

**Jharsuguda Engineering School, Jharsuguda**

**Department of Civil Engineering**



**Lecture Notes**

**on**

**Land Survey-II**

**For 6th Semester Civil Engineering Diploma Students  
under SCTE&VT, Odisha, Bhubaneswar**

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# Tacheometry

## Introduction

It is a method of surveying in which horizontal distances and (relative) vertical elevations are determined from subtended intervals and vertical angles observed with an instrument.

## Uses of Tacheometry

Tacheometry is used for

1. preparation of topographic map where both horizontal and vertical distances are required to be measured;
2. survey work in difficult terrain where direct methods of measurements are inconvenient;
3. reconnaissance survey for highways and railways etc;
4. establishment of secondary control points.

## Instrument

The instruments employed in tacheometry 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.

## Systems of Tachometric Measurement

Depending on the type of instrument and methods/types of observations, tachometric measurement systems can be divided into two basic types:

- (i) Stadia systems and      (ii) Non-stadia systems

### **Stadia Systems**

In these systems, staff intercepts at a pair of stadia hairs present at diaphragm, are considered. The stadia system consists of two methods:

- [Fixed-hair method and](#)
- [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) [Subtense bar method.](#)

## Fixed-hair method or Stadia method

It is the most prevalent method for tacheometric surveying. In this method, the telescope of the theodolite is equipped with two additional cross hairs, one above and the other below the main horizontal hair at equal distance. These additional cross hairs are known as stadia hairs. This is also known as tacheometer.

### Principle of Stadia method

(Figure 23.1) A tacheometer is temporarily adjusted on the station P with horizontal line of sight. Let a and b be the lower and the upper stadia hairs of the instrument and their actual vertical separation be designated as i. Let f be the focal length of the objective lens of the tacheometer and c be horizontal distance between the optical centre of the objective lens and the vertical axis of the instrument. Let the objective lens is focused to a staff held vertically at Q, say at horizontal distance D from the instrument station.

By the laws of optics, the images of readings at A and B of the staff will appear along the stadia hairs at a and b respectively. Let the staff interval i.e., the difference between the readings at A and B be designated by s. Similar triangle between the object and image will form with vertex at the focus of the objective lens (F). Let the horizontal distance of the staff from F be d. Then, from the similar  $\Delta$ s ABF and a' b' F,

$$\frac{AB}{d} = \frac{a'b'}{f}$$

$$\text{Or, } d = \frac{AB}{a'b'} \times f = \frac{s}{i} \times f$$

$$\therefore d = \frac{f}{i} \times s$$

as  $a'b' = ab = i$ . The ratio  $(f / i)$  is a constant for a particular instrument and is known as stadia interval factor, also instrument constant. It is denoted by K and thus

$$d = K.s \text{ ----- Equation (23.1)}$$

The horizontal distance (D) between the center of the instrument and the station point (Q) at which the staff is held is  $d + f + c$ . If C is substituted for  $(f + c)$ , then the horizontal distance D from the center of the instrument to the staff is given by the equation

$$D = Ks + C \text{ ----- Equation (23.2)}$$

The distance C is called the stadia constant. Equation (23.2) is known as the stadia equation for a line of sight perpendicular to the staff intercept.

## Determination of Tacheometric Constants

The stadia interval factor (K) and the stadia constant (C) are known as tacheometric constants.

Before using a tacheometer for surveying work, it is required to determine these constants. These can be computed from field observation by adopting following procedure.

**Step 1 :** Set up the tacheometer at any station say P on a flat ground.

**Step 2 :** Select another point say Q about 200 m away. Measure the distance between P and Q accurately with a precise tape. Then, drive pegs at a uniform interval, say 50 m, along PQ. Mark the peg points as 1, 2, 3 and last peg -4 at station Q.

**Step 3 :** Keep the staff on the peg-1, and obtain the staff intercept say  $s_1$  .

**Step 4 :** Likewise, obtain the staff intercepts say  $s_2$ , when the staff is kept at the peg-2,

**Step 5 :** Form the simultaneous equations, using Equation (23-2)

$$D_1 = K. s_1 + C \text{ -----(i)}$$

$$\text{and } D_2 = K. s_2 + C \text{ -----(ii)}$$

Solving Equations (i) and (ii), determine the values of K and C say  $K_1$  and  $C_1$  .

**Step 6 :** Form another set of observations to the pegs 3 & 4, Simultaneous equations can be obtained from the staff intercepts  $s_3$  and  $s_4$  at the peg-3 and point Q respectively. Solving those equations, determine the values of K and C again say  $K_2$  and  $C_2$ .

**Step 7 :** The average of the values obtained in steps (5) and (6), provide the tacheometric constants K and C of the instrument.

### Anallactic Lens

It is a special convex lens, fitted in between the object glass and eyepiece, at a fixed distance from the object glass, inside the telescope of a tacheometer. The function of the anallactic lens is to reduce the stadia constant to zero. Thus, when tacheometer is fitted with anallactic lens, the distance measured between instrument station and staff position (for line of sight perpendicular to the staff intercept) becomes directly proportional to the staff intercept. Anallactic lens is provided in external focusing type telescopes only.

### Inclined Stadia Measurements

It is usual that the line of sight of the tacheometer is inclined to the horizontal. Thus, it is frequently required to reduce the inclined observations into horizontal distance and difference in elevation.

Let us consider a tacheometer (having constants K and C) is temporarily adjusted on a station, say P ([Figure 23.2](#)). The instrument is sighted to a staff held vertically, say at Q. Thus, it is required to find the horizontal distance  $PP_1$  (= H) and the difference in elevation  $P_1Q$ . Let A, R and B be the staff points whose images are formed respectively at the upper, middle and lower cross hairs of the tacheometer. The line of sight, corresponding to the middle cross hair, is inclined at an angle of elevation  $\theta$  and thus, the staff with a line perpendicular to the line of sight. Therefore  $A'B' = AB \cos \theta = s \cos \theta$  where s is the staff intercept AB. The distance  $D$  (= OR) is  $C + K. s \cos \theta$  (from Equation 23.2). But the distance  $OO_1$  is the horizontal distance H, which equals  $OR \cos \theta$ . Therefore the horizontal distance H is given by the equation.

$$H = (Ks \cos \theta + C) \cos \theta$$

$$\text{Or } H = Ks \cos^2 \theta + C \cos \theta \text{ ----- Equation (23.3)}$$

in which K is the stadia interval factor ( $f / i$ ), s is the stadia interval, C is the stadia constant ( $f + c$ ), and  $\theta$  is the vertical angle of the line of sight read on the vertical circle of the transit.



The distance  $RO_1$ , which equals  $OR \sin \theta$ , is the vertical distance between the telescope axis and the middle cross-hair reading. Thus  $V$  is given by the equation

$$V = (K s \cos \theta + c) \sin \theta$$

$$V = Ks \sin \theta \cos \theta + C \sin \theta \text{ ----- Equation (23.4)}$$

$$\therefore V = \frac{1}{2} Ks \sin 2\theta + C \sin \theta \text{ ----- Equation (23.5)}$$

Thus, the difference in elevation between P and Q is  $(h + V - r)$ , where  $h$  is the height of the instrument at P and  $r$  is the staff reading corresponding to the middle hair.

### Uses of Stadia Method

The stadia method of surveying is particularly useful for following cases:

1. In differential leveling, the backsight and foresight distances are balanced conveniently if the level is equipped with stadia hairs.
2. In profile leveling and cross sectioning, stadia is a convenient means of finding distances from level to points on which rod readings are taken.
3. In rough trigonometric, or indirect, leveling with the transit, the stadia method is more rapid than any other method.
4. For traverse surveying of low relative accuracy, where only horizontal angles and distances are required, the stadia method is a useful rapid method.
5. On surveys of low relative accuracy - particularly topographic surveys-where both the relative location of points in a horizontal plane and the elevation of these points are desired, stadia is useful. The horizontal angles, vertical angles, and the stadia interval are observed, as each point is sighted; these three observations define the location of the point sighted.

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**Example 13.2.** A staff was held vertically at a distance of 46.2 m and 117.6 m from the centre of a theodolite fitted with stadia hairs and the staff intercepts with the telescope horizontal were 0.45 m and 1.15 m respectively. The instrument was then set over a station P of RL. = 150 m, the height of instrument axis being 1.38 m. The stadia hair readings on a staff held vertically at a station Q were 1.2 m, 1.93 m and 2.65 m respectively, while the vertical angle was  $-9^{\circ} 30'$ . Find the distance PQ and RL. of Q.

**Solution.** (Fig. 13.9) By substituting the values in equation

$$D = AS + B, \text{ we get}$$

$$46.2 = A \times 0.45 + B \quad \dots(i)$$

$$117.6 = A \times 1.15 + B \quad \dots(ii)$$

By solving equations (i) and (ii) we get,  $A = 102$  and  $B = 0.3$

$\therefore$  Tacheometric constants are :

Multiplying constant = 102,

Additive constant = 0.3

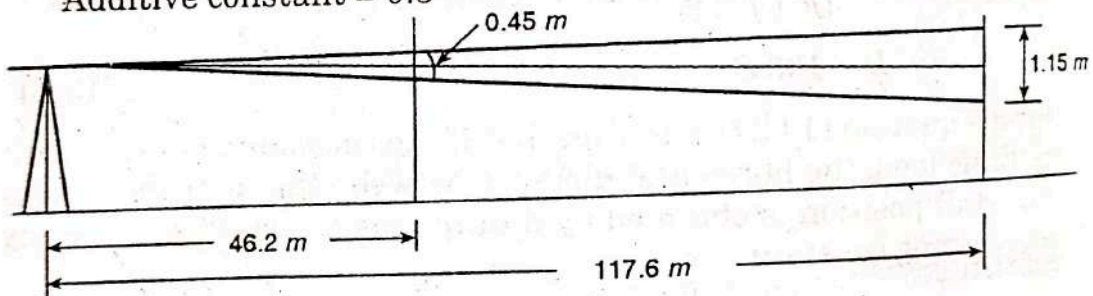


Fig. 13.9 (a)

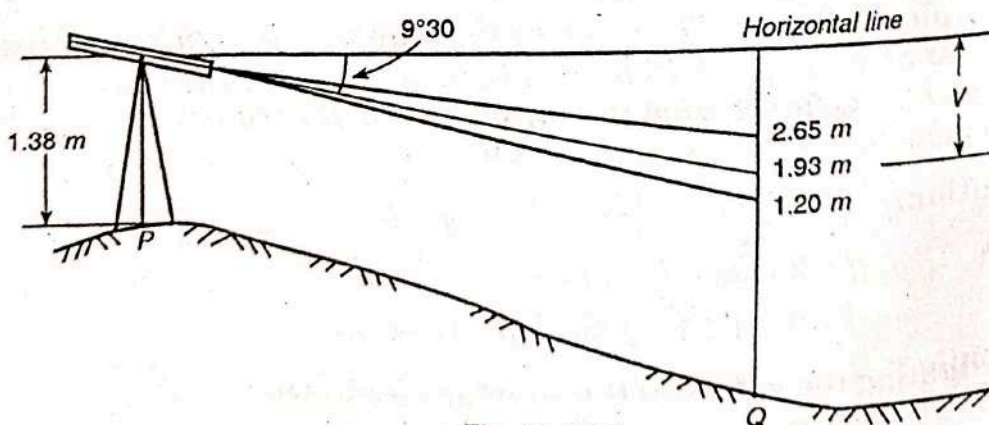


Fig. 13.9 (b)

Calculation of horizontal distance

$$S = 2.65 - 1.20 = 1.45 \text{ m}$$

$$\theta = 9^{\circ}.5$$

$$PQ = As \cos \theta^2 + B \cos \theta.$$

$$= 102 \times 1.45 \cos^2 9^{\circ}.5 + 0.3 \cos 9^{\circ}.5$$

$$= 143.87 + 0.30 = 144.17 \text{ m}$$

$$\text{Vertical Component } V = As \frac{\sin 2\theta}{2} + B \sin \theta$$

$$= 102 \times 1.45 \frac{\sin 19^\circ}{2} + 0.3 \times \sin 9^\circ.5$$

$$= 24.08 \text{ m} + 0.05 \text{ m} = 24.13 \text{ m}$$

$$\begin{aligned} \therefore \text{R.L. of } Q &= \text{R.L. of P} + \text{H.I.} - V - \text{Central hair reading} \\ &= 150.0 + 1.38 - 24.13 - 1.93 \\ &= 151.38 - 26.06 = 125.32 \text{ m. } \quad \text{Ans.} \end{aligned}$$

**Example 13.3.** The stadia readings with horizontal sight on a vertical staff held 50 m away from a tacheometer were 1.284 and 1.780. The focal length of object glass was 25 cm. The distance between the object glass and trunnion axis of the tacheometer was 15 cm.

Calculate the stadia interval.

**Solution.**

From Eqn. (13.2) we know

$$D = \frac{f}{i} s + (f + d) \quad \dots(i)$$

$$D = 50 \text{ m}, f = 0.25 \text{ m}, d = 0.15 \text{ m}$$

$$S = 1.780 - 1.284 = 0.496$$

Substituting the values in Eqn. (i)

$$50 = \frac{0.25 \times 0.496}{i} + (0.25 + 0.15)$$

$$50 = \frac{0.25 \times 0.496}{i} + 0.4$$

$$\text{or } i = \frac{0.25 \times 0.496}{50 - 0.4} = \frac{0.25 \times 0.496}{49.6} = 0.0025 \text{ m}$$

$$= 2.5 \text{ mm. } \quad \text{Ans.}$$

**Example 13.4.** A tacheometer was set up at an intermediate station C of the line AB and following readings were obtained :

Staff Station	Vertical angle	Staff readings		
A	$-6^\circ 20'$	0.445	1.675	2.905
B	$+4^\circ 20'$	0.950	1.880	2.810

The instrument was fitted with an anallatic lens and the constant was 100. Find the gradient of the line joining station A and station B.



**Solution.**

**Staff held at A :**

$$S_1 = 2.905 - 0.445 = 2.460 \text{ m} ; \theta_1 = -6^\circ 20'$$

Applying tacheometric formulae, we get

$$\begin{aligned} \text{Distance } CA &= AS_1 \cos^2 \theta_1 \\ &= 100 \times 2.460 \times \cos^2 6^\circ 20' = 243.0 \text{ m.} \end{aligned}$$

$$\begin{aligned} \text{Vertical component } V_1 &= \frac{AS_1 \sin 2\theta_1}{2} \\ &= 100 \times 2.46 \times \frac{\sin 12^\circ 40'}{2} = 26.971 \text{ m. (-ve)} \end{aligned}$$

**Staff held at B :**

$$S_2 = 2.810 - 0.950 = 1.860 ; \theta_2 = 4^\circ 20'$$

$$\begin{aligned} \therefore \text{Distance } CB &= 100 \times 1.860 \cos^2 4^\circ 20' \\ &= 184.94 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{Vertical component } V_2 &= AS_2 \frac{\sin 8^\circ 40'}{2} \\ &= 100 \times 1.860 \times \frac{\sin 8^\circ 40'}{2} = 14.014 \text{ m (+ve)} \end{aligned}$$

$$\therefore \text{The distance } AB = 243.0 + 184.94 = 427.94 \text{ m.}$$

Let  $X$  be the reduced level of the trunnion axis

$$\begin{aligned} \text{R.L. of station } A &= X - V_1 - \text{central hair reading} \\ &= X - 26.971 - 1.675 = X - 28.646 \end{aligned}$$

$$\begin{aligned} \text{R.L. of station } B &= X + V_2 - \text{central hair reading} \\ &= X + 14.014 - 1.880 = X + 12.134 \end{aligned}$$

**Difference in elevation of A and B**

$$= X + 12.134 - (X - 28.646) = 40.780 \text{ m}$$

$\therefore$  **Gradient of line AB**

$$= \frac{427.94}{40.780} \text{ or } 1 \text{ in } 10.49 \text{ upward} \quad \text{Ans.}$$

**Example 13.6.** A staff was held vertically at a distance of 100 m and 300 m from the centre of a theodolite fitted with stadia hairs and the staff intercepts with the telescope horizontal were 0.990 and 3.000 respectively. The instrument was then set over a station A of R.L. 950.50 m and the height of instrument was 1.42 m. The stadia hair readings of a staff held vertically at station B were 1.00, 1.83 and 2.67 m while the vertical angle was  $-10^{\circ} 00'$ . Find the distance AB and R.L. of B.

**Solution.**

(i) **Calculation of Tacheometric constants :**



Distance	Intercept
100 m	0.990
300 m	3.000

Substituting the above values in the tacheometric equation, i.e.

$$D = A.S. + B$$

$$100 = A \times 0.990 + B \quad \dots(i)$$

$$300 = A \times 3.000 + B \quad \dots(ii)$$

Subtracting Eqn. (i) from Eqn. (ii), we get

$$200 = 2.001 A$$

or 
$$A = \frac{200}{2.001} = 99.5$$

Substituting the value of A in Eqn. (ii), we get

$$300 = 99.5 \times 3.000 + B$$

or 
$$B = 300 - 298.5 = 1.5$$

Tacheometric constants are : 99.5 and 1.5. **Ans.**

(ii) **Calculation of the Horizontal distance AB (Fig. 13.11a)**

Here  $S = 2.67 - 1.00 = 1.67$  ;  $\theta = 10^\circ$

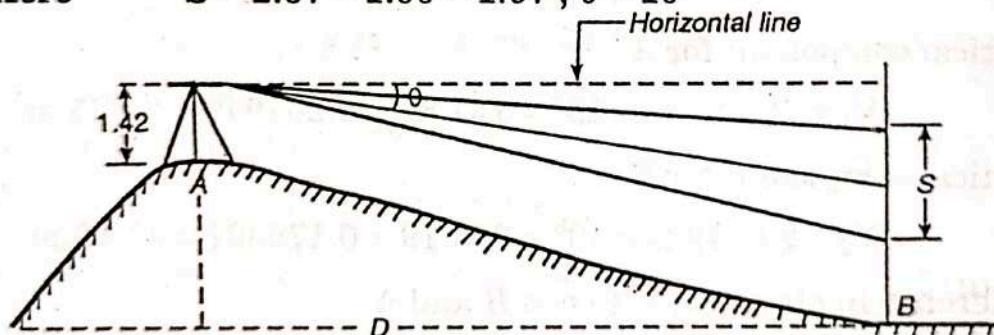


Fig. 13.11a

$$A = 99.5 \text{ and } B = 1.5$$

Substituting these values in equation (13.8 a), we get

$$\begin{aligned} D &= 99.5 \times 1.67 \cos^2 10^\circ + 1.5 \cos 10^\circ \\ &= 99.5 \times 1.67 \times (0.984808)^2 + 1.5 \times 0.984808 \\ &= 161.15 + 1.48 \end{aligned}$$

$\therefore$  Distance  $AB = 162.63 \text{ m. Ans.}$

(iii) **Calculation of R.L. of B**

Vertical component  $V = D \tan \theta$

$$= 162.63 \times 0.176367 = 28.68 \text{ m}$$

R.L. of B = R.L. of A + H.I. -- V - central wire reading



$$= 950.50 + 1.42 - 28.68 - 1.83$$

$$= 921.41 \text{ m} \quad \text{Ans.}$$

**Example 13.7.** The following observations pertain to a tacheometric traverse conducted with a tacheometer fitted with an anallatic lens and having a multiplying constant of 100, the levelling staff having been kept vertical :

Inst. Stn.	Staff Stn.	Hair Reading (m)			Ht. of Inst. (m)	Vertical angle
		upper	middle	lower		
P	Q	0.660	1.750	2.840	1.60	0° 00' 00"
Q	P	0.715	1.810	2.905	1.56	0° 00' 00"
Q	R	1.845	2.520	3.195	1.56	+13° 30' 00"

The R.L. of P is 587.75 metres. Determine the distance PQ and QR and the reduced levels of Q and R.

**Solution.**

(i) Calculation of the distance PQ with instrument at P

$$S = 2.840 - 0.660 = 2.180 \text{ m}$$

$$\therefore PQ = 100 \times 2.180 = 218 \text{ m.}$$

(ii) Calculation of distance PQ with instrument at Q

$$S = 2.905 - 0.715 = 2.190 \text{ m}$$

$$PQ = 100 \times 2.190 = 219 \text{ m.}$$

$$\therefore \text{Mean distance } PQ = \frac{218 + 219}{2}$$

$$= 218.5 \text{ m.} \quad \text{Ans.}$$

(iii) Horizontal distance QR.

$$\text{Here} \quad S = 3.195 - 1.845 = 1.350 \text{ m} ; \theta = 13^\circ 30'$$

Substituting the values of S and  $\theta$  in distance equation for inclined sights.

$$\text{i.e.} \quad D = AS \cos^2 \theta$$

$$\therefore \text{Distance } QR = 100 \times 1.35 \cos^2 13^\circ 30'$$

$$= 100 \times 1.35 \times (0.97237)^2$$

$$= 127.64 \text{ m} \quad \text{Ans.}$$

(iv) Vertical component  $V = D \tan \theta$

$$= 127.64 \times \tan 13^\circ 30'$$

$$= 127.64 \times 0.240079 = 30.64 \text{ m.}$$

(v) R.L. of  $Q = \text{R.L. of } P + \text{H.I. at } P - \text{Central wire reading on staff held at } Q = 587.75 + 1.60 - 1.750 = 587.60 \text{ m}$

Again, if R.L. of  $Q$  is  $x$ , then

$$x + 1.56 - 1.81 = 587.75$$

or  $x = 587.75 + 1.81 - 1.56 = 588.00$

Mean R.L. of

$$Q = \frac{587.60 + 588.00}{2} = 587.80 \text{ m} \quad \text{Ans.}$$

(vi) R.L. of  $R = \text{R.L. of } Q + \text{H.I.} + V - \text{Central wire reading}$

$$= 587.80 + 1.56 + 30.64 - 2.52$$

$$= 617.48 \text{ m} \quad \text{Ans.}$$

**Example 13.8.** *Following observations*



## Types of curves in surveying:- Horizontal and Vertical curves

### What are the Curves?

Road curves are regular bends in roads to bring a gradual change of direction. Similar curves are on railways and canals. Horizontal curves and vertical curves

Curves provided in the horizontal plane are known as horizontal curves, whereas a curve that changes the slope grade of a road, allowing a vehicle to negotiate the elevation rate.

Mainly curves are two types. **1.Horizontal Curves 2.Vertical Curves**

### What is Horizontal curves?

A horizontal curve is a curve in the plan provided to change the direction of alignment. In general, the flat curve should be used in conjunction with transition curves. As for a possible compound and reverse curve without transition should be avoided. To provide access to a particular locality. Making use of the existing right of way.

### Types of Horizontal curves

- Simple curve.
- Compound curve.
- Reverse curve.
- Transition curve.
- Lemniscate curve
- Spiral curve
- Cubic parabolic curve

### Simple curve

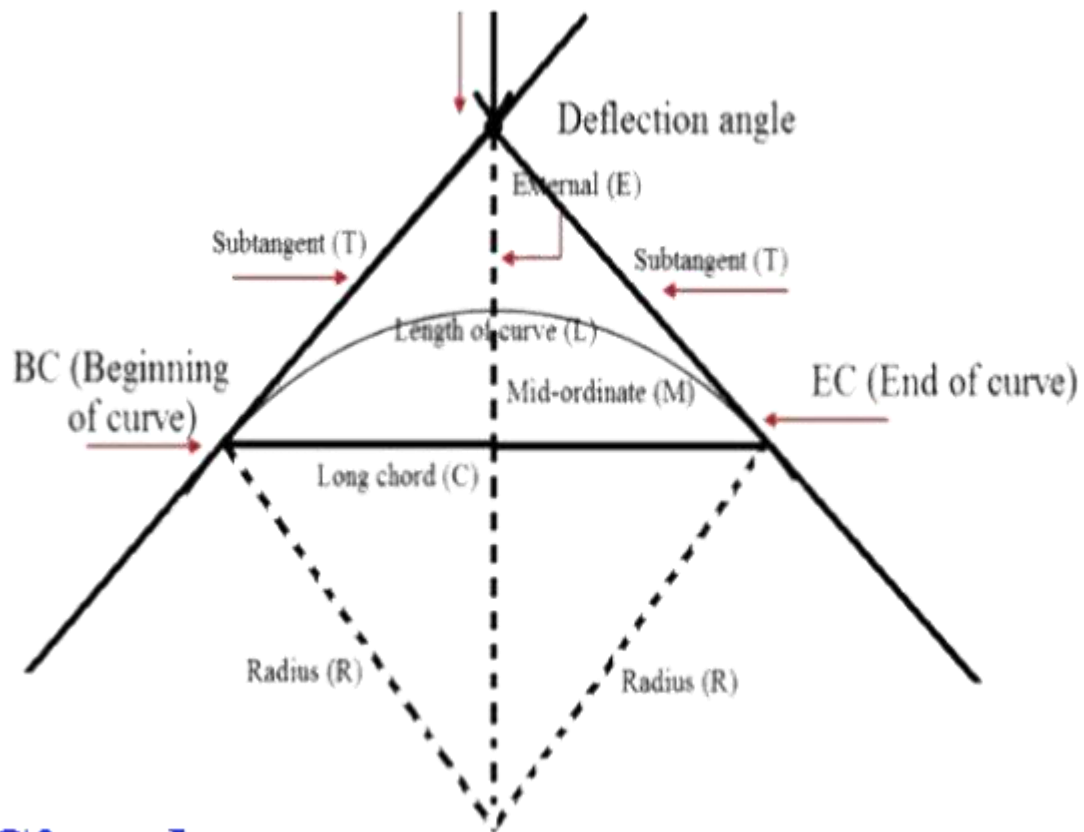
It is a circular curve that consists of a single arch of a uniform radius. It is generally represented of the angle subtended at its center by a chord of 30 m. or by the length of the radius can be calculated from the following equation.

$$R = 1746.5/D$$

Where

R = radius of the curve.

D = degree of curve.

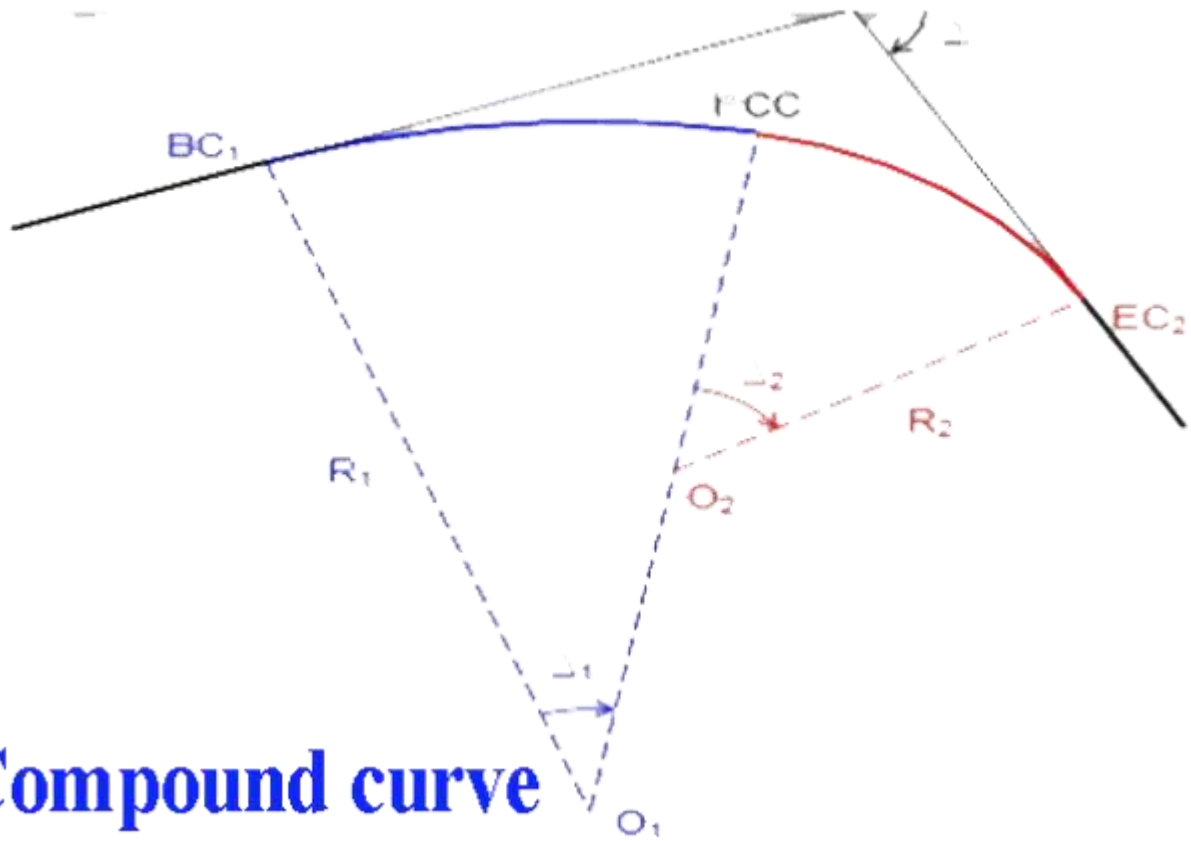


## Simple curve

Simple curves Types of curves in surveying

### Compound curve

This is a curve that is comprised of a series of two or more simple curves of different radius turning in the same general direction. This type of curve is used to avoid cutting or filling. They become advantages when a road has to be placed to fit a ground, like a layout between a river and a cliff, when the bend has to follow a specified path.



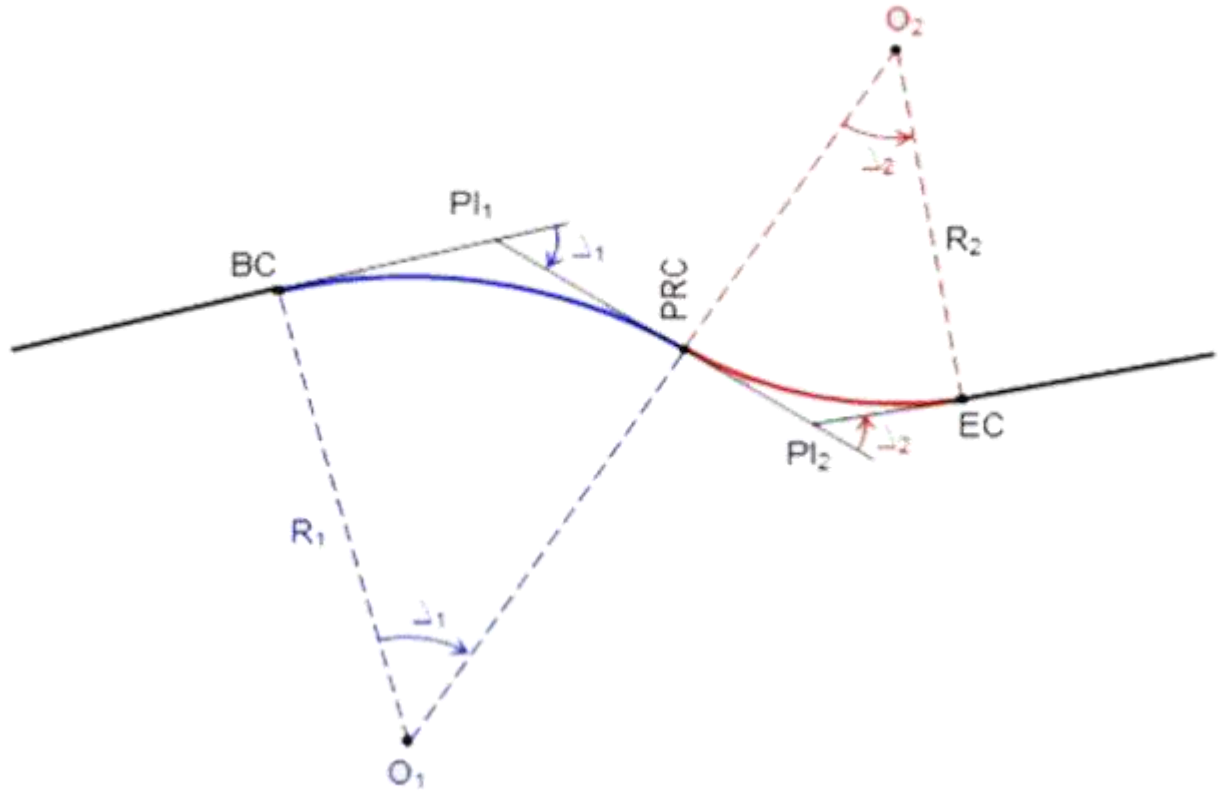
## Compound curve

Compound curve Types of curves in surveying

### Reverse curve

This type of curve consists of two simple curves of the same or different radius which turn in the opposite direction. These curves are suitable for tracks lying in a hilly region and for cross over in station yards. When a circular curve consists of two reverse curves with or without any straight line in between, then it is known as the deviation curve.

This type of curve is generally used at places of the accident, major repair work of the worn-out track. This keeps the track running in the original direction after deviation at the required place.



Reverse curve Types of curves in surveying

### Transition curve

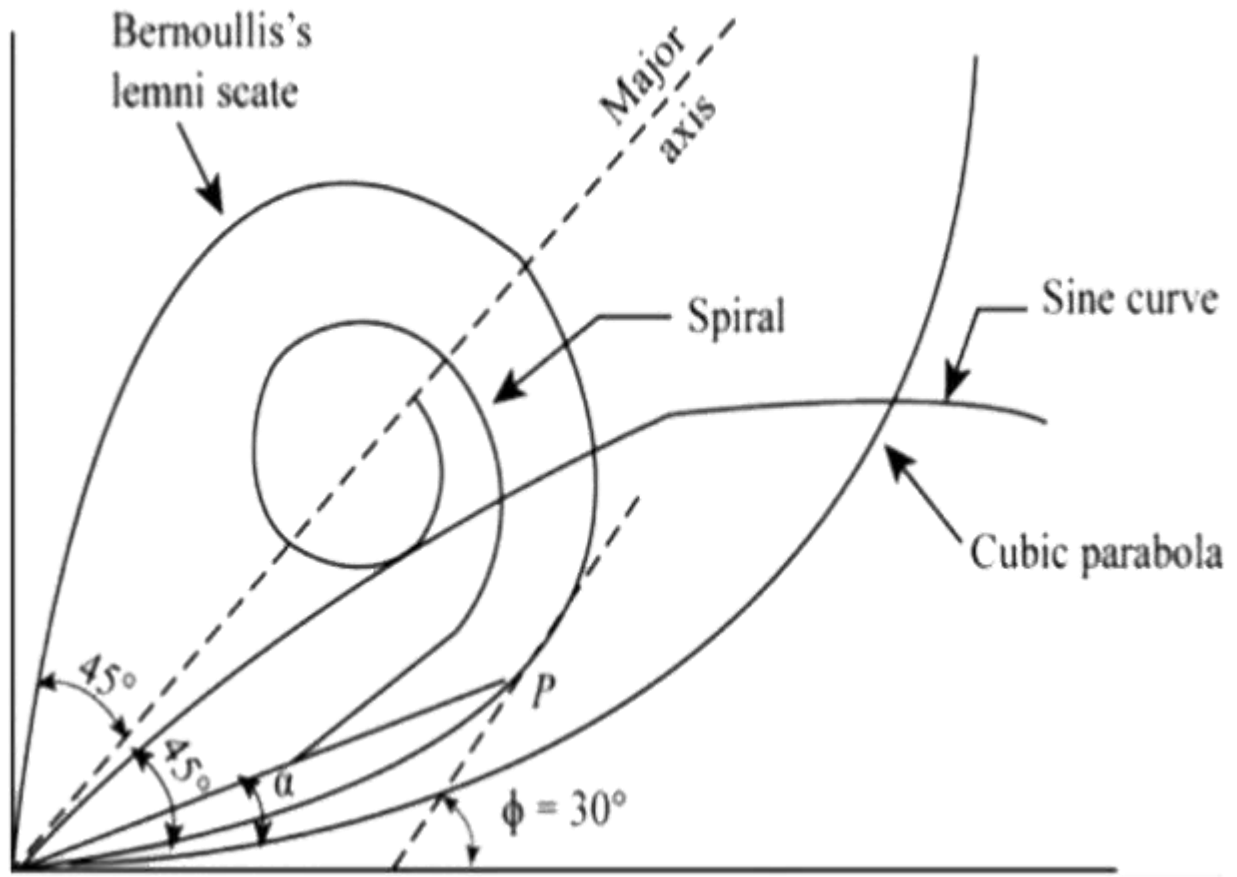
When a vehicle enters or leaves a circular curve of finite radius. It is subjected to an outward centrifugal force. This causes a shock and sway to the passenger and the driver.

The primary purpose of the transition curve is to enable vehicle moving at high speeds to make the change from the tangent section to the curves section, to the tangent section of a track in a safe and comfortable fashion.

The transition curve provides an increase of superelevation to the outer rail above the inner rail and thus reducing shocks or severe jerk on the moving railway vehicle.

It minimizes the wear of rails on curved tracks and provides comfort to the passenger due to the smooth running of the train.

The most common type of transition curve



Transition curve Types of curves in surveying

**Lemniscate curve –**

In this transition curve, radius decreases as the length increases, and hence there is a slight fall of the rate of gain of radial acceleration.

$$L = C \sqrt{\sin^2 h}$$

L = length of polar ray in metres

h = polar angle in radians

C = A constant

**Spiral curve –**

This an ideal transition curve. The radius of this curve is inversely proportional to length traversed. Hence the rate of change of acceleration in this curve is uniform throughout its length.

**Cubic parabolic curve –**

In the case of the curve the rate of decrease of curvature is much low for deflection angles 4° to 9° but beyond 9° there is a rapid increase in the radius of curvature.

$$Y = X^3/(6RL)$$

Y = coordinate of any point

R = radius

L = length of curve

### What are **Vertical curves**? –

A vertical curve is a curve in elevation provided at a change of gradients. Change of gradients becomes necessary due to the topography of a country and to reduce the quantity of earthwork.

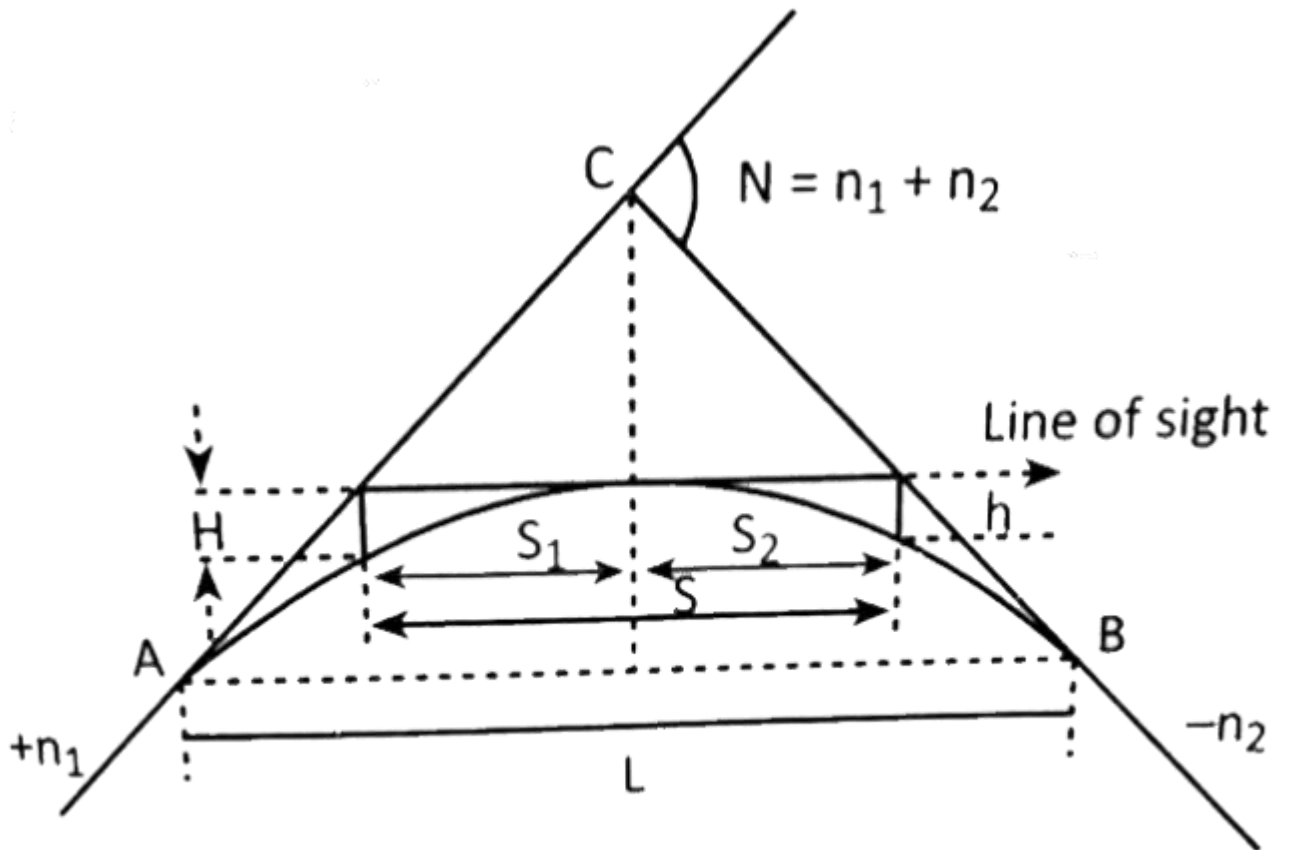
### Types of vertical curves

1. Summit curve.
2. Valley curve.

### Summit curve

1. A position grade meets a negative grade,
2. A position grade meets another milder position graded,
3. A position grade meets a level stretch,
4. A negative grade meets a Steeple's negative grade.

The centrifugal force generated by the movement of a vehicle along a summit curve acts in a direction opposite to the direction in which its weight acts.

