

## Module - I

### Theodolite Survey & Instrument Adjustment

Theodolite is the most precise instrument designed for the measurement of horizontal & vertical angle & has wide applicability in Surveying such as laying off horizontal angles, locating points on line, prolonging survey lines, establishing grades, determining difference in elevations, setting out curves etc.

Theodolites may be classified as:

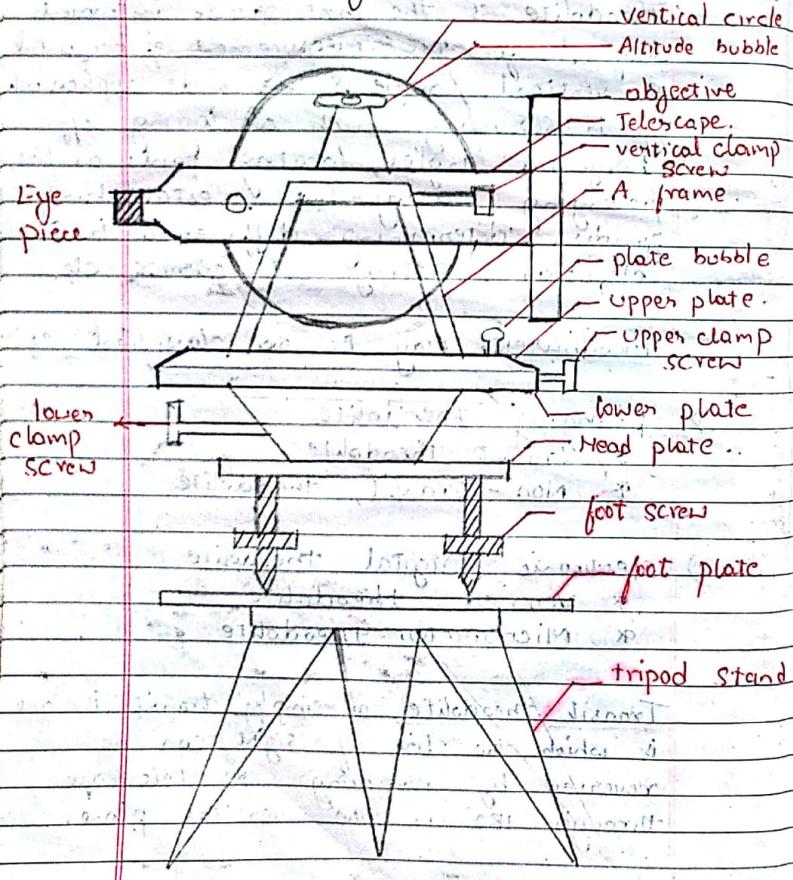
- 1) primary theodolite
- \* Transit theodolite
- \* Non-transit theodolite

- 2) Electronic Digital theodolite
  - \* Vernier theodolite
  - \* Micrometer theodolite

Transit theodolite or simply transit is one in which the line of sight can be reversed by revolving the telescope through  $180^\circ$  in the vertical plane.

Non-transit theodolite or plain or Y-theodolites in which the telescope cannot be transited.

### Essentials of the transit theodolite



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1. The telescope = integral part of the theodolite & is mounted on a spindle known as horizontal axis or trunnion axis. Telescope can be internal focusing or external focusing type. In transit, internal focusing telescope is used.

2. The vertical circle = is a circular graduated arc attached to trunnion axis of the telescope. the graduated arc rotates with the telescope. When the latter is turned about the horizontal axis,

3. Index frame / T frame / vernier frame = The index frame is a T shaped frame consisting of a vertical leg known as clipping arm & a horizontal bar known as vernier arm or index arm. At the two extremities of index arm fitted two verniers to read the vertical circle.

4. The standards or A-frame = Two standards resembling the letter A are mounted on the upper plate. the trunnion axis of the telescope is supported on these.

5. Levelling head = levelling head usually consist of 2 parallel triangular plates known as triblock plates. the upper

tribrach has 3 arms each carrying a levelling screw, lower part of tribrach plate has circular hole through which a plumb bob may be suspended.

6. Two spindles or axis or centre = inner spindle fits into outer spindle.

upper inner spindle is called upper axis since it carries the upper plate. outer spindle carries lower plate.

7. lower plate or scale plate = it is attached to outer spindle. it carries horizontal circle at its bevelled edge & is known as scale plate. it consists of lower clamp screw & tangent screw.

8. upper plate or vernier plate = it is attached to inner spindle & carries two verniers with magnifiers at diametrically opposite. it carries upper clamp & tangent screw.

9. plate level = upper plate carries 2 plate levels placed at right angles to each other. one of plate level is kept parallel to trunnion axis. plate level can be centred by foot screw.

10. tripod = theodolite is supported on a tripod which consists of 3 solid or framed legs. At lower end, legs are provided with pointed steel shoe.

