.3xCos2^{0}45’+ 2.875xSin2^{0}45’

=180.742+0.299+0.138

=181.179m



Angle PAQ=Bearing of AP – Bearing of AQ

= 142^{0}24’–84^{0}36’

=57^{0}48’

Using Cosine rule

$PQ^2=AP^2+AQ^2$ – 2xAPxAQxCos57^{0}48’

$PQ^2=(150.147)^2+(181.179)^2$ –2x150.147x

181.179 x Cos 57^{0}48’PQ=162.41m

Tangential Hair Method

Case : 1 (Both the angle are angles of elevation in this case, staff is held vertically.)

Horizontal distance

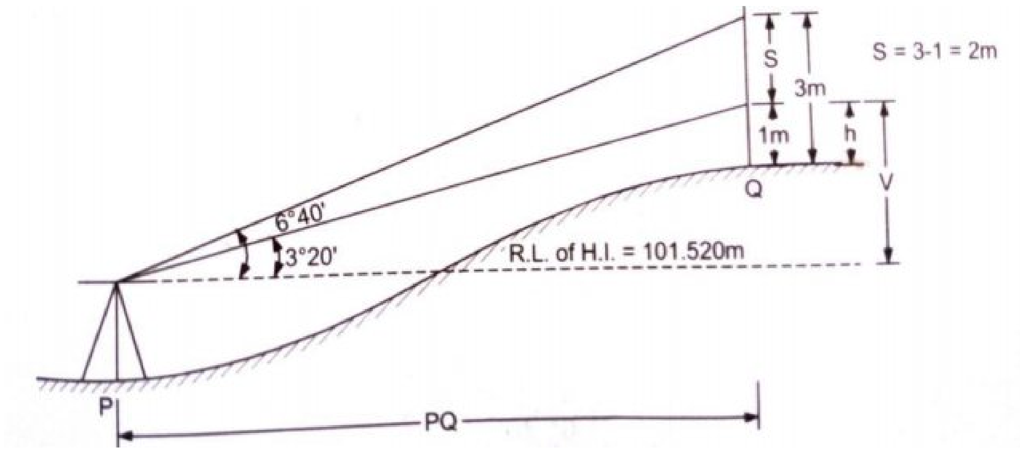
$$D = \frac{S}{(tan\theta_1 - \tan\theta_2)}$$

Vertical Distance

$$V = \frac{Stan\theta_2}{(tan\theta_1 - tan\theta_2)}$$

Example7

The vertical angles to vanes fixed at 1m and 3m above the foot of the staff held vertically at station Q were + 3^{0}20’ and 6^{0}40’ respectively from instrument station P. if the elevation of the instrument axis at station P is 101.520m calculate. The Horizontal distance between P & Q and the elevation of the staff station Q)



S=3–2 =1

$\theta_1 = 6^0 40'$

$\theta_2 = 3^0 20'$

h =1

$$D = \frac{S}{(tan\theta_1 - \tan\theta_2}$$

$$= \frac{2}{\tan 6^0 40' - \tan 3^0 20'}$$

=34.13m

$$V = \frac{Stan\theta_2}{(tan\theta_1 - tan\theta_2)}$$

$$= \frac{2x\tan 3^0 20'}{\tan 6^0 40' - \tan 3^0 20'}$$

=1.99m

Elevation of Staff Station Q= RL of HI +V–h

=101.520+1.99–1.0

=102.510m

Tangential Hair Method

Case : 2 (Both the angle are angles of Depression in this case, staff is held vertically.)

Horizontal distance

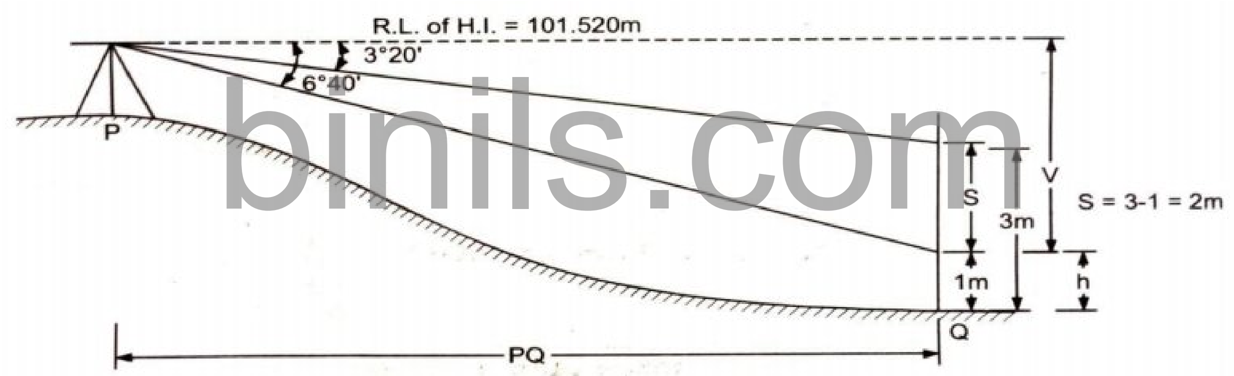
$$D = \frac{S}{(tan\theta_2 - \tan\theta_1}$$