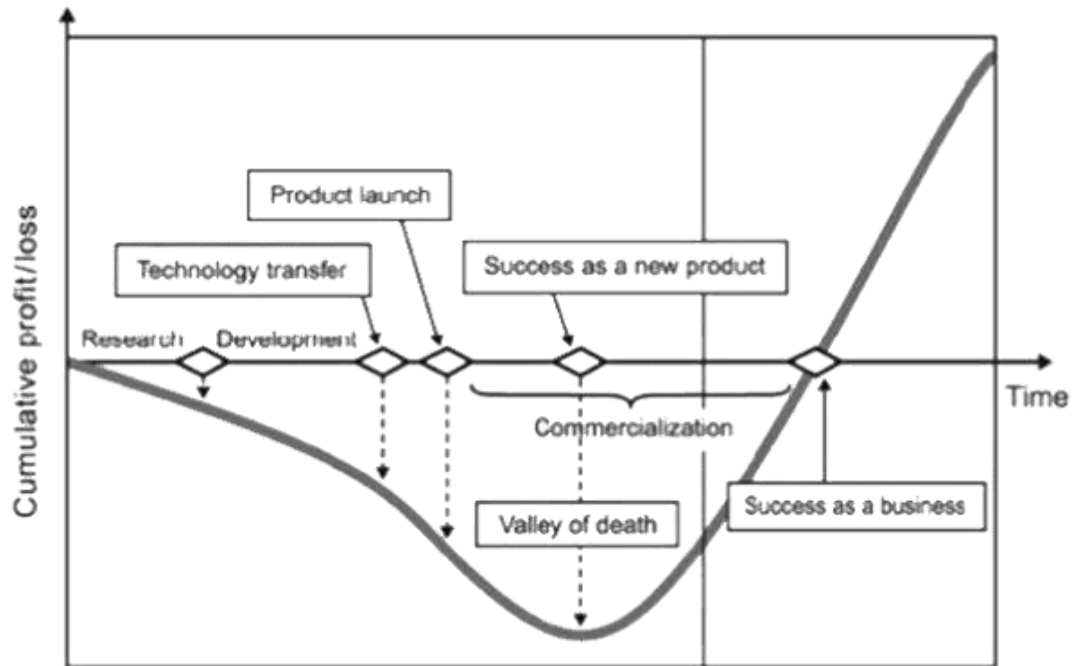


Summit curves Types of curves in surveying

### Valley curve

1. A negative grade meets a positive grades,
2. A negative grade meets a milder negative grade,
3. A negative grade meets a level stretch,
4. A negative grade meets a Stealers positive grade.

The centrifugal force generated by the vehicle moving on a valley curve acts in the same direction as the weight of vehicle.



### Valley curve

The length of the vertical curve depends upon the algebraic difference in grades and determined by rates of change at which it is decided to change the gradient of the liner.

### Simple Circular Curve

Once the alignment of a route is finalized, such as AVCD in [Figure 37.1](#), the change in direction is achieved through provision of circular curves. In [Figure 37.1](#), to change the direction from AV to VC, a circular curve  $T_1GT_2$  is provided. Similarly, from VC to CD,  $T_1G'T_2$  is provided. The straight alignments, between which a curve is provided, are tangential to the curve. Thus,  $AT_1V$  and  $VT_2C$  are tangential to  $T_1GT_2$ . The tangent line before the beginning of the curve is called the Back tangent or the rear tangent. The tangent line after the end of the curve is called the Forward tangent. The line  $AT_1$  is the back tangent and the line  $T_2C$  is the forward tangent for the curve  $T_1GT_2$ . The distinction of the back tangent from the forward tangent depends on the direction of the route surveying. The point at which extension of the back tangent and the forward tangent meet is known as the Vertex (V) or point of intersection (P.I.). The exterior angle at the vertex or point of intersection is known as the Intersection angle (I). It is also known as Deflection angle ( $\Delta$ ) as it represents the deflection angle between the back tangent and the forward tangent. Thus, angle between the line AV produced beyond the vertex V and the line VC represents I (or  $\Delta$ ). The point on the back tangent where the curve begins is known as the Point of Curvature (P.C.). At this point, the alignment of the route changes from a straight line to a curve. This is represented by  $T_1$  in [Figure 37.1](#). The point on the forward tangent where the curve ends is known as the Point of tangency (P.T.). At this point, the alignment of the route changes from a curve to a straight line. It is represented by  $T_2$  in [Figure 37.1](#). The distance between the point of curvature ( $T_1$ ) to the point of intersection (V) along the extension of back tangent is known as Tangent distance (T). It is also equal to the distance between the point of tangency ( $T_2$ ) to the point of intersection along the extension of forward tangent. The distance between the point of intersection (V) and the middle point of the curve is called as External distance (E). The longest possible chord of the circular curve is known as Long chord (L). It is the line joining the point of curvature ( $T_1$ ) and the point of tangency ( $T_2$ ). The distance between the middle



point of the curve and the middle point of the long chord is Mid-ordinate (M). The length of the alignment along the curve between the point of curvature (T<sub>1</sub>) and the point of tangency (T<sub>2</sub>) is known as the Length of curve (l). During the progress of the route, if the direction of deflection is to the right then it is called Right-hand curve (T<sub>1</sub>GT<sub>2</sub>) and it is called left -hand curve, if the curve deflects to the left T'<sub>1</sub>G'T'<sub>2</sub>.

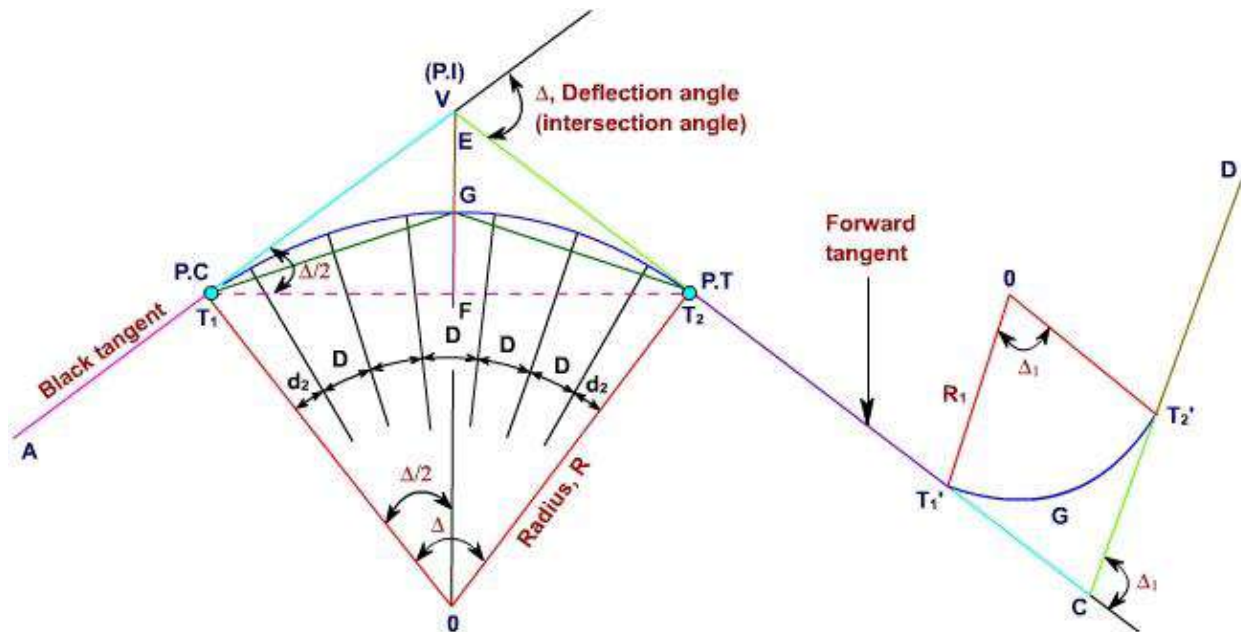


Figure 37.1 Horizontal alignment of a route with circular curve

### Elements of a Simple Circular Curve

Let T<sub>1</sub>GT<sub>2</sub> be the circular curve that has been provided between the tangents AV and VC. The deflection angle, Δ between the tangents is measured in the field. The radius of curvature is the design value as per requirement of the route operation and field topography. The line joining O and V bisects the internal angles at V and at O, the chord T<sub>1</sub>T<sub>2</sub> and arc T<sub>1</sub>GT<sub>2</sub>. It is perpendicular to the chord T<sub>1</sub>T<sub>2</sub> at F. From the Figure 37.1, RT<sub>1</sub> O T<sub>2</sub> = Δ and

$$\angle T_1OV = \angle VOT_2 = \angle VT_1T_2 = \angle T_2T_1 = \frac{\Delta}{2}$$

To compute the elements of a circular curve, consider the radius of the curve OT<sub>1</sub> = OT<sub>2</sub> = R. Further, it is known that the RVT<sub>1</sub> O = RVT<sub>2</sub> O = 90° (since the tangent to a circle is perpendicular to the radius at the point of tangency). The elements of a circular curve required to lay it out in the field with reference to Figure 37.1 are as follows :

**Length of Curve,**

$$l = T_1GT_2$$

$$= \left( \frac{2\pi R}{360^\circ} \right) \times \Delta$$

$$= \frac{\pi R \Delta}{180^\circ} \text{-----Equation (37.1)}$$

**Tangent Length,**

$$T = \text{length } T_1 V = \text{length } T_2 V$$

$$= O T_1 \tan \frac{\Delta}{2} = R \tan \frac{\Delta}{2} \text{-----Equation (37.2)}$$

**Chainages of tangent point :** The chainage of the point of intersection (V) is generally known. Thus,

$$\text{Chainage of } T_1 = \text{Chainage of } V - \text{tangent length (T) -----Equation (37.3)}$$

$$\text{Chainage of } T_2 = \text{Chainage of } T_1 + \text{length of curve (l) -----Equation (37.4)}$$

**Length of the long chord (L) :** Length of the long chord,

$$L = \text{length } T_1 T_2$$

$$= 2 \times R \sin \frac{\Delta}{2} \text{-----Equation (37.5)}$$

**External distance (E) :**

$$E = \text{length } VG$$

$$= VO - GO$$

$$= R \sec \frac{\Delta}{2} - R$$

$$= R \left[ \sec \frac{\Delta}{2} - 1 \right] \text{-----Equation (37.6)}$$

**Mid-ordinate (M) :**

$$M = \text{length } GF = OG - OF$$

$$= R - R \cos \frac{\Delta}{2}$$

$$= R \left( 1 - \cos \frac{\Delta}{2} \right) \text{-----Equation (37.7)}$$

**Designation of a Curve**

A curve is designated either in terms of its degree (D) or by its radius (R).

### Degree of Curve

The degree of a curve (D) is defined as the angle subtended at the centre of the curve by a chord or an arc of specified length.

### Chord Definition

The degree of a curve is defined as the angle subtended at the centre of the curve by a chord of 30 m length.

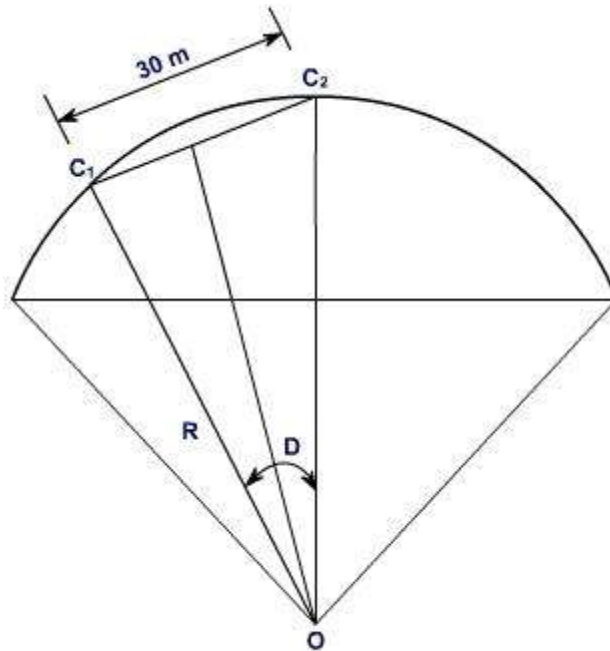


Figure 37.2 Chord definition of a Circular Curve

Let D be the degree of a curve i.e., it is the angle subtended at its centre O by a chord  $C_1C_2$  of 30 m length as shown in [Figure 37.2](#). Thus

$$\sin \frac{D^\circ}{2} = \frac{(30/2)}{R}, \text{ where } R \text{ is the radius of the circular curve}$$

$$\therefore R = \frac{15}{\sin \left( \frac{D^\circ}{2} \right)} \text{----- Equation (37.8)}$$

### Arc Definition

The degree of a curve is defined as the angle subtended at its centre of the curve by an arc of 30 m length.

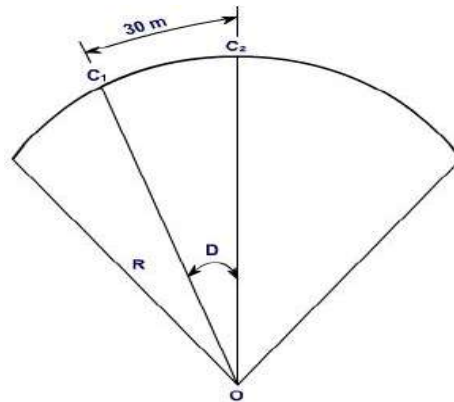


Figure 37.3 Arc definition of a Circular Curve

From [Figure 37.3](#),

$$\frac{D^\circ}{30} = \frac{360^\circ}{2\pi R}$$

$$\text{Or, } D^\circ = \frac{1718.9}{R} \text{ degrees} \quad \text{----- Equation (37.9)}$$

### Radius of Curve

In this convention, a curve is designated by its radius. The sharpness of the curve depends upon its radius. A sharp curve has a small radius. On the other hand, a flat curve has a large radius. Moreover, from (Equation 37.9), it can be found that the degree of curve is inversely proportional to the radius of curve. Thus, a sharp curve has a large degree of curve, whereas a flat curve has a small degree of curve.

### Examples

**Example 37.1** The deflection angle at the point of intersection (chainage 1256.260 m) of two straights is  $43^\circ$ . Find the elements of a  $3^\circ$  circular curve to be set out between the straights.

**Solution** Refer [Figure 37.1](#)

From Equation 37.1, the radius of the circular curve,

$$R = 1718.9 / D = 1718.9 / 3 = 572.97 \text{ m} \sim 573 \text{ m}$$

Let us consider, the radius of the circular curve to be set be,  $R = 575 \text{ m}$

From given data,

the deflection angle,  $\Delta = 43^\circ$

Thus, from Equation 37.2, tangent length  $T = R \tan (\Delta / 2) = 575 \tan (43^\circ / 2)$

$$= 226.498 \text{ m} = 226.50 \text{ m}$$

Length of the curve,  $l = \frac{\pi R \Delta}{180^\circ}$  (From Equation 37.1)

$$= \frac{\pi \times 575 \times 43}{180^\circ} = 431.533 \text{ m}$$

Chainage of  $T_1$  (the point of curve) = Chainage of P.I. – T

$$= 1256.260 - 226.50 = 1029.76 \text{ m}$$

And Chainage of  $T_2$  (the point of tangency) = Chainage of P.C. + l

$$= 1029.76 + 431.533 = 1461.293 \text{ m}$$

Length of the long chord,  $L = 2R \sin (\Delta / 2)$  ----- (Equation 37.5)

$$= 2 \times 575 \times \sin (43^\circ / 2) = 421.476 \text{ m}$$

External distance,  $E = R \left[ \sec \left( \frac{\Delta}{2} \right) - 1 \right]$  ----- (Equation 37.6)

$$= 575 \left[ \sec \left( \frac{43}{2} \right) - 1 \right] = 43.00 \text{ m}$$

Mid-ordinate distance,  $M = R \left( 1 - \cos \frac{\Delta}{2} \right)$  ----- (Equation 37.7)

$$= 575 \left[ 1 - \cos \left( \frac{43}{2} \right) \right] = 40.00 \text{ m}$$

**Example 37.2** To connect XY and ZY, by two right handed circular curves separated by a straight line AB, 250 m long, following measurements were made.

WCB of the lines XY, ZY, AB are  $45^\circ$ ,  $300^\circ$  and  $90^\circ$  respectively. The chainage of the station Y is 1000.00 m. A distance of 1 km is available for the curves alongwith the straight path. If the radius of the first curve is half of that of the second, calculate the following

- The radii of the curves
- The chainage of the point of tangencie

**Solution :**

**(i) Deflection Angles**

Deflection angle for the first curve

$$\begin{aligned} \Delta_1 &= \text{Bearing of AB} - \text{Bearing of XY} \\ &= 90^\circ - 45^\circ = 45^\circ \end{aligned}$$

Deflection angle for the second curve

$$\begin{aligned} \Delta_2 &= \text{Bearing of YZ} - \text{Bearing AB} \\ &= 120^\circ - 90^\circ = 30^\circ \end{aligned}$$

Deflection angle for the straights XY and YZ

$$\Delta = \Delta_1 + \Delta_2 = 45^\circ + 30^\circ = 75^\circ$$

$$\Delta = \square \text{Bearing of YZ} - \text{Bearing of XY} = 120^\circ - 45^\circ = 75^\circ \text{ (Verified)}$$

**(ii) Lengths of the Curves**

Length of the first curve of radius R, say

$$l_1 = \frac{\pi R \Delta_1}{180^\circ} = \frac{\pi R (45^\circ)}{180^\circ} = \frac{\pi R}{4}$$

Length of the second curve of radius, 2R

$$l_2 = \frac{\pi (2R) \Delta_2}{180^\circ} = \frac{\pi (2R) (30^\circ)}{180^\circ} = \frac{\pi R}{3}$$

Total length of the curve,  $l = l_1 + l_2$

### **(iii) Radius of the Curves**

Given, Total length of the curves + straight path = 1000

or,  $l + 250 = 1000$

$$\text{or, } \frac{\pi R}{4} + \frac{\pi R}{3} = 750 \text{ or } R \left( \frac{7\pi}{12} \right) = 750$$

$R = 409.26 \text{ m}$

Let us provide, the first curve having radius,  $R = 410.0 \text{ m}$

Thus, the radius of the second curve,  $2R = 820.0 \text{ m}$

### **(iv) Tangent Length**

$$\text{Tangent length, } T_1 P = R \tan \left( \frac{\Delta_1}{2} \right) = 410 \tan \left( \frac{45^\circ}{2} \right) = 169.827 \text{ m} = PA$$

$$\text{Tangent length, } T_2 Q = 2R \tan \left( \frac{\Delta_2}{2} \right) = 820 \tan \left( \frac{30^\circ}{2} \right) = 219.717 \text{ m} = QB$$

Thus,  $PQ = PA + AB + BQ$

$$= 169.827 + 250 + 219.717 = 639.544 \text{ m}$$

From  $\Delta YPQ$ ,

$$\frac{PY}{\sin \Delta_2} = \frac{PQ}{\sin (180^\circ - \Delta)}$$

$$PY = \frac{639.544}{\sin 105^\circ} \times \sin 30^\circ = 331.054 \text{ m}$$

$$YT_1 = YP + PT_1 = 331.054 + 169.827 = 500.88 \text{ m}$$

Let us provide  $YT_1 = 500$  m;

### **(v) Chainage**

Chainage of  $T_1 = \text{Chainage of } Y - YT_1$

$$= 1000 - 500.00 = 500.00 \text{ m}$$

Chainage of A = Chainage of  $T_1 + l_1$

$$= 500 + \frac{\pi \times 410}{4} = 822.00 \text{ m}$$

Chainage of B = Chainage of A + AB

$$= 822.00 + 250 = 1072.00 \text{ m}$$

Chainage of  $T_2 = \text{Chainage of } B + l_2$

$$= 1072.00 + \frac{\pi \times 410}{4} = 1394.013 \text{ m}$$

### **Try Yourself:-**

**Ex.37-1** A railway curve is to be tangential to each of the following lines :

Lines	W.C.B.	Length (m)
AB	$0^\circ$	-
BC	$90^\circ$	220
CD	$140^\circ$	-

Determine the salient parameters of the simple circular curve.

**Ex.37-2** Two straights AB and BC meet in an inaccessible point B and are to be connected by a simple curve of 600 m radius. Two points P and Q were selected on AB and BC respectively and the following data were obtained.

$$\angle APQ = 150^\circ, \angle CQP = 160^\circ, PQ = 150.0 \text{ m}$$

Calculate the salient elements of the simple circular curve. Considering the chainage of point P to be 100.

### **Answers**

#### **For Exercise 37**

**Ex.37-1** Radius = 150.04 m; Tangent lengths = 150.04 m and 69.96 m; Length of the curve = 361.61 m

**Ex.37-2** Chainage of tangent points 787.19 m and 1310.790 m





### 1.5. SETTING OUT SIMPLE CURVES

The methods of setting out curves can be mainly divided into two heads depending upon instruments used :

(1) *Linear methods.* In the linear methods, only a chain or tape is used. Linear methods are used when (a) a high degree of accuracy is not required, (b) the curve is short.

(2) *Angular methods.* In angular method, an instrument such as a theodolite is used with or without a chain (or tape).

Before a curve is set out, it is essential to locate the tangents, points of intersection (P.I.), point of the curve (P.C.) and point of tangency (P.T.).

**Location of tangent.** Before setting out the curve, the surveyor is always supplied with a working plan upon which the general alignment of tangent is known in relation to the traverse controlling the survey of that area. Knowing offsets to certain points on both the tangents, the tangents can be staked on the ground by the tape measurements. The tangents may then be set out by theodolite by trial and error so that they pass through the marks as nearly as possible. The total deflection angle ( $\Delta$ ) can then be measured by setting the theodolite on the P.I.

**Location of tangent points.** After having located the P.I. and measured  $\Delta$ , the tangent length ( $T$ ) can be calculated from equation 1.5. *i.e.*,

$$T = R \tan \frac{\Delta}{2}$$

The point  $T_1$  (Fig. 1.2) can be located by measuring back a distance  $VT_1 = T$  on the rear tangent.

Similarly, the point  $T_2$  can be located by measuring a distance  $VT_2 = T$  on the forward tangent.

Knowing the chainage of P.I., the chainage of point  $T_1$  can be known by subtracting the tangent length from it. The length of the curve is then added to the chainage of  $T_1$  to get the chainage of  $T_2$ . The tangent points must be located with greater precision.

**Peg Interval.** For the ease in calculations and setting out, it is essential that the pegs on the curve are at regular interval from the beginning to the end. Such interval is known as *peg interval* and the chord joining two such adjacent pegs is known as the full chord or normal chord. The length of the normal chord is generally taken equal to 100 ft in English units or 20 metres, in metric units, so that angle subtended by the normal chord at the centre is equal to the degree of the curve. The stations having the chainages in the multiples of chain lengths are known as full stations. Except by chance, the tangent points will not be full stations (*i.e.*, their chainages will not be multiples of full chains). The distance between the point  $T_1$  and the first peg will be less than the length of the normal chord so that the first peg may be a full station. Thus, the first chord joining the point of curve  $T_1$  to the first peg will be a sub-chord. Similarly, the last chord, joining the last peg on the curve and the tangent point  $T_2$  will be a sub-chord. All other intermediate chords will be normal chords or unit chords. Thus, if the chainage of  $T_1$  is  $n$  chains +  $m$  links, the first chord length will be the remaining portion of the chain length *i.e.*, (100 -  $m$ ) links. Similarly, if the chainage of  $T_2$  is  $n'$  chains +  $m'$  links, the last chord length will be  $m'$  links.

The length of the normal or unit chord should be so selected that there is no appreciable difference between the lengths of the chord and the arc. If the length of the chord is not greater than one-tenth of the radius, it will give sufficiently accurate results, the error being 8 mm in 20 m. For more accurate results, the length of normal chord should be limited to 1/20 of its radius so that the error is only 2 mm in 20 m.



### Linear methods of Setting Out

Following are some of the linear methods for setting out simple circular curves :

- (1) By ordinates or offsets from the long chord.
- (2) By successive bisection of arcs.
- (3) By offsets from the tangents.
- (4) By offsets from chords produced (or by deflection distances).

**Location of tangent points.** If an angle measuring instrument is not available, the following procedure may be adopted, for the location of tangent points (Fig. 1.4) :

(1) Produce two straights to meet at  $V$ .

(2) Select two inter-visible points  $E$  and  $G$  on the two straights, equidistant from  $V$ .  $VE$  and  $VG$  should be as long as possible.

(3) Join  $EG$ , measure it and bisect it at  $F$ . Join  $VF$  and measure it.

From similar triangles,  $VEF$  and  $VT_1O$  we have

$$\frac{VT_1}{OT_1} = \frac{VF}{EF}$$

$$\therefore VT_1 = T = \frac{VF}{EF} \cdot OT_1 = \frac{VF}{EF} \cdot R,$$

Thus, the tangent points  $T_1$  and  $T_2$  can be located by measuring  $VT_1$  and  $VT_2$  each equal to  $T$  along the straights.

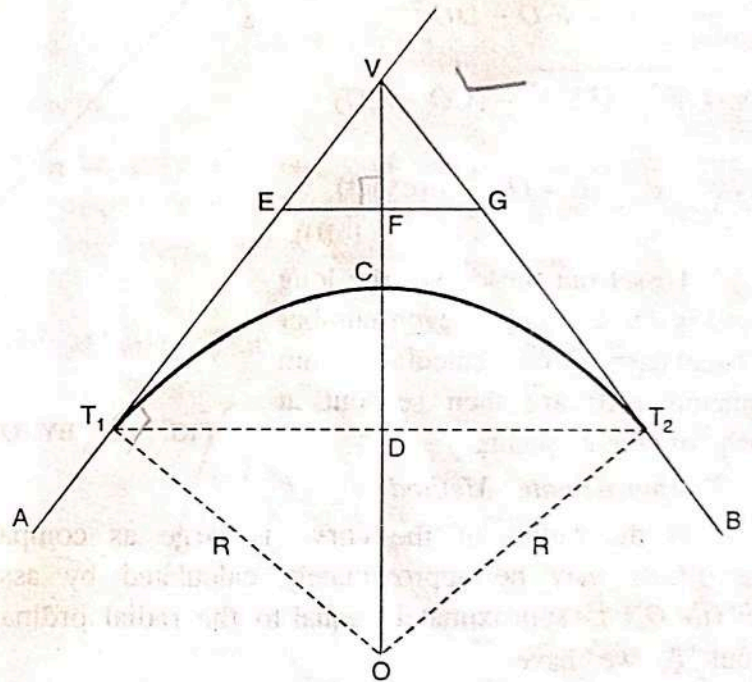


FIG. 1.4. LOCATION OF TANGENT POINTS.

### 1.6. BY ORDINATES FROM THE LONG CHORD : (Fig. 1.5)

Let  $R$  = Radius of the curve.

$O_0$  = Mid-ordinate.

$O_x$  = Ordinate at distance  $x$  from the mid-point of the chord.

$T_1$  and  $T_2$  = Tangent points.

$L$  = Length of the long chord actually measured on the ground.

Bisect the long chord at point  $D$ .

From triangle  $OT_1D$ ,

$$OT_1^2 = T_1D^2 + DO^2$$

or 
$$R^2 = \left(\frac{L}{2}\right)^2 + (CO - CD)^2 = \left(\frac{L}{2}\right)^2 + (R - O_0)^2$$

$$\therefore (R - O_0) = \sqrt{R^2 - \left(\frac{L}{2}\right)^2}$$



$$\text{or } O_0 = R - \sqrt{R^2 - \left(\frac{L}{2}\right)^2} \dots(1.9)$$

In order to calculate the ordinate  $O_x$  to any point  $E$ , draw the line  $EE_1$  parallel to the long chord  $T_1T_2$ . Join  $EO$  to cut the long chord in  $G$ .

$$\begin{aligned} \text{Then } O_x &= EF = E_1D \\ &= E_1O - DO \end{aligned}$$

$$= \sqrt{(EO)^2 - (EE_1)^2} - (CO - CD)$$

$$= \sqrt{R^2 - x^2} - (R - O_0) \dots(\text{exact}) \dots(1.10)$$

To set out the curve, the long chord is divided into an even number of equal parts. Offsets calculated from equation 1.10 are then set out at each of these points.

#### Approximate Method

If the radius of the curve is large as compared to the length of the long chord, the offsets may be approximately calculated by assuming that the perpendicular ordinate  $EF$  (i.e.  $O_x$ ) is approximately equal to the radial ordinate  $EG$ . Then taking  $T_1F = x$  measured from  $T_1$ , we have

$$EG \times 2R = T_1F \times FT_2$$

$$\text{or } O_x \times 2R = x(L - x)$$

$$\therefore O_x = \frac{x(L - x)}{2R} \dots(\text{approx}). \dots(1.11)$$

It should be clearly noted that the distance  $x$  in this method is measured from the tangent point  $T_1$ , while it is measured from the mid-point of the chord in the previous case (equation 1.10).

### 1.7. BY SUCCESSIVE BISECTION OF ARCS OR CHORDS

*Procedure* (Fig. 1.6)

1. Join the tangent points  $T_1, T_2$  and bisect the long chord at  $D$ . Erect the perpendicular  $DC$  and make it equal to the versed sine of the curve. Thus,

$$CD = R \left( 1 - \cos \frac{\Delta}{2} \right) = R - \sqrt{R^2 - \left(\frac{L}{2}\right)^2}$$

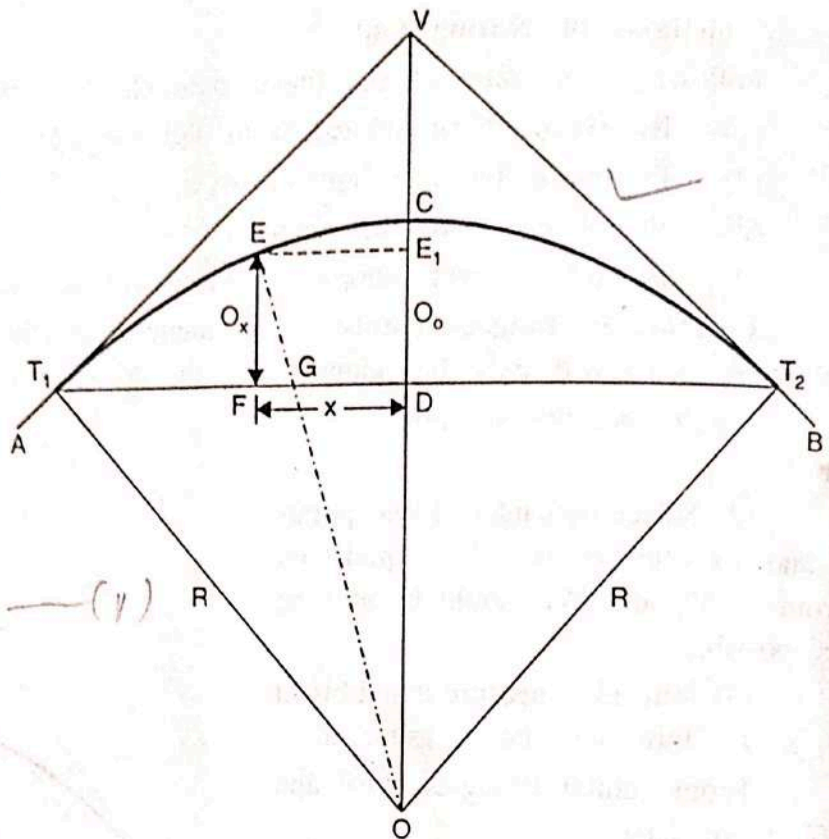


FIG. 1.5. BY ORDINATES FROM THE LONG CHORD.



2. Join  $T_1C$  and  $T_2C$  and bisect them at  $D_1$  and  $D_2$  respectively. At  $D_1$  and  $D_2$ , set out perpendicular offsets  $C_1D_1 = C_2D_2 = R \left( 1 - \cos \frac{\Delta}{4} \right)$  to get points  $C_1$  and  $C_2$  on the curve.

3. By the successive bisection of these chords, more points may be obtained.

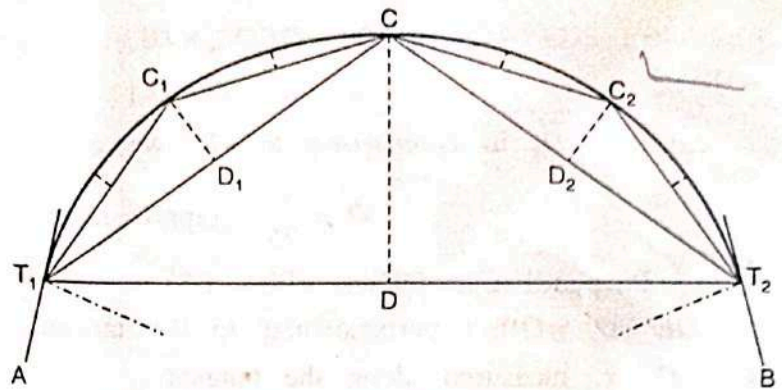


FIG. 1.6. SUCCESSIVE BISECTION OF ARCS.

1.8. BY OFFSETS FROM THE TANGENTS

If the deflection angle and the radius of curvature are both small, the curves can be set out by offsets from the tangent. The offsets from the tangents can be of two types:

- (i) Radial offsets
- (ii) Perpendicular offsets.

(i) Radial Offsets (Fig. 1.7)

Let  $O_x =$  Radial offset  $DE$  at any distance  $x$  along the tangent

$$T_1D = x$$

From triangle  $T_1DO$ ,

$$DO^2 = T_1O^2 + T_1D^2$$

or  $(DE + EO)^2 = T_1O^2 + T_1D^2$

or  $(O_x + R)^2 = R^2 + x^2$

$$\therefore O_x = \sqrt{R^2 + x^2} - R$$

....(exact) ..(1.12)

In order to get an approximate expression for  $O_x$ , expand  $\sqrt{R^2 + x^2}$ . Thus,

$$O_x = R \left( 1 + \frac{x^2}{2R^2} - \frac{x^4}{8R^4} + \dots \right) - R$$

Neglecting the other terms except the first two, we get

$$O_x = R + \frac{x^2}{2R} - R$$

$$O_x = \frac{x^2}{2R} \dots(\text{approx.})$$

...[1.12 (a)]

When the radius is large, the above approximate expression can also be obtained as under :

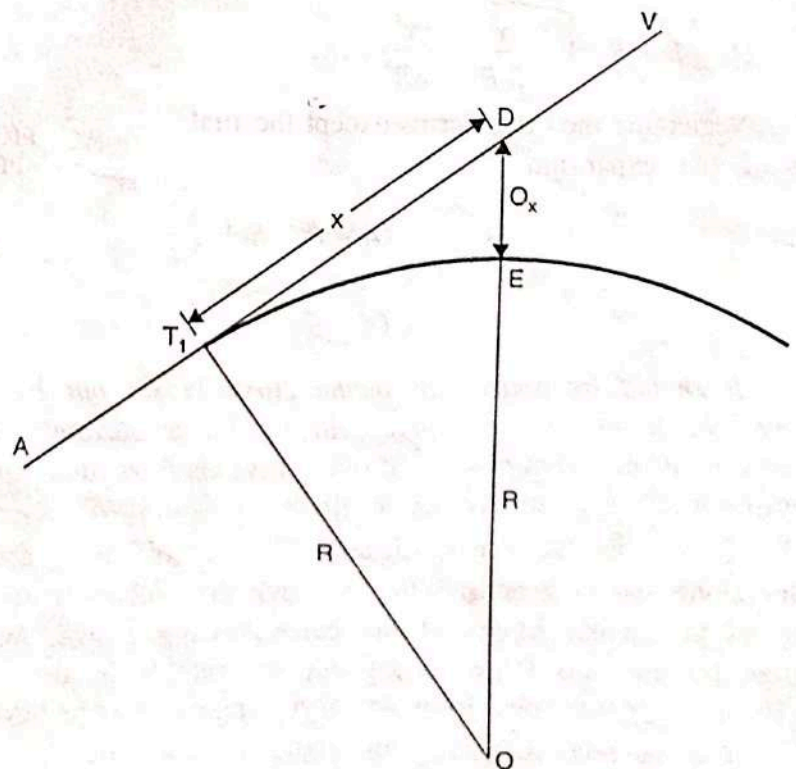


FIG. 1.7. SETTING OUT BY RADIAL OFFSETS.



$$T_1 D^2 = DE(2R + DE)$$

or  $x^2 = O_x (2R + O_x)$

Neglecting  $O_x$  in comparison to  $2R$ , we get

$$O_x = \frac{x^2}{2R} \dots (\text{approximate})$$

(ii) Perpendicular Offsets (Fig. 1.8)

Let  $DE = O_x =$  Offset perpendicular to the tangent

$T_1 D = x$ , measured along the tangent

Draw  $EE_1$  parallel to the tangent.

From triangle  $EE_1 O$ , we have

$$E_1 O^2 = EO^2 - E_1 E^2$$

or  $(T_1 O - T_1 E_1)^2 = EO^2 - E_1 E^2$

or  $(R - O_x)^2 = R^2 - x^2$

From which,  $O_x = R - \sqrt{R^2 - x^2}$   
 ... (exact) ... (1.13)

The corresponding approximate expression for  $O_x$  may be obtained by expanding the term  $\sqrt{R^2 - x^2}$ . Thus,

$$O_x = R - R \left( 1 - \frac{x^2}{2R^2} - \frac{x^4}{8R^4} \dots \right)$$

Neglecting the other terms except the first two of the expansion

$$O_x = R - R + \frac{x^2}{2R}$$

or  $O_x = \frac{x^2}{2R}$

... [1.13 (a)]

*It should be noted that if the curve is set out by the approximate expression given above, the points on the curve will lie on a parabola and not on the arc of a circle. However, if the versed sine of the curve is less than one-eighth of its chord, the curve approximates very closely to a circle.*

To set out the curve, distances  $x_1, x_2, x_3, \dots$  etc., are measured from the first tangent point along the tangent and the perpendicular offsets calculated above are erected with the help of an optical square at the corresponding points. When the distance  $x$  increases, the offsets become too large to set out accurately. In that case, the central position of the curve may be set out from a third tangent drawn through the apex of the curve. The method is useful for small curves only.

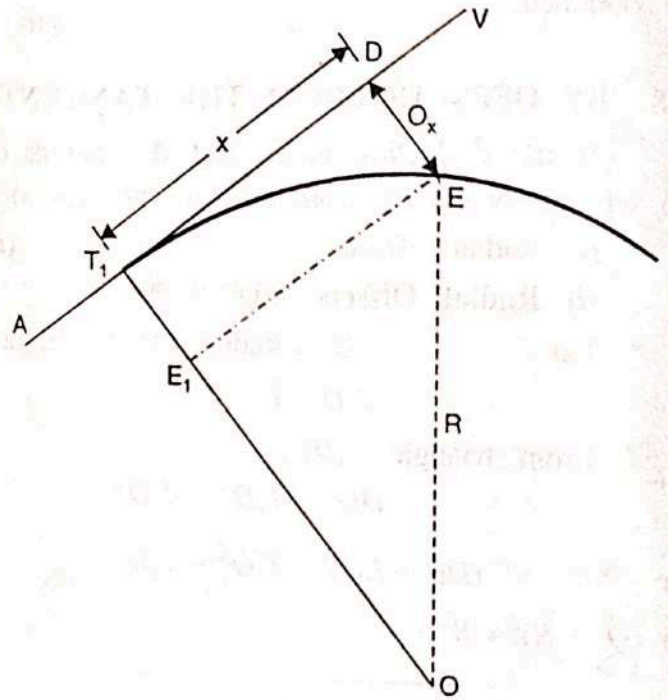


FIG. 1.8. SETTING OUT BY PERPENDICULAR OFFSETS



1.9. BY DEFLECTION DISTANCES (OR OFFSETS FROM THE CHORDS PRODUCED)

The method is very much useful for long curves and is generally used on highway curves when a theodolite is not available.

Let  $T_1A = T_1A =$  initial sub-chord  
 $= C_1$

$A, B, D$  etc. = points on the curve

$AB = C_2$

$BD = C_3$  etc.

$T_1V =$  Rear Tangent

$\angle A_1T_1A = \delta =$  deflection angle of the first chord

$A_1A = O_1 =$  first offset

$B_2B = O_2 =$  second offset

$D_2D = O_3 =$  third offset, etc.

Now, arc  $A_1A = O_1 = T_1A \cdot \delta \dots(i)$

Since  $T_1V$  is the tangent to the circle at  $T_1$

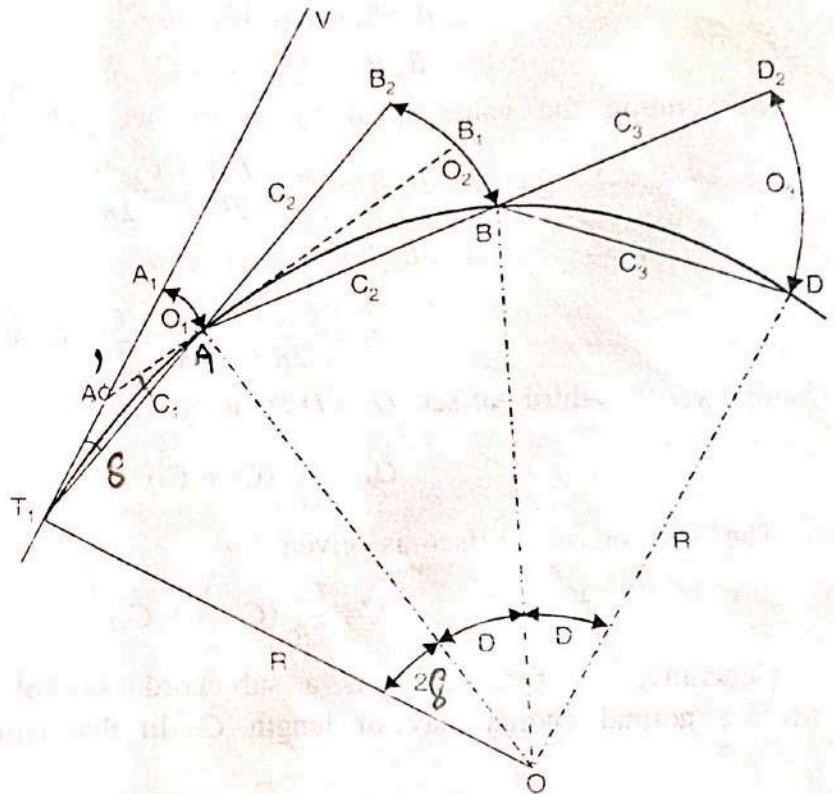


FIG. 1.9. SETTING OUT THE CURVE BY DEFLECTION DISTANCES.

$$\angle T_1OA = 2\angle A_1T_1A = 2\delta$$

$\therefore$  Arc  $T_1A = R \cdot 2\delta$

$$\delta = \frac{T_1A}{2R} \dots(ii)$$

Substituting the value of  $\delta$  in (i), we get

$$\text{Arc } A_1A = O_1 = T_1A \cdot \frac{T_1A}{2R} = \frac{T_1A^2}{2R}$$

Taking arc  $T_1A =$  chord  $T_1A$  (very nearly), we get

$$O_1 = \frac{C_1^2}{2R} \dots[1.14 (a)]$$

In order to obtain the value of the second offset  $O_2$  for getting the point  $B$  on the curve, draw a tangent  $AB_1$  to the curve at  $A$  to cut the rear tangent in  $A'$ . Join  $T_1A$  and prolong it to a point  $B_2$  such that  $AB_2 = AB = C_2 =$  length of the second chord. Then  $O_2 = B_2B$ .