#### Definitions of terms

1) vertical axis = vertical axis is the axis about which the instrument can be rotated in a horizontal plane. this is the axis about which the lower & upper part of plate rotate.

2) horizontal axis = horizontal or trunnion axis is the axis about which the telescope & vertical circle rotate in vertical plane.

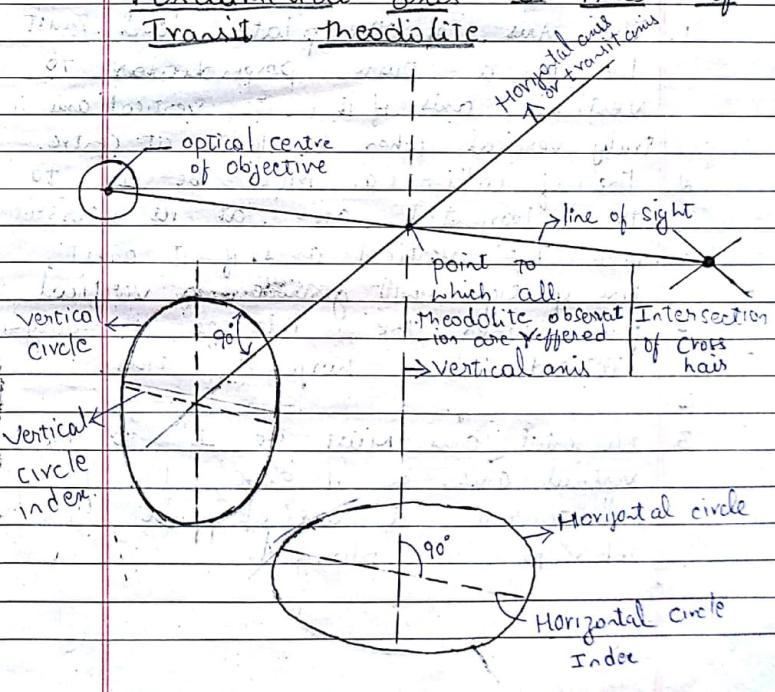
3) the line of sight or line of collimation = line passing through the intersection of horizontal & vertical cross-hair & the optical centre of object glass & its continuation.

4) axis of level tube = the axis of the level tube OR the bubble line is a straight line tangential to the longitudinal curve of the level tube at its centre. the axis of level tube is horizontal when the bubble is central.

5. Centring = process of setting the theodolite exactly over the set station mark is known as centring
6. Transiting = it is the process of turning the telescope in vertical plane through  $180^\circ$  about the horizontal axis. Since line of sight is reversed in this operation, it is also known as plunging or reversing.
7. Swinging the telescope = it is process of turning the telescope in horizontal plane. If telescope is rotated in clockwise direction, it is known as right swing, if telescope is rotated in anti-clockwise direction, it is known as left swing.
8. Face left observation = if the face of vertical circle is to the left of the observer
9. Face right observation = if the face of vertical circle is to the right of the observer.
10. Telescope Normal = Telescope is said to be normal or direct when the face of the vertical circle is to the left of the

11. bubble up:
12. Telescope inverted = A telescope is said to be normal inverted or reversed when vertical circle is to the right & the bubble down.
13. changing face = it is the operation of bringing the face of the telescope from right to left or vice versa.

### Fundamental axes or lines of Transit theodolite



The fundamental lines of a transit are:

1. Vertical axis
2. Horizontal axis
3. Line of collimation
4. Axis of plate level
5. Axis of Altitude level
6. Axis of the Striding level.

the following relations b/w axis should exist

1. The Axis of the plate level must lie in a plane perpendicular to vertical axis. If it exists, vertical axis is truly vertical when bubble is at centre.
2. Line of collimation must be  $\perp$  to the horizontal axis at its intersection with the vertical axis. If it exists, line of sight will generate a vertical plane when the telescope is plunged rotated about horizontal axis.
3. Horizontal axis must be  $\perp$  to the vertical axis. If it exists, line of sight will generate a vertical plane when the telescope is plunged.

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4. Axis of altitude level or telescope level must be parallel to line of collimation if it exists, vertical angles will be free from index error due to lack of parallelism.

5. Vertical circle vernier must read zero when the line of collimation is horizontal. If this exists, vertical angle will be free from index error due to displacement of the vernier.

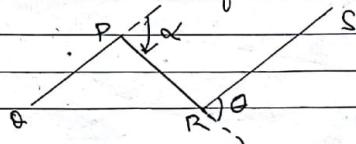
6. Axis of striding level [if provided] must be parallel to the horizontal axis.

#### Uses of transit theodolite.

1. To measure magnetic bearing of line, the theodolite should be provided with either tubular compass or trough compass.
2. To measure direct angles.