Vertical Distance

$$V = \frac{Stan\theta_2}{(tan\theta_2 - tan\theta_1)}$$

Example8

The vertical angles to vanes fixed at 1m and3m above the foot of the staff held vertically at station Q were - 3^0 20' and - 6^0 40' respectively from instrument station P. if the elevation of the instrument axis at station P is 101.520m calculate (i)The Horizontal distance between P & Q and (ii) The elevation of the staff station Q)



S = 3 – 2 = 1,

θ_1 = - $3^0$20' , θ_2 = - $6^0$40', h = 1

$$D = \frac{S}{(tan\theta_2 - \tan\theta_1}$$

$$= \frac{2}{\tan 6^0 40' - \tan 3^0 20'}$$

= 34.13m

$$V = \frac{S\tan\theta_2}{(\tan\theta_2 - \tan\theta_1)}$$

$$= \frac{2 \times \tan 6^0 40'}{\tan 6^0 40' - \tan 3^0 20'}$$

=3.99m

Elevation of Staff station Q=RL of HI +V–h

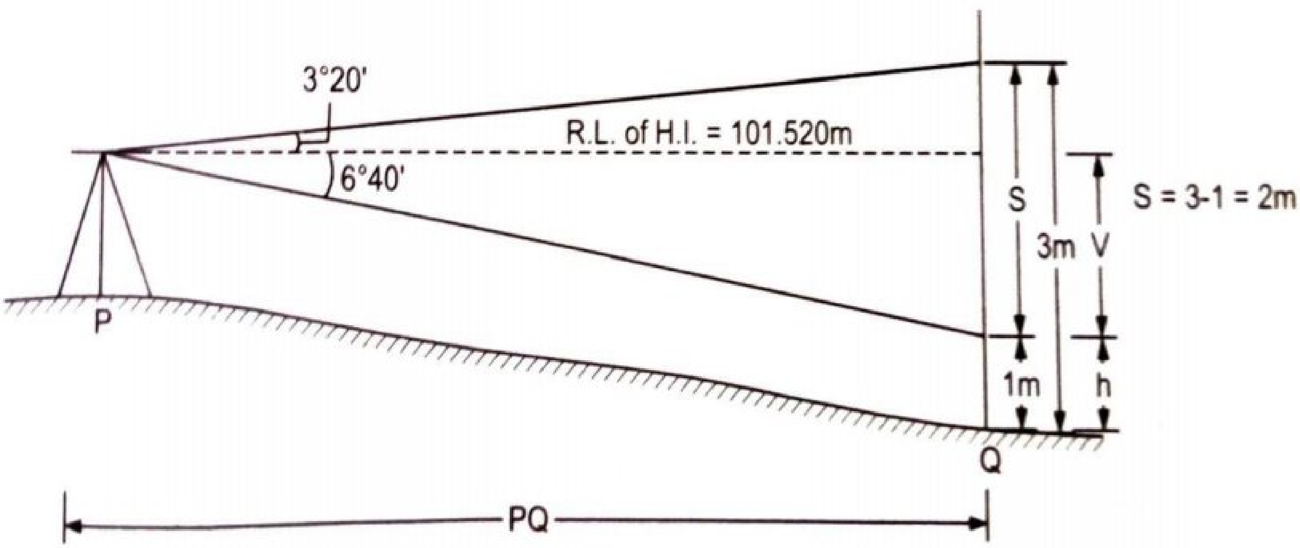
=101.520–3.99–1.0 =96.530m

Example 9

The vertical angles to vanes fixed at 1m and3mabovethefootofthestaffheld verticallyatstationQwere+3^{0}20'and-6^{0}40'respectivelyfrom instrument station P. if the elevation of the instrument axis at station P is 101.520m calculate

(i) The Horizontal distance between P & Q and

(ii) The elevation of the staff station Q)



S = 3 – 2 = 1

$\theta_1 = +3^0 20'$ $\theta_2 = -6^0 40'$

h =1

$$D = \frac{S}{(tan\theta_2 + \tan\theta_1}$$

$$= \frac{2}{\tan 3^0 20' + \tan 6^0 40'}$$

=11.43m

$$V = \frac{Stan\theta_2}{(tan\theta_2 + tan\theta_1)}$$

$$= \frac{2x\tan 6^0 40'}{\tan 6^0 40' + \tan 3^0 20'}$$

=1.34m

Elevation of Staff station Q=RL of HI-V–h

=101.520–1.34–1.0

=99.180m