As from equation 1.14 (a), the offset  $B_1B$  from the tangent  $AB_1$  is given by

$$B_1B = \frac{C_2^2}{2R} \dots(iii)$$

Again,

$\angle B_2AB_1 = \angle A'AT_1$  being opposite angles.

Since  $T_1A'$  and  $A'A$  are both tangents, they are equal in length.



$$\therefore \angle A'T_1A = \delta = \angle A'AT_1$$

$$\therefore \angle B_2AB_1 = \angle A'AT_1 = \delta$$

$$\therefore \text{arc } B_2B_1 = AB_2 \cdot \delta = C_2 \cdot \delta$$

Substituting the value of  $\delta$  from (ii), we get

$$B_2B_1 = C_2 \cdot \frac{T_1A}{2R} = \frac{C_2 \cdot C_1}{2R} \quad \dots(iv)$$

$$\therefore \text{arc } B_2B = B_2B_1 + B_1B$$

$$\text{or } O_2 = \frac{C_2C_1}{2R} + \frac{C_2^2}{2R} = \frac{C_2}{2R} (C_1 + C_2) \quad \dots[1.14 (b)]$$

Similarly, the third offset  $O_3 = D_2D$  is given by

$$O_3 = \frac{C_3}{2R} (C_2 + C_3)$$

The last or  $n$ th offset is given by

$$O_n = \frac{C_n}{2R} (C_{n-1} + C_n) \quad \dots[1.14 (c)]$$

Generally, the first chord is a sub-chord, say of length  $c$ , and the intermediate chords are normal chords, say of length  $C$ . In that case, the above formulae reduce to

$$O_1 = \frac{c^2}{R}$$

$$\text{and } O_2 = \frac{C}{2R} (c + C) \quad \dots[1.14 (d)]$$

$$O_3 = O_4 = \dots O_{n-1} = \frac{C}{2R} (2C) = \frac{C^2}{R} \quad \dots[1.14 (e)]$$

$$\text{and } O_n = \frac{c'}{2R} (C + c') \quad \dots[1.14 (f)]$$

where  $c'$  is the last sub-chord.

### Procedure for Setting Out the Curve

(1) Locate the tangent points  $T_1$  and  $T_2$  and find out their chainages as explained earlier. Calculate the length ( $c$ ) of the first sub-chord so that the first peg is the full station.

(2) With zero mark at  $T_1$ , spread the chain (or tape) along the first tangent to point  $A_1$  on it such that  $T_1A_1 = c =$  length of the first sub-chord.

(3) With  $T_1$  as centre and  $T_1A_1$  as radius, swing the chain such that the arc  $A_1A =$  calculated offset  $O_1$ . Fix the point  $A$  on the curve.

(4) Spread the chain along  $T_1A$  and pull it straight in this direction to point  $B_2$  such that the zero of the chain is at  $A$  and the distance  $AB_2 = C =$  length of the normal chord.

(5) With zero of the chain centred at  $A$  and  $AB_2$  as radius, swing the chain to a point  $B$  such that  $B_2B = O_2 =$  length of the second offset. Fix the point  $B$  on the curve.



spread the chain along  $AB$  and repeat the steps (4) and (5) till the point of ( ) is reached. All intermediate offsets will be equal to  $\frac{C^2}{R}$ , while the last offset will be equal to  $\frac{c'}{2R} (C + c')$ .

The last point so fixed must coincide with the point of tangency ( $T_2$ ) fixed originally by measurements from the vertex. If the discrepancy (sometimes called as the closing error) is more, the curve should be re-set. If the error is less, it should be distributed to all the points by moving them sideways by an amount proportional to the square of their distance from the point  $T_1$ .

The method is mostly used in road surveys and is very satisfactory, specially when a theodolite is not available. However, it has a great defect in that the error in fixing point is carried forward.

### INSTRUMENTAL METHODS

The following are instrumental methods commonly used for setting out a circular curve :

- (1) Rankine's method of tangential (or deflection) angle.
- (2) Two theodolite method.
- (3) Tacheometric method.

#### 1.10. RANKINE'S METHOD OF TANGENTIAL (OR DEFLECTION) ANGLES

*A deflection angle to any point on the curve is the angle at P.C. between the back tangent and the chord from P.C. to that point.*

Rankine's method is based on the principle that the deflection angle to any point on a circular curve is measured by one-half the angle subtended by the arc from P.C. to that point. It is assumed that the length of the arc is approximately equal to its chord.

Let us first derive expression for the tangential angles.

Let  $T_1V$  = Rear tangent

$T_1$  = Point to curve (P.C.)

$\delta_1, \delta_2, \delta_3$  = The tangential angles or the angles which each of the successive chords  $T_1A, AB, BC$  etc. makes with the respective tangents to the curve at  $T_1, A, B$  etc.

$\Delta_1, \Delta_2, \Delta_3 \dots$  = Total tangential angles or the deflection angles to the points  $A, B, C$  etc.

$C_1, C_2, C_3$  = Lengths of the chords  $T_1A, AB, BC \dots$

$A_1A$  = Tangent to the curve at  $A$ .

From the property of a circle,

$$\angle VT_1A = \frac{1}{2} \angle T_1OA$$

or

$$\angle T_1OA = 2 \angle VT_1A = 2\delta_1$$



Now  $\frac{\angle T_1OA}{C_1} = \frac{180^\circ}{\pi R}$

or  $\angle T_1OA = 2\delta_1 = \frac{180^\circ C_1}{\pi R}$

From which  $\delta_1 = \frac{90C_1}{\pi R}$  degrees

$= \frac{90 \times 60C_1}{\pi R} = 1718.9 \frac{C_1}{R}$  minutes.

Similarly,

$\delta_2 = 1718.9 \frac{C_2}{R}$  ;  $\delta_3 = 1718.9 \frac{C_3}{R}$ ,

or, in general,

$\delta = 1718.9 \frac{C}{R}$  minutes ... (1.1)

where  $C$  is the length of the chord.

For the first chord  $T_1A$ , the deflection angle = its tangential angle

or  $\Delta_1 = \delta_1$  ... (1)

For the second point  $B$ , let the deflection angle by =  $\Delta_2$ .

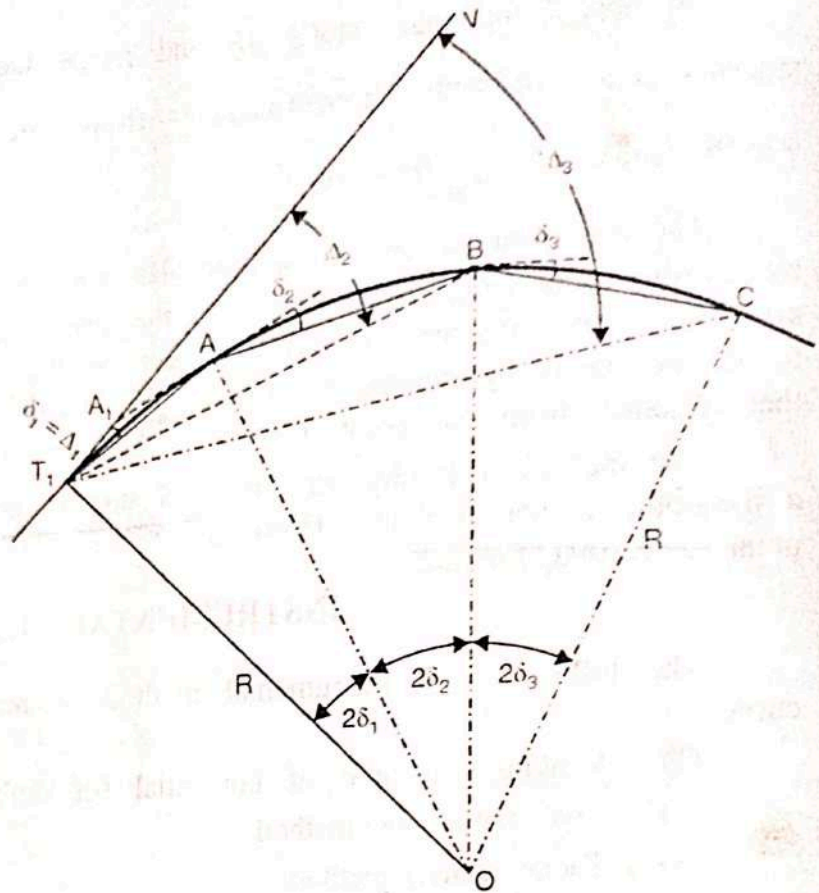


FIG. 1.10. RANKINE'S METHOD OF TANGENTIAL ANGLES.

Since  $\delta_2 =$  tangential angle for the chord  $AB$ ,

$\angle AOB = 2\delta_2$

$\therefore \angle AT_1B =$  Half the angle subtended by  $AB$  at the centre =  $\delta_2$

Now  $\Delta_2 = \angle VT_1B = \angle A_1T_1A + \angle AT_1B$

or  $\Delta_2 = \delta_1 + \delta_2 = \Delta_1 + \delta_2$  ... (2)

Similarly,  $\Delta_3 = \delta_1 + \delta_2 + \delta_3 = \Delta_2 + \delta_3$  ... (3)

and  $\Delta_n = \delta_1 + \delta_2 + \dots + \delta_n = \Delta_{n-1} + \delta_n$  ... (1.16)

Hence, the deflection angle for any chord is equal to the deflection angle for the previous chord plus the tangential angle for that chord.

Check : Deflection angle of the long chord, i.e.,

$\angle VT_1T_2 = \Delta_n = \frac{\Delta}{2}$ , where  $\Delta$  is the intersection angle or the external deflection angle for the curve.

If the degree of the curve is equal to  $D$  for a 20 m chord,

$\delta_2 = \delta_3 \dots = \delta_{n-1} = \frac{1}{2} D$

Similarly, if  $c$  and  $c'$  are the first and the last sub-chords

$\delta_1 = \frac{c}{20} \cdot \frac{D}{2} = \frac{cD}{40}$ , where  $c$  is metres ;  $\delta_n = \frac{c'}{20} \cdot \frac{D}{2} = \frac{c'D}{40}$



$$\Delta_1 = \delta_1 = \frac{cD}{40}$$

$$\Delta_2 = \Delta_1 + \delta_2 = \frac{cD}{40} + \frac{1}{2} D$$

$$\Delta_3 = \Delta_2 + \delta_3 = \frac{cD}{40} + \frac{1}{2} D + \frac{1}{2} D = \frac{cD}{40} + D$$

$$\Delta_n = \Delta_{n-1} + \delta_n = \frac{cD}{40} + (n-2) \frac{D}{2} + \frac{cD}{40}$$

Similarly, if the degree of the curve is equal to  $D$  for a 100 ft chord,

$$\delta_1 = \frac{c \times D}{200} ; \quad \delta_2 = \delta_3 = \dots \delta_{n-1} = \frac{D}{2}$$

$$\delta_n = \frac{c'D}{200}$$

### Procedure for Setting out the Curve

(1) Set the theodolite at the point of curve ( $T_1$ ). With both plates clamped to zero, direct the theodolite to bisect the point of intersection ( $V$ ). The line of sight is thus in the direction of the rear tangent.

(2) Release the vernier plate and set angle  $\Delta_1$  on the vernier. The line of sight is thus directed along chord  $T_1A$ .

(3) With the zero end of the tape pointed at  $T_1$  and an arrow held at a distance  $T_1A = c$  along it, swing the tape around  $T_1$  till the arrow is bisected by the cross-hairs. Thus, the first point  $A$  is fixed.

(4) Set the second deflection angle  $\Delta_2$  on the vernier so that the line of sight is directed along  $T_1B$ .

(5) With the zero end of the tape pinned at  $A$ , and an arrow held at distance  $AB = C$  along it, swing the tape around  $A$  till the arrow is bisected by the cross-hairs, thus fixing the point  $B$ .

(6) Repeat steps (4) and (5) till the last point  $T_2$  is reached.

**Check :** The last point so located must coincide with the point of tangency ( $T_2$ ) fixed independently by measurements from the point of intersection. If the discrepancy is small, last few pegs may be adjusted. If it is more, the whole curve should be reset.

In the case of the left hand curve, each of the calculated values of the deflection angle (*i.e.*  $\Delta_1, \Delta_2$  etc.) , should be subtracted from  $360^\circ$ . The angles so obtained are to be set on the vernier of theodolite for setting out the curve.

In the above method, three men are required : the surveyor to operate the theodolite, and two chainmen to measure the chord lengths with chain or tape. This method is most frequently used for setting out circular curves of large radius and of considerable length.

### Field Notes

The record of deflection angles for various points is usually kept in the following form (next page) :

## Map scale and basics of Map

### Map Scale, Coordinate Systems, and Map Projections

All map users and map viewers have certain expectations about what is contained on a map. Such expectations are formed and learned from previous experience by working with maps. It is important to note that such expectations also change with increased exposure to maps. Understanding and meeting the expectations of map viewers is a challenging but necessary task because such expectations provide a starting point for the creation of any map.

The central purpose of a map is to provide relevant and useful information to the map user. In order for a map to be of value, it must convey information effectively and efficiently. Mapping conventions facilitate the delivery of information in such a manner by recognizing and managing the expectations of map users. Generally speaking, mapping or cartographic conventions refer to the accepted rules, norms, and practices behind the making of maps. One of the most recognized mapping conventions is that “north is up” on most maps. Though this may not always be the case, many map users expect north to be oriented or to coincide with the top edge of a map or viewing device like a computer monitor.

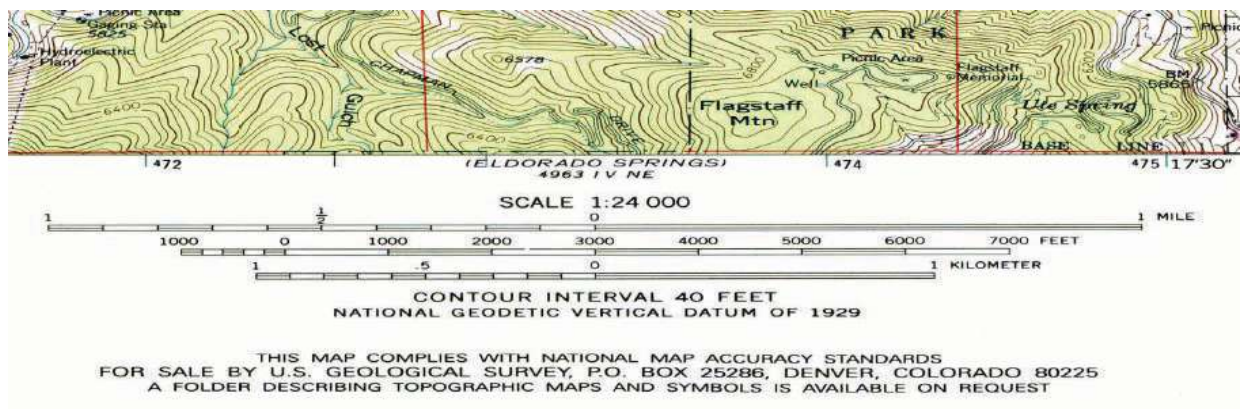
Several other formal and informal mapping conventions and characteristics, many of which are taken for granted, can be identified. Among the most important cartographic considerations are map scale, coordinate systems, and map projections. Map scale is concerned with reducing geographical features of interest to manageable proportions, coordinate systems help us define the positions of features on the surface of the earth, and map projections are concerned with moving from the three-dimensional world to the two dimensions of a flat map or display, all of which are discussed in greater detail in this chapter.

## Map Scale

The world is a big place...really big. One of the challenges behind mapping the world and its resident features, patterns, and processes is reducing it to a manageable size. What exactly is meant by “manageable” is open to discussion and largely depends on the purpose and needs of the map at hand. Nonetheless, all maps reduce or shrink the world and its geographic features of interest by some factor. Map scale refers to the factor of reduction of the world so it fits on a map.

Map scale can be represented by text, a graphic, or some combination of the two. For example, it is common to see “one inch represents one kilometer” or something similar written on a map to give map users an idea of the scale of the map. Map scale can also be portrayed graphically with what is called a scale bar. Scale bars are usually used on reference maps and allow map users to approximate distances between locations and features on a map, as well as to get an overall idea of the scale of the map.

*Figure 2.9 Map Scale from a United States Geological Survey (USGS) Topographic Map*



The representative fraction (RF) describes scale as a simple ratio. The numerator, which is always set to one (i.e., 1), denotes map distance and the denominator denotes ground or “real-world” distance. One of the benefits of using a representative fraction to describe scale is that it is unit neutral. In other words, any unit of measure can be used



to interpret the map scale. Consider a map with an RF of 1:10,000. This means that one unit on the map represents 10,000 units on the ground. Such units could be inches, centimeters, or even pencil lengths; it really does not matter.

Map scales can also be described as either “small” or “large.” Such descriptions are usually made in reference to representative fractions and the amount of detail represented on a map. For instance, a map with an RF of 1:1,000 is considered a large-scale map when compared to a map with an RF of 1:1,000,000 (i.e.,  $1:1,000 > 1:1,000,000$ ). Furthermore, while the large-scale map shows more detail and less area, the small-scale map shows more area but less detail. Clearly, determining the thresholds for small- or large-scale maps is largely a judgment call.

All maps possess a scale, whether it is formally expressed or not. Though some say that online maps and GISs are “scaleless” because we can zoom in and out at will, it is probably more accurate to say that GISs and related mapping technology are multiscale. Understanding map scale and its overall impact on how the earth and its features are represented is a critical part of both map making and GISs.

## Coordinate Systems

Just as all maps have a map scale, all maps have locations, too. Coordinate systems are frameworks that are used to define unique positions. For instance, in geometry we use  $x$  (horizontal) and  $y$  (vertical) coordinates to define points on a two-dimensional plane. The coordinate system that is most commonly used to define locations on the three-dimensional earth is called the geographic coordinate system (GCS), and it is based on a sphere or spheroid. A spheroid (a.k.a. ellipsoid) is simply a sphere that is slightly wider than it is tall and approximates more closely the true shape of the earth. Spheres are commonly used as models of the earth for simplicity.

The unit of measure in the GCS is degrees, and locations are defined by their respective latitude and longitude within the GCS. Latitude is measured relative to the equator at

zero degrees, with maxima of either ninety degrees north at the North Pole or ninety degrees south at the South Pole. Longitude is measured relative to the prime meridian at zero degrees, with maxima of 180 degrees west or 180 degrees east.

Note that latitude and longitude can be expressed in degrees-minutes-seconds (DMS) or in decimal degrees (DD). When using decimal degrees, latitudes above the equator and longitudes east of the prime meridian are positive, and latitudes below the equator and longitudes west of the prime meridian are negative (see the following table for examples).

<b>Nominal location</b>	<b>Absolute location (DMS)</b>	<b>Absolute location (DD)</b>
Los Angeles, US	34° 3' North, 118° 15' West	+34.05, -118.25
Mumbai, India	18° 58' North, 72° 49' East	+18.975, +72.8258
Sydney, Australia	33° 51' South, 151° 12' East	-33.859, 151.211
Sao Paolo, Brazil	23° 33' South, 46° 38' West	-23.550, -46.634

Converting from DMS to DD is a relatively straightforward exercise. For example, since there are sixty minutes in one degree, we can convert 118° 15 minutes to 118.25 (118 + 15/60). Note that an online search of the term “coordinate conversion” will return several coordinate conversion tools.

When we want to map things like mountains, rivers, streets, and buildings, we need to define how the lines of latitude and longitude will be oriented and positioned on the sphere. A datum serves this purpose and specifies exactly the orientation and origins of the lines of latitude and longitude relative to the center of the earth or spheroid.

Depending on the need, situation, and location, there are several datums to choose from. For instance, local datums try to match closely the spheroid to the earth’s surface in a local area and return accurate local coordinates. A common local datum used in the United States is called NAD83 (i.e., North American Datum of 1983). For locations in



the United States and Canada, NAD83 returns relatively accurate positions, but positional accuracy deteriorates when outside of North America.

The global WGS84 datum (i.e., World Geodetic System of 1984) uses the center of the earth as the origin of the GCS and is used for defining locations across the globe.

Because the datum uses the center of the earth as its origin, locational measurements tend to be more consistent regardless where they are obtained on the earth, though they may be less accurate than those returned by a local datum. Note that switching between datums will alter the coordinates (i.e., latitude and longitude) for all locations of interest.

## Map Projections

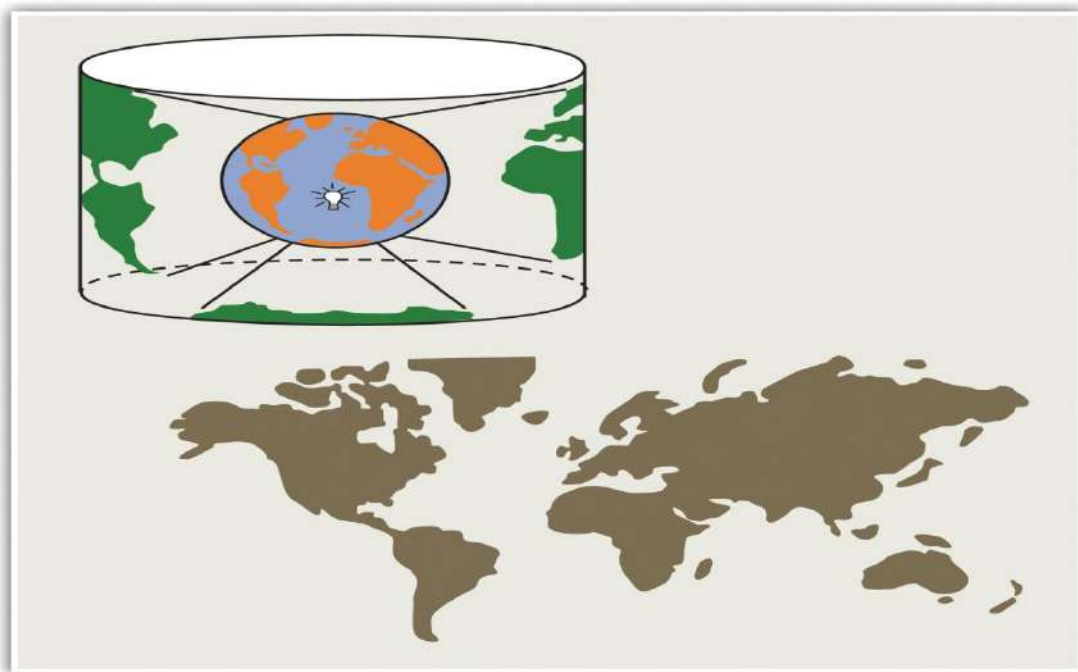
Previously we noted that the earth is really big. Not only is it big, but it is a big round spherical shape called a spheroid. A globe is a very common and very good representation of the three-dimensional, spheroid earth. One of the problems with globes, however, is that they are not very portable (i.e., you cannot fold a globe and put it in your pocket), and their small scale makes them of limited practical use (i.e., geographic detail is sacrificed). To overcome these issues, it is necessary to transform the three-dimensional shape of the earth to a two-dimensional surface like a flat piece of paper, computer screen, or mobile device display in order to obtain more useful map forms and map scales. Enter the map projection.

Map projections refer to the methods and procedures that are used to transform the spherical three-dimensional earth into two-dimensional planar surfaces. Specifically, map projections are mathematical formulas that are used to translate latitude and longitude on the surface of the earth to  $x$  and  $y$  coordinates on a plane. Since there are an infinite number of ways this translation can be performed, there are an infinite number of map projections. The mathematics behind map projections are beyond the scope of this introductory overview (but see Robinson et al. 1995; Muehrcke and

Muehrcke 1998), Muehrcke, P., and J. Muehrcke. 1998. *Map Use*. Madison, WI: JP Publications. and for simplicity, the following discussion focuses on describing types of map projections, the distortions inherent to map projections, and the selection of appropriate map projections.

To illustrate the concept of a map projection, imagine that we place a light bulb in the center of a translucent globe. On the globe are outlines of the continents and the lines of longitude and latitude called the graticule. When we turn the light bulb on, the outline of the continents and the graticule will be “projected” as shadows on the wall, ceiling, or any other nearby surface. This is what is meant by map “projection.”

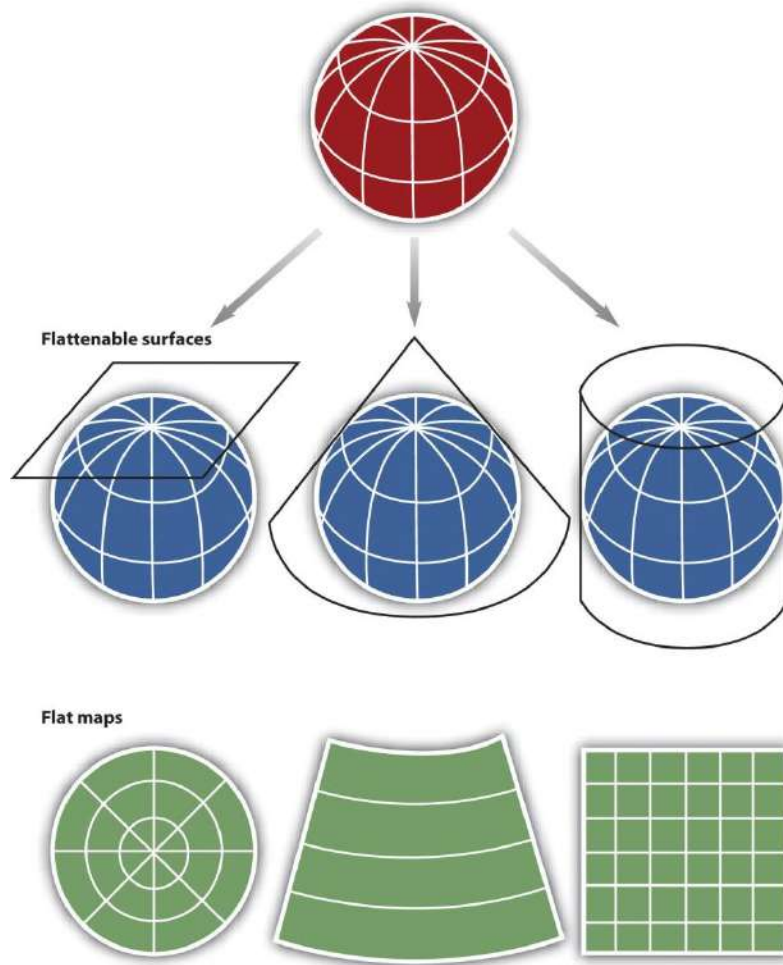
*Figure 2.10 The Concept of Map “Projection”*



Within the realm of maps and mapping, there are three surfaces used for map projections (i.e., surfaces on which we project the shadows of the graticule). These surfaces are the plane, the cylinder, and the cone. Referring again to the previous example of a light bulb in the center of a globe, note that during the projection process, we can situate each surface in any number of ways. For example, surfaces can be

tangential to the globe along the equator or poles, they can pass through or intersect the surface, and they can be oriented at any number of angles.

*Figure 2.11 Map Projection Surfaces*



In fact, naming conventions for many map projections include the surface as well as its orientation. For example, as the name suggests, “planar” projections use the plane, “cylindrical” projections use cylinders, and “conic” projections use the cone. For cylindrical projections, the “normal” or “standard” aspect refers to when the cylinder is tangential to the equator (i.e., the axis of the cylinder is oriented north–south). When the axis of the cylinder is perfectly oriented east–west, the aspect is called “transverse,” and all other orientations are referred to as “oblique.” Regardless the orientation or the

surface on which a projection is based, a number of distortions will be introduced that will influence the choice of map projection.

When moving from the three-dimensional surface of the earth to a two-dimensional plane, distortions are not only introduced but also inevitable. Generally, map projections introduce distortions in distance, angles, and areas. Depending on the purpose of the map, a series of trade-offs will need to be made with respect to such distortions.

Map projections that accurately represent distances are referred to as equidistant projections. Note that distances are only correct in one direction, usually running north–south, and are not correct everywhere across the map. Equidistant maps are frequently used for small-scale maps that cover large areas because they do a good job of preserving the shape of geographic features such as continents.

Maps that represent angles between locations, also referred to as bearings, are called conformal. Conformal map projections are used for navigational purposes due to the importance of maintaining a bearing or heading when traveling great distances. The cost of preserving bearings is that areas tend to be quite distorted in conformal map projections. Though shapes are more or less preserved over small areas, at small scales areas become wildly distorted. The Mercator projection is an example of a conformal projection and is famous for distorting Greenland.

As the name indicates, equal area or equivalent projections preserve the quality of area. Such projections are of particular use when accurate measures or comparisons of geographical distributions are necessary (e.g., deforestation, wetlands). In an effort to maintain true proportions in the surface of the earth, features sometimes become compressed or stretched depending on the orientation of the projection. Moreover, such projections distort distances as well as angular relationships.

As noted earlier, there are theoretically an infinite number of map projections to choose from. One of the key considerations behind the choice of map projection is to reduce the amount of distortion. The geographical object being mapped and the respective scale at which the map will be constructed are also important factors to think about. For instance, maps of the North and South Poles usually use planar or azimuthal projections, and conical projections are best suited for the middle latitude areas of the earth. Features that stretch east–west, such as the country of Russia, are represented well with the standard cylindrical projection, while countries oriented north–south (e.g., Chile, Norway) are better represented using a transverse projection.

If a map projection is unknown, sometimes it can be identified by working backward and examining closely the nature and orientation of the graticule (i.e., grid of latitude and longitude), as well as the varying degrees of distortion. Clearly, there are trade-offs made with regard to distortion on every map. There are no hard-and-fast rules as to which distortions are more preferred over others. Therefore, the selection of map projection largely depends on the purpose of the map.

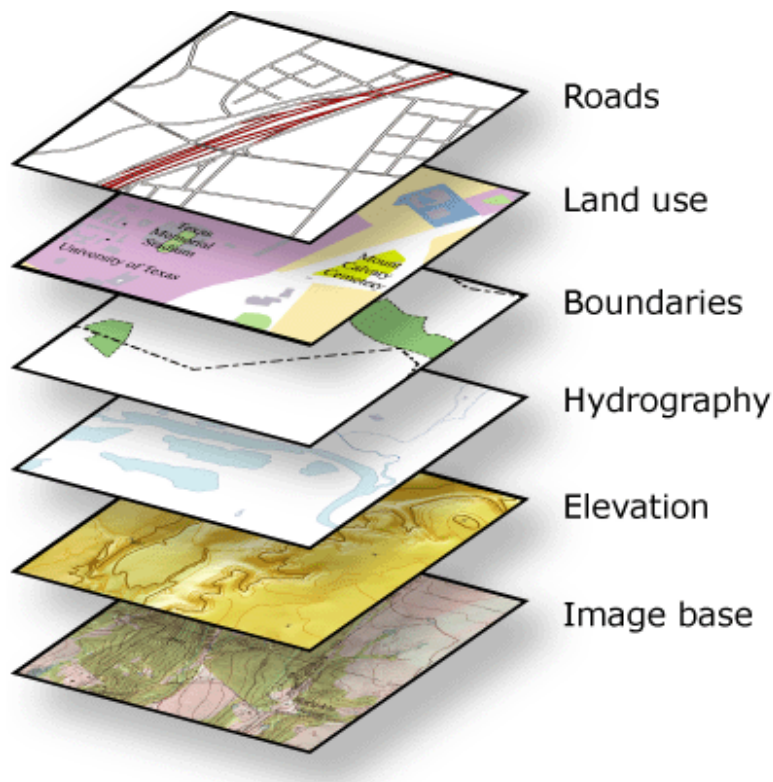
Within the scope of GISs, knowing and understanding map projections are critical. For instance, in order to perform an overlay analysis like the one described earlier, all map layers need to be in the same projection. If they are not, geographical features will not be aligned properly, and any analyses performed will be inaccurate and incorrect. Most GISs include functions to assist in the identification of map projections, as well as to transform between projections in order to synchronize spatial data. Despite the capabilities of technology, an awareness of the potential and pitfalls that surround map projections is essential.

# Maps

A map is a collection of map elements laid out and organized on a page. Common map elements include the map frame with map layers, a scale bar, north arrow, title, descriptive text, and a symbol legend.

The primary map element is the map frame, and it provides the principal display of geographic information. Within the map frame, geographical entities are presented as a series of map layers that cover a given map extent—for example, map layers such as roads, rivers, place names, buildings, political boundaries, surface elevation, and satellite imagery.

The following graphic illustrates how geographical elements are portrayed in maps through a series of map layers. Map symbols and text are used to describe the individual geographic elements.



Map layers are thematic representations of geographic information, such as transportation, water, and elevation. Map layers help convey information through:

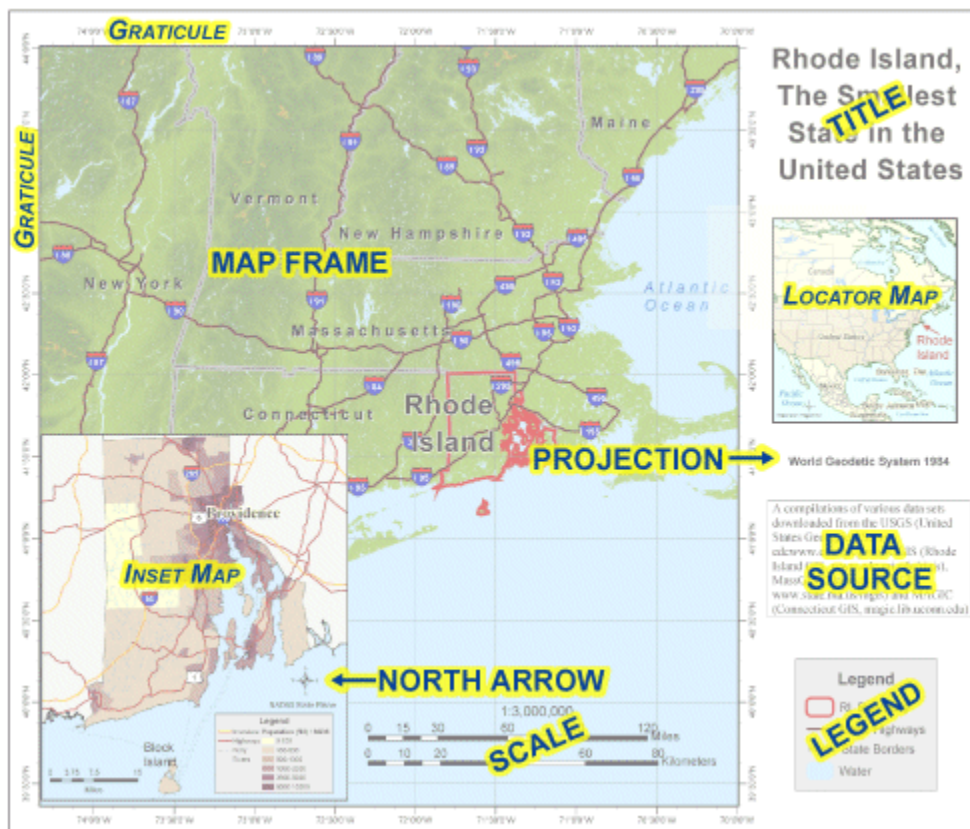
- Discrete features such as collections of points, lines, and polygons
- Map symbols, colors, and labels that help to describe the objects in the map

- Aerial photography or satellite imagery that covers the map extent
- Continuous surfaces such as elevation which can be represented in a number of ways—for example, as a collection of contour lines and elevation points or as shaded relief

## Map Layout and composition

Along with the map frame, a map presents an integrated series of map elements laid out and arranged on a page. Common map elements include a north arrow, a scale bar, a symbol legend, and other graphical elements. These elements aid in map reading and interpretation.

The map layout below illustrates how map elements are arranged on a page.



Often, maps include additional elements such as graphs, charts, pictures, and text that help to communicate additional critical information.

## Spatial relationships in a map

Maps help convey geographic relationships that can be interpreted and analyzed by map readers. Relationships that are based on location are referred to as spatial relationships. Here are some examples.

- Which geographic features *connect* to others (for example, Water Street connects with 18th Ave.)
- Which geographic features are *adjacent* (contiguous) to others (for example, The city park is adjacent to the university).
- Which geographic features are *contained within* an area (for example, The building footprints are contained within the parcel boundary.)
- Which geographic features *overlap* (for example, The railway crosses the freeway.)
- Which geographic features are *near* others (proximity) (for example, The Courthouse is near the State Capitol.)
- The feature geometry *is equal to* another feature (for example, The city park is equal to the historic site polygon).
- The *difference* in elevation of geographic features (for example, The State Capitol is uphill from the water.)The feature is *along* another feature (for example, The bus route follows along the street network.).

Within a map, such relationships are not explicitly represented. Instead, as the map reader, you interpret relationships and derive information from the relative position and shape of the map elements, such as the streets, contours, buildings, lakes, railways, and other features. In a GIS, such relationships can be modeled by applying rich data types and behaviors (for example, topologies and networks) and by applying a comprehensive set of spatial operators to the geographic objects (such as buffer and polygon overlay).

## Classification of Maps

Millions of unique maps are in use throughout the world. Most of these maps can be placed into one of two groups: 1) reference maps; and, 2) thematic maps.

**Reference maps** show the location of geographic boundaries, physical features of Earth, or cultural features such as places, cities, and roads. [Political maps](#), [physical maps](#), [road maps](#), [topographic maps](#), [time zone maps](#), [geologic maps](#), and [zip code maps](#) are all examples of reference maps. A variety of reference maps have been created for almost every country of the world.

**Thematic maps** show the variation of a topic (the theme) across a geographic area. [Weather maps](#) showing daily high temperatures across the United States are familiar examples of a thematic map. They are made by starting with a reference map of the United States. Then temperature data is plotted atop of the reference map using colors to communicate the temperature forecast. [Income maps](#) and [resource maps](#) are other types of thematic maps.

In the sections of this article below, you will find several examples of commonly used reference maps and thematic maps.



## Political Maps

"Political maps" are among the most widely used reference maps. They are mounted on the walls of classrooms throughout the world. They show the geographic boundaries between governmental units such as countries, states, and counties. They show roads, cities and major water features such as oceans, rivers and lakes.

Political maps help people understand the geography of the world. They are usually the first type of map that students are introduced to in school. They are also known as "reference maps" because people refer to them again and again as they have questions.

Political maps are often printed on paper or another physical medium, but they can also be produced in digital form, suitable for viewing online. Every day millions of people visit search engines to find political reference maps. Some of the most popular searches are for "[united states map](#)", "[world map](#)", "[europe map](#)", and "[florida map](#)".

Thousands of different political reference maps have been prepared to show the current geography of the United States. There are maps of the entire nation, maps for each of the 50 states, maps of the 3142 counties (parishes in Louisiana, and boroughs in Alaska) that make up the states. Most counties, boroughs and parishes are further subdivided into even smaller political units. An incredible number of political maps have been prepared just to display the geography of the United States.

The maps most commonly seen in classrooms and offices are [political maps of the world, countries and continents](#). They are often annotated with push pins, sticky notes, photographs, marker flags and string to show the travels of a family, locations of a business, or other locations and activities worthy of display.

## Physical Maps

Physical maps are designed to show the natural landscape features of Earth. They are best known for showing topography, either by colors or as shaded relief. Physical maps often have a green to brown to gray color scheme for showing the elevation of the land. Darker greens are used for near-sea-level elevations, with the color grading into tans and browns as elevations increase. The color gradient often terminates in shades of gray for the highest elevations.

Rivers, lakes, seas and oceans are usually shown in blue, often with a light blue color for the most shallow areas and darkening in a gradient or by intervals for areas of deeper water. Glaciers and ice caps are shown in white colors.

Physical maps usually show the most important political boundaries, such as state and country boundaries. Major cities and major roads are often shown. This cultural information is not the focus of a physical map, but it is often included for geographic reference and to increase the utility of the map for many users.

## Road, Street and Highway Maps

The digital mapping revolution caused an explosion of map creation in the 1990s. In 1996, [MapQuest](#), the first popular online mapping service, allowed anyone with internet access the ability to create customized maps of almost any location in the United States.

Within a few months, millions of people had become "cartographers". They were soon producing more unique maps in a single day than had been created during the entire history of paper cartography!

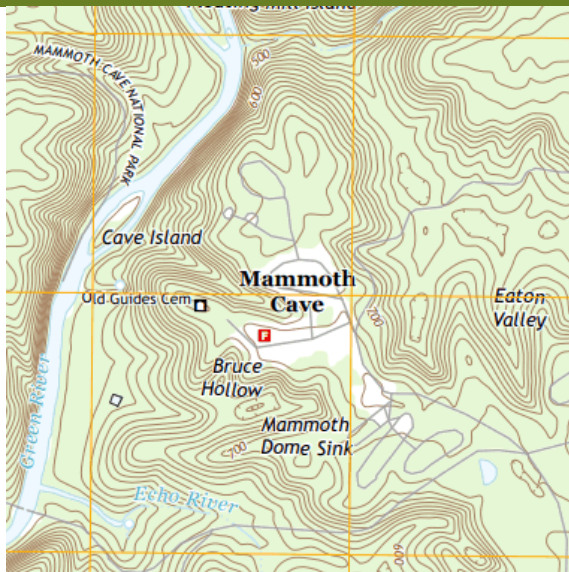
Today, [Google Maps](#) is the world's most popular online mapping system. In addition to maps, the service also provides travel route directions. It can create directions for people who are driving, taking public transportation, walking, cycling or taking a plane.

Billions of unique maps, millions of travel routes, and millions of street views are created each day with Google Maps. It is the first place millions of people go to plan any type of travel.

Google has another product named "[Google Earth](#)" that allows people to view streets, roads and satellite images within a single interface. Google Earth is a free download - the software installs on your computer and fetches the image directly from the Google Earth server.

Finally, for people who want printed maps, the [DeLorme Atlas & Gazetteer](#) is a series of books that contain state-wide map coverage for individual states (or pairs of small adjacent states). The maps present a combination of road, topography, cultural and recreational information. These "hybrid maps" are a favorite of people who work and play outdoors in rural areas.