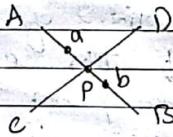
3. To measure deflection angles.



4. To prolong a straight line



5. To locate point of intersection of 2 straight lines



6. To lay off a horizontal angle

7. To lay off an angle by repetition

### Temporary adjustments

Temporary adjustment or station adjustment are those which are made at every instrument setting.

1. Setting over the stations

2. levelling up

3. ~~for~~ eliminating parallax

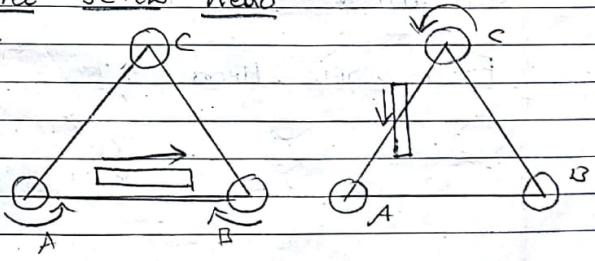
### \* Setting up

i) centring of the instrument over the stations mark by a plumb bob or by optical plummet,

ii) approximate levelling with the help of tripod legs. The tripod leg is so moved circumferentially or side ways without disturbing plumb bob positions. Levelling is done either with reference to a small circular bubble provided on tripod or done by eye judgment.

\* levelling = after having centred & approximately levelled the instrument accurate levelling is done with help of foot screws.

### Three screw head



i Turn the upper plate until the longitudinal axis of the plate level is roughly  $11^{\text{th}}$  to a line joining any 2 of the levelling screws.

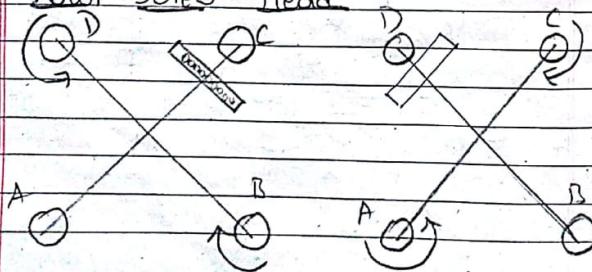
ii Hold these two levelling screws b/w the thumb & fingers & turn them uniformly so that the thumb move either towards each other or away from each other until the bubble is central.

iii Turn upper plate through  $90^{\circ}$  until axis of level passes over the position of the third screw 'c'.

iv Turn the upper this levelling screws until the bubble is central.

v Return upper plate through  $90^{\circ}$  to its original position & repeat step(ii) still bubble at centre.

#### Four Screw Head



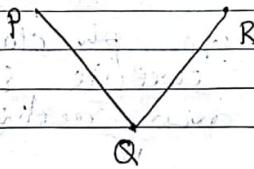
\* Elimination of parallax = parallax is a condition arising when the image formed by the objective is not in the plane of the cross-hairs unless parallax is eliminated, accurate sighting is impossible. Parallax can be eliminated in two steps :-

(1) by focusing the eye-piece = to focus the eye-piece for distinct vision of the cross-hairs, point telescope towards SKY or white paper & move eye-piece in or out till cross hairs are seen sharp.

(2) by focusing the objective = the telescope is now directed towards the object to be sighted & the focusing screw is turned till image appears clear & sharp.

#### Measurement of a horizontal angle by Repetition Method

The method of repetition is used to measure a horizontal angle to a finer degree of accuracy.



### To measure angle POR

1. Set the instrument at O & level it. with the help of upper clamp. Set tangent screw; set  $0^\circ$  reading on vernier A. Note the reading of vernier B.
2. loose the lower clamp & direct the telescope towards the point P. clamp the lower clamp & bisect point P accurately by lower tangent screw.
3. unclamp the upper clamp & turn the instrument clockwise about the inner axis towards R, note the reading of vernier A & B to get approximate value of the angle POR.
4. unclamp the lower clamp & turn the instrument clockwise about inner axis towards R. to sight P again. It should be noted that vernier reading will not be changed in this operation since upper plate is clamped to the lower.
5. unclamp upper plate clamp, turn telescope clockwise & sight R, bisect R & note down reading of verniers A &

B.

6. Repeat the process until the angle is repeated the required no of times the average angle with face left will be equal to final reading divided by no of repetitions.
7. change face & make repetition as above. find the average angle.
8. The average horizontal angle is then obtained by taking average of 2 angles obtained in face left & face right

Instrument  
guided  
to  
A

Face-left	Sight-right	face-right	sight-right	Average
				horizontal
				Angle.

