

[Surveying-II]

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**G PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY**

**DEPARTMENT OF CIVIL ENGINEERING**

**SURVEYING-II**

**LECTURE NOTES**

**ON**

**UNIT-III**

**TRIANGULATION AND SETTING OUT OF WORKS**

## TRIANGULATION

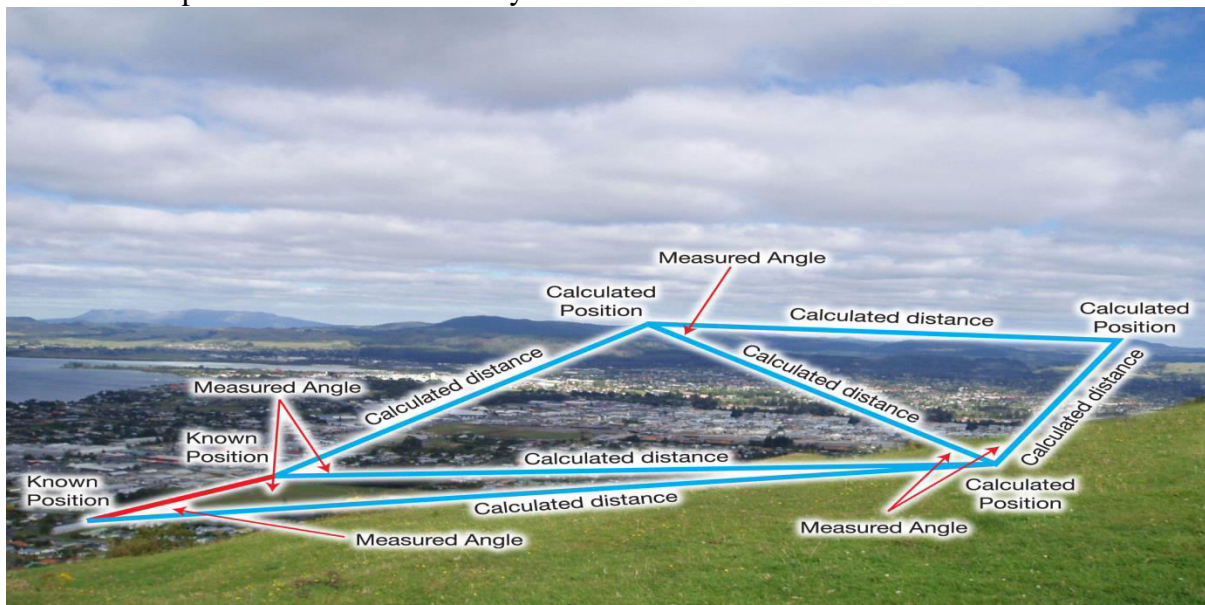
In the past it was difficult to accurately measure very long distances, but it was possible to accurately measure the angles between points many kilometres apart, limited only by being able to see the distant beacon. This could be anywhere from a few kilometres, to 50 kilometres or more.

Triangulation is a surveying method that measures the angles in a triangle formed by three survey control points. Using trigonometry and the measured length of just one side, the other distances in the triangle are calculated. The shape of the triangles is important as there is a lot of inaccuracy in a long skinny triangle, but one with base angles of about 45 degrees is ideal.

Each of the calculated distances is then used as one side in another triangle to calculate the distances to another point, which in turn can start another triangle. This is done as often as necessary to form a chain of triangles connecting the origin point to the Survey Control in the place needed. The angles and distances are then used with the initial known position, and complex formulae, to calculate the position (Latitude and Longitude) of all other points in the triangulation network.

Although the calculations used are similar to the trigonometry taught in high school, because the distance between the survey points is generally long (typically about 30 kilometres) the calculations also allow for the curvature of the Earth.

The measured distance in the first triangle is known as the 'Baseline' and is the only distance measured; all the rest are calculated from it and the measured angles. Prior to the 1950s, this initial baseline distance would have to be very carefully measured with successive lengths of rods whose length were accurately known. This meant that the distance would be relatively short (maybe a kilometre or so) and it would be in a reasonably flat area, such as a valley or plain. The triangles measured from it gradually increased in size, and up onto the hilltops where distant points could be seen easily



Triangulation Network

The angles in the triangles are measured using a theodolite, which is an instrument with a telescope connected to two rotating circles (one horizontal and one vertical) to measure the horizontal and vertical angles. A good quality theodolite used for geodetic surveys would be graduated to 0.1 second of an arc and an angle resulting from repeated measurements would typically have an accuracy of about 1 second of arc, which is equivalent to about 5 cm over a distance of 10 kilometres.

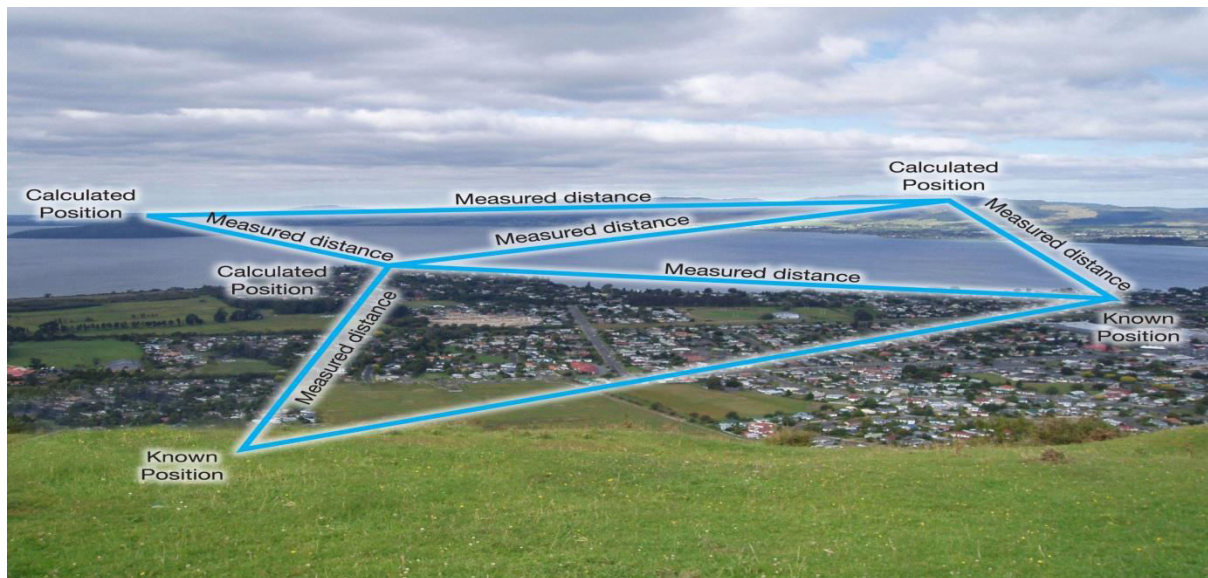
In triangulation the vertical angles are not needed, but they can be used to measure the difference in height between the points.

### **Trilateration:**

In the 1950s, accurate methods of measuring long distances (typically 30 to 50 km) were developed. They used the known speed of light (299,792.458 km per second) and the timed reflection of a microwave or light wave along the measured line. Known as Electromagnetic Distance Measurement (EDM), the two initial types of instrument were the 'Tellurometer', which used a microwave, and 'Geodimeter', which used a light wave.

The distances in a triangle could then be measured directly instead of calculating them from the observed angles. If needed the angles could be calculated. The process of calculating positions through the chain of triangles is then the same as for triangulation.