### Topographic Maps



**Topographic Map** of an area within Mammoth Cave National Park, Kentucky. This map shows Earth's topography using brown contour lines with a contour interval of 20 feet. Roads, place names, streams and other features are also shown.

Areas on the map where the brown contour lines are close together have steep slopes. Areas where the contour lines are spaced far apart have gentler slopes.

## [Topographic Maps](#)

Topographic maps are reference maps that show the shape of Earth's surface. They usually do this with lines of equal elevation known as "contour lines", but elevation can also be shown using [colors](#) (second map), [color gradients](#), [shaded relief](#) and a number of other methods.

Topographic maps are frequently used by hunters, hikers, skiers, and others seeking outdoor recreation. They are also essential tools of the trade for geologists, surveyors, engineers, construction workers, landscape planners, architects, biologists and many other professions - especially people in the military.

Topographic maps also show other important natural features such as lakes, rivers and streams. Their locations are determined by topography, making them important natural elements of topographic maps.

Important cultural features are also shown on topographic maps. These include roads, trails, buildings, place names, bench marks, cemeteries, churches, schools and much more. A standardized set of special symbols has been developed for this use.

Topographic maps have traditionally been printed on large sheets of paper with their four boundaries being lines of longitude and latitude. The [United States Geological Survey](#) is the most widely known organization for producing them. They produce a series of 7.5-minute topographic maps covering most areas of the United States (a 7.5-minute map shows an area that is 7.5 minutes of longitude by 7.5 minutes of latitude). These maps and maps of many other scales are available from USGS in both print and digital form.

Commercial publishers of topographic maps include the [DeLorme Atlas](#) (paper maps in books with state-wide coverage) and [MyTopo](#) (a source of digital and paper maps in traditional topographic and topophoto formats - we are affiliates of [MyTopo](#) and receive a commission on referred sales).

## [Weather Maps](#)

People use an incredible number of weather maps. They are used to show predicted temperatures, predicted precipitation, storm warnings of various kinds, wind speed and direction, chance of precipitation, type of precipitation, snow accumulation, frost prediction and many other aspects of weather.

All of these weather maps are continuously updated to communicate the most current information. They are the world's most frequently consulted thematic maps. Weather maps are presented in newspapers, television programs and especially on websites. Delivering weather maps on websites and through web apps gives people around the world instant access to weather information.

Many weather maps are animated maps that show historical or projected changes in the weather. These are extremely useful for people who need to know how changes in weather will impact their travel, workday, recreation, and many other plans.

## Income Maps

Income maps are a very common type of thematic map. They show variations of income across a geographic area. The standard mapped variable for an income map is median household income.

Income tends to be highly geographic because rural portions of a state or country often have lower median household income than urban areas. Within urban areas, income can also be highly variable because neighborhoods tend to be populated by people with similar income levels.

The United States Census Bureau is a regular producer of income maps for the United States and individual states. After each major census, the Bureau updates its set of income maps and makes them available to the public. The Census Bureau also makes "change in income maps". These show which geographic areas have experienced economic growth or economic decline over a specific time interval.

## Resource Maps

Thematic maps are often made to communicate the geographic distribution of natural resources. These maps might show [countries with the highest diamond production](#) or the [geographic extent of an oil or gas field](#). The map shown here illustrates the geographic pattern of solar generating capacity for the United States.

Resource maps are important because they help governments understand their natural resource assets and the natural resource assets of their allies and potential enemies. Resource maps help mining companies target their [exploration](#) efforts. They are also important for assessing the transportation opportunities and problems associated with the distribution of resources and the location of where they are consumed.

## DEFENCE SERIES MAPS (DSM) -

These are prepared on 1:250,000; 1:50,000 and 1:25,000 scales for the use of defence forces of India for supporting national security requirements. Technically maps of this series are based on WGS-84 Datum and LCC Projection. They contain full features of map with grid, contours and other classified information without any dilution of accuracy; therefore, they are kept under restricted category. Survey of India is only authorized for preparation and printing of DSM. For sale and distribution the responsibilities are assigned to ADGMS (GSGS), Ministry of Defence, DGIS Enclave, Rao Tula Ram Marg, Delhi Cantt.



# Open Series Map

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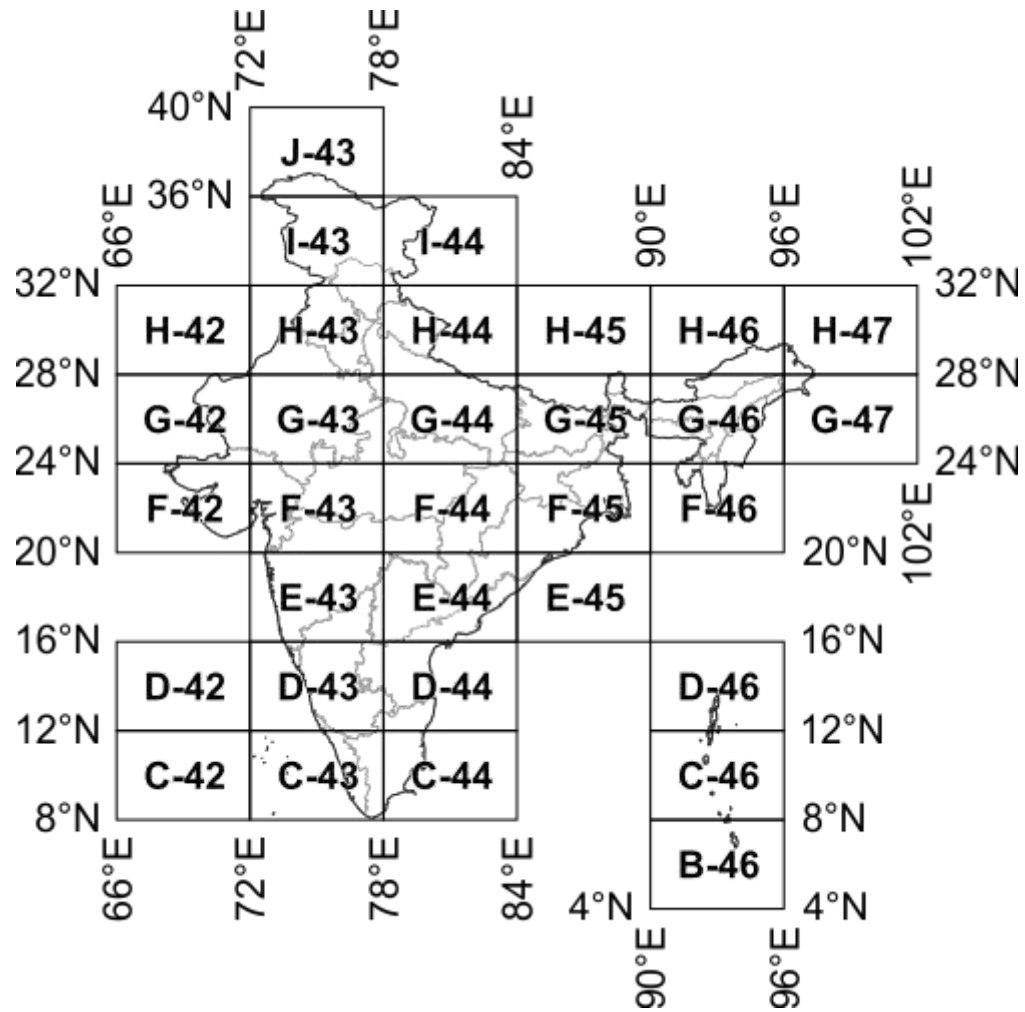
'Open Series Map' have been introduced as per the [National Map Policy of 2005](#) by [Survey of India](#). For the same a new map numbering system has been adopted instead of the previous [India and Adjacent Countries \(IAC\)](#).

The map series is based on [Transverse Mercator projection](#) on [WGS-1984 datum](#). A numbering system based on [International Map of the World \(IMW\)](#) is used.

Map numbering is of the form 'A-12A-1':

1. The [IMW numbering system](#) with minor modification is used upto  $1^{\circ} \times 1^{\circ} / 1:250,000$  scale.
  - a. Since the IMW map number for India will always start with 'N' (India being in the northern hemisphere), the first letter is omitted.
  - b. The next alphabet and number of the IMW map number denotes the  $6^{\circ} \times 4^{\circ}$  region of the IMW series. So sheet with Kalyanpur ( $77.65489^{\circ}E$   $24.11981^{\circ}N$ ) would be in 'G-43' (from ~~N~~G-43):





c. Each  $6^\circ \times 4^\circ$  rectangle is further subdivided into 24 squares of  $1^\circ \times 1^\circ$ . Each square is indicated serially by an alphabet increasing first towards east and then towards south, starting with 'A'. So sheet for Kalyanpur

(77.65489°E 24.11981°N) falls within 'G-43X':

28°N	A	B	C	D	E	F	
27°N	G	H	I	J	K	L	
26°N	M	N	O	P	Q	R	
25°N	S	T	U	V	W	X	
24°N							
	72°E	73°E	74°E	75°E	76°E	77°E	78°E

2. Each 1°×1° square is further divided into 16 squares of 15'×15' (15 minutes×15 minutes). Each square is indicated serially by a number increasing first towards south and then towards east, starting with '1' (similar to the system adopted in [India and Adjacent Countries](#)). So for the map sheet for Kalyanpur (77°39.293'E 24°7.187'N) would be 'G-43X-12':

25°N	1	5	9	13	
45'	2	6	10	14	
30'	3	7	11	15	
15'	4	8	12	16	
24°N					
	77°E	15'	30'	45'	78°E

Lookup Open Series Map map numbers in [Map Number Lookup](#).

## Further Reading/References

- [Guidelines for Implementing National Map policy](#) (has layout of OSM sheets on page 5, PDF - 904 KiloBytes).
- [National Map Policy](#) (PDF - 41 KiloBytes).
- [Toposheet Number to OSM sheet Number](#) (PDF - 655 KiloBytes).

In this unit, an introduction to some important modern surveying equipment and their use has been explained. The first section deals with the angle measuring equipment such as micro-optic and electronic theodolites. In the next section, the EDM has been discussed. This is followed by a discussion on electronic and auto levels. The penultimate section provides details on the Total Station that can be used for angle, distance and height measurements in one go. In the last section, an introduction to the latest technology, namely GPS, has been provided.

## Objectives

After studying this unit, you should be able to

- get an overview of some commonly used modern surveying equipment and their uses, and
- understand the working of these new generation equipment for field surveying jobs.

## 5.2 MICRO-OPTIC AND ELECTRONIC THEODOLITES

As you know that the survey field measurements include distances (horizontal and sloping) and angles (horizontal and vertical) measurement. The latter can be measured with a transit, or theodolite. You have already studied the use of vernier theodolites that are designed to read angles to the closest minute, 20 seconds or 10 seconds. Over the years, the vernier theodolites have been in practice for conducting surveys of ordinary precision. For very precise surveys, these have been superseded by modern theodolites. The modern theodolites can be categorised as micro-optic and electronic theodolites. Unlike vernier theodolite, the observations are taken through an auxiliary eyepiece (i.e. through optics) in the micro-optic theodolites and hence the name. In electronic theodolites, the observations are taken from the visual displays. These can read, record, display and store horizontal and vertical angles in the electronic recorder attached to them.

### 5.2.1 Micro-optic Theodolites

The design of these instruments is such that these become compact and light-weight. These are generally characterised by a three-foot screw levelling head and an optical plummet. There is a circular level for approximate levelling and a plate level for precise levelling. Optical plummet is provided for accurate centering particularly in windy climatic conditions. The plummet consists of a small eyepiece generally built into the tribach. The graduations are marked on horizontal and vertical circles made up of glass. The observations are read through an optical reading system that consists of a series of prisms. The vertical circle is normally graduated such that  $0^\circ$  corresponds to the telescope pointing upwards towards the zenith. The graduations increase clockwise with  $90^\circ$  and  $270^\circ$  marked on the horizontal line and  $180^\circ$  on the vertical line pointing downwards towards the nadir. The glass circles are read with the aid of an eyepiece adjacent to the telescope. The angles can be read to a least count of 1". Many manufacturers have developed a variety of micro-optic theodolites each having a particular optical system such as circle microscope system, optical scale system, single reading optical micrometer and double reading optical micrometer etc.



A list showing the performance of some of the direction measuring equipment is given in Table 5.1.

**Table 5.1 : Some Micro-optic Theodolites for Angle Measurement**

Sl. No.	Name of Instrument	Make	Least Count	
			Direct (Seconds)	Estimation (Seconds)
1.	T2 (Universal)	Leica, Switzerland	1.0	0.5
2.	T3 (Precision)	Leica, Switzerland	0.2	0.1
3.	T4 (Astronomy)	Leica, Switzerland	0.1	0.05
4.	Theo 010	Zeiss, Germany	1.0	0.1

Wild T3 theodolite is used for geodetic triangulation and all other precise surveys whereas Wild T4 theodolite is commonly used for astronomical determination of co-ordinates and azimuth. Wild T2 and Zeiss Theo 010 are commonly used for engineering surveys.

### 5.2.2 Electronic Theodolites

A major change in the design of theodolites has occurred in recent years with the introduction of electronic circle reading systems to their design. The electronic theodolites are similar to micro-optic theodolites in their design and operation. However, the difference lies in the system of taking reading. Here, the observations are taken through digital readouts or displays. The commonly used displays are Light-Emitting Diodes (LED) and Liquid Crystal Displays (LCD). The direct display of angular readings eliminates the guessing and interpolations associated with the vernier scale and micrometer readings in other theodolites. The angles can be measured to a least count of 1" with precision ranging from 0.5" to 10". One of the significant characteristics of these theodolites is that the data can be recorded in a data collector attached with the theodolite. The data can then be processed in a computer for subsequent analyses. The theodolites have a zero set button for initial setting of the readings. Once attached with EDM, it can then be used as a Total Station (to be discussed in Section 5.4 of this unit). A typical electronic theodolite is shown in Figure 5.1.



**Figure 5.1 : An Electronic Theodolite with Data Collector**

### 5.2.3 Working of Micro-optic and Electronic Theodolites

The working of these theodolites is more or less similar to that of a vernier theodolite. The major difference is in the centering procedure, which is through optical plummet instead of the conventional plumb bob centering. For an easy and quick set up, following steps may be followed :

- (a) Place the instrument over the point with the tripod plate as horizontal as possible.
- (b) From a distance of 1 to 2 meter, check if the instrument appears to be set over the station. If not, adjust the location and check again. Move in the direction  $90^\circ$  to the original setting and repeat the steps.
- (c) Through the optical plummet, look the station mark and then firmly push in the tripod legs into the ground.
- (d) Manipulate the levelling screws while simultaneously looking through the optical plummet until its cross hair is exactly over the station mark.
- (e) Level the theodolite with the circular bubble in the usual fashion.
- (f) Look into the optical plummet to confirm that its cross hair is quite close to the station mark.
- (g) The circular bubble can now be brought into centre by turning one or more levelling screws.
- (h) The tripod clamp is now loosened to slide the instrument on the flat tripod top till the optical plummet cross hair is exactly centered over the station mark.
- (i) The instrument can now be precisely levelled using longitudinal bubble in the usual fashion as we do in vernier theodolite.
- (j) Start measuring the horizontal and vertical angles.

The instrument can be used for various surveying operations such as laying off angles, prolonging a straight line, balancing in, intersection of two lines etc.

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## 5.3 ELECTRONIC DISTANCE MEASUREMENT (EDM)

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For providing precise horizontal control using trilateration (Section 6.3.1 of this block), it is necessary that the distances be measured as accurately as possible. The advent of EDM has made this possible. The EDM was first introduced in the late 1950. Since then, many refinements to these equipment have been made. The earlier EDMs were very big, heavy and expensive. With the advancements in electronic and computer technologies, these have become smaller, simpler and less expensive. The EDMs come in two parts : the instrument and the reflector.

### The Instrument

The EDMs are generally of two types : electro-optical systems and electronic systems. The electro-optical systems use either light and laser waves or infrared waves whereas electronic systems use microwaves. The microwave systems require transmitter/receiver at both ends of the line to be measured. The infrared system requires a transmitter at one end and a reflector at the other end. The microwave systems are capable of measuring distances up to a limit of 100 kms whereas the infrared EDMs come in three

IS NOT SO PORTABLE AS TO THE P...

### 14.25. PARALLAX IN AERIAL STEREOSCOPIC VIEWS

*Parallax of a point is the displacement of the image of the point on two successive exposures.*

*The difference between the displacements of the images of two points on successive exposures is called the difference in parallax between the two points.*

In Fig. 14.51, two points *A* (lower) and *B* (higher) are being photographed by the two positions *O* and *O'* of an aerial camera. If the plane is moving at a speed of 200 km/hour and if the exposures are taken at an interval of 20 seconds, the lens centre moves a ground distance of about 1110 metres between the two exposures. Suppose that between the two exposures, the image of the lower object *A* has moved a distance 6.05 cm across the focal plane of the camera, and

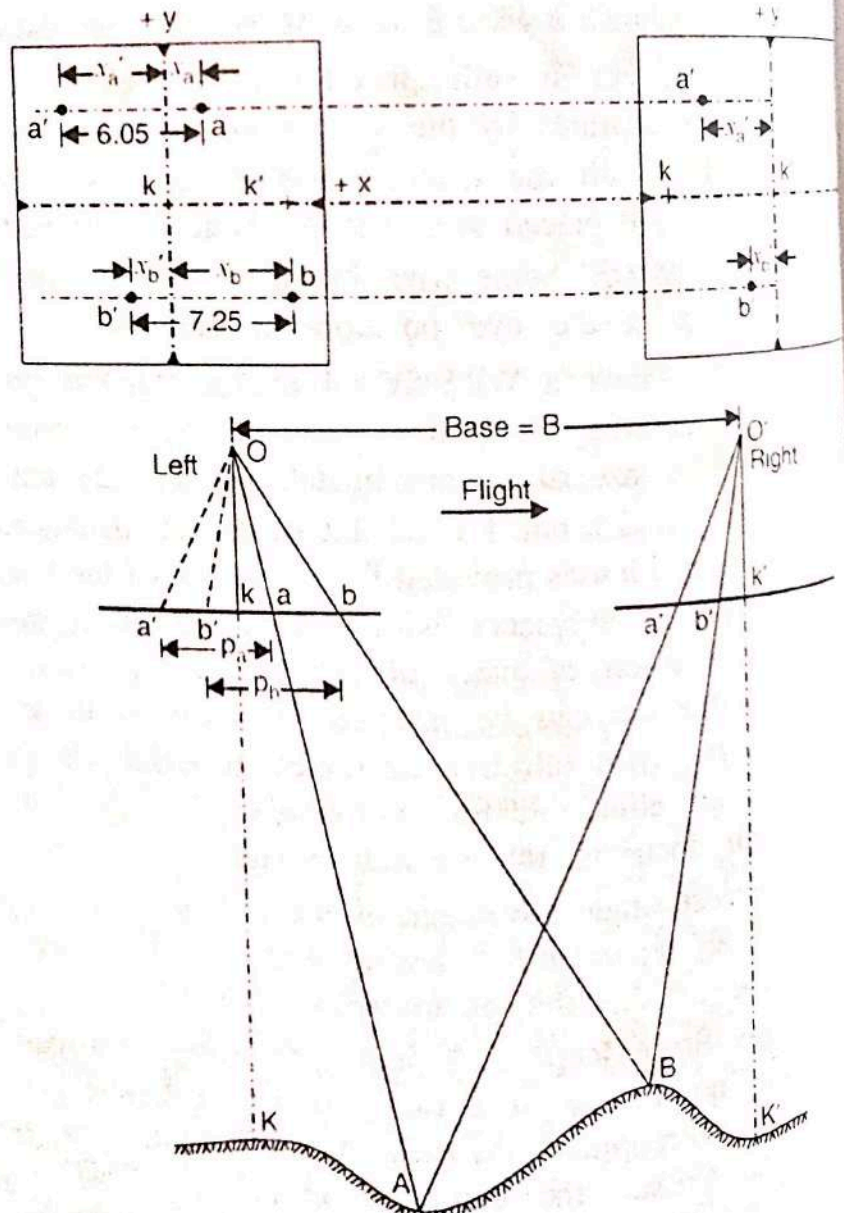


FIG. 14.51. PARALLAX.



the image of the higher object  $B$  has moved a distance of 7.25 cm. Then the parallax of the lower point is 6.05 cm and that of the higher point is 7.25 cm.

In the left photograph,  $a$  and  $b$  are the images of the two points.  $k'$  is the transferred principal point of the right photograph. Both the images  $a$  and  $b$  are to the right of the  $y$ -axis of the left photograph. In the right photograph,  $a'$  and  $b'$  are the images of the same points, both the images being to the left of the  $y$ -axis. Thus the images ( $a, b$ ) on the left photographs have moved to ( $a', b'$ ) between the two exposures. The movement  $aa'$  (shown on the left photographs) is the parallax of  $A$ , and  $bb'$  is the true parallax of  $B$ . The parallax of the higher point is more than the parallax of the lower point. Thus, each image in a changing terrain elevation has a slightly different parallax from that of a neighboring image. This point-to-point difference in parallax exhibited between points on a stereopair makes possible the viewing of the photographs stereoscopically to gain an impression of a continuous three dimensional image of a terrain.

The following are the ideal conditions for obtaining aerial stereoscopic views of the ground surface :

- (1) two photographs are taken with sufficient overlap.
- (2) the elevation of the camera positions remains the same for the two exposures.
- (3) the camera axis is vertical so that the picture planes lie in the same horizontal plane.

**Algebraic Definition of Parallax :** As defined earlier the displacement of the image of a point on two successive exposures is called the parallax of the point. On a pair of overlapping photographs, the parallax is thus equal to the  $x$ -coordinate of the point measured on the left-hand photograph (or previous photograph) minus the  $x$ -coordinate of the point measured on the right-hand photograph (or next photograph). Thus

$$p = x - x'$$

...(14.23)

Thus,  $x$ -axis passes through the principal point and is parallel to the flight line, while the  $y$ -axis passes through the principal point and is perpendicular to the line of flight. In general, however, the flight-line  $x$ -axis is usually very close to the collimation mark  $x$ -axis, because of the effort made to eliminate drift and crab at the time of photography.

Thus, in Fig. 14.51, the parallax of points  $A$  and  $B$  are given by

$$p_a = x_a - x'_a \quad \text{and} \quad p_b = x_b - x'_b$$

In substituting the numerical values of  $x$  and  $x'$ , their proper algebraic sign must be taken into consideration. Thus, in Fig. 14.51, if  $x_a = 2.55$  cm,  $x'_a = -3.50$  cm,  $x_b = -4.05$  cm and  $x'_b = -3.20$  cm, we have

$$p_a = + 2.55 - (-3.50) = 6.05 \text{ cm}$$

$$p_b = + 4.05 - (-3.20) = 7.25 \text{ cm.}$$

### 14.26. PARALLAX EQUATIONS FOR DETERMINING ELEVATION AND GROUND CO-ORDINATES OF A POINT

Let  $A$  be a point whose ground co-ordinates and elevation are to be found by parallax measurement.



Let  $K$  be the ground position of the principal point  $k$  of the left photograph, and  $X$  and  $Y$  be the ground co-ordinates of  $A$  with respect to the ground co-ordinate axes, which are parallel to the photographic  $x$  and  $y$  co-ordinate axes, and with  $K$  as the origin.  $M$  is an imaginary point which has got the same elevation as that of  $A$ , and which lies on the ground  $X$ -axis.  $a$  and  $m$  are the images of  $A$  and  $M$  on the right photographs, and  $a'$  and  $m'$  are the corresponding images on the left photograph. Let  $(x, y)$  be the co-ordinates of  $a$  on the left photograph, and  $(x', y')$  be the co-ordinates of  $a'$  on the right photograph.

From triangles  $OKM$  and  $Okm$ , we have

$$\frac{Ok}{OK} = \frac{Om}{OM} = \frac{km}{KM}$$

$$\frac{f}{H-h} = \frac{Om}{OM} = \frac{x}{X} \quad \dots(1)$$

From triangles  $Oam$  and  $OAM$ , we have

$$\frac{Om}{OM} = \frac{am}{AM}$$

But  $\frac{Om}{OM} = \frac{f}{H-h}$  from (1) and  $\frac{am}{AM} = \frac{y}{Y}$

Hence  $\frac{am}{AM} = \frac{y}{Y} = \frac{f}{H-h}$

Similarly, from triangles  $O'K'M$  and  $O'k'm$ ,

$$\frac{O'k'}{O'K'} = \frac{O'm'}{O'M} = \frac{k'm'}{K'M} \quad \text{or} \quad \frac{f}{H-h} = \frac{x'}{X}$$

and from triangles  $O'MA$  and  $O'm'a'$ , we have

$$\frac{O'm'}{O'M} = \frac{a'm'}{AM} \quad \text{or} \quad \frac{f}{H-h} = \frac{y'}{Y}$$

From equations (2) and (4), we have  $\frac{f}{H-h} = \frac{y}{Y} = \frac{y'}{Y}$

or  $y = y'$

Equation 14.34 establishes that there is no  $y$  parallax in a stereoscopic pair of photographs

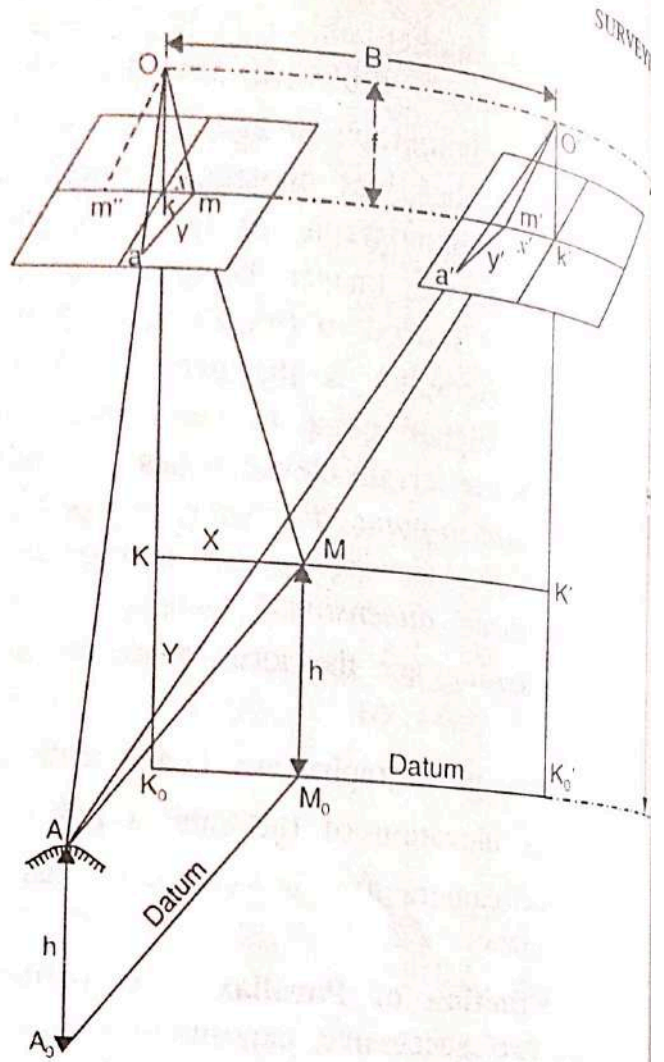


FIG 14.52. PARALLAX EQUATIONS FROM RAPALLAX MEASUREMENTS.



In the left photograph (Fig. 14.52), draw  $Om''$  parallel to  $O'm'$  of right photograph.  
 Then, in the triangles  $Om''m$  and  $OMO'$  :

$OO'$  is parallel to  $m''m$

$Om$  coincides with, and is parallel to  $OM$

$Om''$  is parallel to  $o'm'$

Hence they are similar, and their corresponding altitudes are  $f$  and  $(H - h)$  respectively.

Thus,  $\frac{f}{H - h} = \frac{mm''}{OO'}$

But  $mm'' = km + km'' = x - x' = p$  and  $OO' = B = \text{air base}$

$\frac{f}{H - h} = \frac{p}{B}$  ... (5)

or

$H - h = \frac{Bf}{p}$  ... (14.35)

This is the parallax equation for the elevation of the point.

Again from equations (1) and (2),

$X = \frac{H - h}{f} x$  and  $Y = \frac{H - h}{f} y$

But  $\frac{H - h}{f} = \frac{B}{p}$ , from (5)

Hence  $X = \frac{B}{p} x$  and  $Y = \frac{B}{p} y$  ... (14.36)

This is the parallax equation for the ground co-ordinates of the point.

**Difference in Elevation by Stereoscopic Parallaxes**

In Fig. 14.53,  $A_1 A_2$  is a flagpole being photographed from two camera positions  $O$  and  $O'$ . The top  $A_2$  of the flagpole has an elevation of  $h_2$  above the datum, and the bottom  $A_1$  has an elevation of  $h_1$  above the datum.  $H$  is the camera height for both the exposures.

In the left photographs,  $a_1$  and  $a_2$  are the two images of  $A_1$  and  $A_2$ , and their  $x$ -co-ordinates are  $x_1$  and  $x_2$  respectively.

Similarly, in the right photograph,  $a'_1$  and  $a'_2$  are the images of  $A_1$  and  $A_2$  respectively, and their  $x$ -co-ordinates are  $x'_1$  and  $x'_2$  respectively.

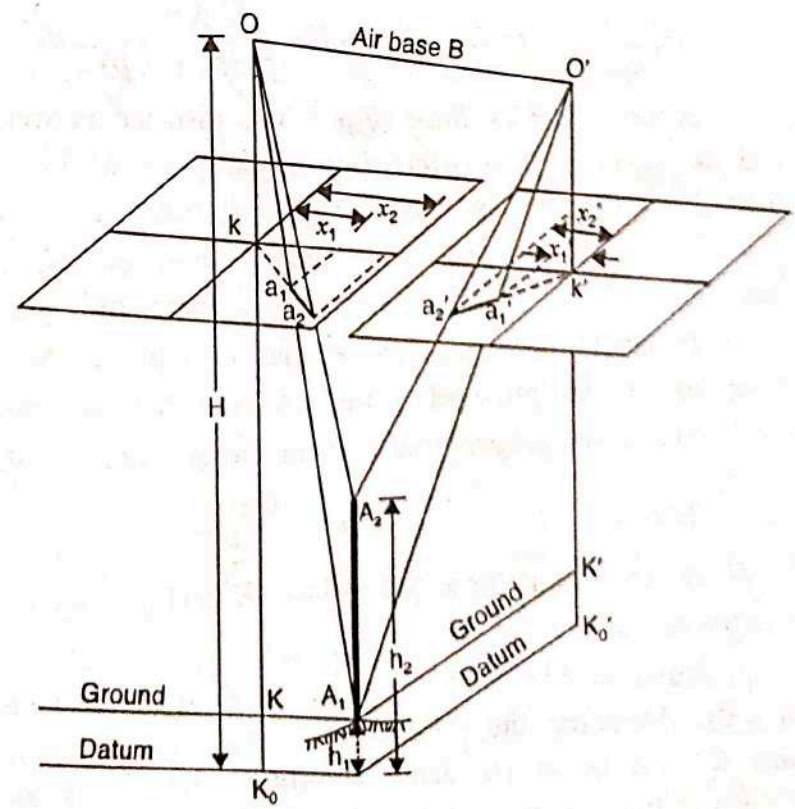


FIG. 14.53. DIFFERENCE IN ELEVATION BY STEREOGRAPHIC PARALLAXES.



Evidently, the parallax  $p_1$  for the bottom of the flagstaff is given by

$$p_1 = x_1 - x'_1$$

Similarly, the parallax  $p_2$  for the top of the flagstaff is given by

$$p_2 = x_2 - x'_2$$

Hence the difference in parallax ( $\Delta p$ ) of top and bottom points is given by

$$\Delta p = p_2 - p_1 = (x_2 - x'_2) - (x_1 - x'_1)$$

From equation 14.35, the elevation of any point is given by

$$h = H - \frac{Bf}{p}$$

Hence, for the top and bottom of flagstaff, we get

$$h_1 = H - \frac{Bf}{p_1} \quad \text{and} \quad h_2 = H - \frac{Bf}{p_2}$$

$\therefore$  Difference in elevation ( $\Delta h$ ) is given by,

$$\Delta h = h_2 - h_1 = \left( H - \frac{Bf}{p_2} \right) - \left( H - \frac{Bf}{p_1} \right) = \frac{Bf}{p_1} - \frac{Bf}{p_2}$$

or

$$\Delta h = \left( \frac{p_2 - p_1}{p_1 p_2} \right) Bf$$

or

$$\Delta h = \frac{\Delta p}{p_1 p_2} Bf$$

Now

$$\Delta p = p_2 - p_1 \quad \text{or} \quad p_2 = p_1 + \Delta p$$

Hence, we have

$$\Delta h = \frac{\Delta p}{p_1 (p_1 + \Delta p)} \cdot Bf$$

**Mean Principal Base ( $b_m$ )** : The distance between the principal point of a photograph and the position of transferred principal point of its next photograph obtained under flash through stereoscope is called *principal base*. Thus, in Fig. 14.51,

$kk' = b =$  principal base of left photograph

$k'k = b' =$  principal base of right photograph.

It should be noted that  $b$  and  $b'$  will not be equal since the elevation of ground positions of the principal points ( $K$  and  $K'$ ) are not the same.

The *mean principal base* is the mean value of the principal bases of the photographs.

Thus,

$$b_m = \frac{b + b'}{2}$$

If the ground principal points ( $K$  and  $K'$ ) have the same elevation, then under ideal conditions,  $b_m = b$ .

Now, in Fig. 14.53, let the datum pass through the bottom  $A_1$  of the flagstaff ( $h_1 = 0$ ). Assuming the ground to be now the datum plane, the ground principal points ( $K$  and  $K'$ ) will be at the same elevation, and the parallax of the principal points (*i.e.*, the principal base) will be equal to  $b$ . If  $H$  is the height of camera above the datum (*i.e.*, above  $A_1$  now), the general relationship between  $b$  and  $B$  is given by



$$\frac{B}{b} = \frac{H}{f} \quad \text{or} \quad B = \frac{Hb}{f} = s \times b \quad \dots(14.39)$$

where  $s$  is the scale of the photograph at datum elevation. Substituting this value of air base in equation 14.38, we get

$$\Delta h = \frac{\Delta p}{p_1 (p_1 + \Delta p)} \cdot Hb$$

Since  $K, K'$  and  $A_1$  are all at the same elevation, their parallaxes are the same.

Hence

$$p_1 = \text{parallax of principal points} = b$$

Hence, we get the parallax equation

$$\Delta h = \frac{H \Delta p}{b + \Delta p} = \frac{H \Delta p}{p_1 + \Delta p} \quad \dots(14.40)$$

While using equations 14.40, the following assumptions must always be kept in mind:

(1) The vertical control point (i.e., point  $A_1$ ) and the two ground principal points lie at the same elevation.

(2) The flying height ( $H$ ) is measured above the elevation of the control point and not sea level (unless the control point happens to lie at sea level).

In practical applications, the mean principal base ( $b_m$ ) is used in place of  $b$ , and flying height above the average terrain is taken as the value of  $H$ .

#### Alternative form of Parallax Equation for $\Delta h$

We have, 
$$p_1 = \frac{fB}{H - h_1} \quad \text{and} \quad p_2 = \frac{fB}{H - h_2}$$

$$\therefore \Delta p = p_2 - p_1 = fB \left( \frac{1}{H - h_2} - \frac{1}{H - h_1} \right) = fB \frac{h_2 - h_1}{(H - h_1)(H - h_2)}$$

But 
$$\Delta h = h_2 - h_1 \quad \text{and} \quad h_2 = \Delta h + h_1$$

$$\therefore \Delta p = fB \frac{\Delta h}{(H - h_1)(H - \Delta h - h_1)}$$

or 
$$\Delta p (H - h_1)^2 - \Delta p (H - h_1) \Delta h = fB \Delta h$$

or 
$$\Delta h [(H - h_1) \Delta p + fB] = (H - h_1)^2 \Delta p$$

or 
$$\Delta h = \frac{(H - h_1)^2 \Delta p}{(H - h_1) \Delta p + fB}$$

Dropping the suffix of  $h$ , we get

$$\Delta h = \frac{(H - h)^2 \Delta p}{(H - h) \Delta p + fB} \quad \dots[14.41(a)]$$

where  $h$  is the elevation of lower point above datum.

Putting  $fB = Hb$ , we get 
$$\Delta h = \frac{(H - h)^2 \Delta p}{(H - h) \Delta p + bH} \quad \dots(14.41)$$

It should be noted that the above equation is in its most general form. Eq. 14.40 is the special form of this, and can be obtained by putting  $h = 0$  (i.e., lower point at datum) in Eq. 14.41). Thus



$$\Delta h = \frac{(H - 0)^2 \Delta p}{(H - 0) \Delta p + bH} = \frac{H^2 \Delta p}{H \Delta p + bH} = \frac{H \Delta p}{\Delta p + b}$$



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Lecture – 25  
DIGITAL LAND SURVEYING  
**ERRORS IN TOTAL STATION**

**DR. JAYANTA KUMAR GHOSH**  
CIVIL ENGINEERING DEPARTMENT



# CONTENTS

- **INTRODUCTION**
- **CALIBRATION**
- **ERRORS IN TOTAL STATION**
- **SUMMARY**
- **REVIEW QUESTIONS**
- **FURTHER READING**



# INTRODUCTION

- **TS should be in permanent adjustment before using it for observations.**
- **Seldom achieved in practice and give rise to instrumental errors in TS.**
- **To be ensured through regular monitoring of instrumental errors**
- **one face measurements are rampant in field and thus, it is important to determine the magnitude of the errors and correct them.**
- **Instrumental errors can be measured and corrected using electronic calibration.**





# CALIBRATION

- Calibration parameters of a TS changes because of mechanical shock, temperature changes, rough handling etc.
- Calibration of TS is to done following the procedure given in manual of the instrument.
- Calibration should be done before deployment of instruments for field observation
  - for the first time
  - after long storage
  - After rough or long transportation
  - After long periods of work
  - Following big changes in temperature
  - Regularly for precision work.



# CALIBRATION....

- **Before calibration, TS should be in ambient temperature**
- **Instrument s/w automatically apply corrections as calibrations parameters get determined.**



# SOURCES OF ERRORS

The lack in permanent adjustment in TS leads to following instrumental errors

- **HORIZONTAL COLLIMATION ERROR**
- **TILTING AXIS ERROR**
- **VERTICAL COLLIMATION**
- **COMPENSATOR INDEX ERROR**
- **ECCENTRICITY ERROR**
- **CIRCLE GRADUATION ERROR**
- **COLLIMATION OF LASER POINTER**

Regular calibration adopting proper field procedures need to be implemented to eliminate or reduce the effects of these errors.



# SOURCES OF ERRORS ...

## HORIZONTAL COLLIMATION

- Axial error when line of sight is not perpendicular to the horizontal axis
- Effects horizontal circle reading
- Increases with steep sightings
- Eliminated through both face observations.
- For single face observation, by finding out the angle of deviation through calibration
- If exceeds limit, get adjusted through manufacturer.





# SOURCES OF ERRORS ....

## TILTING AXIS ERROR

- When horizontal axis is not perpendicular to the vertical axis
- Causes line of sight in an inclined plane as the telescope is plunged
- Effects horizontal circle reading for tilted sight.
- Eliminated through both face observations and for equal BS & FS distances
- For single face observation, by finding out the tilting axis error through calibration
- If exceeds limit, get adjusted through manufacturer.



# SOURCES OF ERRORS...

## VERTICAL COLLIMATION

- When the  $0^\circ - 180^\circ$  line of the vertical circle does not coincide with the vertical axis.
- **Effects vertical circle reading**
- **Eliminated through both face observations**
- **For single face observation, by finding out the index error,  $i$  through calibration**
- **It gets applied directly to vertical angle**
- **If exceeds limit, get adjusted through manufacturer.**



# SOURCES OF ERRORS....

## COMPENSATOR INDEX ERROR

- Errors due to improper leveling of TS, gets compensated automatically through compensator by measuring the residual tilt and applying corrections to the horizontal and vertical circle readings.
- Compensators usually get longitudinal error,  $l$  in the direction of line of sight and transverse error,  $l$  in the direction of perpendicular to  $l$ .
- Known as zero point errors
- Eliminated through both face observations
- For single face observation, by finding out the zero point errors through calibration
- If exceeds limit, get adjusted through manufacturer.



# SOURCES OF ERRORS....

## COLLIMATION OF LASER POINTER

- Arises in reflector less measurements using laser beam.
- Due to non-coincidence of the pointing of the laser beam with the line of collimation
- Causes error in both circles readings as well as in distance.
- Eliminated through both face observations
- For single face observation, by finding out the angle of deviation through calibration
- If exceeds limit, get adjusted through manufacturer.