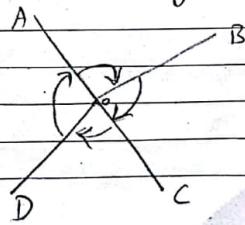
Sling - right		Average		Sling - right		Average	
Sling	Face	Mean	Horizontal Angle	Sling	Face	Mean	Horizontal Angle
face - right	A	0° 40'	52° 41' 20"	face - right	B	0° 40'	52° 41' 20"
face - right	C	0° 40'	52° 41' 20"	face - right	D	0° 40'	52° 41' 20"
face left	A	0° 40'	52° 41' 20"	face left	B	0° 40'	52° 41' 20"
face left	C	0° 40'	52° 41' 20"	face left	D	0° 40'	52° 41' 20"
face right	A	0° 40'	52° 41' 20"	face right	B	0° 40'	52° 41' 20"
face right	C	0° 40'	52° 41' 20"	face right	D	0° 40'	52° 41' 20"

### Errors elimination by Method of Repetition

- 1) Error due to eccentricity of verniers are eliminated by taking both vernier reading.
- 2) Errors due to inadjustment of line of collimation & the transits axis are eliminated by taking both face reading.
- 3) The error due to inaccurate graduations are eliminated by taking reading at different parts of circle.
- 4) Errors due to inaccurate bisection of the object, eccentric centring etc. May be even be balanced to some extent.

### Measure an angle by direction method or reiteration method.

Reiteration method, is suitable for the measurement of a angle of a group having common vertex point. Several angles are measured successively & finally the horizon is closed.



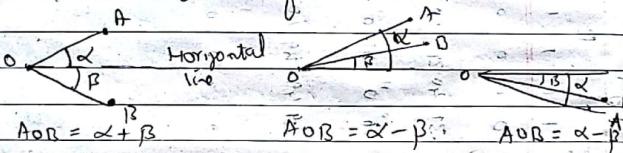
### To measure angles;

1. set the instrument over 'O' & level it, set vernier zero & bisection point A
- 2) loose upper clamp & turn telescope clockwise to B. Read both verniers A & B. Mean of vernier reading is taken as angle AOB.
- 3) similarly, bisect C, D etc, thus closing circle. Each included angle is obtained by taking difference b/w two consecutive readings.
- 4) on first final sight A, the reading of verniers should be same as the original setting. If not find the error. If error is small distribute it equally to all angles. If error is large repeat the experiment.
- 5) repeat procedure with other faces

		Average		A0B		B0C		C0D		D0A		Date _____ Page _____	
		Horizontal Angle.	Avg.	D	54° 31' 30"	D	54° 31' 30"	B	54° 31' 30"	B	54° 31' 30"		
Sight	Face-right												
Sight	Face-right												
Sight	Face-right												
Sight	Face-left												

## Measurement of vertical angles

Vertical angle is the angle which the inclined line of sight to an object makes with the horizontal. It may be an angle of elevation or angle of depression depending upon whether the object is above or below the horizontal plane passing through the trunnion axis of the instrument.



$$A'OB' = \alpha - \beta$$

$$AOB = \alpha - \beta$$

## Permanent adjustment

Permanent adjustment are made to establish the relationship b/w the fundamental lines of the theodolite. They are essential for the accuracy of observations.

i) Adjustment of horizontal plate level = The axis of the plate levels must be  $\perp^{\text{re}}$  to vertical axis.

ii) Collimation adjustment = line of collimation should coincide with axis of telescope & the axis of objective slide & should be at right angle to horizontal axis.

iii) Horizontal axis adjustment = horizontal axis must be  $\perp^{\text{re}}$  to vertical axis.

iv) adjustment of telescope level = telescope level or altitude level must be  $\perp^{\text{re}}$  to the line of collimation.

v) vertical circle index adjustment = vertical circle vernier must be read zero when line of collimation is horizontal.

## Test for Adjustment of horizontal plate level

\* set up the instrument on firm ground, clamp the lower motion clamp &

(levelling of foot screw procedure, temporary adjustment)

## Test for adjustment of collimation

\* Set instrument at convenient point & level it.

\* with eye of the instrument left, take a reading on staff held on peg driven at a distance of about 100m from the instrument station O.

Let staff reading be  $b_1$ , also note the vertical angle  $\alpha$ :

- \* change face. Set the vertical vernier to former angle  $\alpha$  & again read read staff on 'B': if reading is equal to previous reading  $b_1$   $\Rightarrow$  adjustment is necessary.

### adjustment

If not, note down reading as  $b_2$ . move horizontal hair by means of vertical diagram screw until the mean of 2 reading  $b_1$  &  $b_2$  is obtained.

the adjustment is correct.

### Adjustment

- \* if not, mark another point B in line of sight near base of same object. Mark another point C midway b/w A & B:

\* Sight on point C & clamp upper motion. Raise the telescope. The line of sight will not strike the point P. Raise or lower adjustable end of horizontal axis by means of screw near top of frame until line of sight passes through point P.