Sometimes both angles and distances were measured in some triangles to check on the observations and improve the accuracy of the calculations



Trilateration Network

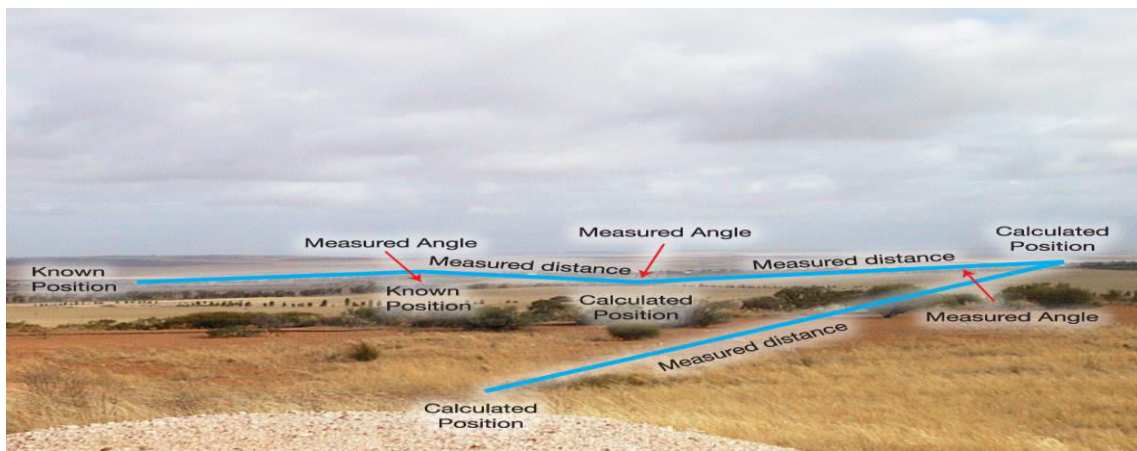
The early EDM instruments could measure long distances with an accuracy of about 5 parts per million (i.e. 5 mm for every km or to 150 mm over a 30 km line), but later versions were more accurate, able to measure with an accuracy of about 1 part per million (1 mm per kilometre or 30 mm over a 30 km line) These days there are also many types of accurate and compact EDM instruments integrated with an electronic theodolite and known generically as a 'Total Station'. These instruments can also measure with an accuracy of about 1 part per million, but generally only for shorter lines of about one kilometre.

### Traversing

Triangulation and Trilateration are difficult and sometimes impossible in flat country where there are not many hills. This is often the situation in outback areas of Australia.

With EDM this problem can be minimised by measuring the distances and angle between successive survey control points. With a known starting position and orientation (or two known starting

Positions) repeating this process through a chain of points allows the position of each point to be calculated. However, in a traverse, if a mistake is made, it may not be obvious, so these traverses generally close back onto their starting point to form a loop, or finish on another known position. The difference between the known finishing position and the calculated position for this point is the misclose and indicates the accuracy of the traverse measurements and calculations.



Traversing Network

For small projects traversing is often used with 'Total Station' equipment. Variations on triangulation and trilateration are also often used on small surveys, particularly to measure to inaccessible points.

### Uses of Triangulation:

- To establish accurate control points for plane and geodetic surveys of large areas
- To determine size and shape of the earth by making observations for latitude and longitude, gravity
- To establish accurate horizontal control for various engineering projects

**Classification of Triangulation:** The basis of the classification of triangulation figures is the accuracy with which the length and azimuth of a line of the triangulation are determined. Triangulation systems of different accuracies depend on the extent and the purpose of the survey. The accepted grades of triangulation are:

1. First order or Primary Triangulation
2. Second order or Secondary Triangulation
3. Third order or Tertiary Triangulation

### 1. FIRST ORDER OR PRIMARY TRIANGULATION:

The first order triangulation is of the highest order and is employed either to determine the earth's figure or to furnish the most precise control points to which secondary triangulation may be connected. The primary triangulation system embraces the vast area (usually the whole of the country). Every precaution is taken in making linear and angular measurements and in performing the reductions. The following are the general specifications of the primary triangulation:

1. Average triangle closure : Less than 1 second
2. Maximum triangle closure : Not more than 3 seconds
3. Length of base line : 5 to 15 kilometres
4. Length of the sides of triangles : 30 to 150 kilometres
5. Actual error of base : 1 in 300,000
6. Probable error of base : 1 in 1,000,000
7. Discrepancy between two  
Measures of a section : 10 mm kilometres
8. Probable error or computed distance : 1 in 60,000 to 1 in 250,000
9. Probable error in astronomic azimuth : 0.5 seconds

### 2. SECONDARY ORDER OR SECONDARY TRIANGULATION

The secondary triangulation consists of a number of points fixed within the framework of primary triangulation. The stations are fixed at close intervals so that the sizes triangles formed are smaller than the primary triangulation. The instruments and methods used are not of the same utmost refinement. The general specifications of the secondary triangulation are:

1. Average triangle closure : 3 sec
2. Maximum triangle closure : 8 sec
3. Length of base line : 1.5 to 5 km
4. Length of sides of triangles : 8 to 65 km
5. Actual error of base : 1 in 150,000

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6. Probable error of base : 1 in 500,000

7. Discrepancy between two

Measures of a section : 20 mm kilometres

8. Probable error or computed distance : 1 in 20,000 to 1 in 50,000

Probable error in astronomic azimuth: 2.0 se

3. THIRD ORDER OR TERTIARY TRIANGULATION:

The third-order triangulation consists of a number of points fixed within the framework of secondary triangulation, and forms the immediate control for detailed engineering and other surveys. The sizes of the triangles are small and instrument with

Moderate precision may be used. specifications for a third-order triangulation are as follows:

1. Average triangle closure : 6 sec
2. Maximum triangle closure : 12 sec
3. Length of base line : 0.5 to 3 km
4. Length of sides of triangles : 1.5 to 10 km
5. Actual error of base : 1 in 75, 0000
6. Probable error of base : 1 in 250,000
7. Discrepancy between two  
Measures of a section : 25 mm kilometres
8. Probable error or computed distance : 1 in 5,000 to 1 in 20,000
9. Probable error in astronomic Azimuth: 5 sec.

**Operations of Triangulation:**

There are two types of operation in triangulation process they are a mainly: filed work and office work

**Filed work:**

1. It is divided into further operations Reconnaissance, selection of triangulation stations, marking of triangulation station, selection of site foe base line etc...
2. Erection of signals and towers
3. Measurement of base line
4. Measurement of horizontal angles
5. Astronomical observations to determine the azimuth of lines.

**Office work:**

1. Adjustment of Observed angles
2. Computations of the lengths of the sides
3. Computations of latitudes and departures & azimuths of all sides
4. Computations of independent co-ordinates

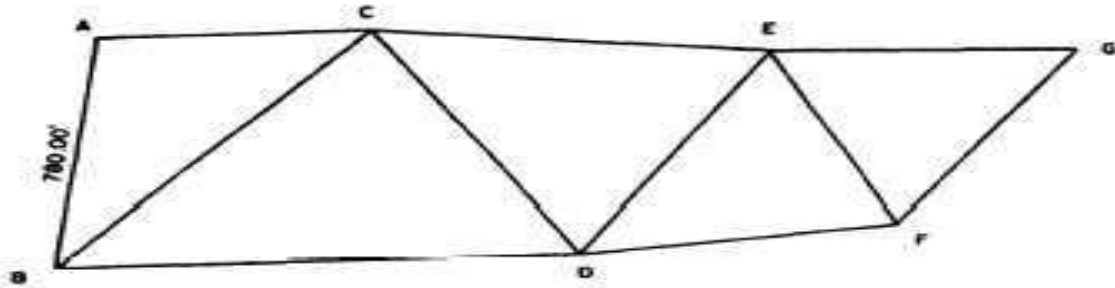
**Layout of Triangulation:** The triangles in triangulation system can be arranged in a number of ways. Some of the commonly used arrangements, also called layouts are as follows

- 1) Single chain of triangles
- 2) Double chain of triangles

- 3) Braced quadrilaterals
- 4) Centred triangles and polygons
- 5) A combination of the above system