# SOURCES OF ERRORS....

## ECCENTRICITY ERROR

- If geometric centers of the graduated circles (Horizontal & Vertical) do not coincide with the center of rotation.
- **Errors are small**
- **By taking average of the measurements taken on opposite sides of the circles.**

## CIRCLE GRADUATION ERROR

- **Non-uniform graduations around the circumference of a circle (Horizontal/Vertical or both).**
- **Causes errors in both the circle measurements**
- **Errors are small**
- **Minimise or eliminate by taking measurements at different locations of circles.**



## Summary of Lecture 25

- **Requires permanent adjustment in TS before using it for observations.**
- **The lack in permanent adjustment in TS leads to : horizontal collimation error, tilting axis error, compensator index error, vertical collimation, collimation of laser pointer, eccentricity error, circle graduation error.**
- **Regular calibration adopting proper field procedures are done to eliminate or reduce the effects of these errors.**



# Review Questions

- 1. Write short notes on the following : (i) Horizontal collimation error; (ii) Tilting axis error; (iii) Compensator index error; (iv) Vertical collimation error; (v) Collimation of laser pointer error.**
- 2. Explain how errors in TS may be eliminated or reduced?**



# Further reading

1. **Surveying for Engineers (2006) by J. Uren & W.F.Price**
2. **Elementary Surveying – An introduction to Geomatics(2012) By C.D.Ghilani & P.R.Wolf.**

**Next Class**

**“OTHER Errors in TS”**





# Thanking You



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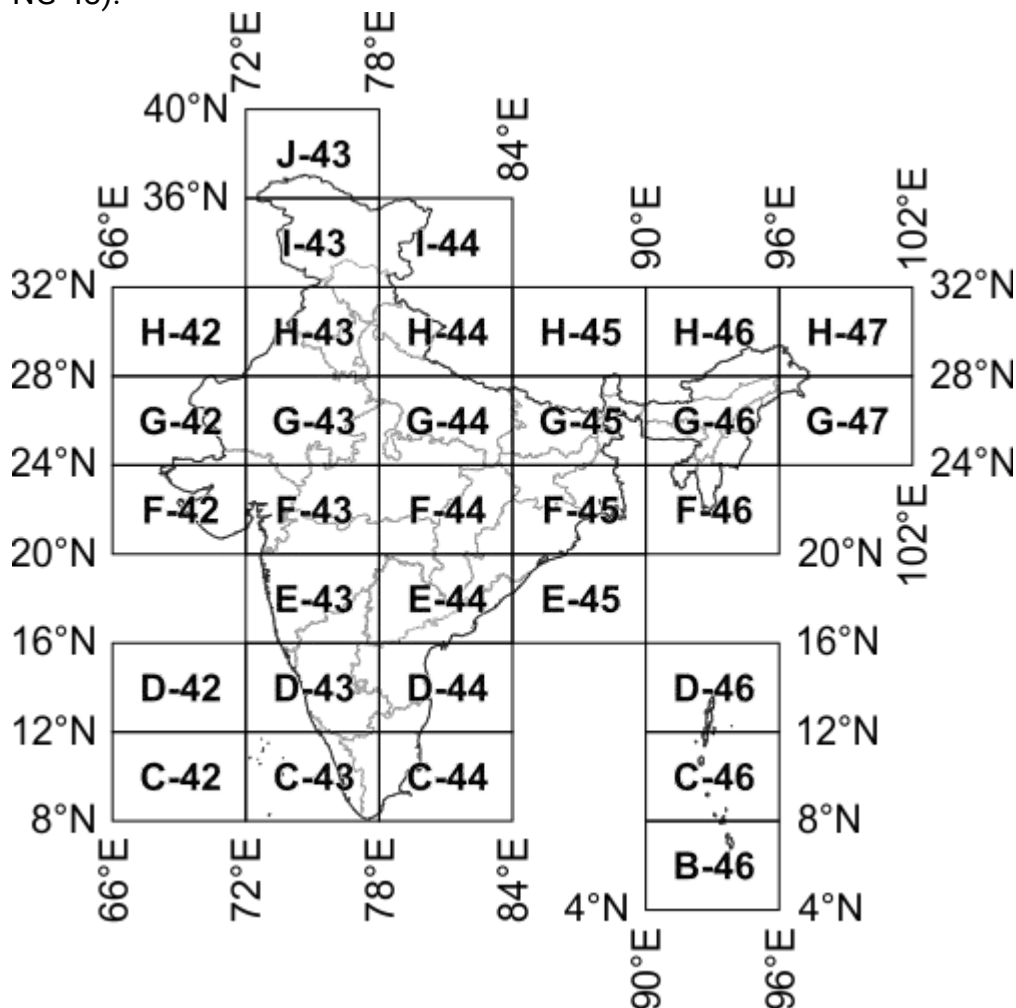
# Open Series Map

'Open Series Map' have been introduced as per the [National Map Policy of 2005](#) by [Survey of India](#). For the same a new map numbering system has been adopted instead of the previous [India and Adjacent Countries \(IAC\)](#).

The map series is based on [Transverse Mercator projection](#) on [WGS-1984 datum](#). A numbering system based on [International Map of the World \(IMW\)](#) is used.

Map numbering is of the form 'A-12A-1':

1. The [IMW numbering system](#) with minor modification is used upto  $1^{\circ} \times 1^{\circ} / 1:250,000$  scale.
  - a. Since the IMW map number for India will always start with 'N' (India being in the northern hemisphere), the first letter is omitted.
  - b. The next alphabet and number of the IMW map number denotes the  $6^{\circ} \times 4^{\circ}$  region of the IMW series. So sheet with Kalyanpur ( $77.65489^{\circ}E$   $24.11981^{\circ}N$ ) would be in 'G-43' (from NG-43):



- c. Each  $6^\circ \times 4^\circ$  rectangle is further subdivided into 24 squares of  $1^\circ \times 1^\circ$ . Each square is indicated serially by an alphabet increasing first towards east and then towards south, starting with 'A'. So sheet for Kalyanpur ( $77.65489^\circ\text{E}$   $24.11981^\circ\text{N}$ ) falls within 'G-43X':

28°N	A	B	C	D	E	F	
27°N	G	H	I	J	K	L	
26°N	M	N	O	P	Q	R	
25°N	S	T	U	V	W	X	
24°N							
	72°E	73°E	74°E	75°E	76°E	77°E	78°E

2. Each  $1^\circ \times 1^\circ$  square is further divided into 16 squares of  $15' \times 15'$  (15 minutes  $\times$  15 minutes). Each square is indicated serially by a number increasing first towards south and then towards east, starting with '1' (similar to the system adopted in [India and Adjacent Countries](#)). So for the map sheet for Kalyanpur ( $77^\circ 39.293'\text{E}$   $24^\circ 7.187'\text{N}$ ) would be 'G-43X-12':

25°N	1	5	9	13	
45'	2	6	10	14	
30'	3	7	11	15	
15'	4	8	12	16	
24°N					
	77°E	15'	30'	45'	78°E

Lookup Open Series Map map numbers in [Map Number Lookup](#).

## Further Reading/References

- [Guidelines for Implementing National Map policy](#) (has layout of OSM sheets on page 5, PDF - 904 KiloBytes).
- [National Map Policy](#) (PDF - 41 KiloBytes).
- [Toposheet Number to OSM sheet Number](#) (PDF - 655 KiloBytes).

Survey of India topographical maps:  
Reference scheme of Open Series  
Map (OSM)

Anupam Das  
Panihati Mahavidyalaya



❑ 'Open Series Map' have been introduced as per the [National Map Policy of 2005](#) by [Survey of India](#).

❑ Enhanced by the latest technology (RS and GIS) to meet the multidisciplinary needs of national security, suitable national development and new information market.

❑ The OSM numbering system based on [International Map of the World \(IMW\)](#) is used.

❑ The '[International Map of the World \(IMW\)](#)' was a project which started in 1913 to create a complete map of the world as per internationally agreed and consistent specifications

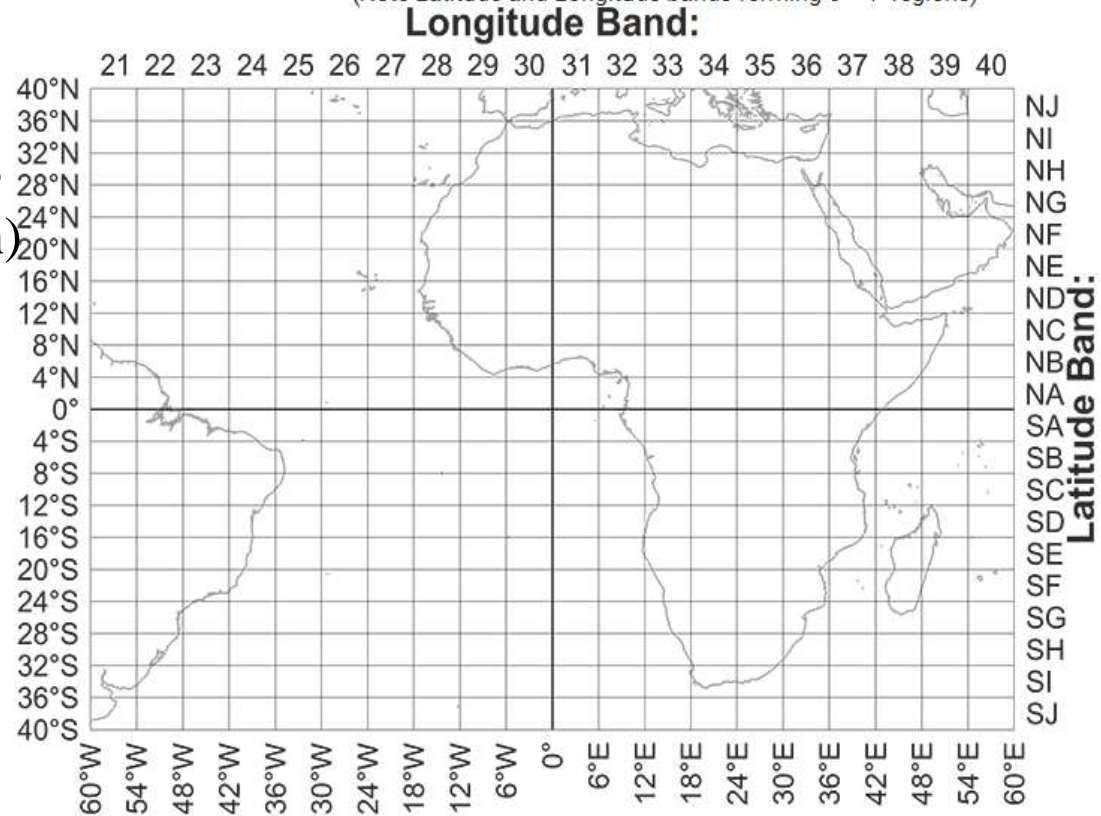
# The International Map of the World series

Map numbering is of the form '**NA-12A**'

- The first letter is either '**N**' or '**S**' to denote the hemisphere (North/South) with respect to the equator.

- A second letter denotes the 4° latitude band with alphabet increasing as latitude moves away from equator. So sheets between 12°N to 8°N would be '**NC**' and between 4°S to 8°S would be '**SB**'.

International Map of the World scheme for a part of the world:  
(Note Latitude and Longitude bands forming 6°×4° regions)



The next number denotes the 6° longitude band with numbering starting at 1 from 180°W (i.e. 1 between 180°W and 174°W) going on to 60 (i.e. between 174°E-180°E). So sheet between 72° to 78°E and 12°N to 8°N will be '**NC-43**'. Similarly between 132°W to 126°W and 4°S to 8°S would be '**SB-9**'. The longitude band span increased to 12° from 60° latitude and to 24° from 76° latitude due to the decrease in physical span of longitude band.

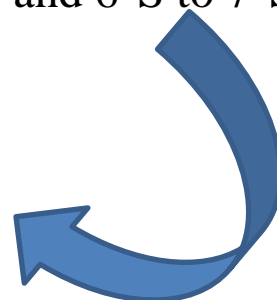
•Each  $6^\circ \times 4^\circ$  rectangle is further subdivided into 24 squares of  $1^\circ \times 1^\circ$ . Each square is indicated serially by an alphabet increasing first towards east and then towards south, starting with 'A'.

•So for sheet between  $74^\circ$  to  $75^\circ$ E and  $11^\circ$ N to  $10^\circ$ N we get **NC-43I**:

12°N	A	B	C	D	E	F	
11°N	G	H	I	J	K	L	
10°N	M	N	O	P	Q	R	
9°N	S	T	U	V	W	X	
8°N							
	72°E	73°E	74°E	75°E	76°E	77°E	78°E

4°S	A	B	C	D	E	F	
5°S	G	H	I	J	K	L	
6°S	M	N	O	P	Q	R	
7°S	S	T	U	V	W	X	
8°S							
	132°W	131°W	130°W	129°W	128°W	127°W	126°W

For sheet between  $128^\circ$ W to  $127^\circ$ W and  $6^\circ$ S to  $7^\circ$ S we get **SB-9Q**:



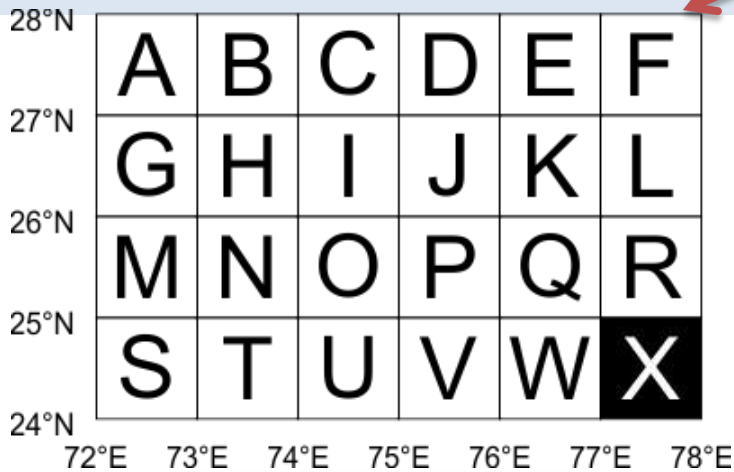
# OSM NUMBERING SYSTEM



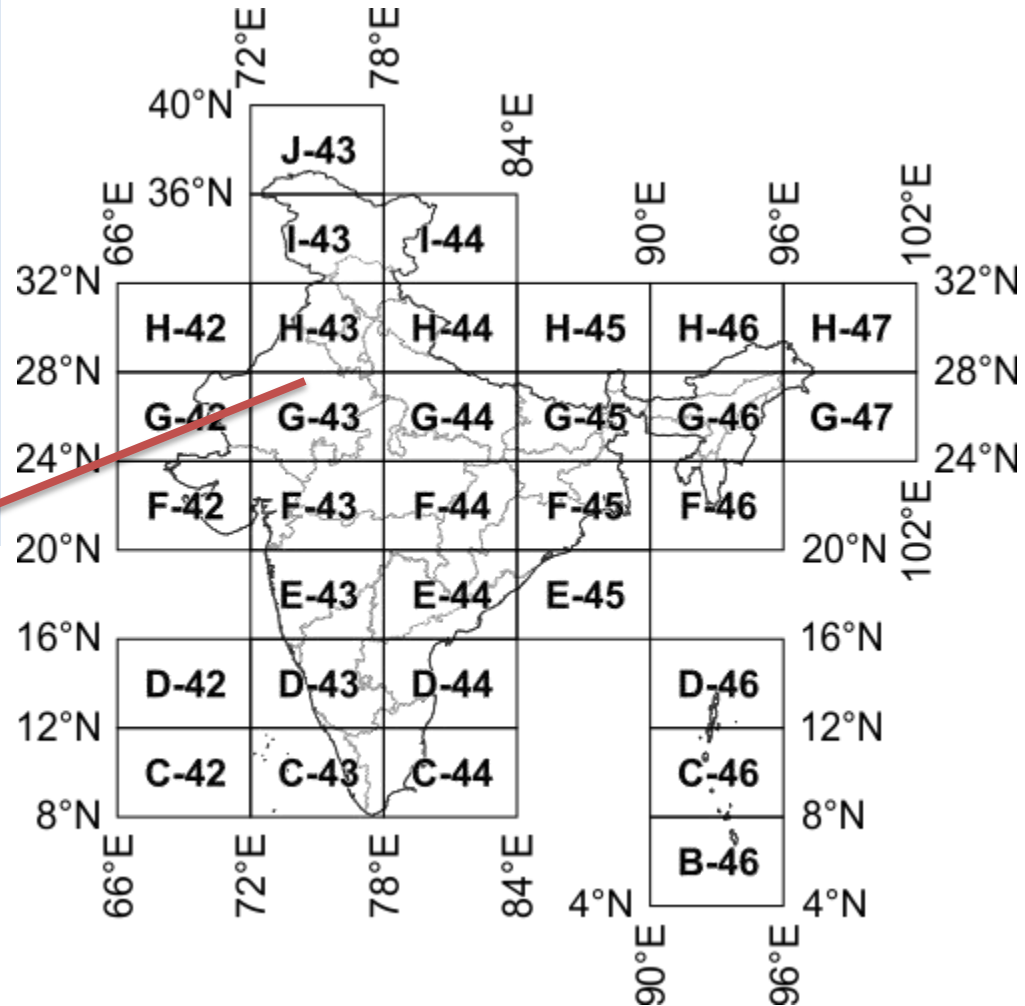
The next alphabet and number of the IMW map number denotes the  $6^\circ \times 4^\circ$  region of the IMW series. So sheet with Kalyanpur ( $77.65489^\circ\text{E}$   $24.11981^\circ\text{N}$ ) would be in '**G-43**' (from NG-43):

Since the IMW map number for India will always start with 'N' (India being in the northern hemisphere), the first letter is omitted.

Each  $6^\circ \times 4^\circ$  rectangle is further subdivided into **24 squares of  $1^\circ \times 1^\circ$** . Each square is indicated serially by an alphabet increasing first towards east and then towards south, starting with 'A'. So sheet for Kalyanpur ( $77.65489^\circ\text{E}$   $24.11981^\circ\text{N}$ ) falls within '**G-43X**':



DEGREE SHEET: G43X  
1:250,000

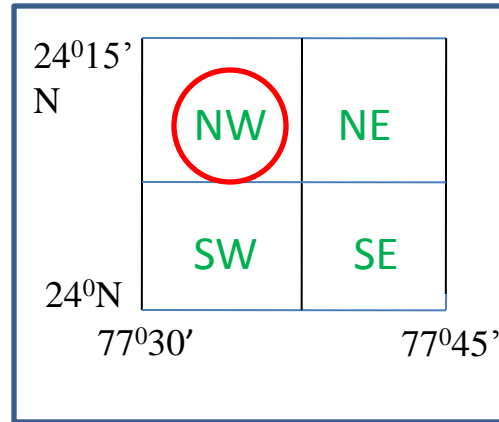


Million sheets, 1: 1000,000

Each  $1^{\circ} \times 1^{\circ}$  square is further divided into 16 squares of  $15' \times 15'$  (15 minutes  $\times$  15 minutes). Each square is indicated serially by a number increasing first towards south and then towards east, starting with '1' (similar to the system adopted in [India and Adjacent Countries](#)). So for the map sheet for Kalyanpur ( $77^{\circ}39.293'E$   $24^{\circ}7.187'N$ ) would be '**G-43X-12**':

A 15' minute sheet can be divided in *two types*:

**First**, each sheet contains 4 quadrant sheets ( $7'30'' \times 7'30''$ ) on 1:25,000 scale and designated as NW, NE, SE and SW.



Quadrant Sheet: G43X12NW  
1:25,000



15' Sheet: G43X12  
1:50,000

**Second**, each contains 25 sheets of dimension (3' X 3') on 1:10,000 scale and are designated by alphabets, A-Y.

24°15' N	A	F	K	P	U	
24°12'						
24°09'	B	G	L	Q	V	
24°06'	C	H	M	R	W	
24°03'	D	I	N	S	X	
24°N	E	J	O	T	Y	
	77°30'E	77°33'	77°36'	77°39'	77°42'	77°45'

3' Sheet: G43X12U  
1:10,000

25°N	1	5	9	13	
45'	2	6	10	14	
30'	3	7	11	15	
15'	4	8	12	16	
24°N	77°E	15'	30'	45'	78°E

	1	6	11	16	21
	2	7	12	17	22
	3	8	13	18	23
	4	9	14	19	24
	5	10	15	20	25

77°30'E      77°30'36"      77°31'12"      77°31'48"      77°32'24"      77°33'E

Each 3'-Sheet contains 25 sheets of (36" x 36") on 1:2000 scale and are designated by numerals, 1-25.

- ☐ These are the largest scale maps published by the SOI, larger than cadastral maps (1:4000).
- ☐ LS sheets

IS NOT SO PORTABLE AS TO THE P...

### 14.25. PARALLAX IN AERIAL STEREOSCOPIC VIEWS

*Parallax of a point is the displacement of the image of the point on two successive exposures.*

*The difference between the displacements of the images of two points on successive exposures is called the difference in parallax between the two points.*

In Fig. 14.51, two points *A* (lower) and *B* (higher) are being photographed by the two positions *O* and *O'* of an aerial camera. If the plane is moving at a speed of 200 km/hour and if the exposures are taken at an interval of 20 seconds, the lens centre moves a ground distance of about 1110 metres between the two exposures. Suppose that between the two exposures, the image of the lower object *A* has moved a distance 6.05 cm across the focal plane of the camera, and

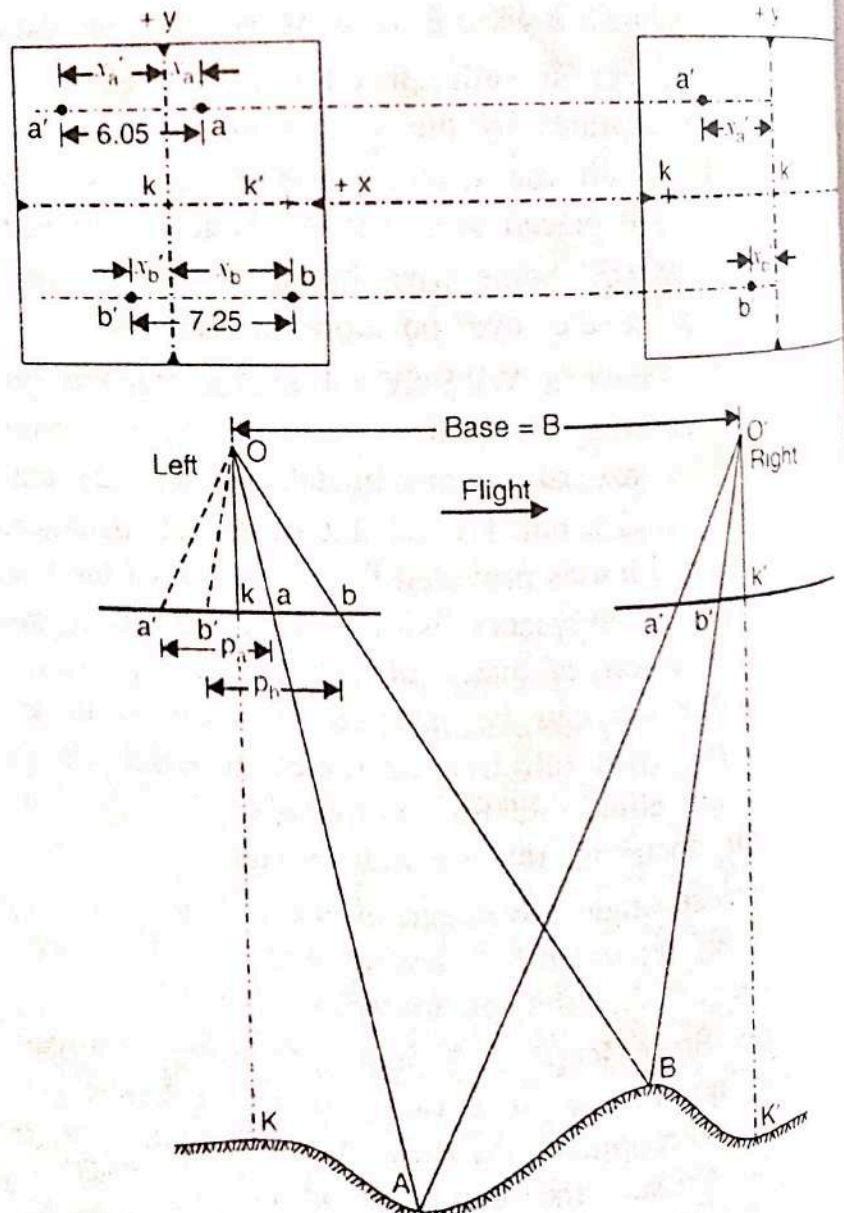


FIG. 14.51. PARALLAX.



the image of the higher object  $B$  has moved a distance of 7.25 cm. Then the parallax of the lower point is 6.05 cm and that of the higher point is 7.25 cm.

In the left photograph,  $a$  and  $b$  are the images of the two points.  $k'$  is the transferred principal point of the right photograph. Both the images  $a$  and  $b$  are to the right of the  $y$ -axis of the left photograph. In the right photograph,  $a'$  and  $b'$  are the images of the same points, both the images being to the left of the  $y$ -axis. Thus the images ( $a, b$ ) on the left photographs) is the parallax of  $A$ , and  $bb'$  is the true parallax of  $B$ . The parallax of the higher point is more than the parallax of the lower point. Thus, each image in a changing terrain elevation has a slightly different parallax from that of a neighboring image. *This point-to-point difference in parallax exhibited between points on a stereopair makes possible the viewing of the photographs stereoscopically to gain an impression of a continuous three dimensional image of a terrain.*

The following are the ideal conditions for obtaining aerial stereoscopic views of the ground surface :

- (1) two photographs are taken with sufficient overlap.
- (2) the elevation of the camera positions remains the same for the two exposures.
- (3) the camera axis is vertical so that the picture planes lie in the same horizontal plane.

**Algebraic Definition of Parallax :** As defined earlier the displacement of the image of a point on two successive exposures is called the parallax of the point. On a pair of overlapping photographs, the parallax is thus equal to the  $x$ -coordinate of the point measured on the left-hand photograph (or previous photograph) minus the  $x$ -coordinate of the point measured on the right-hand photograph (or next photograph). Thus

$$p = x - x'$$

...(14.23)

Thus,  $x$ -axis passes through the principal point and is parallel to the flight line, while the  $y$ -axis passes through the principal point and is perpendicular to the line of flight. In general, however, the flight-line  $x$ -axis is usually very close to the collimation mark  $x$ -axis, because of the effort made to eliminate drift and crab at the time of photography.

Thus, in Fig. 14.51, the parallax of points  $A$  and  $B$  are given by

$$p_a = x_a - x'_a \quad \text{and} \quad p_b = x_b - x'_b$$

In substituting the numerical values of  $x$  and  $x'$ , their proper algebraic sign must be taken into consideration. Thus, in Fig. 14.51, if  $x_a = 2.55$  cm,  $x'_a = -3.50$  cm,  $x_b = -4.05$  cm and  $x'_b = -3.20$  cm, we have

$$p_a = + 2.55 - (-3.50) = 6.05 \text{ cm}$$

$$p_b = + 4.05 - (-3.20) = 7.25 \text{ cm.}$$

### 14.26. PARALLAX EQUATIONS FOR DETERMINING ELEVATION AND GROUND CO-ORDINATES OF A POINT

Let  $A$  be a point whose ground co-ordinates and elevation are to be found by parallax measurement.



Let  $K$  be the ground position of the principal point  $k$  of the left photograph, and  $X$  and  $Y$  be the ground co-ordinates of  $A$  with respect to the ground co-ordinate axes, which are parallel to the photographic  $x$  and  $y$  co-ordinate axes, and with  $K$  as the origin.  $M$  is an imaginary point which has got the same elevation as that of  $A$ , and which lies on the ground  $X$ -axis.  $a$  and  $m$  are the images of  $A$  and  $M$  on the right photographs, and  $a'$  and  $m'$  are the corresponding images on the right photograph. Let  $(x, y)$  be the co-ordinates of  $a$  on the left photograph, and  $(x', y')$  be the co-ordinates of  $a'$  on the right photograph.

From triangles  $OKM$  and  $Okm$ , we have

$$\frac{Ok}{OK} = \frac{Om}{OM} = \frac{km}{KM}$$

$$\frac{f}{H-h} = \frac{Om}{OM} = \frac{x}{X} \quad \dots(1)$$

From triangles  $Oam$  and  $OAM$ , we have

$$\frac{Om}{OM} = \frac{am}{AM}$$

But  $\frac{Om}{OM} = \frac{f}{H-h}$  from (1) and  $\frac{am}{AM} = \frac{y}{Y}$

Hence  $\frac{am}{AM} = \frac{y}{Y} = \frac{f}{H-h}$

Similarly, from triangles  $O'K'M$  and  $O'k'm$ ,

$$\frac{O'k'}{O'K'} = \frac{O'm'}{O'M} = \frac{k'm'}{K'M} \quad \text{or} \quad \frac{f}{H-h} = \frac{x'}{X}$$

and from triangles  $O'MA$  and  $O'm'a'$ , we have

$$\frac{O'm'}{O'M} = \frac{a'm'}{AM} \quad \text{or} \quad \frac{f}{H-h} = \frac{y'}{Y}$$

From equations (2) and (4), we have  $\frac{f}{H-h} = \frac{y}{Y} = \frac{y'}{Y}$

or  $y = y'$

Equation 14.34 establishes that there is no  $y$  parallax in a stereoscopic pair of photographs

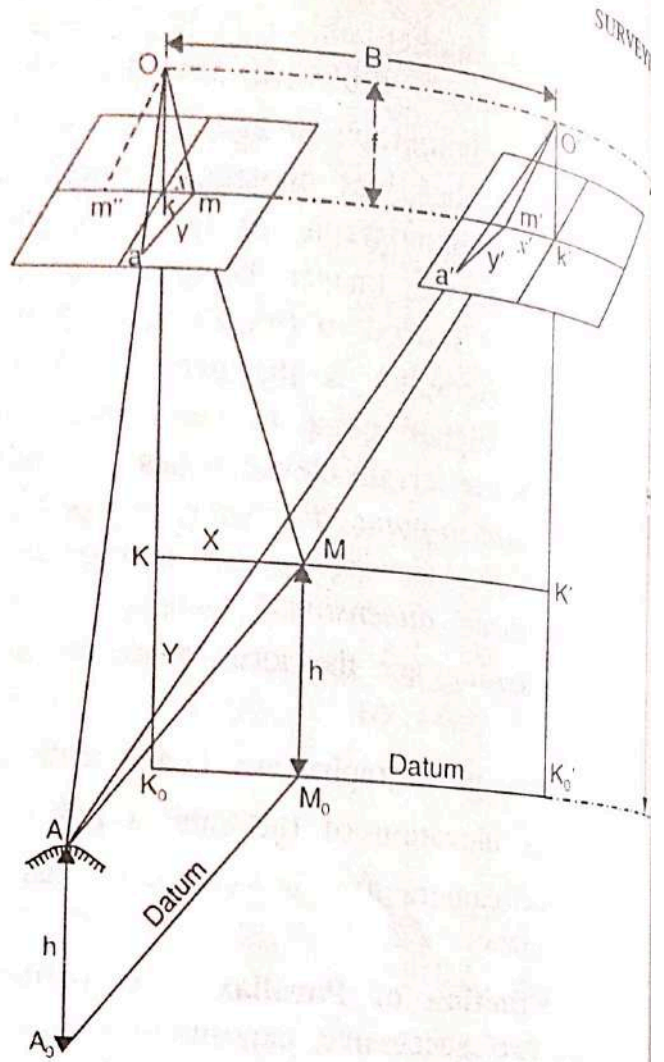


FIG 14.52. PARALLAX EQUATIONS FROM RAPALLAX MEASUREMENTS.



In the left photograph (Fig. 14.52), draw  $Om''$  parallel to  $O'm'$  of right photograph.  
 Then, in the triangles  $Om''m$  and  $OMO'$  :

$OO'$  is parallel to  $m''m$

$Om$  coincides with, and is parallel to  $OM$

$Om''$  is parallel to  $o'm'$

Hence they are similar, and their corresponding altitudes are  $f$  and  $(H - h)$  respectively.

Thus,  $\frac{f}{H - h} = \frac{mm''}{OO'}$  But  $mm'' = km + km'' = x - x' = p$  and  $OO' = B = \text{air base}$

$$\frac{f}{H - h} = \frac{p}{B} \quad \dots(5)$$

or  $H - h = \frac{Bf}{p} \quad \dots(14.35)$

This is the parallax equation for the elevation of the point.  
 Again from equations (1) and (2),

$$X = \frac{H - h}{f} x \quad \text{and} \quad Y = \frac{H - h}{f} y$$

But  $\frac{H - h}{f} = \frac{B}{p}$ , from (5)

Hence  $X = \frac{B}{p} x$  and  $Y = \frac{B}{p} y \quad \dots(14.36)$

This is the parallax equation for the ground co-ordinates of the point.

**Difference in Elevation by Stereoscopic Parallaxes**

In Fig. 14.53,  $A_1A_2$  is a flagpole being photographed from two camera positions  $O$  and  $O'$ . The top  $A_2$  of the flagpole has an elevation of  $h_2$  above the datum, and the bottom  $A_1$  has an elevation of  $h_1$  above the datum.  $H$  is the camera height for both the exposures.

In the left photographs,  $a_1$  and  $a_2$  are the two images of  $A_1$  and  $A_2$ , and their  $x$ -co-ordinates are  $x_1$  and  $x_2$  respectively.

Similarly, in the right photograph,  $a'_1$  and  $a'_2$  are the images of  $A_1$  and  $A_2$  respectively, and their  $x$ -co-ordinates are  $x'_1$  and  $x'_2$  respectively.

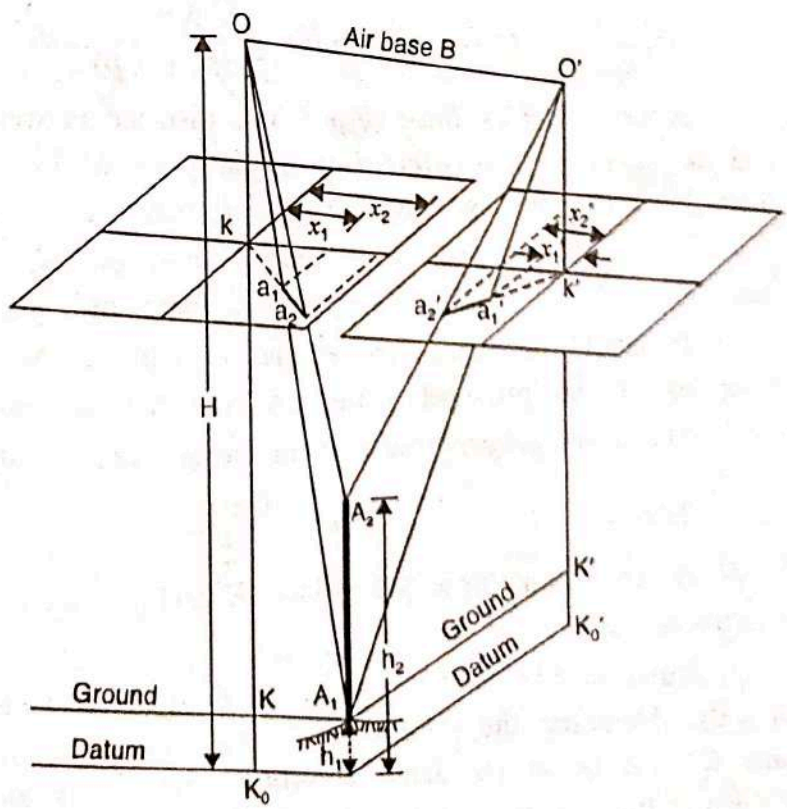


FIG. 14.53. DIFFERENCE IN ELEVATION BY STEREOGRAPHIC PARALLAXES.



Evidently, the parallax  $p_1$  for the bottom of the flagstaff is given by

$$p_1 = x_1 - x'_1$$

Similarly, the parallax  $p_2$  for the top of the flagstaff is given by

$$p_2 = x_2 - x'_2$$

Hence the difference in parallax ( $\Delta p$ ) of top and bottom points is given by

$$\Delta p = p_2 - p_1 = (x_2 - x'_2) - (x_1 - x'_1)$$

From equation 14.35, the elevation of any point is given by

$$h = H - \frac{Bf}{p}$$

Hence, for the top and bottom of flagstaff, we get

$$h_1 = H - \frac{Bf}{p_1} \quad \text{and} \quad h_2 = H - \frac{Bf}{p_2}$$

$\therefore$  Difference in elevation ( $\Delta h$ ) is given by,

$$\Delta h = h_2 - h_1 = \left( H - \frac{Bf}{p_2} \right) - \left( H - \frac{Bf}{p_1} \right) = \frac{Bf}{p_1} - \frac{Bf}{p_2}$$

or

$$\Delta h = \left( \frac{p_2 - p_1}{p_1 p_2} \right) Bf$$

or

$$\Delta h = \frac{\Delta p}{p_1 p_2} Bf$$

Now

$$\Delta p = p_2 - p_1 \quad \text{or} \quad p_2 = p_1 + \Delta p$$

Hence, we have

$$\Delta h = \frac{\Delta p}{p_1 (p_1 + \Delta p)} \cdot Bf$$

**Mean Principal Base ( $b_m$ )** : The distance between the principal point of a photograph and the position of transferred principal point of its next photograph obtained under flash through stereoscope is called *principal base*. Thus, in Fig. 14.51,

$kk' = b =$  principal base of left photograph

$k'k = b' =$  principal base of right photograph.

It should be noted that  $b$  and  $b'$  will not be equal since the elevation of ground positions of the principal points ( $K$  and  $K'$ ) are not the same.

The *mean principal base* is the mean value of the principal bases of the photographs.

Thus,

$$b_m = \frac{b + b'}{2}$$

If the ground principal points ( $K$  and  $K'$ ) have the same elevation, then under ideal conditions,  $b_m = b$ .

Now, in Fig. 14.53, let the datum pass through the bottom  $A_1$  of the flagstaff ( $h_1 = 0$ ). Assuming the ground to be now the datum plane, the ground principal points ( $K$  and  $K'$ ) will be at the same elevation, and the parallax of the principal points (*i.e.*, the principal base) will be equal to  $b$ . If  $H$  is the height of camera above the datum (*i.e.*, above  $A_1$  now), the general relationship between  $b$  and  $B$  is given by



$$\frac{B}{b} = \frac{H}{f} \quad \text{or} \quad B = \frac{Hb}{f} = s \times b \quad \dots(14.39)$$

where  $s$  is the scale of the photograph at datum elevation. Substituting this value of air base in equation 14.38, we get

$$\Delta h = \frac{\Delta p}{p_1 (p_1 + \Delta p)} \cdot Hb$$

Since  $K, K'$  and  $A_1$  are all at the same elevation, their parallaxes are the same.

Hence

$$p_1 = \text{parallax of principal points} = b$$

Hence, we get the parallax equation

$$\Delta h = \frac{H \Delta p}{b + \Delta p} = \frac{H \Delta p}{p_1 + \Delta p} \quad \dots(14.40)$$

While using equations 14.40, the following assumptions must always be kept in mind:

(1) The vertical control point (i.e., point  $A_1$ ) and the two ground principal points lie at the same elevation.

(2) The flying height ( $H$ ) is measured above the elevation of the control point and not sea level (unless the control point happens to lie at sea level).

In practical applications, the mean principal base ( $b_m$ ) is used in place of  $b$ , and flying height above the average terrain is taken as the value of  $H$ .

#### Alternative form of Parallax Equation for $\Delta h$

We have, 
$$p_1 = \frac{fB}{H - h_1} \quad \text{and} \quad p_2 = \frac{fB}{H - h_2}$$

$$\therefore \Delta p = p_2 - p_1 = fB \left( \frac{1}{H - h_2} - \frac{1}{H - h_1} \right) = fB \frac{h_2 - h_1}{(H - h_1)(H - h_2)}$$

But 
$$\Delta h = h_2 - h_1 \quad \text{and} \quad h_2 = \Delta h + h_1$$

$$\therefore \Delta p = fB \frac{\Delta h}{(H - h_1)(H - \Delta h - h_1)}$$

or 
$$\Delta p (H - h_1)^2 - \Delta p (H - h_1) \Delta h = fB \Delta h$$

or 
$$\Delta h [(H - h_1) \Delta p + fB] = (H - h_1)^2 \Delta p$$

or 
$$\Delta h = \frac{(H - h_1)^2 \Delta p}{(H - h_1) \Delta p + fB}$$

Dropping the suffix of  $h$ , we get

$$\Delta h = \frac{(H - h)^2 \Delta p}{(H - h) \Delta p + fB} \quad \dots[14.41(a)]$$

where  $h$  is the elevation of lower point above datum.

Putting  $fB = Hb$ , we get 
$$\Delta h = \frac{(H - h)^2 \Delta p}{(H - h) \Delta p + bH} \quad \dots(14.41)$$

It should be noted that the above equation is in its most general form. Eq. 14.40 is the special form of this, and can be obtained by putting  $h = 0$  (i.e., lower point at datum) in Eq. 14.41). Thus



$$\Delta h = \frac{(H - 0)^2 \Delta p}{(H - 0) \Delta p + bH} = \frac{H^2 \Delta p}{H \Delta p + bH} = \frac{H \Delta p}{\Delta p + b}$$



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Lecture – 4

# GLOBAL POSITIONING SYSTEM (GPS) INTRODUCTION

DR. JAYANTA KUMAR GHOSH  
CIVIL ENGINEERING DEPARTMENT



# CONTENTS

## 1. INTRODUCTION

## 2. GPS ARCHITECTURE

- SPACE SEGMENT
- CONTROL SEGMENT
- USER SEGMENT
  - RECEIVER
  - SOFTWARE

## 3. SUMMARY

## 4. GLOSSARY

## 5. REVIEW QUESTIONS

## 6. FURTHER READING



# INTRODUCTION

- **Acronym of NAVSTAR (Navigational Satellite for Timing and Ranging ) GPS (Global Positioning System);**
- **A space-based all weather radio navigation system;**
- **Provides precise PNT (position, navigation and time) to unlimited number of concurrent users all over the world continuously and nearly instantaneously, 24 hours a day and 365 days in a year.**





# INTRODUCTION ...

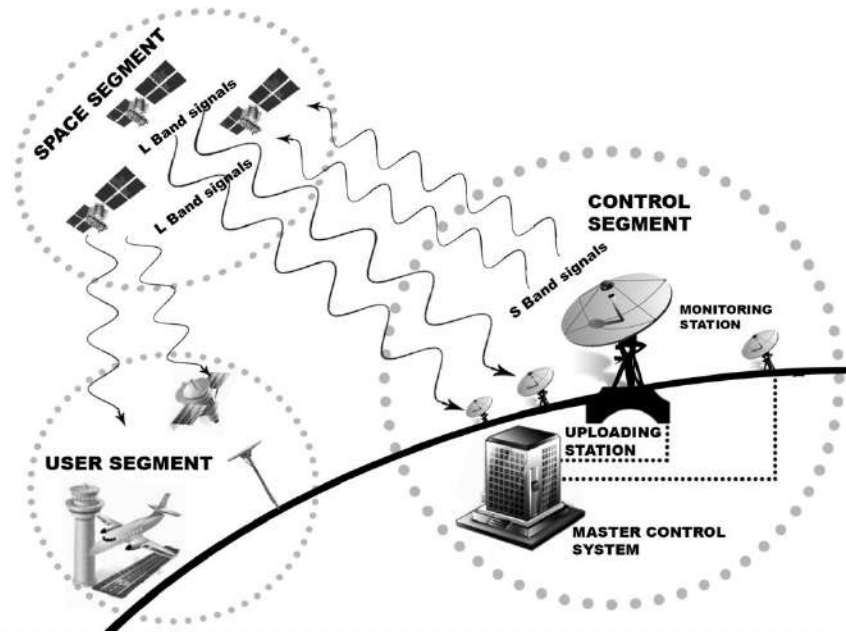
- Provides location in a three-dimensional global reference system;
- Conducts accurate surveying even in real-time.
- Much more efficient, economic, flexible and less time consuming in carrying out land surveying;
- Provides significant gains in productivity over traditional surveying methods.
- Brought a paradigm shift in the instrumentation and methods in land surveying.