### Test for horizontal axis adjustment

#### [Spire test]

- \* Set up the instrument near a spire or some other elevated object. Let P be the top point.
- \* sight point 'P' & with both horizontal motions clamped, depress the telescope & mark a point A in line of sight near the base of the object.
- \* Change face of instrument, & again sight on point P. Depress the telescope. If the line of sight now strikes the point A marked previously,

### Test for adjustment of telescope level

- \* fix 2 pegs A & B on fairly level ground about 100m apart. Set up the theodolite at 'O' exactly midway b/w A & B. Clamp the vertical circle & the telescope level is the centre of its mm by means of tangent screw of vertical circle.

- \* with bubble centre, take reading on Staff held on A & B & find the difference b/w this readings.

- \* Shift instrument & set it up at O, on line BA produced, at about 20m from A.
- \* Take staff reading on A & B & find difference. If difference is equal to first difference, the adjustment is correct.

### Adjustment:

- \* if not, calculate the correct staff reading on A & B as explained in 2-peg.
- \* bring horizontal hair exactly to the correct reading on B by means of tangent screw of a vertical circle.
- \* adjust bubble tube.
- \* sight staff on near peg & note whether calculated correct reading is obtained.

### Test for Adjustment of Horizontal plate level:

- \* centre plate bubbles & then bring telescope bubble exactly to the centre of its run by means of vertical tangent screw, as is the first adjustment, & then read the vernier of vertical circle. If it read

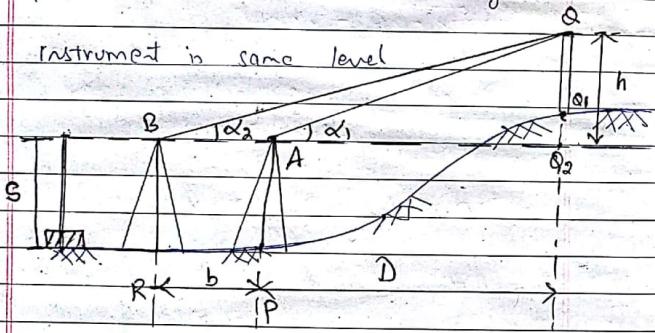
## Trigonometric levelling

Trigonometric levelling is the process of determining the differences of elevations of stations from observed vertical angle & known distance.

### Base of object inaccessible.

i) Instrument station in same vertical plane as the elevated object.

ii) Instrument in same level



i Set up theodolite at 'P' & level it accurately with respect to altitude bubble.

ii Direct telescope towards 'Q' & bisect it accurately. Clamp both the plates. Read the vertical angle  $\alpha_1$ .

iii) Transit telescope so that line of sight is reversed. Mark the second instrument station 'R' on the ground. Measure the distance RP accurately with vertical vernier set to zero reading, take reading on staff kept at nearby BM.

iv) Shift instrument to R & set up theodolite. Measure vertical angle  $\alpha_2$  to Q with both face observations.

v) With the vertical vernier set to zero reading, & the altitude bubble in the centre of the run, take the reading on the staff kept at the nearby BM.

Instrument axis at the same level.

$$h = Q_2$$

$\alpha_1$  = angle of elevations from A to Q

$\alpha_2$  = Angle of elevations from B to Q

S = Staff reading on BM

b = Horizontal distance b/w the instrument station

D = Horizontal distance b/w P & Q

consider  $\triangle AQQ_2$ ,  $\tan \alpha_1 = \frac{h}{D}$

$$h = D \tan \alpha_1 \quad \text{--- (1)}$$

from  $\Delta^{\circ} BQQ_2 \rightarrow \tan \alpha_2 = \frac{h}{D+b}$   
 $h = (D+b) \cdot \tan \alpha_2 \quad \text{--- (2)}$

equate eq. (1) & (2)

$$\begin{aligned} D \tan \alpha_1 &= (D+b) \tan \alpha_2 \\ D \tan \alpha_1 &= D \tan \alpha_2 + b \tan \alpha_2 \\ D \tan \alpha_1 - D \tan \alpha_2 &= b \tan \alpha_2 \end{aligned}$$

$$D [\tan \alpha_1 - \tan \alpha_2] = b \tan \alpha_2$$

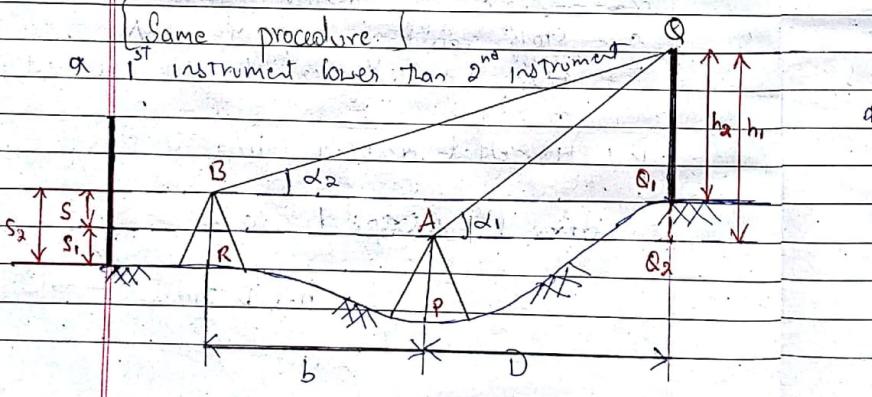
$$D = \frac{b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2}$$

sub in eq. (1)

$$h = \frac{b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2} \tan \alpha_1$$