**1) Single chain of triangles:**

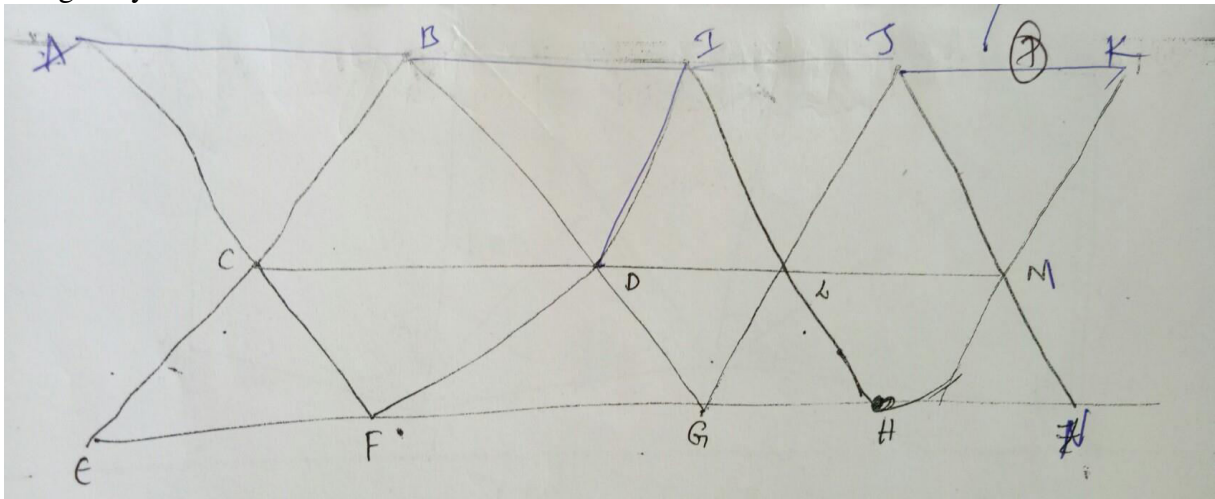
When the control points are required to establish in a narrow strip of terrain such as a valley between ridges, a layout consisting of single chain of triangles is generally used below. This system is rapid and economical due to its simplicity of sighting four other stations, and does not involve observations of long diagonals



On the other hand, simple triangles of a triangulation system provide only one route through which distances can be computed, and hence, this system does not provide any check on the accuracy of observations. Check base lines and astronomical observations for azimuths have to be provided at frequent intervals to avoid excessive accumulation of errors in this layout.

**2) Double chain of triangles:**

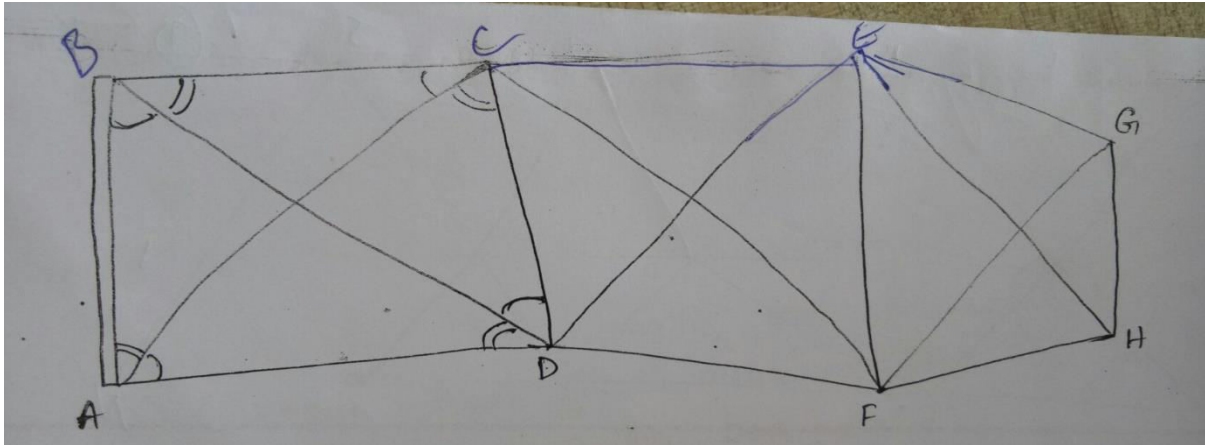
A layout of double chain of triangles is shown below. This arrangement is used for covering the larger width of a belt. This system also has disadvantages of single chain of triangles system.



**3) Braced Quadrilaterals:**

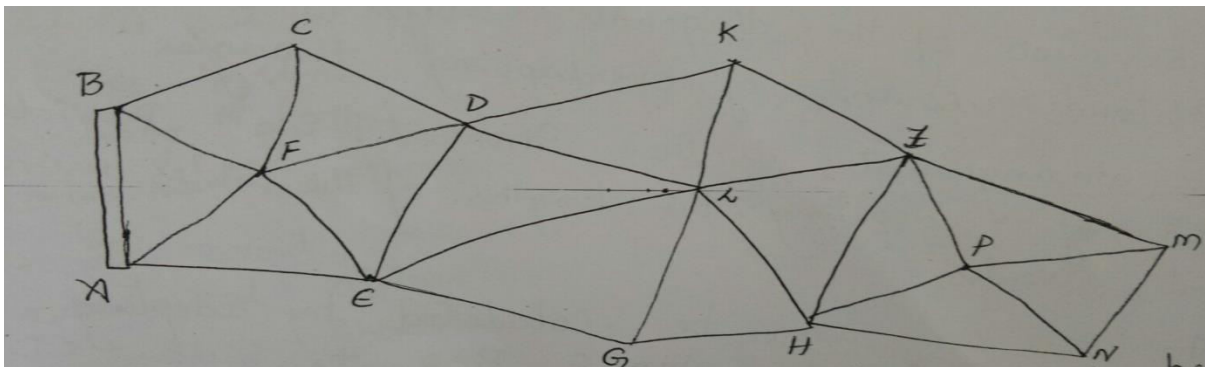
A triangulation system consisting of figures containing four corner stations and observed diagonals shown below in a diagram known as a layout of braced quadrilaterals. In fact, braced quadrilaterals consist of overlapping triangles. This system is treated to be the strongest and the best arrangement of triangles, and it provides a means of computing the lengths of the sides using different combinations of sides and angles. Most of the triangulation systems use this method





**4) Centred triangles and Polygons:**

A triangulation system which consists of figures containing interior stations in triangle and polygon as shown below is known as centred triangles and polygons this layout in a triangulation system is generally used when vast area in all directions is required to be covered. The centred figures generally are quadrilaterals, pentagons, or hexagons with central stations. Though this system provides check on the accuracy of the work, generally it is not as strong as the braced quadrilateral arrangement. Moreover, the progress of work is quite slow due to the fact that more settings of the instrument are required



**5) A combination of the above system:** A combination of above systems in sometimes used.

**SIGNALS:**

They are the devices erected to define the exact position of a station a signal is placed at each station so that the line of sights is established between triangulation stations. There are two types of signals are used in this triangulation they are mainly: a) Opaque signals and b) Luminous signals

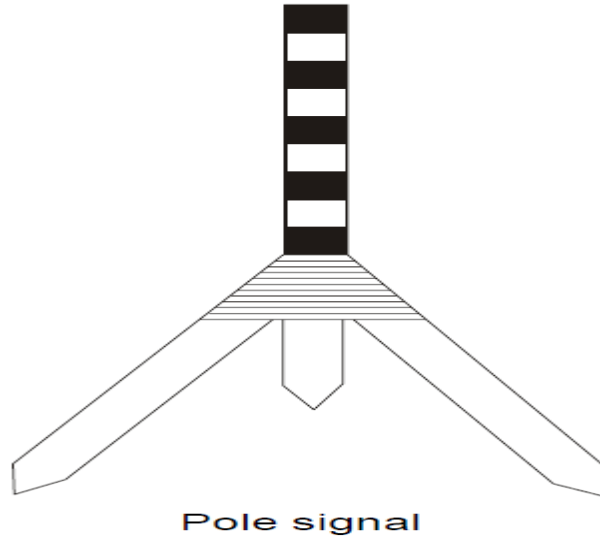
Opaque signals:

The opaque or non-luminous signals used during day Various forms and the ones most commonly used are the following

- Pole Signal
- Target Signal
- Pole and Brush Signals
- Stone Cairn
- Beacon

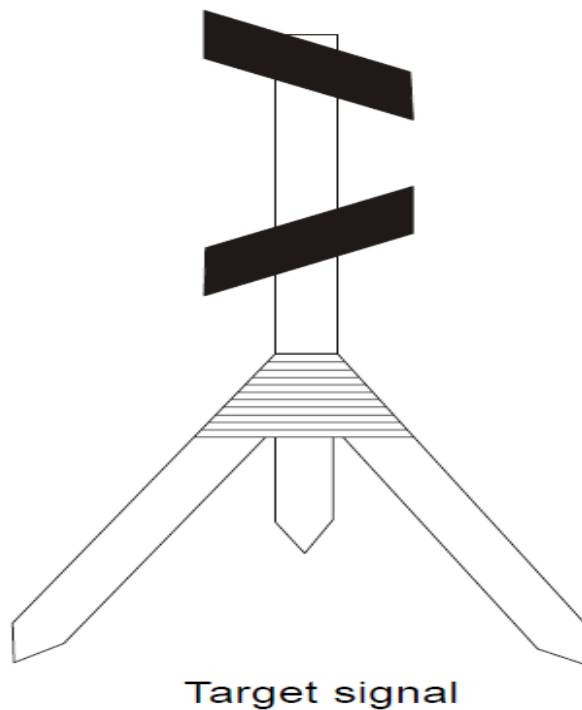
**Pole Signal:**

It consists of a round pole painted black and white in alternate and is supported vertically over the station mark on a tripod. Pole signals are suitable up to a distance of 6 km



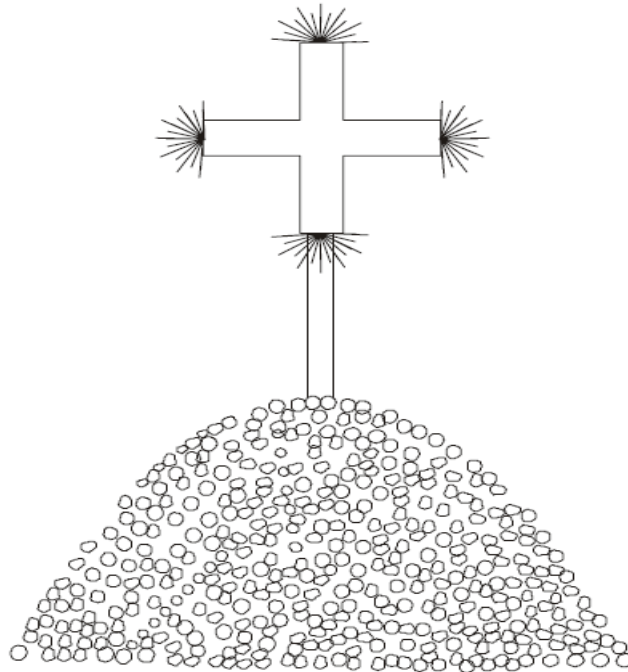
**Target signal:**

It consists of a pole carrying two square or rectangular targets placed at right angles to each other the targets are generally made of cloth stretched on wooden frames Target signals are suitable up to a distance of 6 km.



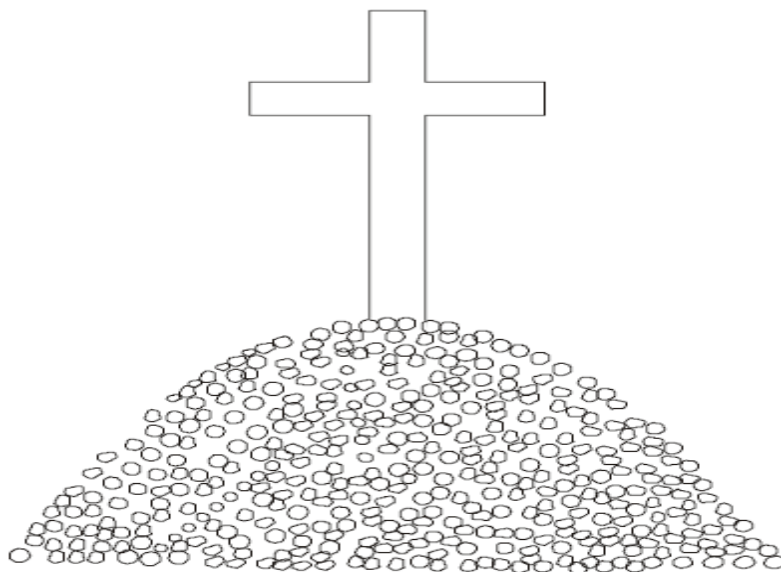
**Pole and Brush Signals:**

It consists of a straight pole about 2.5 meter long with a bunch of long grass tied symmetrically round the top making a cross. The signal is erected vertically over the station mark by heaping a pile of stones up to 1.7 meters round the pole. A rough coat of white wash is applied to make it more conspicuous to be seen against a black back ground.



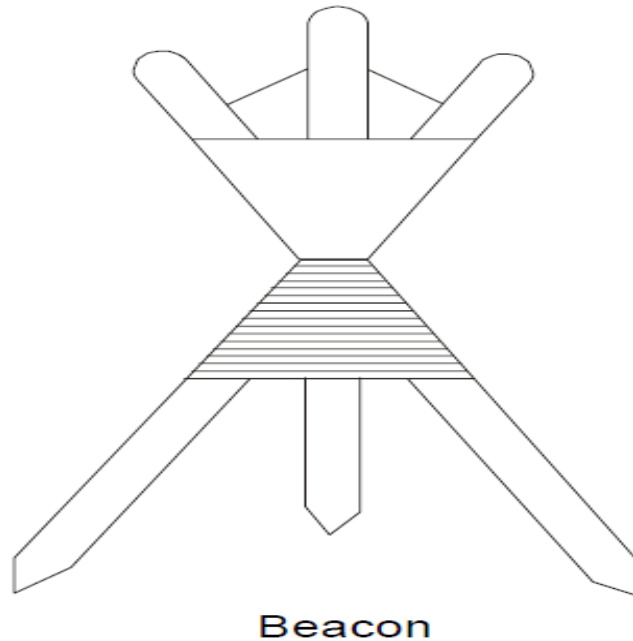
**Pole and brush signal**

**Stone Cairn:** It consists of stones built up to a height of 3 meters in a conical shape. This white washed opaque signal is very useful if the back-ground is dark.



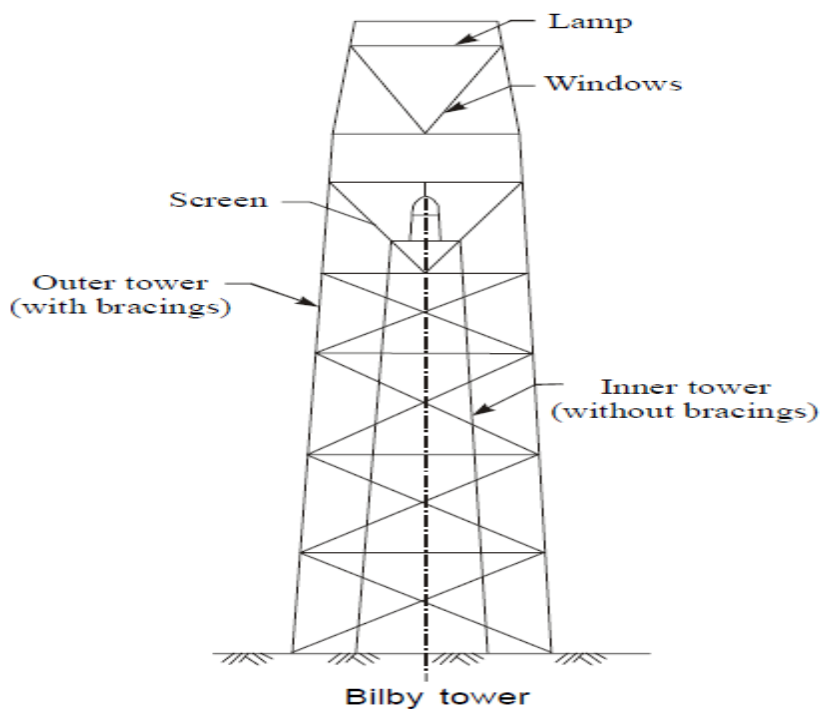
**Stone cairn**

**Beacon:** It consists of red and white cloth tied round the three straight poles. This can be easily centred over the station marks. Beacons are useful when simultaneous observations are made at both the stations. These are all the Opaque signals are used for triangulation survey.