# GPS Architecture

Three broad divisions: space segment (SS), control segment (CS) and user segment (US)

- SS can interface with both CS and US through one way ranging signals in radio-frequency L band signals;
- CS communicates with the SS through S band signal;
- US receives one way ranging signals only from SS.



# SPACE SEGMENT

- SS of GPS consists of pre-designed orbits around the earth and a constellation of satellites.
- Orbits and satellite constellation have been designed in such a way that a user, anywhere on earth under an open sky, does receive signals from at least four satellites at any time.

- **Orbits :**

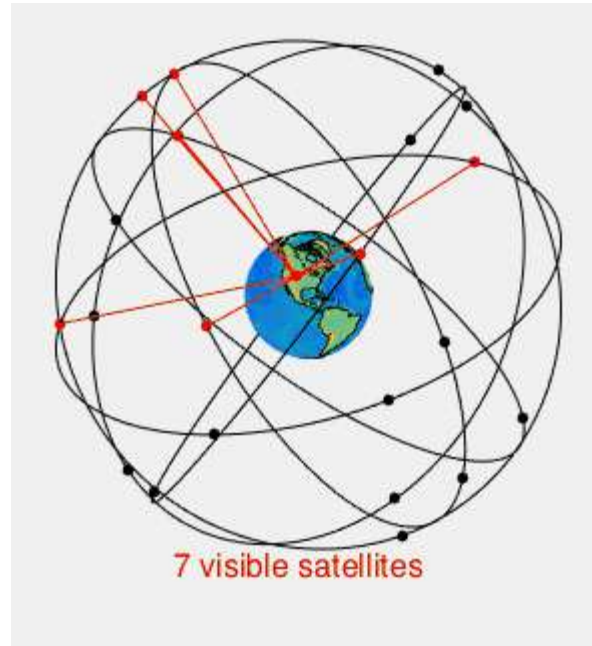
- altitude ~ 20,200 km from the surface of the earth
- nominally circular in shape
- arranged in six equally-spaced orbits surrounding the Earth.
- Orbital planes inclined at angle of 55° with equatorial plane
- Have stationary ground tracks

## Satellite Constellation

- At least four SVs in each orbit
- Orbital period is 12 sidereal hours
- Receives information from CS
- Broadcasts one way ranging signals.



# GPS SPACE SEGMENT



[<https://en.wikipedia.org/wiki/File:GPS24goldenSML.gif>]



# CONTROL SEGMENT

Comprises :

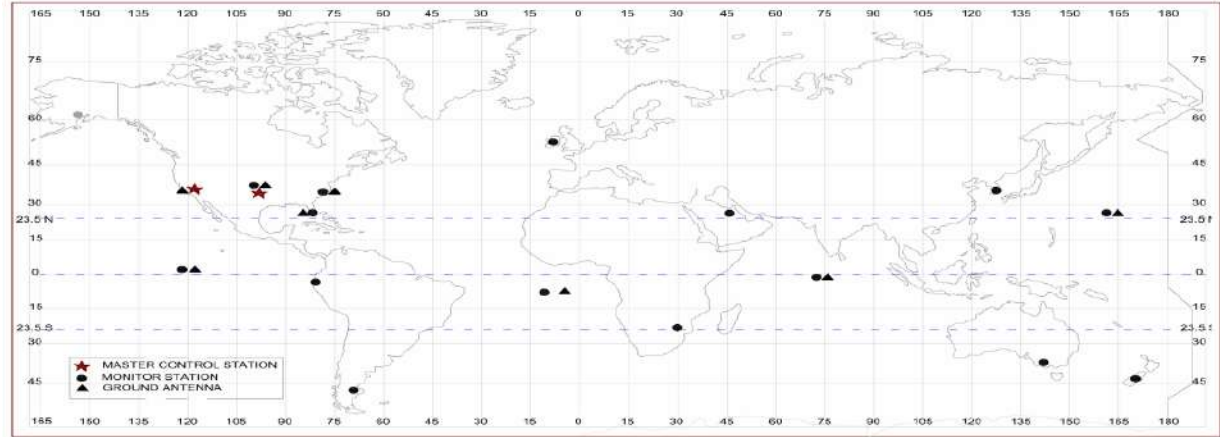
2 Master Control stations  
(MCS)

16 Monitoring stations

12 Ground Antennas

## Monitoring station

- Check position, speed, altitude and health of tracked SVs
- Collects GPS signals, navigation data, atmospheric data, gravity measurements and their variations.
- Pass collected information to MCS.



Geo-locations of Control Stations

# CONTROL SEGMENT....

## MCS

- computes space coordinates of SVs
- Evaluates health of SVs
- Generates navigation data
- Performs satellite maintenance
- Resolves satellites' performance anomalies
- Maintain optimal GPS constellation.
- Through ground antennas, MCS provides commands, keeps control and uploads navigation messages and other data to the GPS satellites.

## Ground Antennas

- collects, stores data from MCS
- CS provides commands and keeps control on satellites;
- Uploads to the GPS satellites using S band signals (2–4 GHz).



# USER SEGMENT....

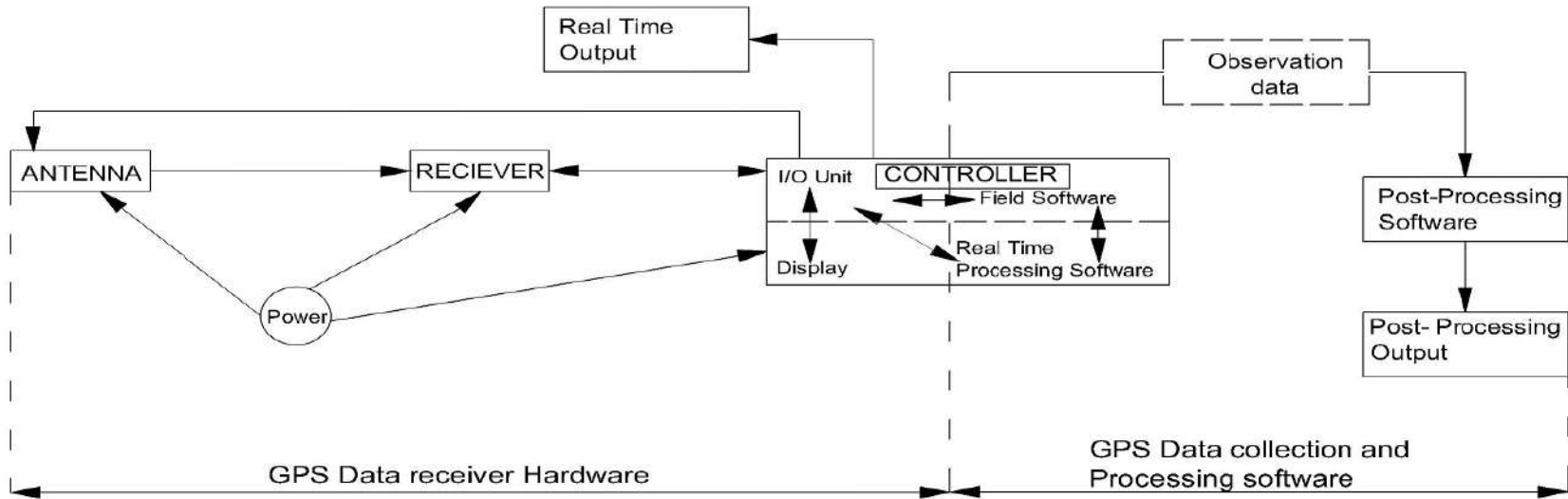
The user segment of GPS system consists of an electronic hardware, the GPS receiver and software.

- GPS receivers fundamentally consist of three basic constituents: antenna, GPS receiver and controller and a controller.
- Interconnected



# USER SEGMENT....

Software – two fundamental types: the field software including firmware; and processing software.



Different units of GPS user segment – their connectivity and functional flow diagram



# Summary of Today's Class

- **GPS surveying is efficient, economic, flexible and less time consuming.**
- **GPS is being used for establishment of control points for land surveying.**
- **GPS system consist SS, CS and US.**
- **Only US is of concern to GPS users.**
- **US comprises of GPS receiver and host of software.**
- **GPS receiver consists of antenna, receiver and controller (field computer along with I/O).**
- **Software comprises of firmware, OS, field software, Processing (Real Time & Post-processing) software and application software.**
- **Different units of a receiver work as per instructions from controller through different software.**
- **Receiver processes one way ranging L band signals from SVs and pass processed information to store or use further.**



# REVIEW QUESTIONS

1. State relevance of control points in land surveying.
2. Why GPS is being preferred for establishment of control point in digital land surveying?
3. State the full name of GPS. Why it is called so?
4. Explain the architecture of GPS system along with a line diagram.
5. State and explain the working of the salient elements of the most important segment of GPS system in the perspective of user.



## Further reading:

- A Text Book on GPS Surveying by Jayanta Kumar Ghosh, CreateSpace Independent Publishing Platform (An Amazon Company), US [[www.amazon.com/dp/1522952748](http://www.amazon.com/dp/1522952748)].
- Ghosh, J.K., Ojaswa,S and Goyal, A (2006). **Establishment of Local Control Points for Mapping using GPS**, [Geospatial World](#), October , pp
- Ghosh, J.K. and Ch. V.A. Rao, (2001). GPS Control Point Positioning. Asian GPS Conference held at New Delhi (October 29-30, 2001) pp 43-46.
- 

**Meet You Next Class on “GPS SIGNAL”**



# Thanking You



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Lecture – 05

# GPS SIGNAL (CIVILIAN PERSPECTIVE)

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# Contents

## 1. INTRODUCTION

## 2. GPS Signal

- Carrier Waves
- Ranging Codes
- NAVIGATION Data

## 3. SUMMARY

## 4. GLOSSARY

## 5. REVIEW QUESTIONS

## 6. FURTHER READING



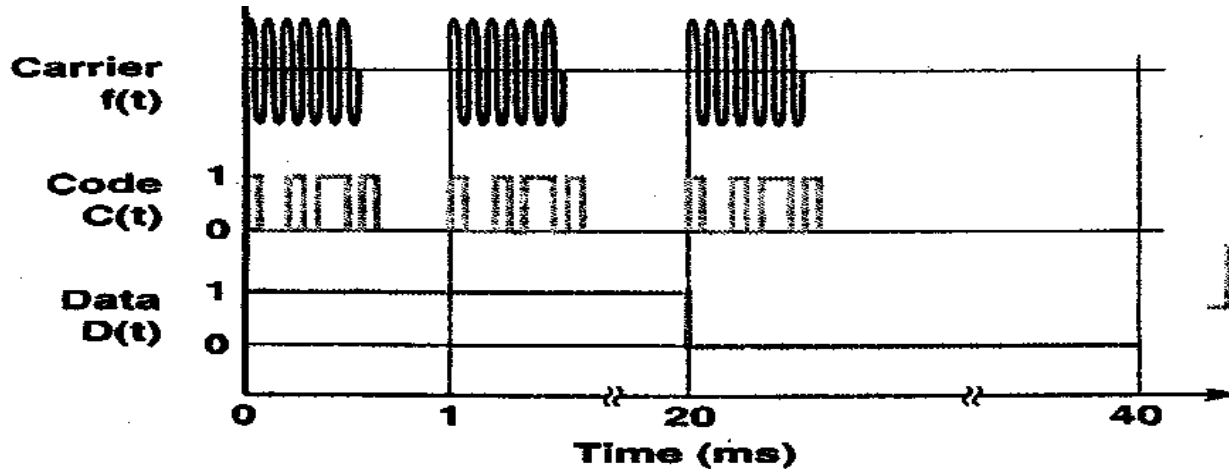
# INTRODUCTION

- User segment receives broadcast signals from GPS SVs.
- These GPS signals contain wealth of information.
- To extract necessary data and desired parameters, users need to make use of particular portion of the GPS signal
- Thus, it is important for users to know & understand the contents of a GPS signal.



# COMPONENTS OF GPS SIGNAL

GPS signals contain navigational data, code and carrier radio-waves. Data and code are put together first and then get modulated to carrier frequency.





# CARRIER WAVES

- Required for safe transmission of GPS signal from SVs to user and for precise measurement of time.
- From the beginning, SVs transmit GPS signal containing two carrier waves in radio-range: Link1 or L1 and Link2 or L2.
- IIR/IIR(M) SVs transmit an additional component with L2 carrier, for civilians, known as L2C signal.
- The block IIF SVs provide one more carrier L5 containing one full component for civil users.
- Thus, at present, three full civil signals are available from GPS constellation.



# LINK1(L1) Carrier Wave

- Frequency 1575.42 MHz or  $154f_0$  MHz;
- Contains two types of codes
  - P(Y)-code in phase and
  - C/A-code in quadrature phase.
- Both the codes are modulated to navigation data through modulo-2 addition.
- The peak power spectral density of the C/A signal exceeds that of the P code L1 signal.



# LINK2(L2C) Carrier Wave

- L2C Civil Signal
- Frequency 1227.60 MHz or  $120f_0$  MHz carrier
- Has higher effective power than L1 C/A signal and thus, available more under trees.
- Can be acquired faster with higher reliability and has greater operating range.
- L2C signal alone provides 65% more uncertainty in position than that of L1 C/A signal alone.
- Availability of two civilian signals help in directly measure, and subsequently to remove ionospheric error.



# LINK5(L5) Carrier frequency

- Frequency -  $115f_0$  or 1176.45 MHz carrier
- contents depend on the SVs from which it is being transmitted.
- In phase modulated with I5-code, NAV data and synchronization sequence.
- Quadrature phase - modulation of Q5-code with different synchronization sequence.
- Higher transmission power than L1 C/A or L2C signal, wider bandwidth, longer spreading codes etc.
- L5 is the most advanced of the three Civilian GPS signals.



# CIVIL SIGNALS

- In combination with L1 C/A and L2C, L5 provides a highly robust service for civilian users.
- Each of the three civil GPS signals has one or more key advantages.
  - L1 C/A has the lowest ionospheric error
  - L2C has the best cross-correlation performance and
  - L5 has the highest power and lies in ARNS (Aeronautical Radio Navigation Service) band.

Thus, each signal will be prevalent in its domain of strength.





# RANGING CODES

- Provide identification of received signals and transmission time.
- **GPS signal contains**
  - Precision [P/P(Y) (for unauthorized user)] code as the principal navigation
    - **Coarse-Acquisition (C/A) PRN Code for acquisition of the precision code.**
  - L2 Civil-Moderate (L2 CM) code
  - **L2 Civil-Long (L2 CL) code**
  - I5 and Q5 codes (with L5)



# Precision (P)-code

- Precision (P)-code is the principal code of a GPS signal modulated to both L1 and L2 carriers.
- It has chipping rate 10.23 MHz ( $f_0$ ) and of chip length 29.3 meter.
- Period : 7 days and unique to each satellite.
- Satellite gets identified by its PRN week number.
- In order to restrict its accessibility to authorized users, P code gets encrypted with W code, a secret code of 20 bps, by modulo-2 addition. This results in a code is termed as P(Y) code.
- It is primarily deployed to obtain precise position by US military and its allies.



# Coarse-Acquisition (C/A) Code

- Chipping rate: 1.023 MHz (1023 Mbits)
- Chip length : 293m
- Period : 1 msec
- Each satellite transmits a different set of C/A-code.



# Civil Codes

## L2 CM & L2CL

- With L2 carrier in phase quadrature
- Chipping rate : 511.5 KHz ( $f_0/20$ )

## L2CM

- Consists of a stream of 10230 chips
- Period: 20 milliseconds.
- Modulated to CNAV data.
- Provides PNT accuracy equivalent to that provided by the P-code for civil users.

## L2CL

- Consists of a stream of 767250 chips
- Period: 1.5 seconds.
- No navigation data gets modulated with it.



# I5 and Q5 Codes

## I5 & Q5

- Available in L5 carrier of GPS signal
- Chipping rate of 10.23 MHz ( $f_0$ )
- Period : 1 millisec
- Contains PRN code sequence of 10,230 chips.

## I5 (In-phase)

- Contains modulated PRN codes with 10-bit Neuman-Hoffman code having chip rate of 1 kHz and NAV data

## Q5 (In Quadrature phase)

- contains only modulated PRN codes with 20-bit Neuman-Hoffman code at 1 kHz.

Short synchronized Neuman Hoffman codes are provided for better spectral separation, bit synchronization and protection from narrowband interference.





# NAVIGATIONAL DATA

- GPS signal contain downlink system data, popularly known as navigational message or NAV data.
- C/A and P (or P(Y)) codes are modulated to legacy navigation (LNAV) data,  $D(t)$ ;
- L2 CM codes are modulated to civil navigation (CNAV) data,  $DC(t)$ ;
- L5 IS codes modulated to CNAV data of  $D5(t)$  variety.
- navigation messages broadly contain SV ephemeris data, SV clock correction parameters, SV health data, information for authorized users, epoch of observation, time, user range accuracy index, signal delay information, atmospheric correction terms, UTC conversion parameter values etc.



# Summary of Today's Class

- GPS users makes use of GPS signal broadcast by SVs.
- GPS signal contains navigational data, PRN codes and carrier radio-waves.
- GPS signal may contain three types of carrier waves- L1, L2 & L5; 5 different civil PRN codes (C/A, CM, CL, I5, Q5) and different navigational messages [Legacy navigation (LNAV) data with C/A , Civil Navigation (CNAV) data, DC(t) with CM and D5(t) with I5].
- At present, three full civil signals are available from GPS constellation - L1 [C/A], L2C [CL or CM or C/A] and L5 [I5 & Q5].
- Combinations of L1 C/A, L2C and L5 provide a robust civilian service.
- Individually, L1 C/A has the lowest ionospheric error; L2C has the best cross-correlation performance and L5 has the highest power and lies in ARNS.



# Review Questions

1. How information about GPS signal will be helpful for GPS surveying.
2. Explain in detail the contents of GPS signal.
3. State functions of different components of a GPS signal.
4. Write a brief note on navigation data. How navigation data is useful for GPS surveying?
5. State and explain about the different types of codes available in GPS signal along with their relevance for GPS positioning.
6. State and explain about the different types of frequencies available in GPS signal along with their specific utility in GPS surveying.



## Further reading:

- A Text Book on GPS Surveying by Jayanta Kumar Ghosh, CreateSpace Independent Publishing Platform (An Amazon Company), US [[www.amazon.com/dp/1522952748](http://www.amazon.com/dp/1522952748)].

Meet You Next Class on “GPS – USER SEGMENT”



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Lesson - 09

# GPS POSITION

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# CONTENTS

1. INTRODUCTION
2. GPS Position
3. Conversion Geodetic to Cartesian
4. Salient Surfaces
5. Heights
6. Height transformation
7. Conversion Global to Local
8. SUMMARY
9. REVIEW QUESTIONS
10. FURTHER READING



# INTRODUCTION

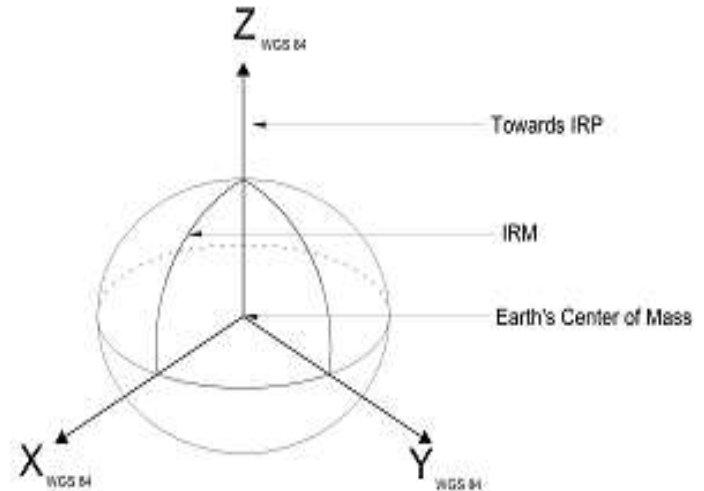
- **GPS Observations provides location of point in a global reference system.**
- **to understand GPS positioning, it is required to know the different types of surfaces, heights.**
- **engineering works get accomplished in local reference system.**
- **to derive location in local reference, it is required to know the different types of conversions.**



# GPS Position

## Cartesian coordinates (X,Y,Z);

- **Origin** : Centre of mass of the Earth including oceans and atmosphere.
- **Z-Axis** : The direction of IERS Reference Pole (IRP) – IRP directed towards CTP (Conventional Terrestrial Pole) as defined by BIH (the Bureau International de l'Heure) with an uncertainty of 0.005".
- **X-axis** : Intersection of IERS Reference Meridian (IRM) and the plane passing through the and normal to the Z-axis. (IRM coincides with BIH zero meridian (epoch 1984.0) with an uncertainty of 0.005").
- **Y-axis** : A right-handed, Earth Centered Earth Fixed (ECEF) orthogonal coordinate system, measured in the plane of the CTP Equator.



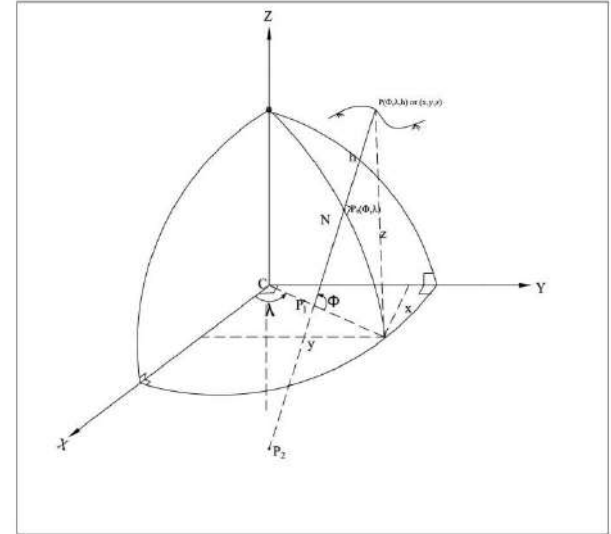
# WGS 84....

## Reference Ellipsoid

A geocentric ellipsoid of revolution with center of mass of the earth as origin and the Z-axis of the WGS 84 Coordinate System as the rotational minor axis having semi-major axis ( $a$ ) : 6378137.0 m and reciprocal of flattening,  $1/f$  : 298.257223563.

## Geodetic Coordinates ( $\phi$ , $\lambda$ , $h$ )

**Geodetic latitude ( $\phi$ )** of any location on the surface of the earth is the angle measured between the plane of the WGS84 ellipsoidal equator and the normal to the ellipsoid which extends to the earth's location above the WGS84 ellipsoid. **Geodetic longitude ( $\lambda$ )** of any location on the surface of the earth is measured in the plane of the WGS84 ellipsoidal equator between the IRM (International Reference Meridian) and the meridian passing through the position. **Geodetic height ( $h$ )** is the distance of the point along normal from the WGS84 ellipsoid.



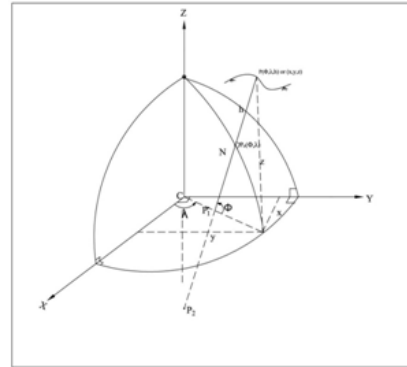


# Conversion : Geodetic TO Cartesian

The Cartesian coordinates  $(x, y, z)$  can be obtained from its (in the same coordinate system) geodetic coordinates  $(\varphi, \lambda, h)$ , using the relation:

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} (R + h) \cos \varphi \cos \lambda \\ (R + h) \cos \varphi \sin \lambda \\ \left( R \frac{b^2}{a^2} + h \right) \sin \varphi \end{bmatrix}$$

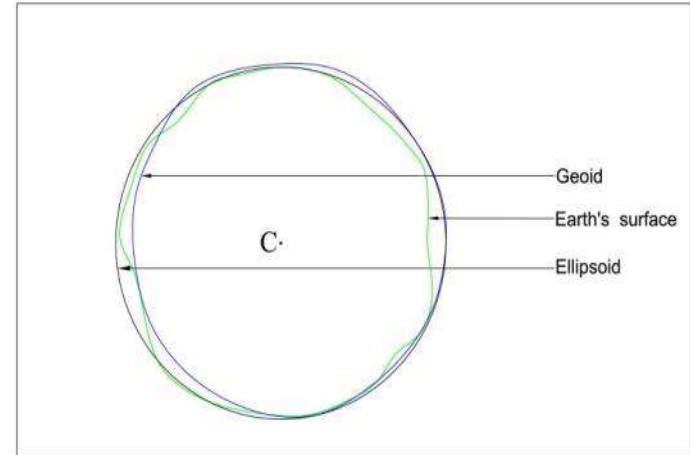
where  $R$  is the radius of curvature of the prime vertical at  $P_0$  passing through  $P$  and can be obtained from  $R = \frac{a^2}{(a^2 \cos^2 \varphi + b^2 \sin^2 \varphi)^{1/2}}$



# SALIENT SURFACES

Three types

- (i) actual surface of the earth
- (ii) geoid, a geo-equipotential surface that best approximates the mean sea level around the earth
- (iii) Ellipsoid, a geometrical figure of the earth that is defined by an ellipse revolved about its minor axis



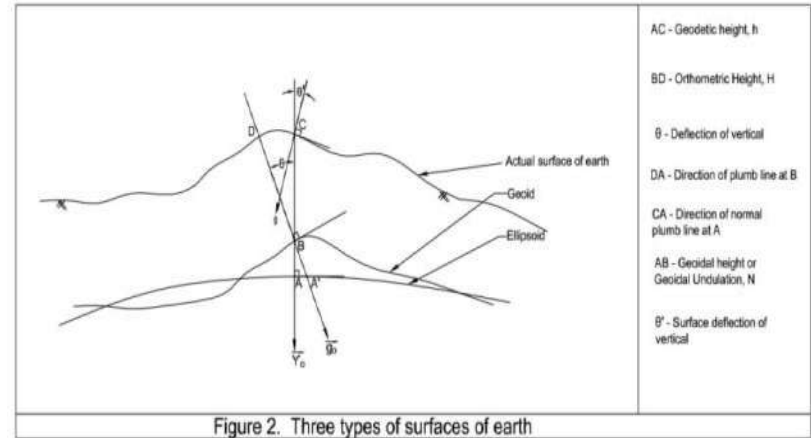
# HEIGHTS

- Ellipsoid height : height of a point on the surface of the earth with reference to an ellipsoid surface as datum.
- Orthometric Height (H): height of a point on the surface of the earth with earth's geoid surface as datum.
- Geoid height (N): The separation between a reference ellipsoid (WGS 84 for GPS) and earth's geoid is called the geoid height or geoidal undulation i.e., the height of the geoid above the ellipsoid,  $N$ , is called the geoid undulation.
- EGM2008
- Online computation can be carried out using the URL (<http://geographiclib.sourceforge.net/cgi-bin/GeoidEval>)

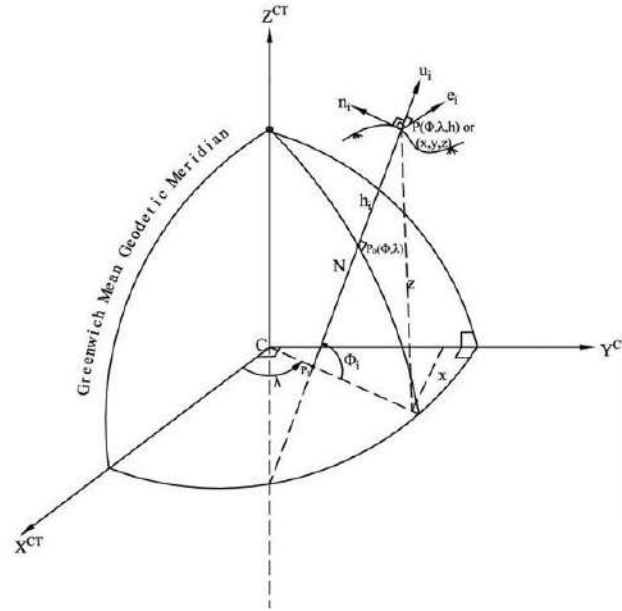


# HEIGHT TRANSFORMATION

- Depending on the position of the geoid and ellipsoid surfaces, the relation between orthometric height ( $H$ ) and its geodetic height ( $h$ ) is given by  $H=h \pm N$



# GLOBAL TO LOCAL (N,E,H)



$$[L_q] = [L_p] + \begin{bmatrix} -\sin\phi_n \cos\lambda_p & -\sin\phi_n \sin\lambda_p & \cos\phi_n \\ \sin\lambda_p & \cos\lambda_p & 0 \\ \cos\phi_p \cos\lambda_p & \cos\phi_p \sin\lambda_p & \sin\phi_p \end{bmatrix} \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix}$$



# Summary of Today's Lesson

GPS provides positions in WGS84 Cartesian coordinates (X, Y, Z) as well as Geodetic Coordinates ( $\varphi$ ,  $\lambda$ , h).

**Three prominent surfaces of the Earth are the actual surface of the earth, the geoid and an ellipsoid.**

**Three types of heights: Ellipsoids, Orthometric & Geoid height.**

**Orthometric height i.e., height above geoid is the important for engineering works.**

**Civil engineering works primarily makes use of Local coordinates in North, East and Vertical height system.**



# REVIEW QUESTIONS

1. How GPS provides the position of a point/ station. Explain through labeled figures?
2. How geodetic coordinates of any point/ station may be converted to its Cartesian coordinates?
3. Name and explain the different surfaces of the earth along with a diagram.
4. Define the following terms along with their significance in surveying: ellipsoidal height, Orthometric height and Geoid height.
5. How do we define the local coordinates of a point? Explain how local coordinate of a point may be obtained.



## Further reading:

- A Text Book on GPS Surveying by Jayanta Kumar Ghosh, CreateSpace Independent Publishing Platform (An Amazon Company), US [[www.amazon.com/dp/1522952748](http://www.amazon.com/dp/1522952748)].
- Ghosh, J.K., Ojaswa,S and Goyal, A (2006). GPS Based Control Points for Mapping, Coordinates, October , pp 24-27.

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LESSON-10

# PRINCIPLE OF GPS POSITIONING & GPS OBSERVABLES

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CIVIL ENGINEERING DEPARTMENT





# CONTENTS

**1. INTRODUCTION**

**2. PRINCIPLE OF POSITIONING**

**3. GPS OBSERVABLES**

**4. QUALITY OF GPS OBSERVABLES**

**3. SUMMARY**

**4. REVIEW QUESTIONS**

**5. FURTHER READING**



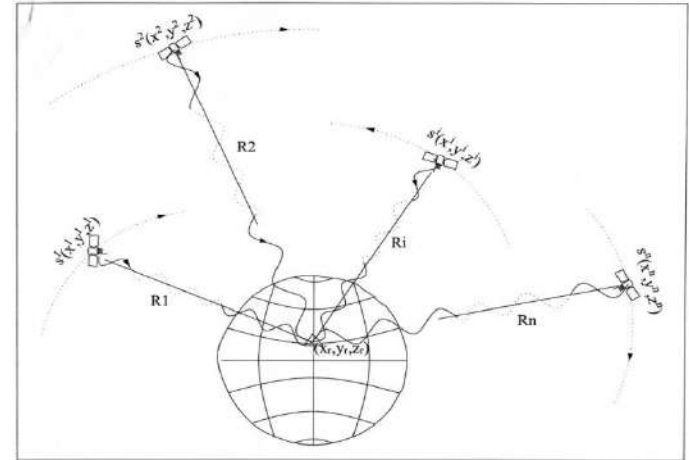
# INTRODUCTION

- **GPS surveying is being carried out to determine the position of points using signals received from GPS SVs.**
- **Unknown positions are determined the principle of Analytical RESECTION**



# PRINCIPLE OF GPS POSITIONING

- Unknown position determined from known distances of three pre well-defined positions.
- Three known positions and their three known distances from the unknown position (represented by three unknown coordinates) provide three distance equations. Solution of these three equations provides location of unknown position.
- In GPS, satellites positions and their ranges (distances of the satellites from the receiver) are available in their respective signals.
- From these data, unknown position of the receiver get computed applying the method of resection.
- Clock synchronization error is considered as fourth unknown thus need signal from at least four satellites.



# GPS Observables

- **Two types : code pseudo-range and phase observables;**
- **Either or both are used for GPS positioning.**
- **Code pseudo-ranges for autonomous and less precise/accurate positioning**
- **Phase observables for more precise/accurate positioning.**
- **Phase positioning makes use of code position as the basis for its precise positioning.**
- **GPS observables biased with errors.**



# GPS Observables...

## CODE PSEUDO-RANGE

- Computed by multiplying the time of transmission of GPS code signal (from the SV to user receiver) with its velocity of propagation.
- Ranges based on these measurements do not represent the true ranges of SVs but their pseudo-ranges.
- $PR_1 = TR_1 + c.t_r + E$   
where,  $PR_1$  represents code pseudo-range between a satellite and a receiver;  $TR_1$  represents true/geometric-range within between the satellite and the receiver;  $c.t_r$  is receiver clock error;  $e$  is the error in pseudo-range observable.





# GPS Observables...

## CARRIER PHASE OBSERVABLE

- The carrier phase of a GPS signal at the epoch of its emission from SV differs from its phase at the epoch of its reception by user receiver.
- **Difference in phase of a GPS signal at the epoch of its emission from SV from its phase at the epoch of its reception by user receiver.**
- Includes integer number of cycles of the carrier frequency between these epochs
- **During GPS observation, receiver measures fractional part of phase difference.**
- Receiver also keeps count of the number of cycles that have been arrived from the satellite since its first epoch of measurement.
- **Number of full cycles that the signal travelled between the SV and receiver before the first epoch of measurement remains unknown and known as integer ambiguity.**
- Integer ambiguity remains associated with all the measurements
- **Carrier phase observables are associated with errors ( $E$ , in terms of phase angle).**
- Error associated with carrier phase observables is different from that associated with pseudo-range.
- **Carrier phase observables of different carrier frequencies i.e., of the L1, L2 and L5 will be different.**



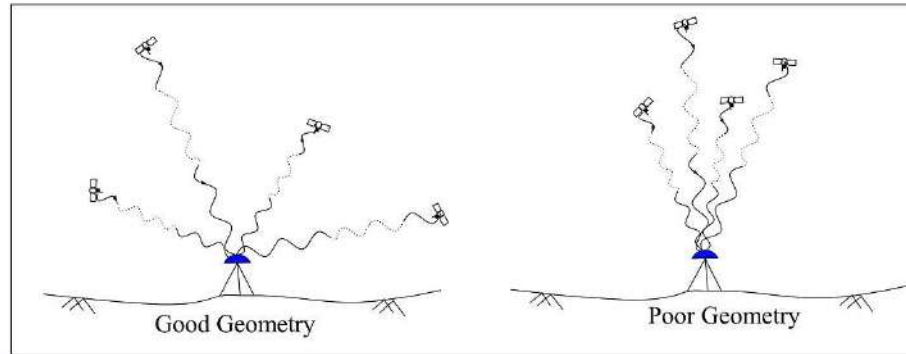
# QUALITY OF GPS OBSERVABLES

- **Quality of the observables also depends on the amount of errors associated with them.**
- **Errors associated with GPS observables are analyzed in terms of their effect on the range determination.**
- **Quantities like Dilution of precision (DOP), User range accuracy (URA), user range error (URE) helps to define/designate quality of GPS observables.**



# QUALITY OF GPS OBSERVABLES: SATELLITE GEOMETRY

- Quality of GPS observables also depends on the satellites-receiver geometry at the epoch of its observation.
- Good geometry if these are spatially well distributed in the sky considering zenith point of the receiver as the centre for distribution.
- Poor geometry if SVs are in clustered form
- Good geometry provides better quality observables and poor of degenerated quality.
- Geometry quantified through dilution of precision (DOP).
- DOP values defines the quality of the GPS observables.
- Lower the DOP value, better is the quality of observables.
- Guiding DOP values depend on the type of surveying.



# QUALITY OF GPS OBSERVABLES: URA

## USER RANGE ACCURACY (URA)

- URA of any particular GPS signal is being specified in its navigation message.
- In word three, bits 13 through 16 provide the URA index of the SV.
- URA value is a conservative estimate of RMS error for estimation of accuracy in pseudorange measurements.



# QUALITY OF GPS OBSERVABLES: URE

## User Range Error (URE)

- Error budget present in measurement of range between a user's receiver and the observation satellite is known as user range error (URE).
- URE is being computed by taking square root of the sum of the squares of the individual errors.





# Summary of Today's Class

1. Analytical Resection is the PRINCIPLE for GPS positioning.
2. Ranges of the satellites get obtained from GPS observables
3. GPS observables are of Two types : code pseudo-range and phase observables.
4. Code pseudo-range is obtained multiplying the time of transmission of GPS code signal (from the SV to user receiver) with its velocity of propagation.
5. Difference in phase of a GPS signal at the epoch of its emission from SV from its phase at the epoch of its reception by user receiver. Includes integer number of cycles of the carrier frequency between these epochs.
6. Number of full cycles that the signal travelled between the SV and receiver before the first epoch of measurement remains unknown and known as integer ambiguity.
7. Observables contain errors. Thus, observables are pseudo-ranges. 7. Quality of the observables also depends on the amount of errors associated with them.
8. Quantities like Dilution of precision (DOP), User range accuracy (URA), user range error (URE) helps to define/designate quality of GPS observables.
9. Lower the DOP value, better is the quality of observables.



# REVIEW QUESTIONS

1. State and explain the basic principle of GPS positioning.
2. Explain why we need observations from at least four satellites for GPS positioning.
3. What is GPS observables? How many types of GPS observables are there? State primary uses of GPS observables.
4. Write notes on : (i) Code observable; (ii) Phase observable; (iii) Integer Ambiguity; (iv) Satellite Geometry.
5. How nature of Code observable differs from Phase observable.
6. State and explain some quantities which define the quality of GPS observables.



## Further reading:

- A Text Book on GPS Surveying by Jayanta Kumar Ghosh, CreateSpace Independent Publishing Platform (An Amazon Company), US [[www.amazon.com/dp/1522952748](http://www.amazon.com/dp/1522952748)].

Meet You Next Class on  
“ERRORS IN GPS OBSERVABLES”



# Creating Maps in ArcMap: A Quick Guide

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## Overview

Making maps in ArcMap is very easy: **Browse geospatial data** in ArcMap and **choose an appropriate presentation**. This workshop will guide you through all necessary steps in the following table.

No.	Steps	Sections to check	Difficulties
1	Load geospatial data and basemap into ArcMap	1.1	Data formats and folder connection
2	Identify the features and attributes to present	1.3	Layer order, feature selection, and (briefly) frequent-used projections
3	Define how to show the data	2.2	Transparency (raster and vector), data classification, and layer file
4	Add maps components	2.3	Geospatial data references
5	Export maps	2.4	Resolution and file formats

## Table of Contents

- 1. Browse Geospatial Data ..... 2
  - 1.1. Load Data ..... 2
  - 1.2. Add Basemap..... 5
  - 1.3. Browse the Data ..... 7
- 2. Mapping..... 8
  - 2.1. Distinction between Geospatial Data and Map Components..... 9
  - 2.2. Key Options of Geospatial Data Representations ..... 10
  - 2.3. Map Components ..... 19
  - 2.4. Map Printing (Exporting) Options..... 23

## 1.1 Load data

# 1. Browse Geospatial Data

## 1.1. Load data

To launch ArcMap, please click: **Start -> All Programs -> ArcGIS -> ArcMap 10**. By default, a start-up splash window will appear once ArcMap has loaded (Figure 1).

Click **OK** to proceed. You can ignore all other options. They are redundant.

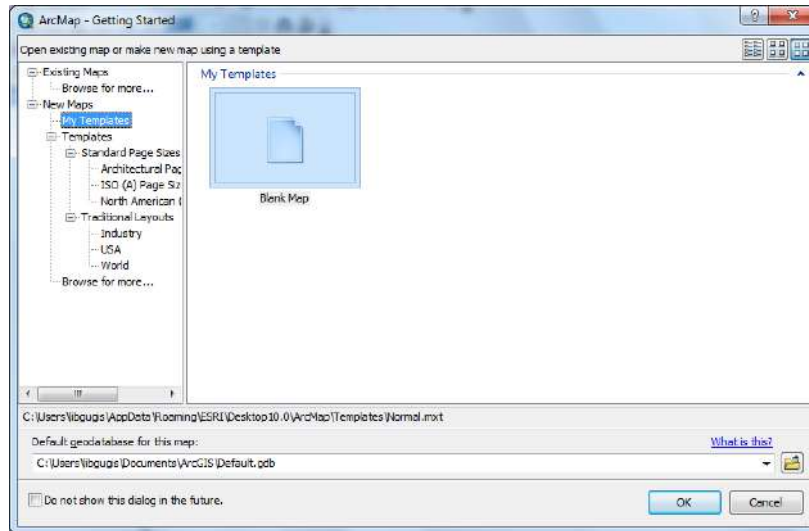



Figure 1. The start-up splash window of ArcMap

There are two ways to add data: Click the **Add Data**  button (Figure 2), which opens a window similar to Figure.