RL of Q = BM + S + h

2) Instrument axes at different level.



$\Delta^{\circ} AQQ_1, \tan \alpha_1 = \frac{h_1}{D}$   
 $h_1 = D \tan \alpha_1 \quad \text{--- (1)}$

$$\begin{aligned} \Delta^{\circ} BQQ_2, \tan \alpha_2 &= h_2 \\ (b+D) \tan \alpha_2 &= h_2 \\ h_2 &= (b+D) \tan \alpha_2 \quad \text{--- (2)} \\ h_2 - h_1 &= S \\ \text{where } S &= S_2 - S_1 \\ D \tan \alpha_1 + b \tan \alpha_2 &= D \tan \alpha_2 + S \\ D [\tan \alpha_1 - \tan \alpha_2] - b \tan \alpha_2 &= S \end{aligned}$$

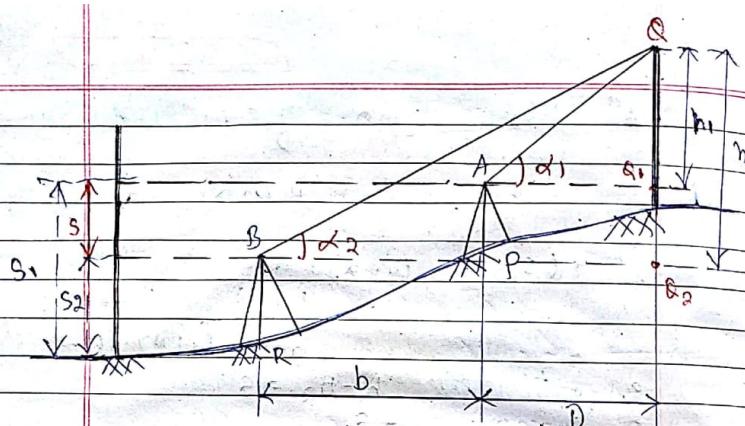
$$D = \frac{S + b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2}$$

$$\therefore h_1 = \frac{S + b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2} \tan \alpha_1$$

$$\begin{aligned} \text{RL of Q} &= BM + S_2 + h_2 \\ \text{or RL of Q} &= BM + S_1 + h_1 \end{aligned}$$

1<sup>st</sup> instrument at higher level than 2<sup>nd</sup> instrument.

[Same procedure]



$$\Delta^r AQQ, \tan \alpha_1 = -\frac{h_1}{D}$$

$$h_1 = D \tan \alpha_1 \quad (1)$$

$$\Delta^r BQQ, \tan \alpha_2 = -\frac{h_2}{b+D}$$

$$h_2 = [b+D] \tan \alpha_2 \quad (2)$$

$$h_2 - h_1 = s \quad \text{when } s = S, -S$$

$$[b+D] \tan \alpha_2 - D \tan \alpha_1 = s$$

$$b \tan \alpha_2 + D \tan \alpha_2 - D \tan \alpha_1 = s$$

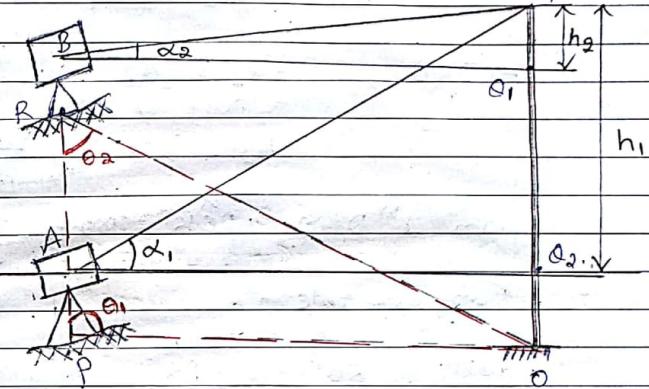
$$b \tan \alpha_2 + D [\tan \alpha_2 - \tan \alpha_1] = s$$

$$D = \frac{s - b \tan \alpha_2}{\tan \alpha_2 - \tan \alpha_1}$$

$$h_1 = \left[ \frac{s - b \tan \alpha_2}{\tan \alpha_2 - \tan \alpha_1} \right] \tan \alpha_1$$

$$RL \text{ of } Q = BM + S_1 + h_1$$

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Instrument station not in same vertical plane as the elevated object



Let P & R be two instrumental stations not in same vertical plane as that of Q.