**TOWER:**

A tower is erected at the triangulation station when the station or the signal or both are to be elevated to make indivisibility between stations. The height of tower depends upon the character of the terrain and the length of the sight

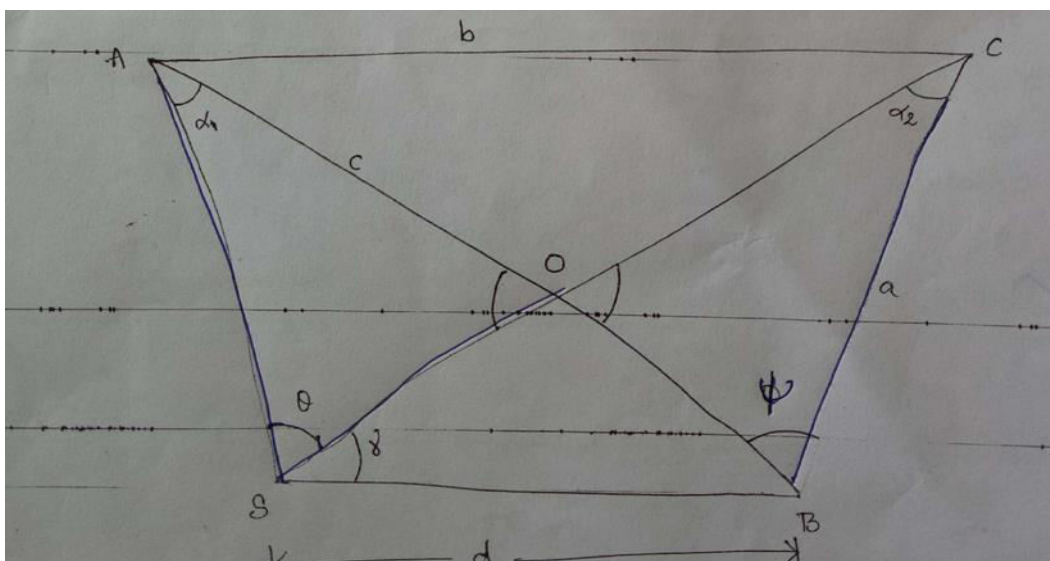


Towers generally have two independent structures. Outer structure is for supporting the observer and the signal whereas the inner one is for supporting the instrument only. The two structures are made entirely independent of each other so that the movement of the observer does not disturb the instrument setting. Two towers may be made of masonry, timber or steel. Timber scaffolds are most commonly used, and have been constructed to heights over 50 m.

### Satellite station:

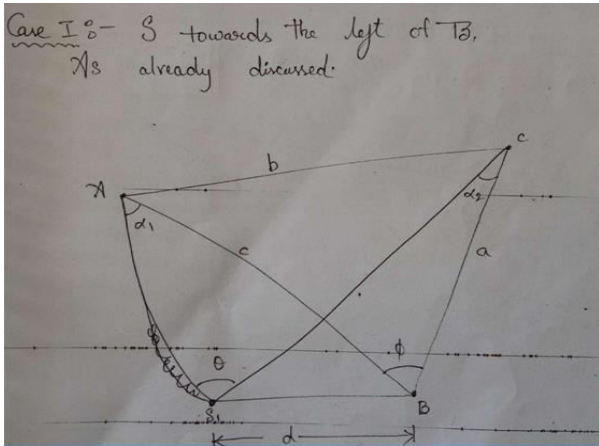
- In order to secure well condition triangle or better inter visibility objects such as church tops, flag poles or towers etc. are sometime selected as triangulation stations
- If the instruments is impossible to set up over that point a subsidiary station known as a satellite station or false station is selected as near as possible to the main station
- Observations are made to the other stations with the same precision from the satellite station
- Object of station marks is to provide a surface mark with a permanent mark buried below the surface on which a target or instruments is to centred over it
- Should be bronze or copper marks cemented into rock or concrete surface
- Normally station marks are buried below the ground surface to protect from the disturbances
- Control points can be constructed in concrete with centre mark in bronze or copper and buried at the required place
- Few dead measurements are taken using permanent features around the station and keep as a diagram

### Reduction to centre:

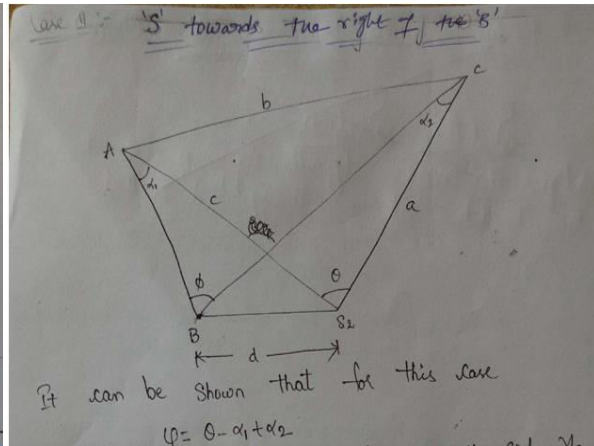


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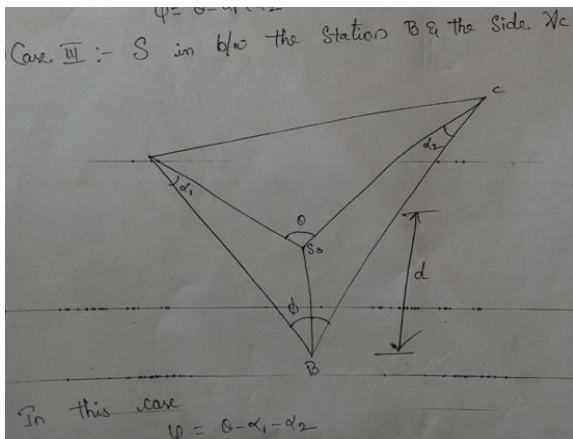
- The angles are then corrected and reduced to what they would be from the true station
- The operation applying to this correction due to the eccentricity of the station is generally known as reduction to centre
- Distance between true station and satellite station is determined by method of trigonometric levelling and they are four cases of satellite station.



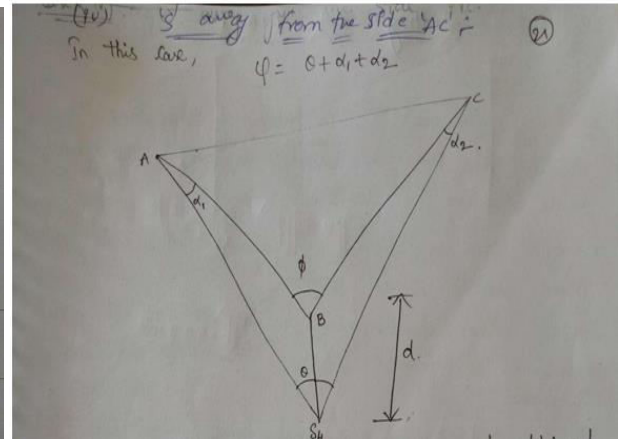
Case (I)



Case (II)



Case (III)



Case (IV)

**Base line & Extension of base line:** In selecting site for a base line, the following requirement should be considered.