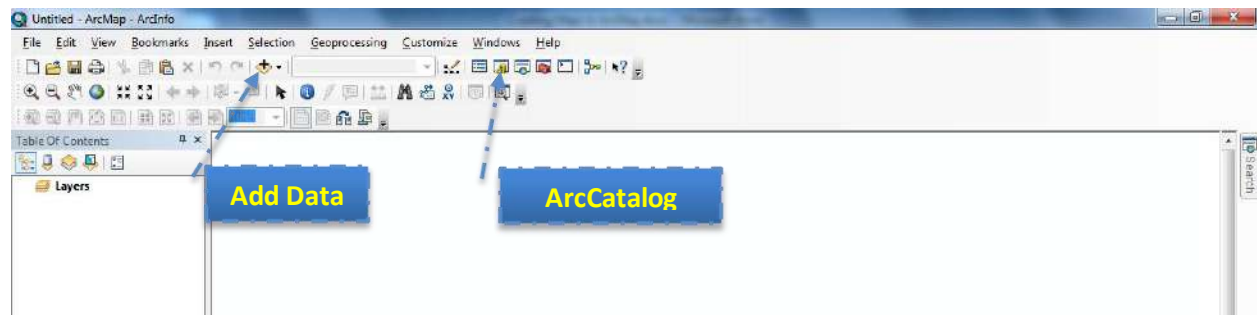


Figure 2. Main Windows with Marks on Add Data and ArcCatalog



## 1.1 Load data

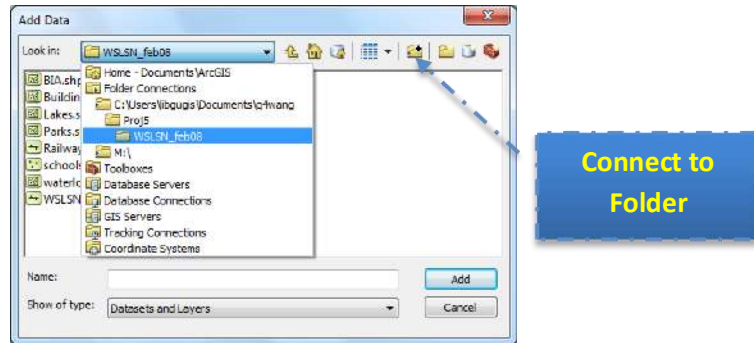



Figure 3. The Pop-up Window of "Add Data"

To browse to the file you want to play with, you can link to the folder containing all these files by clicking the **Connect to Folder**  button in Figure 3, then browse to add the folder that contains your files and click **OK**. After that, you can locate the files listed below and add them in at one time by holding the **Ctrl** or **Shift** button when you are clicking mouse button to make selections. Please click the **Add** button just like any other file explorer dialogs in Windows to close the dialog.

- **Public\_schools.shp**: All public school locations in the City of Waterloo;
- **waterloo\_city.shp**: The administrative boundary of the City of Waterloo;
- **waterloo\_streets.shp**: Street network in the City of Waterloo;

When data is loaded, all files will be listed in the left pane (table of contents) in Figure 4. The geographic features (contents) are displayed in the right pane. And most controls can be found on the top pane (or by right-clicking on the object you are working at and checking the pop-up window).

## 1.1 Load data



### **Frequently-used File Formats in ArcGIS:**

- **Feature Data:** Feature data are usually organized as points, lines, and polygons in vector format.
  - **Shapefile:** The most commonly used geospatial data format. Although it appears to be one file in ArcMap, shapefile includes **multiple files** with the same file name, but different extensions. \*.shp, \*.dbf, and \*.shx are must-have.
  - **Personal Geodatabase:** These files are based on Microsoft Access (\*.mdb). From user perspective, all kinds of geodatabase are the same, which include multiple layers (different geospatial data) in one geodatabase.
  - **File Geodatabase:** File geodatabase is a folder that contains geospatial data, which is newly introduced to ArcGIS. In ArcMap, file geodatabase is shown as a file rather than a folder. This might be the reason why ESRI adds “connect to folder” in ArcMap 10. Hence, when you navigate to the file you want to open but are unable to do so, ALWAYS check if you should go one level upper to link to the folder first. You can open the file in the next step.
  - **Further Reading:**
    - [http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Types\\_of\\_geodatabases/003n00000007000000/](http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/Types_of_geodatabases/003n00000007000000/)
    - [http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/About\\_geographic\\_data\\_formats/00r90000006r000000/](http://help.arcgis.com/en/arcgisdesktop/10.0/help/index.html#/About_geographic_data_formats/00r90000006r000000/)
- **Raster Data:** Raster data uses grid to represent a region with values as a “field”. Images explicitly have the parameter of resolution. Typical raster data is:
  - **GeoTIFF:** They have the file extension of \*.tif. The key difference between normal TIFF file and GeoTIFF is that GeoTIFF has projection information. Hence, normal TIFF files cannot be correctly added to the desired location.
  - **GeoJPEG:** Similar to GeoTIFF, but they have \*.jpg extension.
  - **Usage:** Raster data can be air photos, satellite images, elevation data (DEM). But raster data tends to be huge and slow to load.
- **External Data:** ESRI also supports some file formats produced by other vendors due to their popularity. Typical ones are:
  - **AutoCAD:** \*.dwg files can be added, imported and converted into ArcMap.
  - **Google Earth:** \*.kml files are supported by ArcGIS as well. However, conversion from KML into Shapefile is required, which can be done using ArcToolbox or some online services.
  - **Further Reading:** Wikipedia on GIS File Formats  
[http://en.wikipedia.org/wiki/GIS\\_file\\_formats](http://en.wikipedia.org/wiki/GIS_file_formats)

## 1.1 Load data

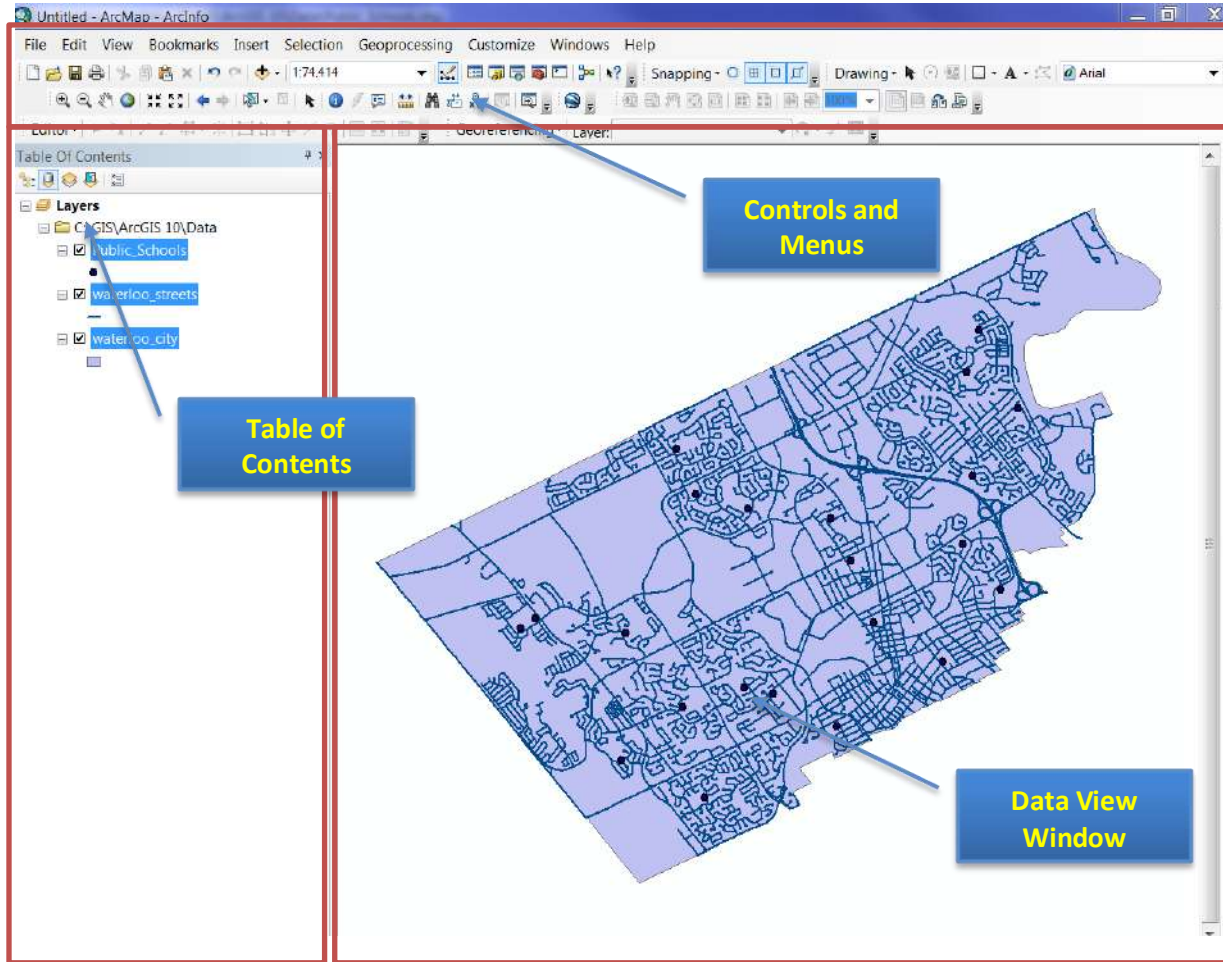


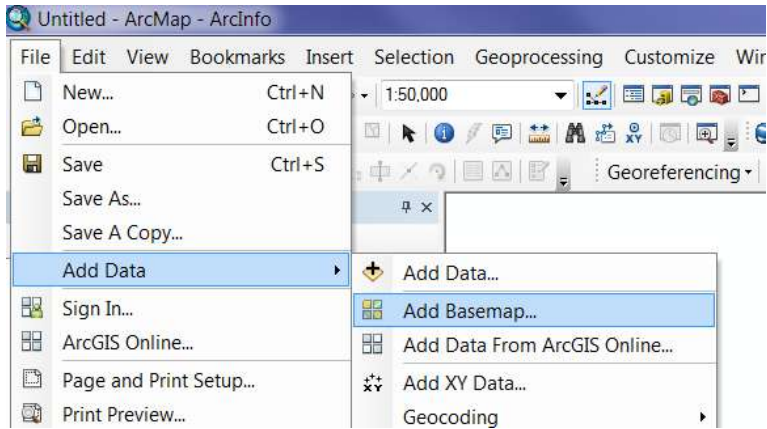
Figure 4. Structure of the Main Window

## 1.2 Add a ESRI Basemap

When users want to overlay a basemap and city boundary (**waterloo\_city.shp**) together to produce a map like Google map View (i.e. <http://maps.google.ca/maps?q=waterloo,+ontario&hl=en&ll=43.48257,-80.533905&spn=0.134519,0.219727&sll=43.470394,-80.538411&sspn=0.016818,0.027466&hnear=Waterloo,+Waterloo+Regional+Municipality,+Ontario&t=m&z=12>), they can add a basemap directly from Esri Basemap (Internet).

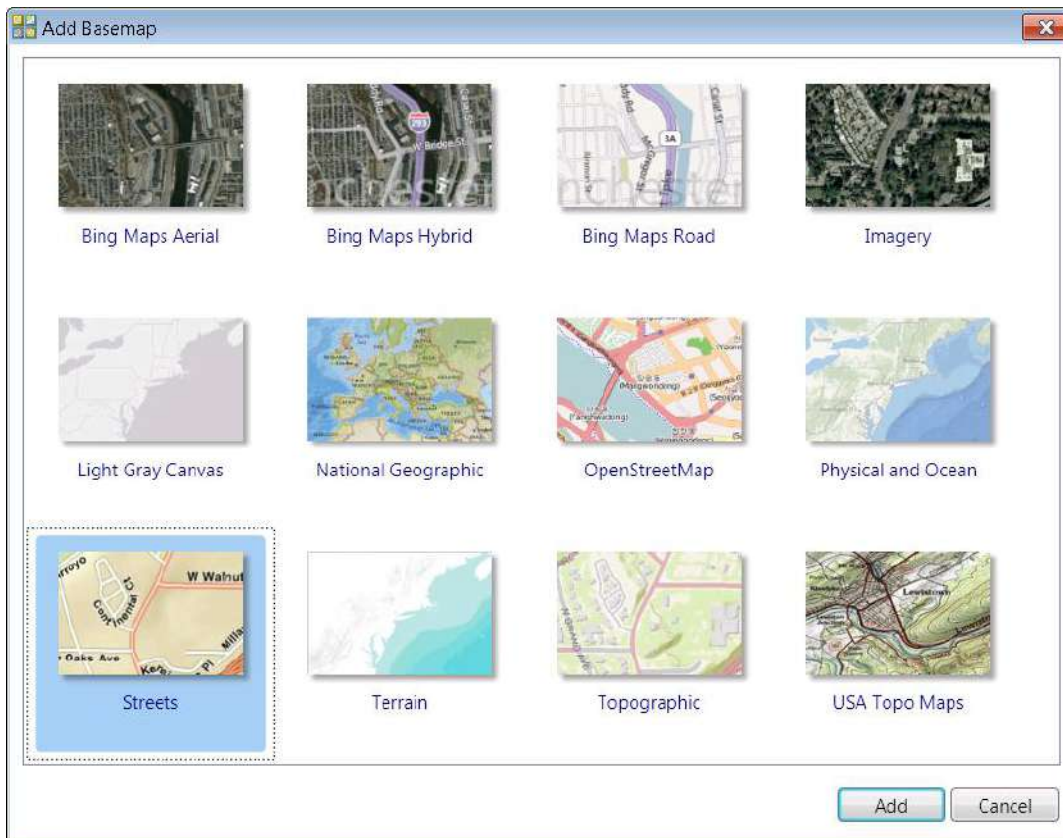
To add a basemap, go to **File -> Add data -> Add Basemap Layer (Figure 5)**

## 1.1 Load data



**Figure 5 Steps to add a basemap layer**

Currently 12 different basemaps are available. You can select either 'Street' or 'Topographic' as the basemap (Figure 6).



**Figure 6. ESRI basemap layers**




## 1.3 Browse Geographic Features

### 1.3 Browse Geographic Features

In ArcMap 10, ESRI starts to put most controls to browse data into one tool bar (Figure 7). If you cannot find this toolbar, please go to **Customize** -> **Toolbars** and check the **Tools** on.



Figure 7. The Toolbar with Data Browsing Controls

Most icons are intuitive and self-explained. If you are not sure what function it has, please put your mouse on that icon. A pop-up text will show and further explanation. In Figure 7, an example is shown when the mouse is hovering over the icon . The pop-up window explains its functionality: “Select Features by Rectangle”, which means that you can draw a rectangle over some area, and all features within (or have parts within) this rectangle will be selected for further operations.

In addition to the toolbar, some functions on attribute data are put in the pop-up window when you right click on one layer (a geospatial data file or a feature class) in the table of contents (Figure 8). When you click on “Open Attribute Table”, a table with all information on features will be shown (Figure 9).

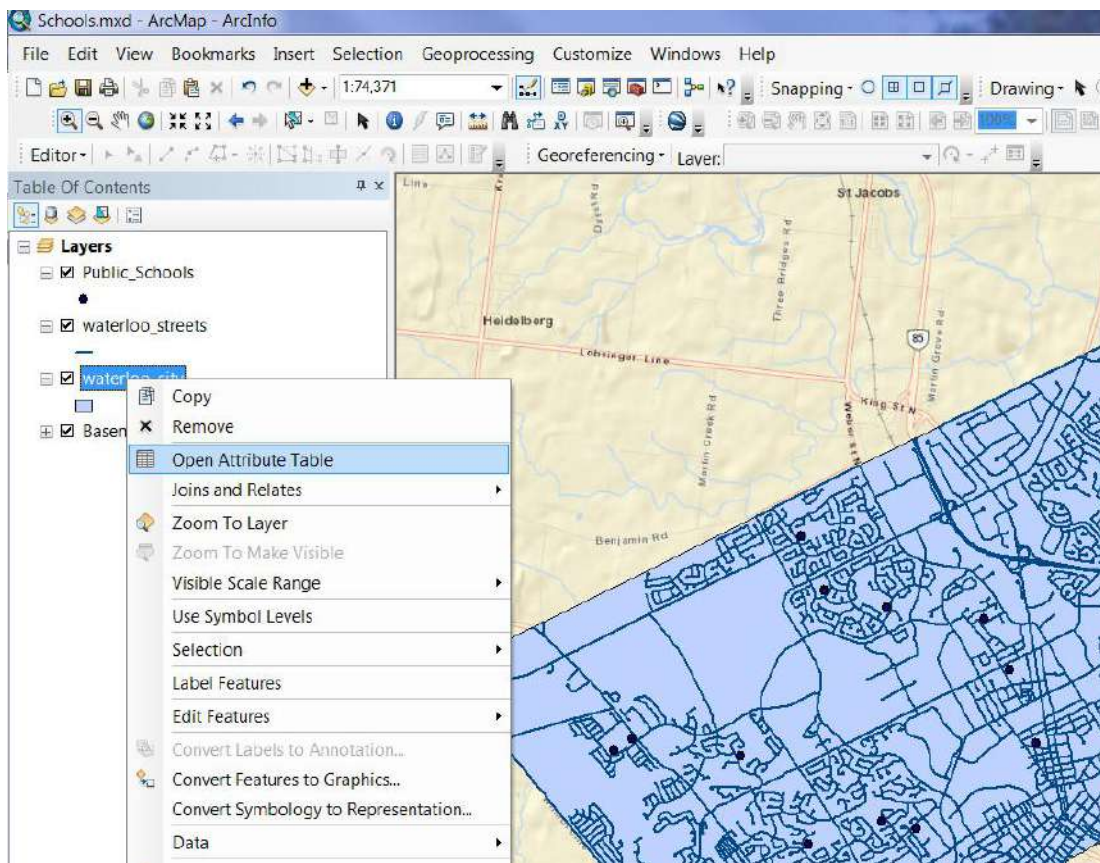
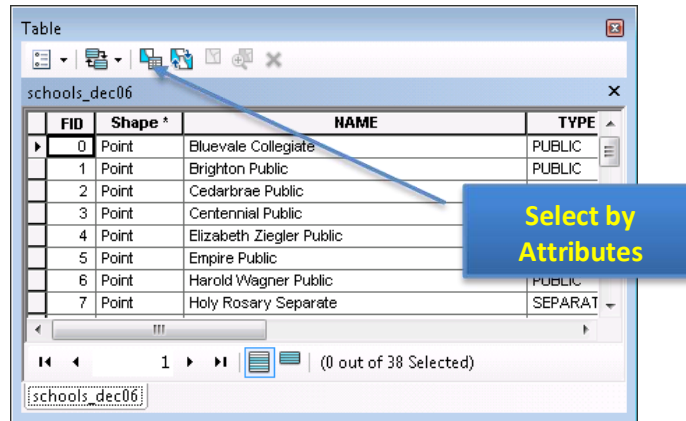


Figure 8. Pop-up Window with Options on a Layer

### 1.3 Browse Geographic Features



**Figure 9. Attribute Data Window**

These controls can be classified and summarized into the following table:

	Geographic Operations	Attribute Operations
<b>Browse</b>		Right-click on the layer (Figure 8 and 9)
<b>Search/Identify</b>		
<b>Select</b>		(Figure 9)



## 2.1 Distinction between Geospatial Data and Map Components

## 2. Mapping

### 2.1. Distinction between Geospatial Data and Map Components

This section is more concept- oriented. To simplify mapping process, ArcGIS divides mapping into two categories: data view, which focuses on data manipulation and representation (symbology), and layout view, which provides functionality of adding legend, scale bar, north arrow, etc.

- **All data representations should be set in data view.** Key operations include the change of layer order, symbology customization, layer transparency, labeling, and annotations. Most of data representations can be saved in a layer file (\*.lyr), because they are more data associated.
- **Layout view shows the virtual map you will get.** Layout view works in a What You See Is What You Got (WYSIWYG) fashion. The output will be the same as what you see in the layout view, where you can add map elements and change the paper and output settings. Map setting will be save in a \*.mxd file.

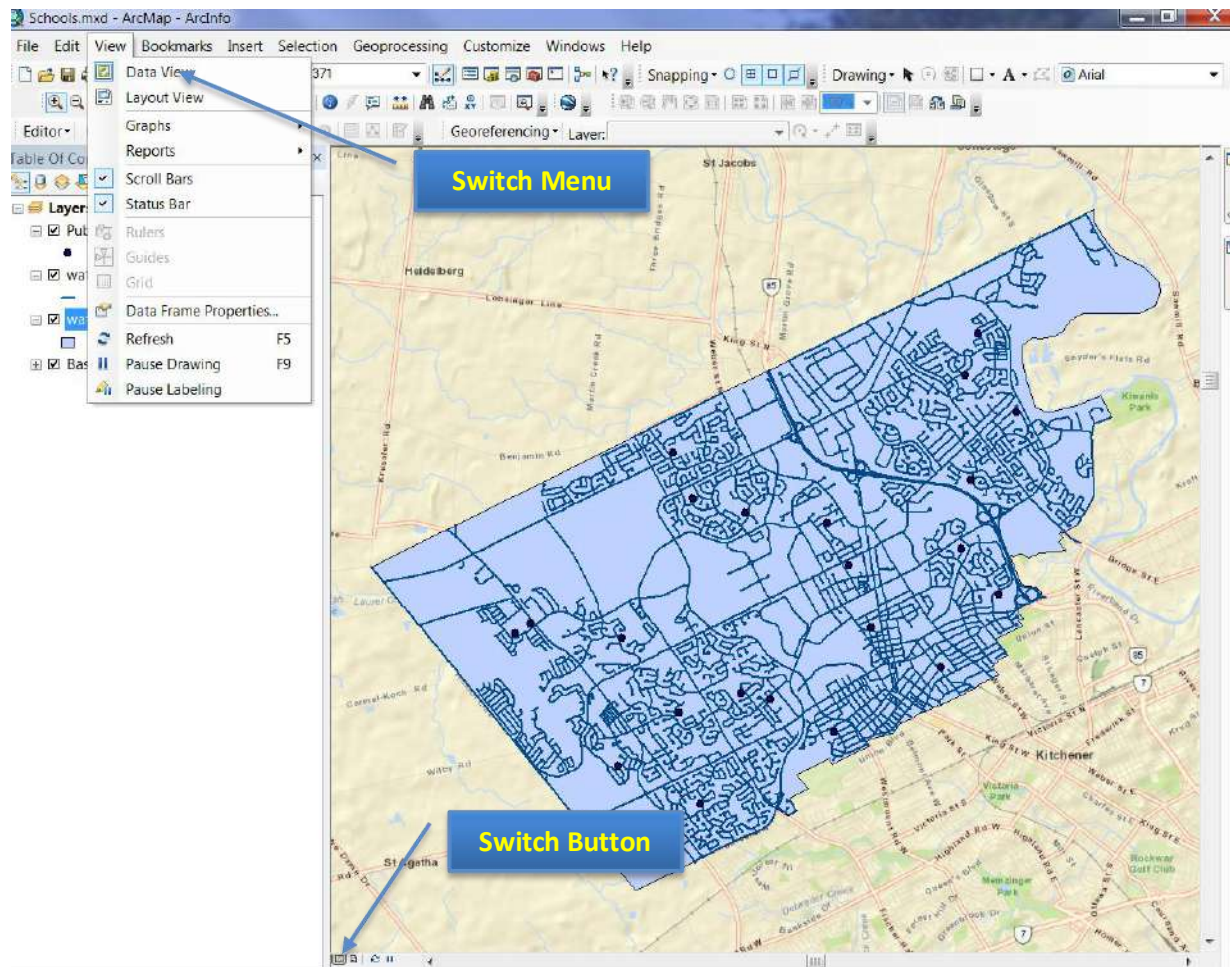


Figure 10. Switch between Data View and Layout View

## 2.2. Key Options of Geospatial Data Representations

### 2.2. Key Options of Geospatial Data Representations

Main options of changing geospatial data representations are *layer order*, *layer transparency*, *symbology*, *label*, and *annotation*. Apart from the first one (layer order) and last one (annotations), all the rest locate in the pop-up window (Figure 11) when you right-click the layer you want to modify and select '**Properties**' (Figure 12). They are under either the **symbology** or **labels** tab.

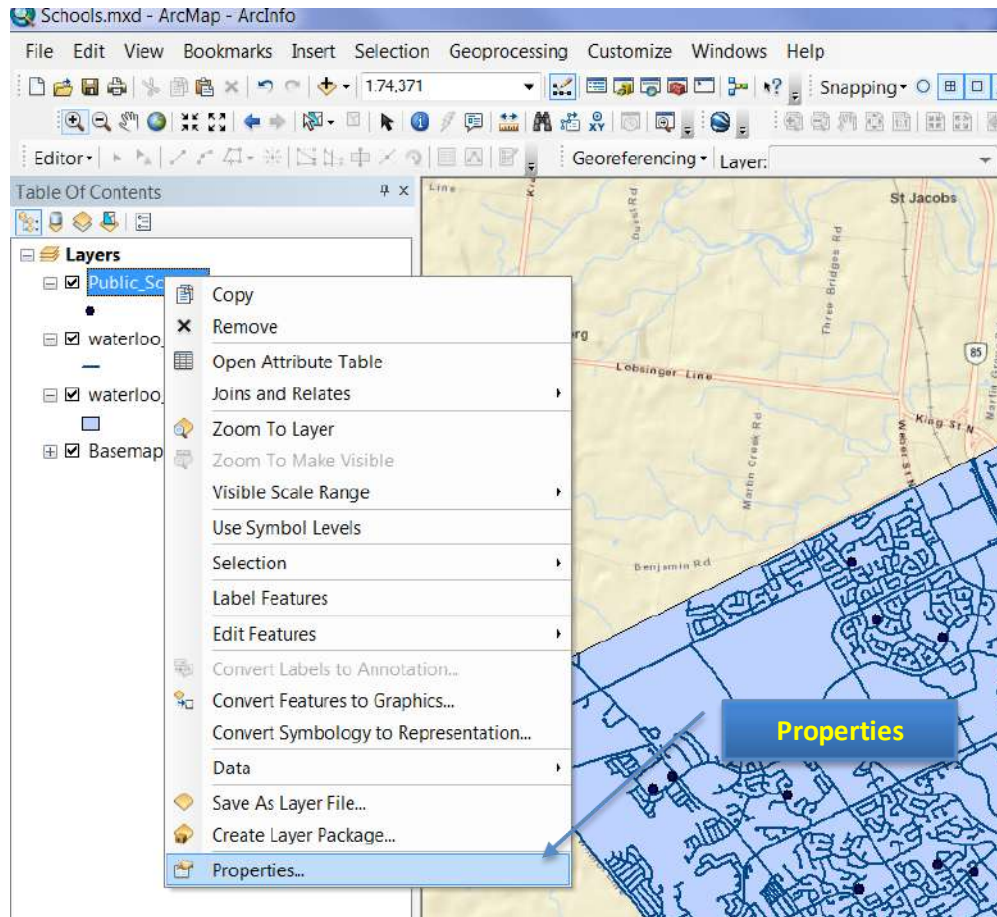


Figure 11. Pop-up Window of a Layer's Property

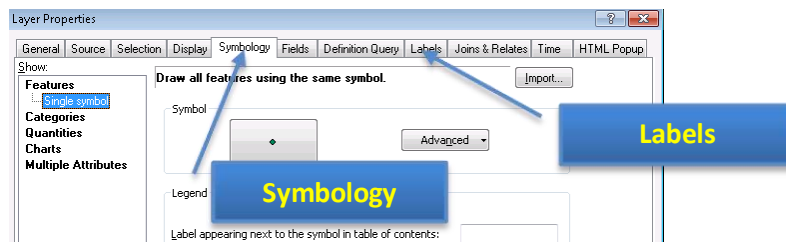


Figure 12. The **Properties** Window

All options will be introduced as subsections in the following.

## 2.2. Key Options of Geospatial Data Representations

### 2.2.1. Layer Order and Transparency

The boundary layer (waterloo\_city.shp) can be made as “halo” (no fill color) polygons allowing the overlaying basemap to be visible. The detailed steps will be introduced after the concept of layer order.

#### Layer Order

ArcMap displays geospatial data according to the order in the table of contents: the bottom layer will be drawn on the screen first and covered by upper layer. Hence, the layer on the top in the table of content will be displayed as the top layer in the map. **By default, ArcMap shows points, lines, polygons, and raster data (images, DEMs, etc) from the top to the bottom respectively** so that the visibility is maximized. *If two layers belong to the same feature class, i.e., point features, the newly added one will be on top of the older one.*

When there are multiple raster files, layer visibility and order are important. You can change layer visibility by switching the checkboxes left to the layer name in table of contents (Figure 13). And the display order can be changed by simply dragging the layer toward or away from the top.

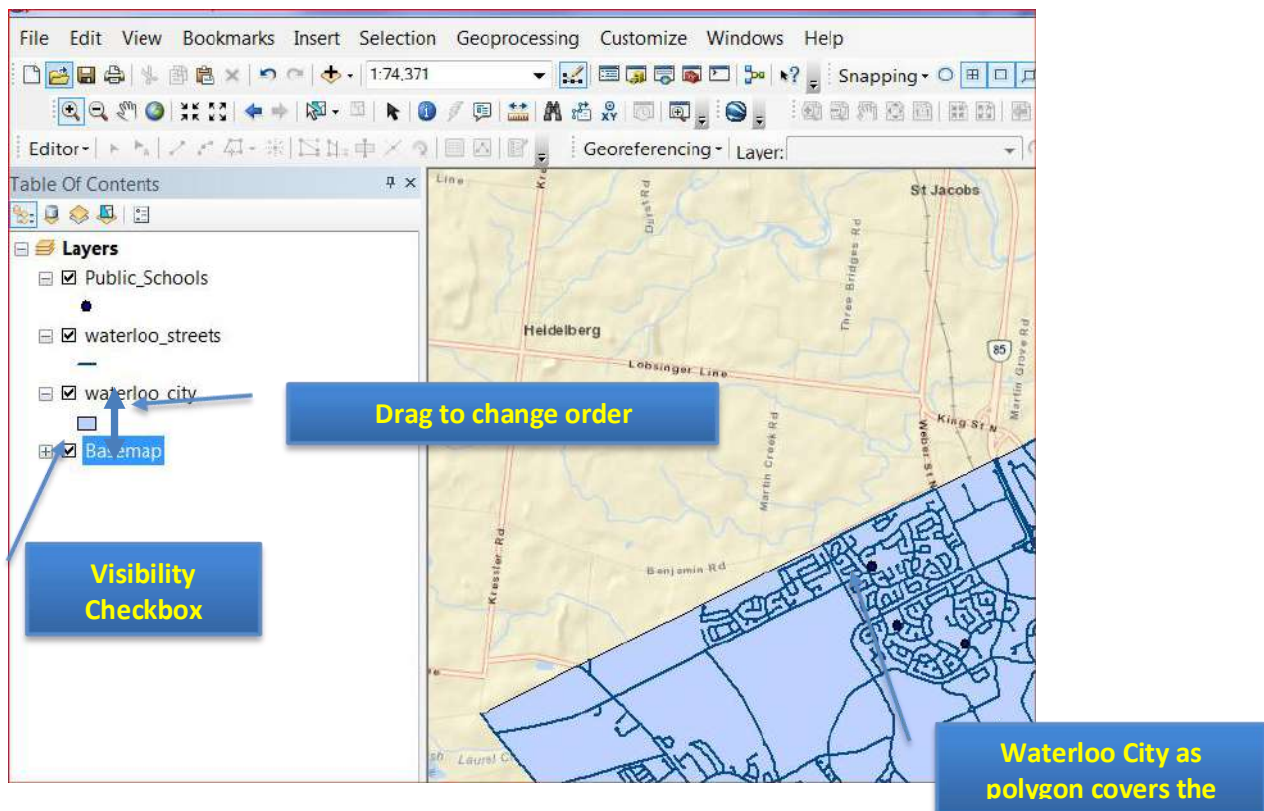


Figure 13. Layer Visibility and Order Control



## 2.2. Key Options of Geospatial Data Representations

### Layer Visibility

When a polygon layer, such as **waterloo\_city**, is added over an image (**basemap**), the image under the polygon is invisible (Figure 13). But users often like to only show the city boundary as long as the image. In this case, you can either set layer transparency or polygon fill color as 'none'.

To do so, please **right-click on the polygon layer** (waterloo\_city) and select **Properties** first (Figure 9). Then please switch to the tab **Symbology** and click on the symbol itself (Figure 14).

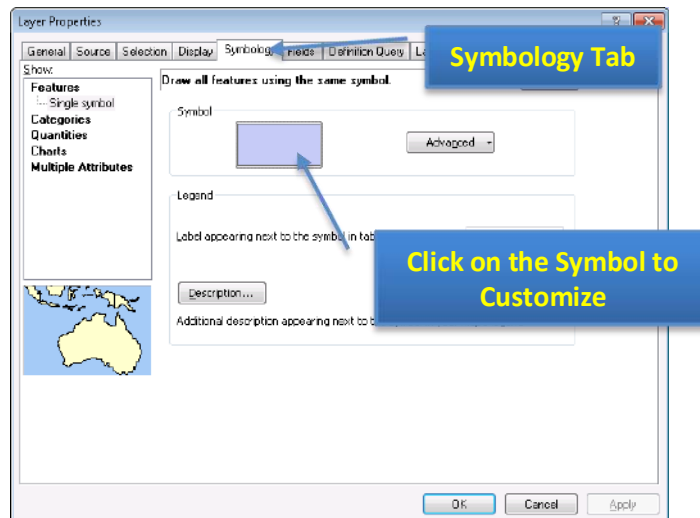


Figure 14. Properties of Symbology

When the pop-up window shows (Figure 15), you can change the **Fill Color** to **No Color** and increase the **Outline Width** (0.4 point is somewhat narrow).

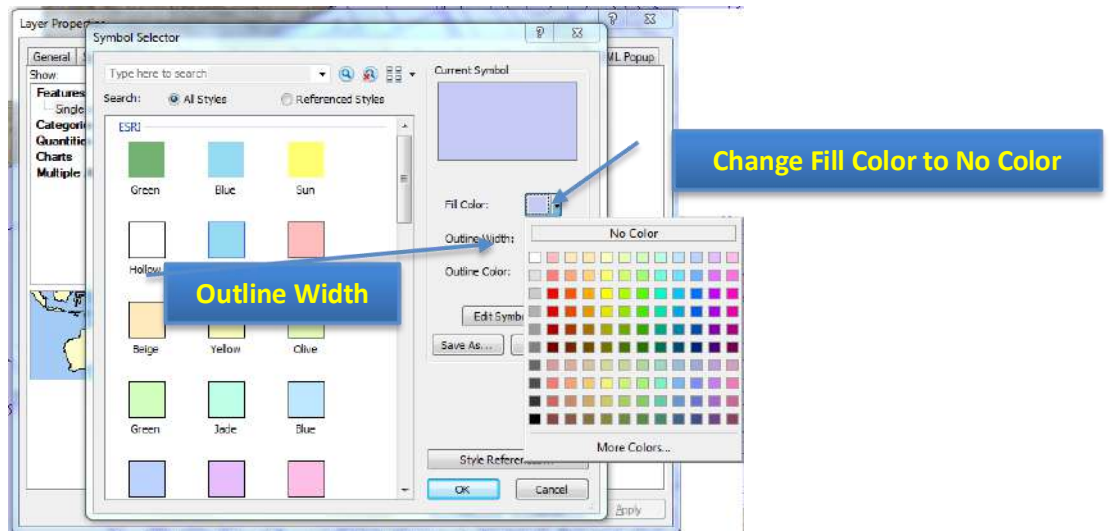


Figure 15. Make Hollow Polygons

## 2.2. Key Options of Geospatial Data Representations



### Layer Transparency:

An alternative (actually more generic) way of preventing overlaying is right-click the layer and select properties (Figure 9) first, and go to the **Display** tab. You can freely change the transparency as the parameter (percentage) of **"Transparent"** (or **"Transparency"** for raster layers).

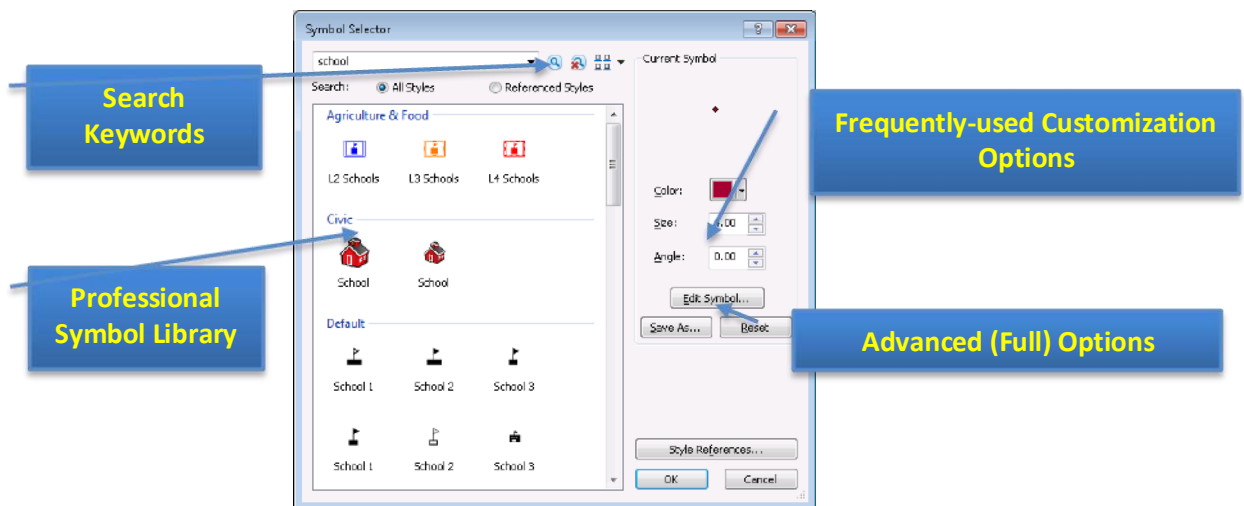
### 2.2.2. Symbology and Label

#### Symbology

Symbology is critical in making maps, which are classified into four categories in ArcMap. Due to its complexity, these four categories and their normal usages will be briefly introduced in the note region with further reading. We will only focus on symbol customization and classification symbols, which are mostly used.

Please right-click the **public\_schools** layer and select **Properties**. Then switch to the **Symbology** tab and click on the **Symbol** (Figure 14). The pop-up window (Figure 16) contains three main parts. In most cases, you will simply choose a symbol from the symbol library (other than making hollow polygons mentioned in 2.2.1.). Depending on the type of the feature (point, line, or polygon), the options change accordingly.

You can type in **school** and click the search icon (magnifier) to search all symbols related to school representations.



**Figure 16. Symbology Customization Window with Explanations**

There are cases when you want to differentiate features in a layer based on some attribute. For instance, I want to know the type of public school (elementary or secondary), which is the top layer in Figure 11. Different types will be marked in colors. To do so, we should **right-click** on the school layer,

## 2.2. Key Options of Geospatial Data Representations

select **properties**, and go to the **symbology** tab, which is the same as shown in Figure 12. But, instead of by-default **Features** option, we should click and select the **categories** option (Figure 15). The steps to follow are also shown in Figure 17:

1. Click on the **Categories** first and make sure the “**Unique Value**” is chosen;
2. Draw down the dropdown of **Value Field**, and select TYPE as the classification attribute;
3. Click on the **Add All Values** button to add all distinct values under the TYPE attribute into consideration;
4. **(Optional)** Click on the **Color Ramp** dropdown and select your favourite color schema.

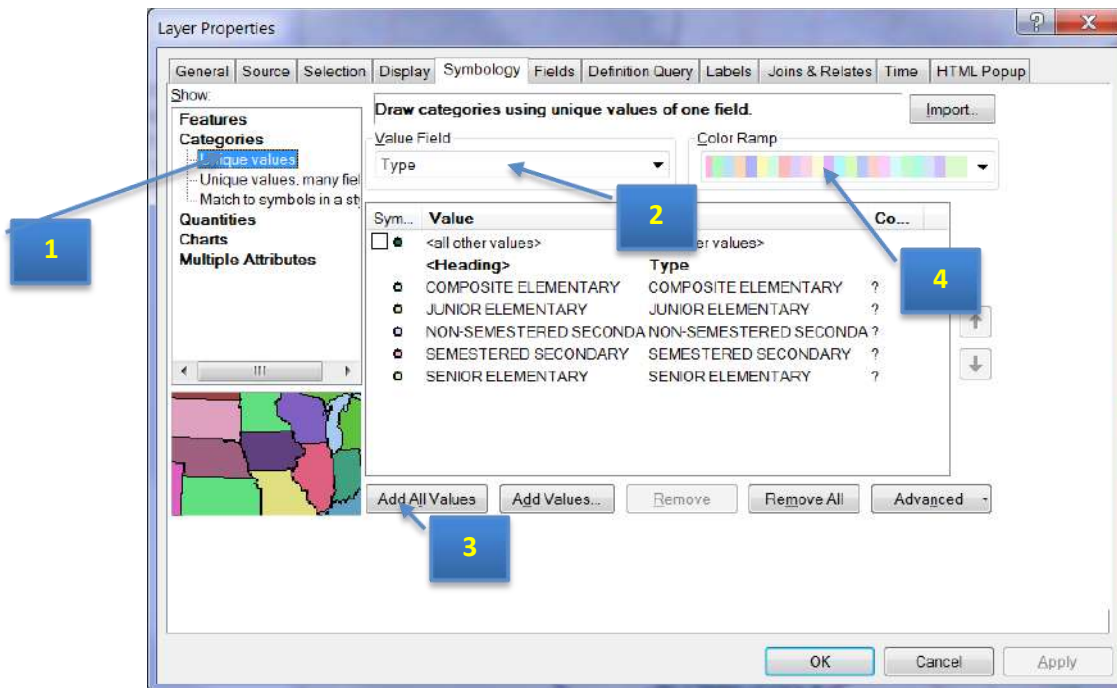



Figure 17. Classifying Features using Colors

The result is shown in Figure 18. Please note that you can still customize individual symbol for each category (size, shape, etc) by double clicking corresponding class on either the left pane or the line in symbology window (Figure 18). The pop-up window is very similar to the window in Figure 16. Please

choose **School 1**  and assign a color for each school type.