\* Set instrument at P & level it accurately with respect to the altitude bubble. Measure the angle of elevation  $\alpha_1$  to Q.

\* Sight point R with reading on horizontal circle as jens & measure the angle RPO, ie horizontal angle  $\alpha_1$  at P.

\* Take backsight 'S' on the staff kept at BM.

\* Shift instrument to R & measure  $\alpha_2$  &  $\theta_2$ .

$$\Delta AQQ_2, \tan \alpha_1 = \frac{h_1}{D}$$

$$h_1 = D \tan \alpha_1 \quad \text{--- (1)}$$

$$\Delta BQQ_1, \tan \alpha_2 = \frac{h_2}{D}$$

$$h_2 = D \tan \alpha_2 \quad \text{--- (2)}$$

$$\text{from } \Delta \text{ PRO, } \hat{PQR} = 180 - (\theta_1 + \theta_2) \\ = \pi - (\theta_1 + \theta_2)$$

from sine rule,

$$\frac{PR}{\sin \theta_2} = \frac{RQ}{\sin \theta_1} = \frac{PQ}{\sin(\pi - (\theta_1 + \theta_2))}$$

$$\frac{RQ}{\sin \theta_2} = \frac{RQ}{\sin \theta_1} = \frac{b}{\sin(\pi - (\theta_1 + \theta_2))}$$

$$D = \frac{b \sin \theta_2}{\sin(\theta_1 + \theta_2)}$$

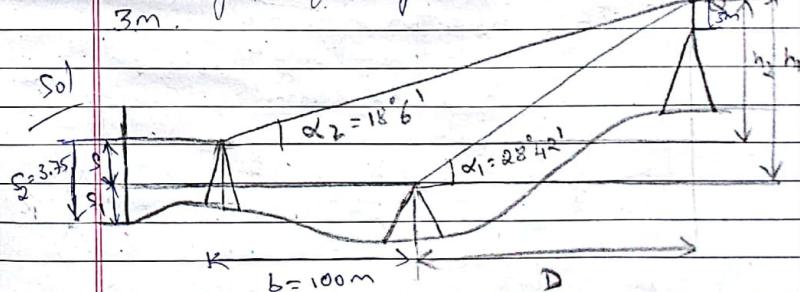
$$h_1 = \frac{b \sin \theta_2 \tan \alpha_1}{\sin(\theta_1 + \theta_2)}$$

$$\text{RL of Q} = Bm + S + h_1$$

$$h_2 = \frac{b \sin \theta_2}{\sin(\theta_1 + \theta_2)}$$

### Problems

1. In order to ascertain the elevation of the top (Q) of the signal on a hill, observations were made from 2 instrument station P & R at a horizontal distance 100m apart, the station P & R being in line with Q. the angles of elevation of Q at P & R were  $28^{\circ} 42'$  &  $18^{\circ} 6'$ . the staff reading upon the bench mark of elevation 287.28 were 2.870 & 3.75 when the instrument was at P & R. the telescope being horizontal. Determine the elevation of the foot of the signal if the height of signal above its base is 3m.



$$S = S_2 - S_1 = 3.75 - 2.87 = 0.88 \text{ m}$$

$$D = \frac{s + b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2}$$

$$= \frac{0.88 + (100 \times \tan 18^\circ 6')}{\tan 28^\circ 42' - \tan 18^\circ 6'}$$

$$\boxed{D = 152.1 \text{ m}}$$

$$h_1 = D \tan \alpha_1$$

$$= 152.1 \times \tan 28^\circ 42'$$

$$\boxed{h_1 = 83.29 \text{ m}}$$

$$\text{RL of } Q = BM + S_1 + h_1$$

$$= 287.28 + 2.87 + 83.29$$

$$\text{RL of } Q = 373.44 \text{ m}$$

$$\text{RL of base of signal} = 373.44 - 3 = \underline{\underline{370.44 \text{ m}}}$$

$$\text{Check, } h_2 = (b+D) \tan \alpha_2$$

$$= (100 + 152.1) \tan 18^\circ 6'$$

$$h_2 = 82.396 \text{ m}$$

$$\text{RL of } Q = BM +$$

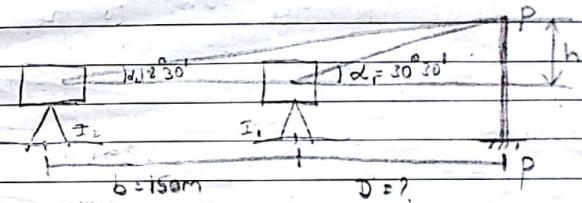
$$= S_2 + h_2 = 3.75 + 82.396 + 287.$$

$$> 373.426 \text{ m}$$

$$\text{RL of foot of } Q = \underline{\underline{370.42 \text{ m}}}$$

8. Theodolite was kept at 2 stations I<sub>1</sub>, I<sub>2</sub> 150m apart. The height of the instrument in both the cases are same. The vertical angle observed was 20° 30' from I<sub>1</sub>, 18° 30' from I<sub>2</sub>. Find the horizontal distance of P from station I<sub>2</sub> if the elevation of P is 1355.765m.