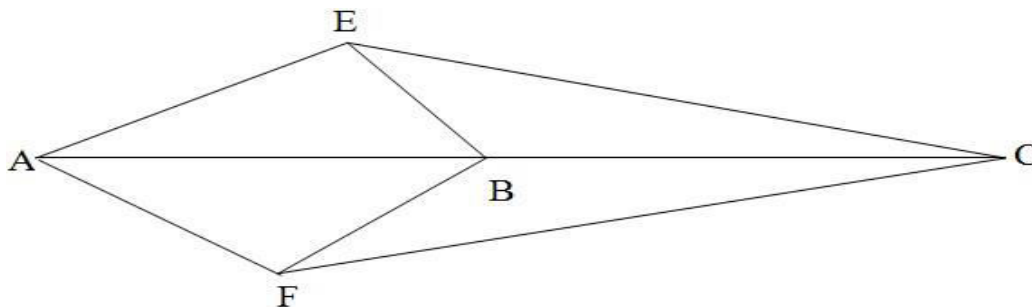
1. The site should be fairly levelled or uniformly sloping or gauntly undulating.
2. Should be free from obstructions throughout the entire length.
3. Ground should be firmed and smooth.
4. The site should can be such that the whole length can be laid out the extremities of the line being intrevesible at ground level.
5. The site should be such that well shaped triangle can be obtained in connecting the end stations of the base line to the main triangulation stations.

**Equipments for baseline Measurements:**

1. Tape
2. Straining Device
3. Spring balance or weight and pulley
4. Thermometers and a finely divided scale
5. Marking tripod or station rakes
6. Supporting tripods or stakes

Extension of Baseline: The length of a base line is usually not greater than. As it is not possible to obtain a possible side for a long base, the usually practice is to measure a short base and extend it by means of well conditioned triangles

First Method: Suppose it is required to prolong a base line AB. Let CB, the extremities of the base, is fixed accurately in line AB prolonged by a theoligize centred over station A or B such that E and F are clearly visible from it and well shaped triangles are formed.



From  $\triangle BCE$ , find  $BC_1$

From  $\triangle BCE$ , find  $BC_2$

From  $\triangle ACE$ , find  $BC_3 = (AC - AB)$

From  $\triangle ACE$ , find  $BC_4 = (AC - AB)$

$$\text{Then } BC = \frac{(BC)_1 + (BC)_2 + (BC)_3 + (BC)_4}{4}$$

$$\text{Then } AC = AB + BC$$

**Second Method:**

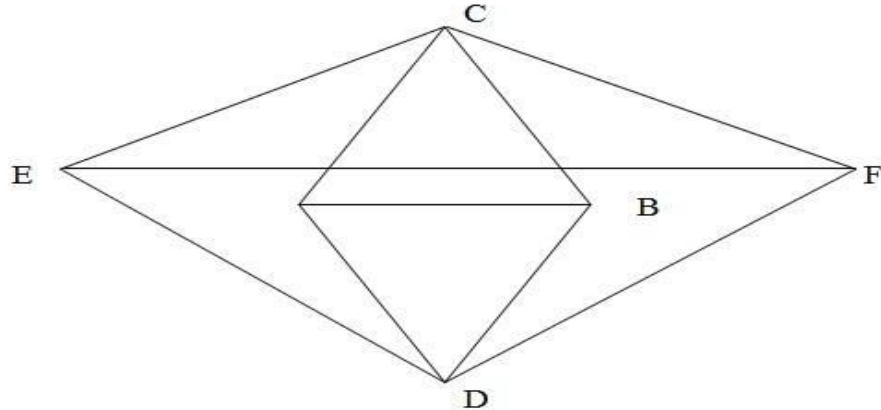
Another and more common method of extension of a base line is shown in the figure. In this method the base a gradually enlarged through the medium of well proportioned triangles. The base AB is extended to CD by selection suitable stations C and D on the opposite side of AB.

*From  $\triangle ABC$ , find  $AC$  and  $Cb$*

*From  $\triangle ACD$ , find  $CD_1$*

*From  $\triangle BCD$ , find  $CD_2$*

$$CD = \frac{(CD)_1 + (CD)_2}{2}$$



### Setting out of works

Introduction: The method of setting out is the reverse of surveying process. The process involves the positions and levels of building lines and road alignments shown on the construction plans to be established on the ground by various techniques and instruments

### **HORIZONTAL CONTROLS & ITS METHODS:**

The horizontal control consists of reference marks of known plan position, from which salient points of designed structures may be set out. For large structures primary and secondary control points are used. The primary control points are triangulation stations. The secondary control points are reference to the primary control stations.

#### **Reference Grid:**

Reference grids are used for accurate setting out of works of large magnitude. The following types of reference grids are used:

- Survey Grid
- Site Grid
- Structural Grid
- Secondary Grid

Survey grid is one which is drawn on a survey plan, from the original traverse. Original traverse stations form the control points of the grid. The site grid used by the designer is the one with the help of which actual setting out is done. As far as possible the site grid should be actually the survey grid. All the design points are related in terms of site grid coordinates. The structural grid is used when the structural components of the building are large in numbers and are so positioned that these components cannot be set out from the site grid with sufficient accuracy. The structural grid is set out from the site grid points. The secondary grid is established inside the structure, to establish internal details of the building, which are otherwise not visible directly from the structural grid.



### VERTICAL CONTROL & ITS METHODS:

The vertical control consists of establishment of reference marks of known height relative to some special datum. All levels at the site are normally reduced to the nearby bench mark, usually known as master bench mark.

The setting of points in the vertical direction is usually done with the help of following rods:

- Boning rods and travellers
- Sight Rails
- Slope rails or batter boards
- Profile boards

#### **Boning Rod:**

A boning rod consists of an upright pole having a horizontal board at its top, forming a 'T' shaped rod. Boning rods are made in set of three, and many consist of three 'T' shaped rods, each of equal size and shape, or two rods identical to each other and a third one consisting of longer rod with a detachable or movable 'T' piece. The third one is called traveling rod or traveler.

**Sight Rails:** A sight rail consist of horizontal cross piece nailed to a single upright or pair of uprights driven into the ground. The upper edge of the cross piece is set to a convenient height above the required plane of the structure, and should be above the ground to enable a man to conveniently align his eyes with the upper edge. A stepped sight rail or double sight rail is used in highly undulating or falling ground.

#### **Slope rails or Batter boards:**

There are used for controlling the side slopes in embankment and in cuttings. The consist of two vertical poles with a sloping board nailed near their top. The slope rails define a plane parallel to the proposed slope of the embankment, but at suitable vertical distance above it. Travelers are used to control the slope during filling operation.

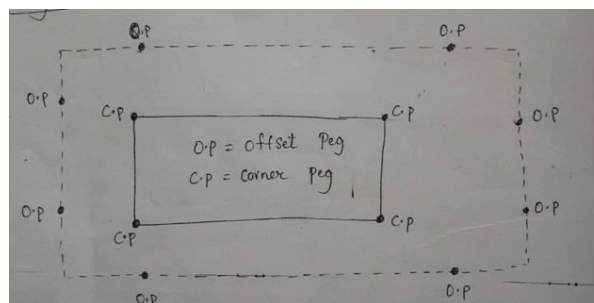
#### **Profile boards:**

These are similar to sight rails, but are used to define the corners, or sides of a building. A profile board is erected near each corner peg. Each unit of profile board consists of two verticals, one horizontal board and two cross boards. Nails or saw cuts are placed at the top of the profile boards to define the width of foundation and the line of the outside of the wall

Positing of a structure: There are three types of positing of structure

- Offset from the existing building
- Co-ordinates from the site grid
- Offset from the baseline