Sol



$$D = \frac{b \tan \alpha_2}{\tan \alpha_1 - \tan \alpha_2}$$

$$= \frac{150 \tan 18^\circ 30'}{\tan 20^\circ 30' - \tan 18^\circ 30'}$$

$$\boxed{D = 197.28 \text{ m}}$$

$$H = D \tan \alpha_1$$

$$= 197.28 \tan 20^\circ 30'$$

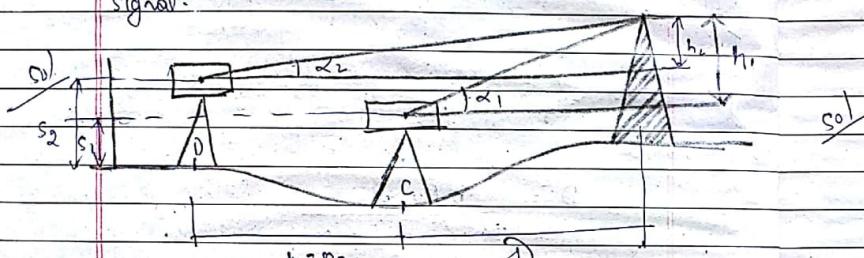
$$\boxed{H = 116.2 \text{ m}}$$

$$\text{RL of } P = [BM + BS] + h$$

$$= 1355.765 + 116.2$$

$$\boxed{\text{RL of } P = 1471.965 \text{ m}}$$

3. In order to find elevation of the top of signal observation were made from station C & D inline with signal & they are 80m apart. vertical angle observed to the top of signal from C & D are  $30^\circ 45'$  &  $16^\circ 10'$ . the staff readings on the bench mark of RL 178.450 is 2.85 & 3.58 observed from stations -C & D. What is the RL to the top of signal.



$$\alpha_1 = 30^\circ 45', \alpha_2 = 16^\circ 10', RL = 178.45$$

$$s_1 = 2.85 \quad s_2 = 3.58$$

$$S = s_2 - s_1 = 0.73$$

$$D = S + b \tan \alpha_2$$

$$\tan \alpha_1 - \tan \alpha_2$$

$$= \frac{0.73 + 80 \tan 16^\circ 10'}{\tan 30^\circ 45' - \tan 16^\circ 10'}$$

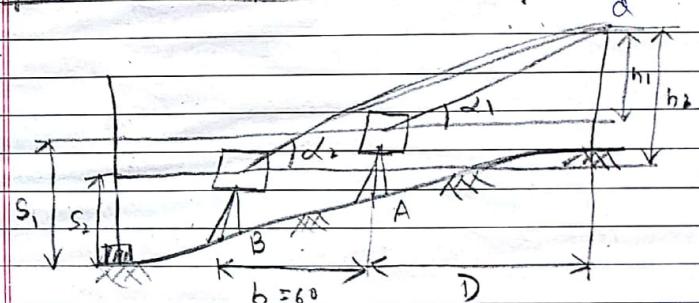
$$D = 78.483 \text{ m}$$

$$h_1 = D \tan \alpha_1 = 46.69 \text{ m}$$

$$RL @ \text{top of signal} = BM + s_1 + h_1 = 227.99 \text{ m}$$

- 4 Determine the elevation of top of the signal on a hill where the observation were made from a station A & B, 60m apart. & they are in same vertical plane also determine the horizontal distance b/w A & the signal point Q.

Instrument station	vertical angle	Staff reading	BM
A	$18^\circ 30'$	2.815	105.06
B	$12^\circ 40'$	3.865	



$$D = \frac{S - b \tan \alpha_2}{\tan \alpha_2 - \tan \alpha_1}$$

$$S = s_1 - s_2 \\ = 2.815 - 3.865 \\ S = 0.95 \text{ m}$$

$$= \frac{0.95 - 60 \tan 12^\circ 40'}{\tan 12^\circ 40' - \tan 18^\circ 30'}$$

$$D = 114.112 \text{ m}$$

$$h_1 = D \tan \alpha_1 = 114.112 \times \tan 18^\circ 30' = 38.18 \text{ m}$$

$$RL @ Q = 105.06 + 2.815 + 38.18 = 146.05 \text{ m}$$