#### **Offset pegs:**



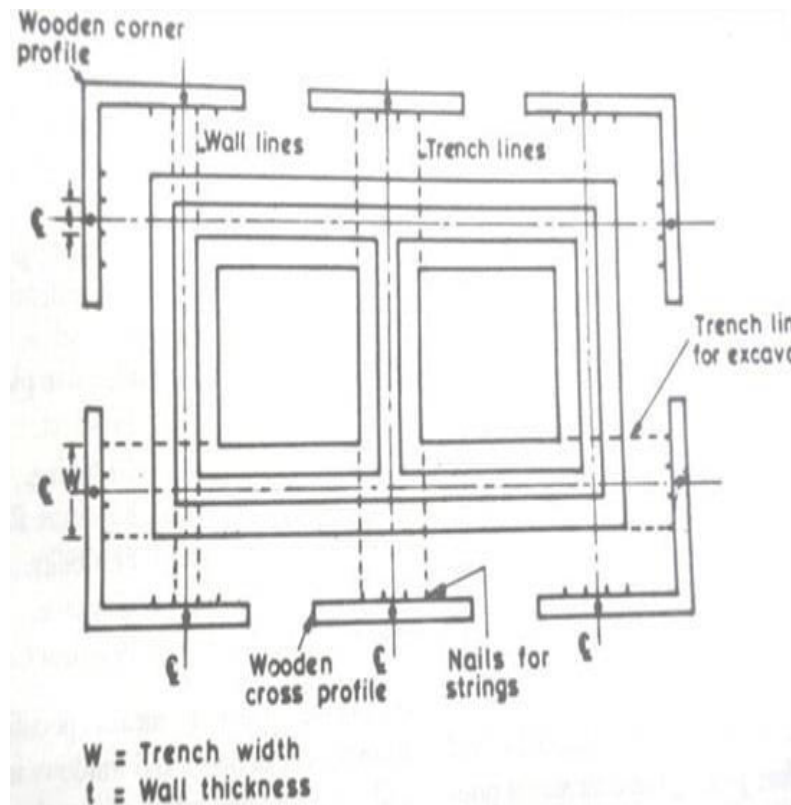
- The corner of the building can be located by the methods discussed in the preceding section
- For Permanent reference points ,offset pegs are driven into the ground
- The offset distance from the three corners should be sufficiently large so that offset pegs are not disturbed during excavation
- The corners of the building can be relocated by measuring the distance from the offset pegs

### **Setting out of a foundation:**

- 1) First of all, the corners of the building are marked and then the lengths of the sides are checked by diagonal measurements.
- (2) The axial lines (centre lines) of the trenches are marked with the help of profiles, sighting rails, strings and pegs.
- (3) The off-sets are measured from axial lines and the frontage lines are placed in their correct position relative to local requirements.
- (4) The position of cross walls should be measured along the main walls and squared from these walls if desired, the total width of trenches being carefully outlined.

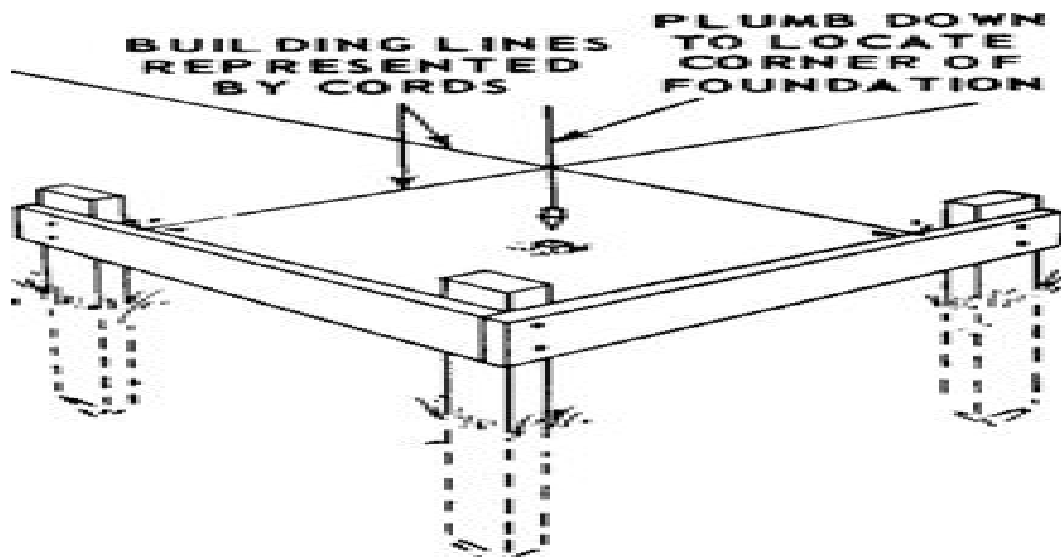
### **The following points should be observed while setting out trenches:**

- Profiles, nails, strings and lime are used for Setting out the foundation plan
- Sight rails may be erected at the corners of a building to determine the correct position of trenches.
- A theodolite may be used for marking accurately the axial lines 'or' centre lines.
- Strings are tied and stretched to the nails on profiles 'or' on pegs for horizontal control of dimensions
- Vertical reference pillars are erected at a distance of 1 meter from the edges of excavation for vertical control of building during construction.
- All the levels on site should be obtained from a fixed datum previously determined by the Surveyor. The depth of trenches and other levels should also be regulated by measurements from this point.
- The bottom of all trenches should be well rammed before placing the concrete in position.



**Batter board:**

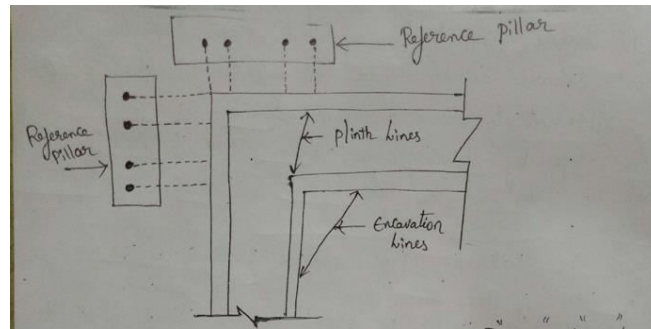
Horizontal boards nailed to corner posts located just outside the corners of a proposed building to assist in the accurate layout of foundation and excavation lines.



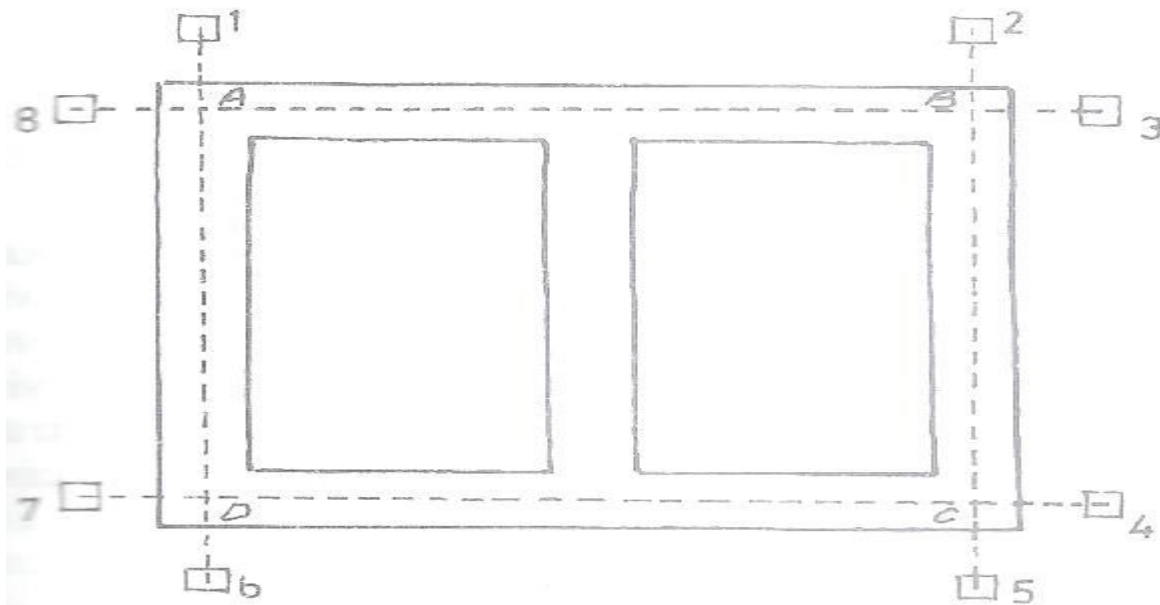
One of a pair of horizontal boards which are nailed (at right angles to each other) to three posts set beyond the corners of a building excavation; used to indicate a desired location; strings, fastened to these boards, are used to indicate the exact corner of a building.. One of the boards set across a pipe trench to carry a cord or wire grade line.

### Reference pillars:

- For large important works, reference pillars of masonry or concrete are constructed near each corner point
- The top of the pillars is set at some fixed level usually the plinth level
- Bolts indicating the plinth lines on the plan are also embedded



### Setting out with a theodolite:



Before Commencement, of the excavation of trenches for foundation, a setting out plan is prepared on paper. The setting out plan is a dimensioned ground floor plan, usually drawn to scale of 1:50. The plan is fully dimensioned at all breaks and openings. One of the methods of setting out of foundations with theodolite is to first mark the centre line of the longest outer wall of building by stretching a string between wooden pegs driven at its ends. This serves as the reference line for marking the centre line of all the walls of the building. The

centre line of the wall, which is perpendicular to the long wall, is marked by setting up a right angle. Right angle is set up by forming triangles with sides 3,4 and 5 units long. If we fix the two sides of the right angles triangle to be 3 m, and 4 m, then the third side i.e. the hypotenuse should be taken a 5 m. The dimensions should be set out with a steel tape. The alternative method of setting out right angle is by the use of theodolite. This instrument is also helpful in setting out acute or obtuse angles. Small right-angled Projections are usually set out with mason's square.

The method of Setting out of Foundations described above is not so reliable for important works as there is likelihood of the wooden pegs being pulled up or displaced. In an accurate method, the centre lines of the building walls are carefully laid by means of small nails fixed into the head of the wooden pegs driven at the quoins. In case of rectangular buildings, the diagonal from the opposite corners are checked for their equality. Small brick walls, pillars or platforms are constructed 90cm clear of the proposed foundation trench. The platforms are about 15 cm wider than the trench width and are plastered at top. The tops of all platforms or pillars should be at the same level preferably at plinth or floor level of building. The strings are then stretched over the nails in the pegs and the corresponding lines are marked on the wet plastered platforms top by pressing the stretched string on the plastered surface by a trowel. The outside lines of the foundation trench and the plinth lines are marked on the wet plastered platform top in the similar manner.

Before starting excavation, the strings are stretched between the outside lines of the foundation trench marked over the platform top and the cutting lines are marked on the ground by lime powder. If necessary, the lines may be marked by a daghbel or pick-axe

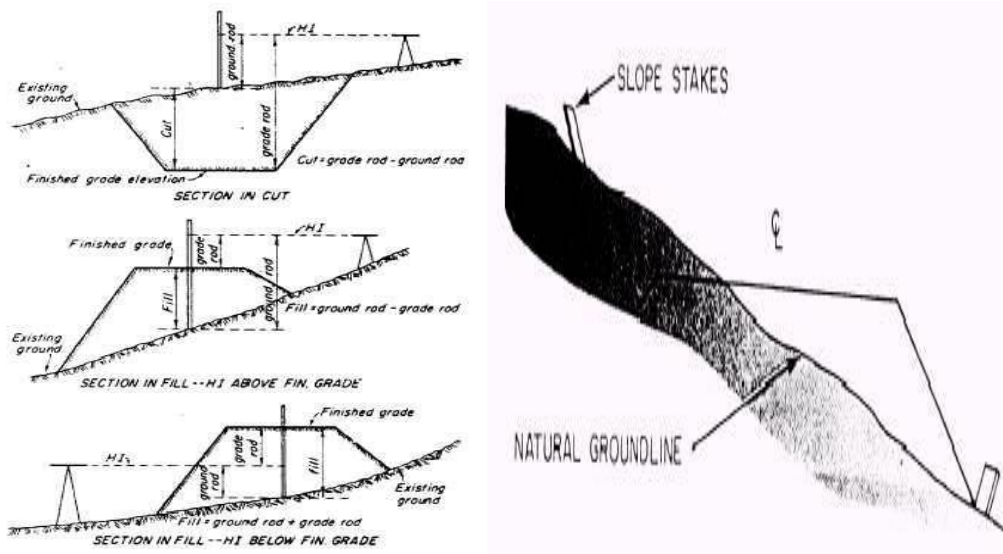
### **Graded stakes:**



Grade stake are set on a route, such as a road or railway to indicate the depth of cut or fill at a given location.

### **Slope stakes:**

Slope staking is a special form of levelling to determine the point at which the proposed slope intersects the existing ground. Since these stakes define the actual construction limits, they are set in the early stages of a contract and as such require preservation for later use. Slope stakes are necessary to determine if the roadway is being built to the required lines and grades. The slope stake is the tool that is used to ensure that slopes are graded correctly and fill or cuts are made to the required elevations.

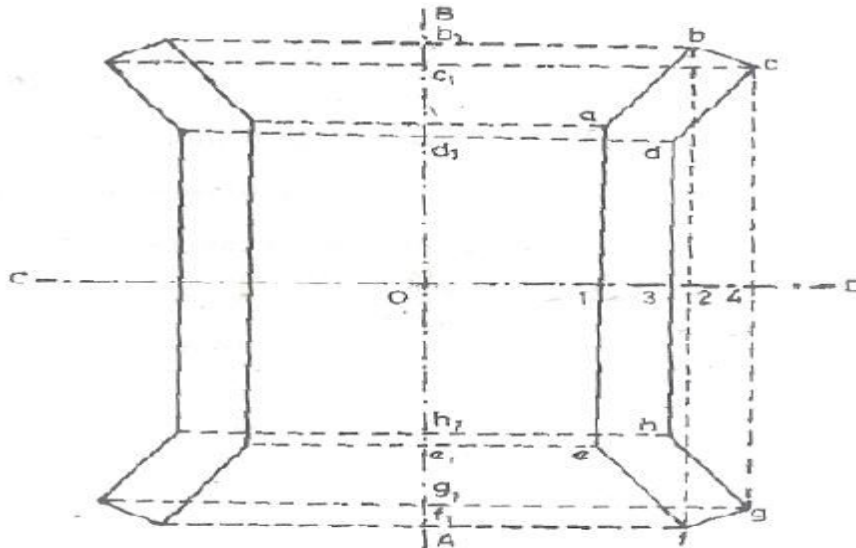


**Setting out of culvert:**



**Culvert**

- Fix a peg at O
- Set up theodolite over O
- Bisect the point B. and fix the number of points along OB.
- Transits the telescope and fix a number of points along OA.
- Set out the line CD at right angle to AB and fix a number of points
- Necessary to define the line CD.
- Set off the distance O1, O2, O3, O4 etc along CD. On side of O and 1a, 2b, 3c, 4d, etc along AB on either side of O. fix arrow at these points
- In similar manner other corner of the wing walls and abutments maybe marked by their co-ordinates and pegs are driven



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**Setting out of Sewer:**

- Fix stakes on the ground at the centre line of the proposed sewer at 20m intervals.
- Set out a parallel line to the proposed centre line of the sewer on one side at a distance apart so that it may not get disturbed during excavation.
- Excavate the sewer trench of desired width and depth.
- Erect cross heads at 30meter apart and each change of gradient and direction.
- Set the top edge of each sight rail truly horizontal with help of a spirit level.
- Drive in a nail on the top edge at the centre of the sight rail to define the centre line of the sewer.
- Establish the gradient of the line joining top edge of two consecutive sight Rails as that of the invert of the sewer