## 2.2. Key Options of Geospatial Data Representations

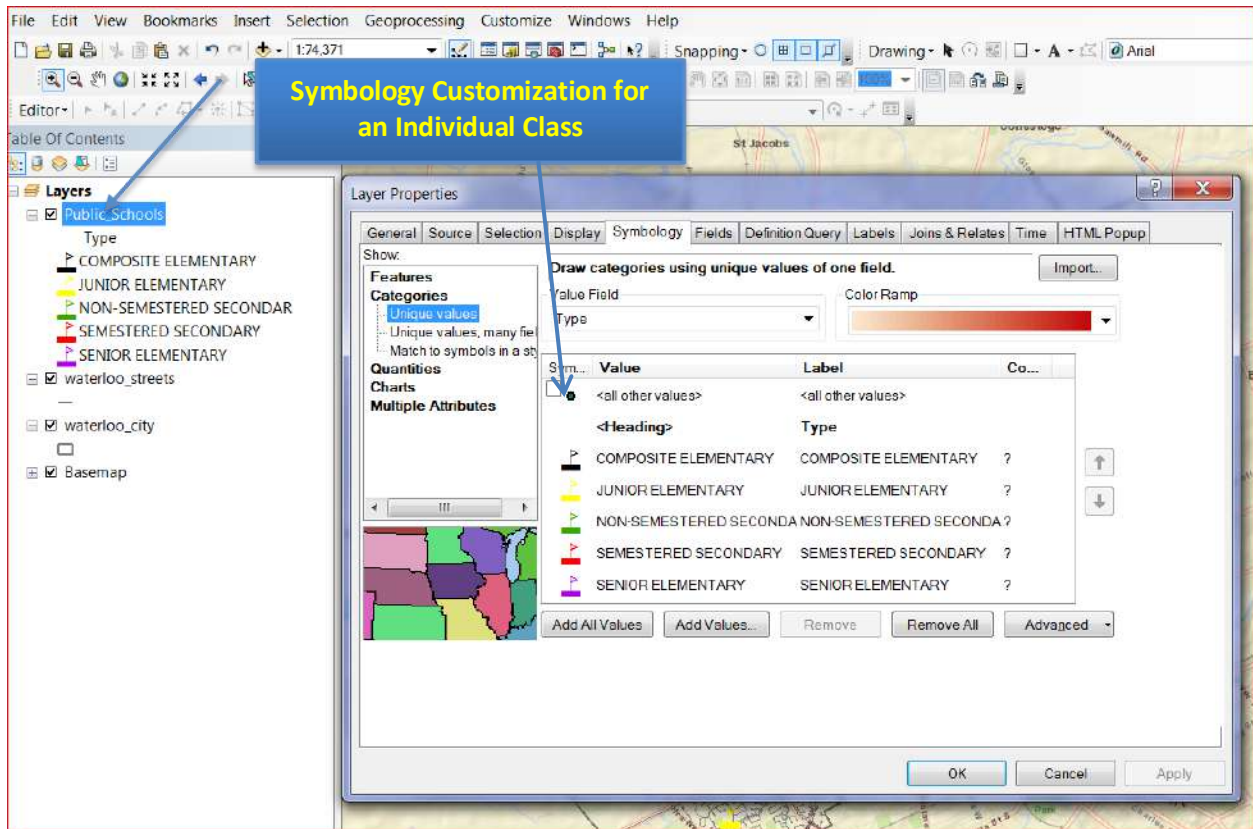


Figure 18. Classified Symbols and Further Customization

### Label

The labels are an important feature of a map. By marking some property up on the map, for stance, the name of the marked location, labels can make your map more useful, informative, and visually appealing.

To add labels to your map, please **right-click** on the layer that you want to add marks on (public-school) and select **Properties** (Figure 14). Then follow the steps below:

1. Select the **Labels** tab and check on (off by default) "Label features in this layer".
2. Choose the attribute you want to display (**SchoolName**) on the map in the dropdown of **Label Field** (Figure 19).
3. Change Font (**7 pt size and Bold**), so that it is clearly shown on the map.
4. You can click on the **Apply** button to see the effect until it is satisfactory. Then click **OK** to save your setting and exit.

## 2.2. Key Options of Geospatial Data Representations

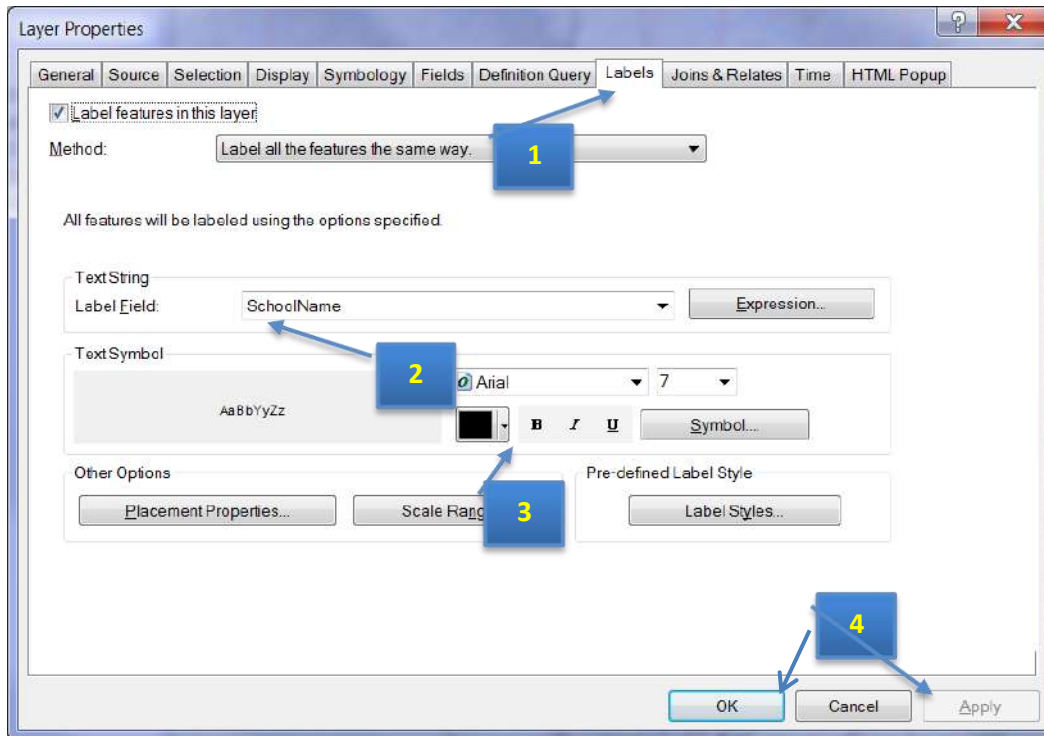


Figure 19. Label Setting Window

To ensure a clear label, the option of mask can be used **Symbol**, which locates to the right of Font options as a **Symbol** button (Figure 19). Please click it and then click the **Edit Symbol** button, since label is a kind of symbol (text symbol) too. Navigate to the **Mask** tab shown in the figure below. Change the option of **Style** to **Halo** and size as '1' (Figure 20).

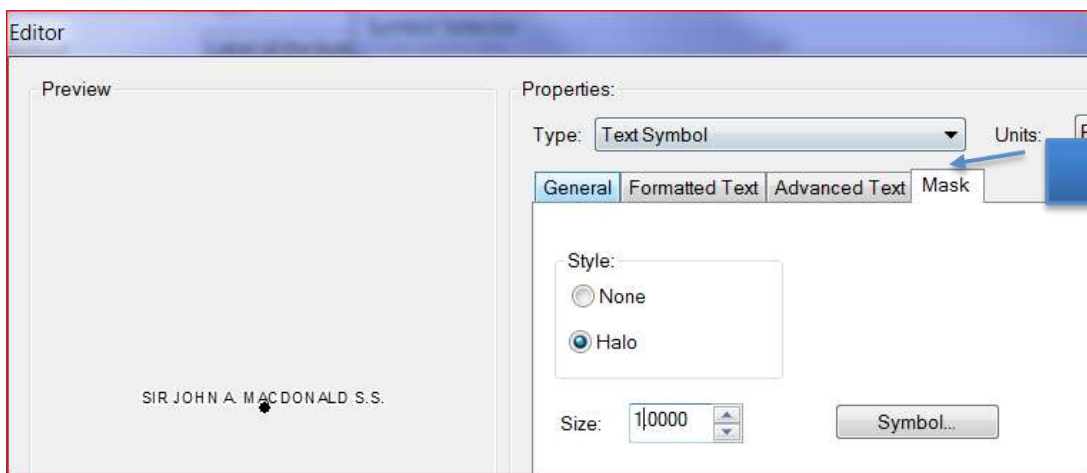


Figure 20. Change Mask Option for Clearer Labels

## 2.2. Key Options of Geospatial Data Representations



### Symbology Types and Their Normal Usage:

- *Features: Mainly used when you just want to mark geographic features on a map.*
- *Categories: Suit for the case when feature classification is needed.*
- *Quantities: Appropriate when numbers involve, i.e., population, income, depth, etc.*
- *Charts: Employed when not only quantity but also the relative importance is important as well. For instance, incomes from different types of consumers.*
- *Multiple Attributes: Utilized when multiple criteria are involved, which main not be quantitative. It can be regarded as a generalized case of Charts.*

### 2.2.3. Annotations

Annotations look like labels. The key difference is that annotation can be any text you want to add on the map, regardless to whether the information has been included in the geospatial data.

For instance, if you want to add a point showing the location of the University of Waterloo, please follow the steps below (**Please note that annotations can only be edited under the data view**):

1. Turn on the **Draw** toolbar. To do so, please click on the menu of **Customize -> Toolbars -> Draw** (Figure 21).

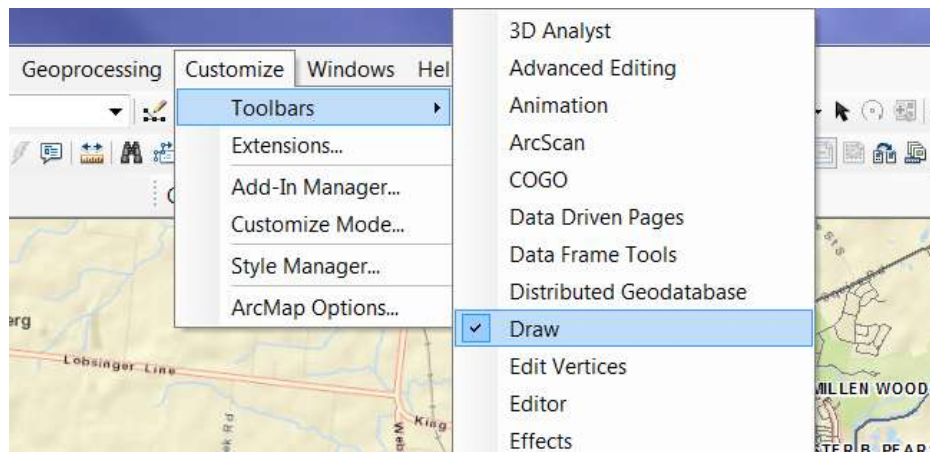


Figure 21. The Way of Turning on the Draw Toolbar

2. Add Marker. Click on  and select **Marker**. Then browse and point to the location you want to add the marker (South Campus Hall in this case) and click. A marker will be added to the location.



Figure 22. The Draw Toolbar

## 2.2. Key Options of Geospatial Data Representations

3. Add Text. Click **A** and choose **New Text**. Click on the map, somewhere close to the marker you just made and type in accordingly (i.e. “University of Waterloo”).

Result is shown in Figure 23.

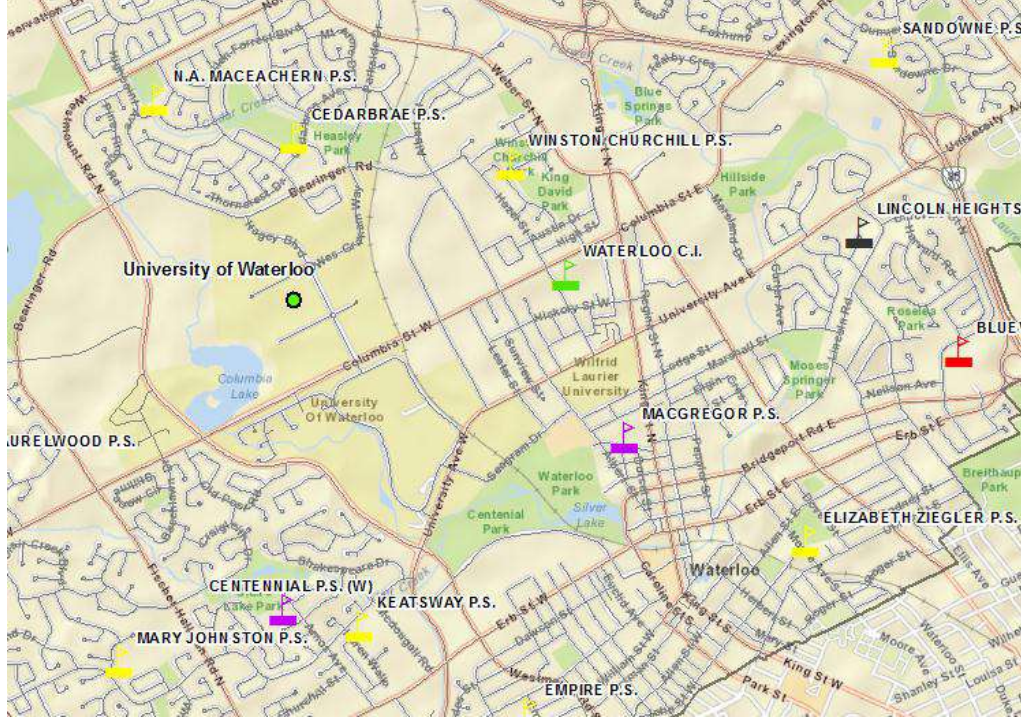


Figure 23. Map after Adding Labels (with Mask) and Annotations

**i** Some Other Types of Annotations:

- **Annotate a polygon:** Sometimes you may want to annotate a polygon. The easiest way to do so is to choose **Polygon Text**. Please modify the text style (color, size, etc) and the filled color accordingly, which locates at the right part of the Draw Toolbar (Figure 19).
- **Annotate along the road:** ArcMap also allows to you to put your annotations warp along the road, which looks nicer. To do so, please choose **Splined Text**. Then make single clicks along the road, which defines the display route. Type in the texts and enter. The text will be shown along the route you made.

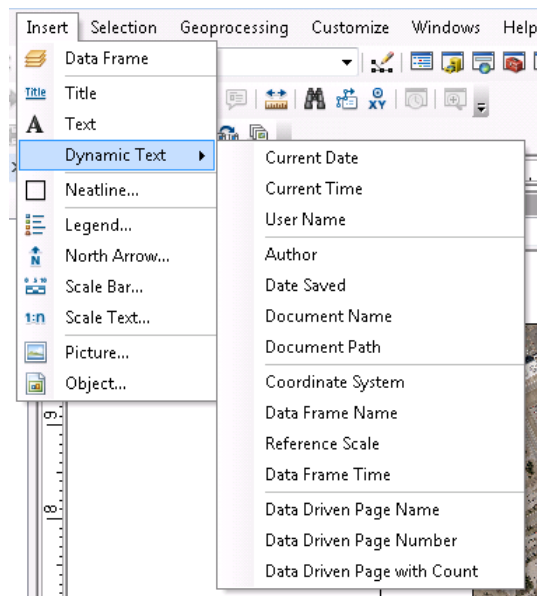


## 2.4. Export Maps

### 2.3. May Layout Map Components

Switch to **Layout View** to start adding map components, all components are gathered in the menu of **Insert** (Figure 24). The key ones are:

- The title of the map (Purpose/Content);
- The scale of the map (Measurement);
- The North Arrow (Orientation);
- The Legend (how to interpret the map);
- (Optional) The reference (where you obtain the data).



**Figure 24. All Map Components Available**

Map titles are just a specific kind of text box with some pre-defined fonts. Hence, the usage of title and text are identical and intuitive: type in the content and customize the text properties.

Add scale bar or scale text is also intuitive. The only thing that should be noted as the display unit, such as meters, degrees, miles, etc. You can customize it by clicking the **Properties** button in the **Scale Bar (or Text) Selector**, which is the pop-up window when you choose **Insert -> Scale Bar (or Scale Text)**. In the **Scale and Units** tab, you can choose an appropriate unit in the **Division Units** dropdown (Figure 25). In addition, you can change the font style under the **Format** tab as well.

In this example, please use Scale Text with meters as units, shown like: 1 cm = 75 meters.

Add North Arrow is the easiest task, which is very similar to add a scale bar. Just choose a pre-defined north arrow from the library shown in the left pane is ok. If your North Arrow is difficult to be distinguished from the background, you can add some background color, which has similar effect of “mask” for labels. This option normally locates in the **Frame** tab (Figure 26). Legend, scales, and texts all have similar options.



## 2.4. Export Maps

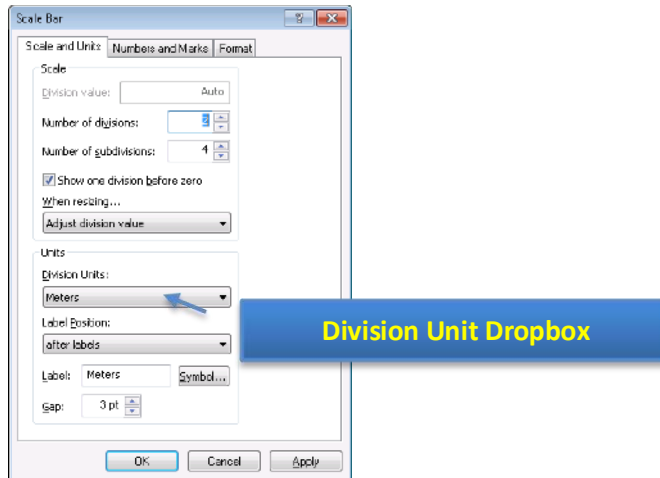


Figure 25. The Scale Bar (or Text) Property Window

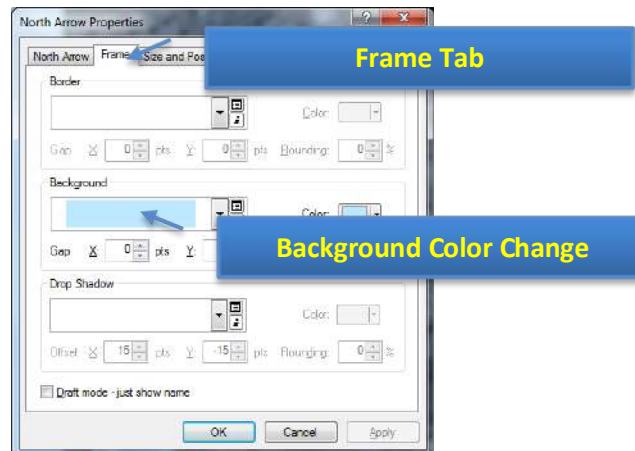






Figure 26. Change Background Color in Frame Tab

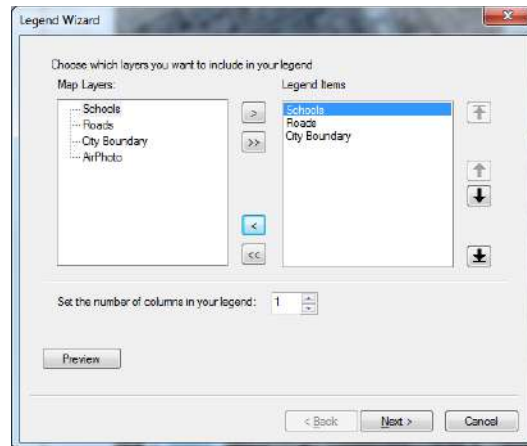
Adding Legend is somewhat complex and deserves some explanation. When **Insert** -> **Legend** is selected, ArcMap will use a wizard guiding you through various options of making a legend.

At the first step, you will be asked about which layers need legend and the order of adding legend (Figure 27). The left pane **Map Layers** displays all layers (geospatial data) available for the map. The right pane **Legend Items** shows the layers that will be added to the legend in order.

- **Add/Remove Layers:** You can decide the layers to be added to the legend by clicking  to add or  to remove. Please **remove the airphoto layer**, since the band information for raster images is not useful (Figure 24).

## 2.4. Export Maps

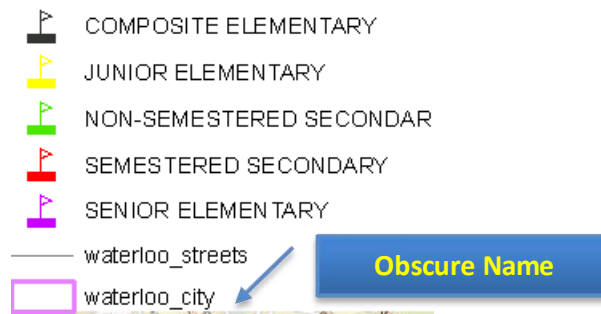
- Change the Display Orders: The legend items will be added strictly in the order shown in the **Legend Items** pane. You can change the order by clicking a layer first (displayed in the blue bar) and move it up  or move it down .



**Figure 5. The First Step of Adding Legend**

In the following three steps (four steps in total), ArcMap will ask you about some options to display the legend. None of them is critical and requires customization (especially for normal users). You can just accept all default configuration and click **next** until **Finish** it. You will get the legend that looks like in Figure 28.

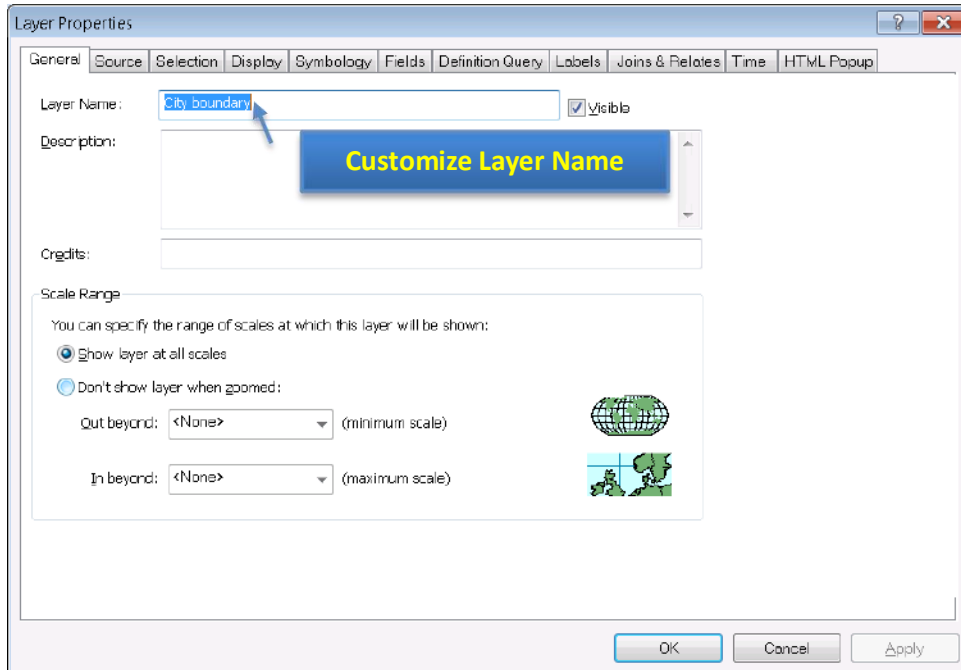
### Legend



**Figure 28. An Example of Generated Legend**

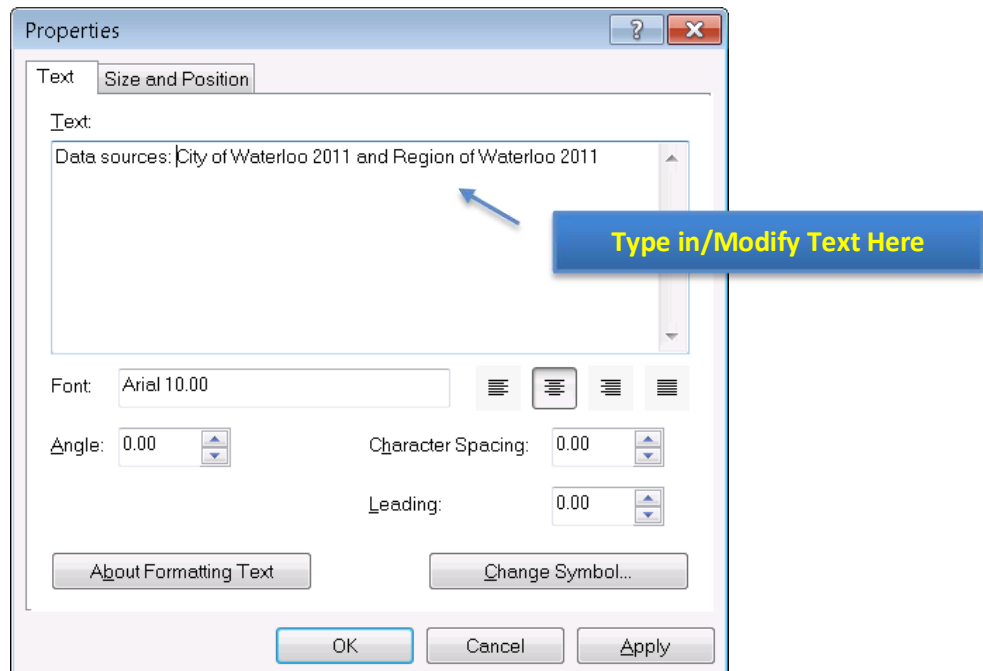
It is easy to find that the name displayed in the legend is difficult to understand. For instance, users won't know what "waterloo\_city" means. In this case, you can modify the name in the **table of content** pane (Figure 4). To do so, you can **right-click** on the "waterloo-city" layer and select **Properties** (Figure 14). At this time, please switch to the **General** tab. Then you can type the more meaningful name in the **Layer Name**: City boundary (Figure 29). You can use the same method to change "waterloo\_streets" to "Roads".

## 2.4. Export Maps




**Figure 29. The General Tab to Change Layer Name**

Lastly, we're going to add a citation to the map. Click on **Insert** -> **Text** under the layout view and type in your citation.



**Figure 30. Property Window of Text in Layout View**

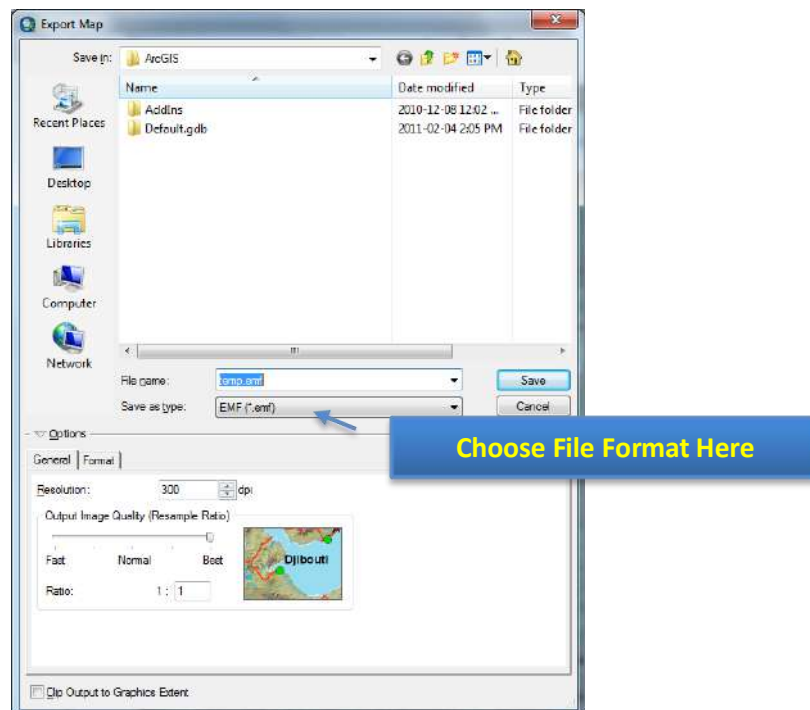
## 2.4. Export Maps

 Some Components that are also frequently added:

- Author of the Map: Users may want to know who creates the map;
- Date Saved (Created/Modified): The more frequent a region changes, the more important it is for users to know when the map is created;
- Coordinate System: The globe is not flat, but a map is. Any kind of projection used to make the map distorts the reality in some way. Hence, it is critical for users to know how reliable their measurements on the map are, especially for pilots and navigators.

### Export Maps

When you are satisfied with everything in the map and are ready to deliver, you can export your map by the menu of **File -> Export Map**, which will pop-up a dialog (Figure 31).



**Figure 6. Export Map Dialog**

You can specify the directory and file name of the map in this dialog. But, most importantly, you need to choose an appropriate file format by click on the **Save as type** dropbox. The most frequent-used formats are JPEG and PDF. JPEG is a popular graphic file format, which is easy to be inserted into word as a graph, while PDF is best used for sharing. The printed copy of PDF will be identical regardless of your computer (and printer) environment.

## 2.4. Export Maps

Please note that if the purpose of your map is to be shown on screen, **96 dpi** resolution is good enough. It is especially true when you want to publish your map online, given that lower resolution maps are much smaller, and therefore, easier to transfer via Internet. If you need hard copies of your map, please make sure that the resolution is set to **300 dpi** or **600 dpi**. Otherwise the output map might be obscure.

Other than export map to other file formats, you can directly print out hardcopies of your map by **File -> Print**. You can preview the result via **File -> Print Preview** to ensure satisfactory result. And, of course, you can customize page and printer setup via **File -> Page and Print Setup**, such as page orientation (portrait and landscape), page size, printer configuration (color or grey), and so on. All these operations are intuitive and very similar to other applications, such as Microsoft Word.



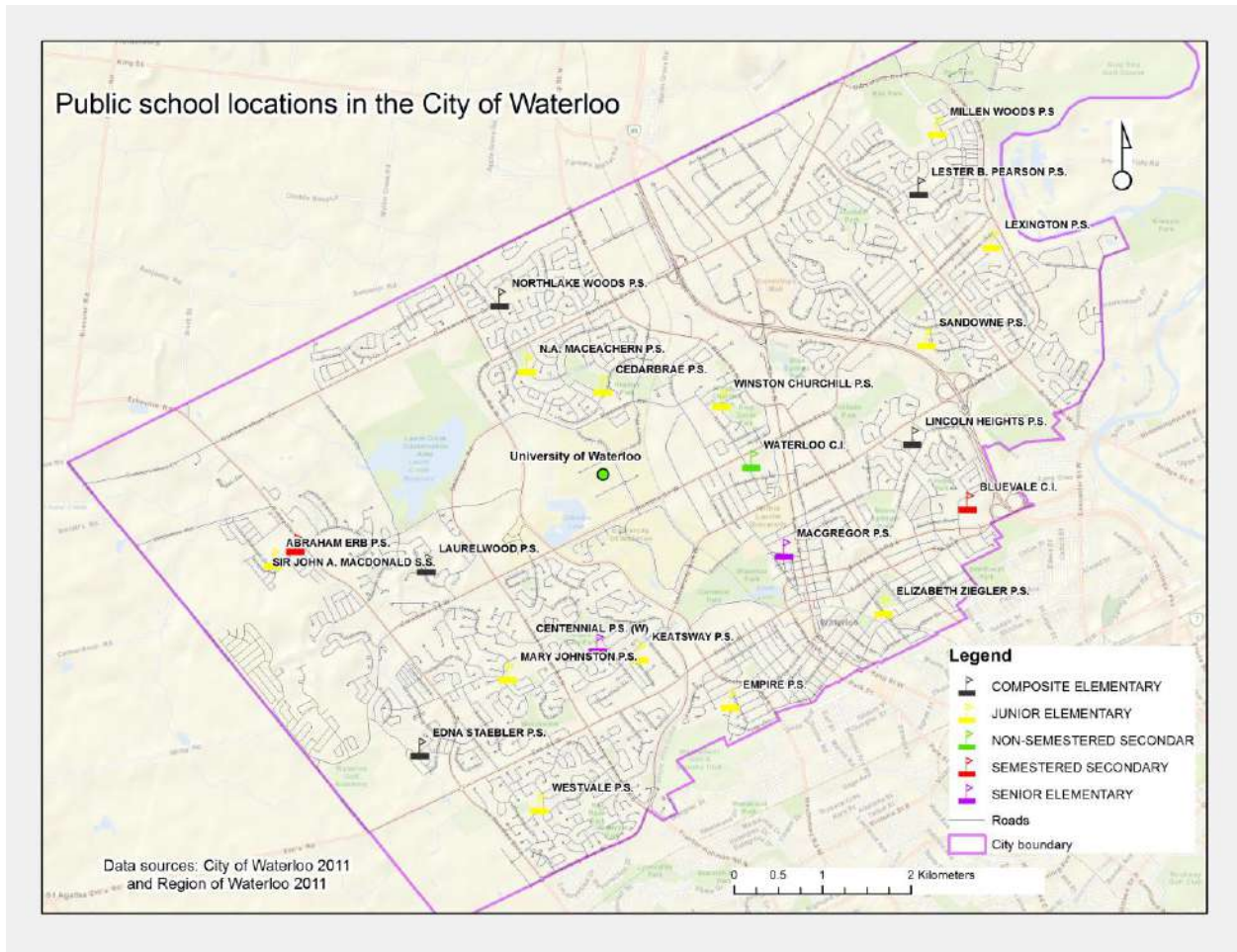
### *Brief Explanation of Graphic File Formats:*

- *EMF file: Enhanced Metafile, specified for Windows, which can be regarded as an alternative of TIFF file. EMF is an not recommended option;*
- *EPS file: Enhanced PostScript file, specified by Adobe for printer drivers. It is popular in open-source editors, for instance, LaTeX and TeX. But it seems to be a buggy option. Try to avoid it;*
- *AI file: Adobe Illustrator file. A major vector graphic file format. A good choice if you work with Adobe products, such as Illustrator, Flash, and Macromedia ones;*
- *SVG file: Scalable Vector Graphics, an open-source vector graphic standard. It is becoming more and more popular and can be accepted by many vendors;*
- *BMP file: BitMap file, which is a mature loss-less uncompressed raster format. The quality is great. But its file size tends to be huge. It can be used if you need both high-quality output and compatibility ;*
- *PNG file: Portable Network Graphics, which is an open-source standard designed to replace BMP and GIF. It is a true-color loss-less raster file format. PNG file is slightly larger than JPEG (compressed with quality loss). And some old browsers and operating systems do not support PNG files;*
- *TIFF file: Tagged Image File Format. A major raster graphic file format provided by Adobe (AI for vector). Best to be used for raster file editing on Adobe Products, such as Photoshop;*
- *GIF file: Graphics Interchange Format. An uncompressed raster file format with 256-color limitation. Hence, if your map contains only a few colors (vector-based data), GIF is a good candidate.*



## 2.4. Export Maps

The final map may look as one below.



Created by Qian Wang in 2011 and modified by Steve Xu in 2012

## 1.0 CONCEPT AND DEFINITION OF GIS

### Definition of GIS according to various authors

“A GIS is a specific information system applied to geographic data and is mainly referred to as a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems” (Burroughs, 1986, NCGIA, 1990)

“Geographical Information System is a powerful computerized information system for spatial data referenced by the geographic coordinates. GIS is a set of tools for collecting, storing, retrieving (at will), transforming, analyzing and displaying spatial data from the real world for a particular purpose. It may also be elaborated as an computerized information system for spatial data and is designed to acquire, store, retrieve, manipulate, analyze and display these data according to user defined specifications” (Clarke, 1986).

“GIS is an information technology which stores, analyses and displays both spatial and non-spatial data.... GIS is actually a technology and is not necessarily limited to the confines of a single, well-defined software system” (Parker, 1988)

“GIS is any manual or computer based set of procedures used to store and manipulate geographically referenced data” (Aronoff, 1989)

## 2.0 COMPONENTS OF GIS

A GIS has the following well defined components:

1. Computer Hardware
2. Software
3. Spatially/ Geographically referenced data
4. Personnels involved

### Computer Hardware

The hardware is the important component of GIS anatomy which includes the computer and the peripheral devices that the users interact with directly in carrying out GIS operations. The present day platforms for a GIS range from low end PCs to high end Workstations with a wide range of system capabilities in terms of performance, memory and hard disk. Thus the hardware components for GIS include-

- Processor
- Monitor
- Input devices like
  - Key board
  - Mouse
  - Digitizer
  - Scanner
- Storage devices like
  - Floppy disk
  - CDs
  - Hard Disk
  - Magnetic Tapes (DAT) etc
- Output devices like
  - Monitor

- Printer
- Plotter

### Software

Softwares are programmes, which contain a set of instructions to be performed by hardwares to derive the desired outputs. The major GIS softwares include:

- ARCINFO (developed by ESRI, USA)
- ARCVIEW (developed by ESRI, USA)
- AUTOCAD MAP (developed by AutoDesk Inc.)
- MAPINFO (Mapinfo corporation)
- SPANS (PCI Geomatics, Canada)
- ISROGIS (India)
- GISNIC (NIC, India)
- GRAM<sup>++</sup> (CSRE, IIT, Bombay)

### Spatially Referenced Data

The spatially referenced data are the data, which describe the entities and events of the real world in terms of their-

- Position or Location (with respect to a known coordinate system)
- Attributes (the spatial and non-spatial characteristics associated with them)
- Spatial relationship with each other (Topology or Geometry)

Every spatial entity or event has specific position or location as it pertains to some space in our real world. So without having knowledge regarding location, we cannot identify an entity or event. As for example, "Bhubaneswar" is a spatial entity, but to identify it, we must first describe its location in terms of geographical coordinates (i.e. Latitude and Longitude).

Apart from its location, the Bhubaneswar also needs some other characteristic definition to be defined. These characteristics are called attributes. As for example, after location the name "Bhubaneswar" needs to be described. The attributes may be spatial or non-spatial. As for example, the "Area" is a spatial attribute whereas the "Name" is non-spatial attribute.

Every spatial entity or event has a geometric relationship with other spatial entities or events. For better analysis of spatial data, the understanding of this relationship is necessary. This relationship is called "Topology". This may include adjacency, containment and connectivity.

### Personnel Involved

A GIS is useless without the people who design, programme and maintain it, supply it with data, and interpret its results.

## 3.0 DATA STRUCTURE IN GIS

As the spatially referenced data has two components:

- Spatial component (which describes location and geometry of the spatial feature or event)
- Attribute component (which describes the characteristics of the spatial feature or event)

The organization or structuring of this data can be studied under two headings:

- Spatial data model  
There are two ways of modeling or structuring spatial component of the geographically referenced data:
  - Raster model
  - Vector model
- Attribute data model  
There are three classical ways of representing attribute data:
  - Hierarchical model

- Network model
- Relational model

### Raster Model

It is an explicit representation of spatial component of data in which a set of cells is located by coordinates and each cell is independently addressed with the value of an attribute. In other words it is the representation of spatial component of data in terms of grids or pixels.

### Vector Model

It is an implicit representation of spatial component of data in which three main geographical entities such as point, line, and polygon are used to describe the spatial entities or events. In other words in vector representation, the spatial features or events are represented in terms of either point or line or polygon.

## COMPARISON BETWEEN RASTER AND VECTOR

PARAMETER	VECTOR	RASTER
Precision	Acurate & More precise	Limited by grid size
Redundancy	Less	More(As each cell is partitioned) So need encoding schemes
Attributes	Linkage to DBMS relations direct	Grid represents attributes Indirect linkages to relations
Complexity	High (Complex algorithms & processing)	Easy to organise & process
Outputs	High quality on plotters Cartographic quality	Mainly printer outputs
Analysis	Spatial & attribute integration, Complexity is higher.	Amenable to map algebra & easy to analyse
Remote Sensing interface	Indirect (Need to convert to vector)	Direct (Analysis of images possible)
Simulation	Complex & difficult	Simulation of new datasets Possible
Inputs	Digitisation or Vector Conversion of scanned Outputs	Amenable to scanning or rasterization of digitised vectors.

### Hierarchical Model

Hierarchical model assumes that each part of the hierarchy can be reached using a "Key" that fully describes the data structure. These models are good for data retrieval, but disadvantageous since it leads to data redundancy which increases storage and access costs.

**Network Model**

In a network data model an entity can have multiple parents as well as multiple child relationship. It is very useful in cases where much more rapid linkage is required, particularly in data structures for graphic features where adjacent items in a map or figure need to be linked together even though the actual data about their coordinates may be written in very different parts of the database.

**Relational Model**

The relational database model in its simplest form stores no pointers and has no hierarchy of data fields within a record. Instead, the data are stored as collection of values in the form of simple records, known as "Tuples", containing an ordered set of attribute values that are grouped together in two dimensional tables, known as relations. Each table or relation is usually a separate file. The pointer structures in network models and the keys in hierarchical models are replaced by data redundancy in the form of identification codes that are used as unique keys to identify the records in each file.

This structure of attribute data organization is very flexible which can meet the demands of all possible queries using rules of Boolean logic and other mathematical operations. It is also easy for update, retrieval, maintenance, analysis etc.

**4.0 FUNCTIONALITIES/TOOLS OF GIS**

The GIS softwares along with other elements, offer a variety of tools or functionalities for performing a wide range of desired data input, storage, editing, manipulation, analysis and presentation related activities, which can be grouped under four major modules:

1. Data input, modeling, storage module
2. Data retrieval, editing, manipulation and management module
3. Analysis module
4. Presentation and output generation module

**Data input, modeling and storage**

After the data is collected through different primary and secondary sources from the real world, they are input to the GIS system. The spatial component of the data is entered through various devices like:

- Digitizer
- Scanner
- Mouse etc

The attribute data is entered through the keyboard. The various data input and modeling related activities include:

- Data layering
- Digitization
- Attribute data entry
- Importing digital data from other formats
- Linking of attribute data to spatial data etc

**Data retrieval, editing, manipulation and management**

During the data input processes many errors exist in the database due to human biasness, error in source data, defects in data input devices etc. So before going for any analysis, the database needs to be edited and rectified properly. The data editing functionalities may include:



- Editing spatial data
  - Adding, deleting, copying, moving features (Points, lines, polygons)
  - Rotating, Splitting and joining features
- Editing attribute data

As the data is collected from various sources due to non-availability of all the required and relevant at a single source, the data need to be standardized so that integrated analysis will be possible. For this various manipulation and management functionalities are applied which include:

- Transformation of all data to a common coordinate system and map projection
- Map joining and Edge matching of maps of adjacent areas
- Densification and smoothening of arcs etc

### **Analysis functions**

The GIS offers a range of desired analysis functions to be performed on the GIS-database containing spatial as well as attribute component. The analysis functionalities may broadly include:

- Arithmetic Operations
  - Addition, Subtraction, Multiplication, Division, Exponential, functions, Trigonometric functions etc
- Geometric Operations
  - Computation of areas, distances, coordinates etc
- Logical Operations
  - Boolean functions like And, Or, Nor, Not etc.
  - Set operations like equal to, greater than, less than, intersection, union etc
- Statistical operations
  - Sum, maxima, minima, average, dispersion etc.
- Search and query operations
- Selection and Reclassification
- Spatial integration (Overlaying)
- Spatial proximity (Buffering)
- Neighborhood operations (Interpolation and Surface (3-D) generation etc.)
- Connectivity and Network operations (Optimal path allocation, Finding best route etc)

### **Presentation and Output generation**

For better understanding and perception, after the various analysis have been made, the resultant information is presented and output is derived in terms of maps, charts, diagrams, tables etc. "Cartography" is the science of making maps and charts. So, the maps and charts are prepared according to cartographic symbolization principles.

**CARTOGRAPHIC VARIABLES**

differences in:	symbols		
	point	line	area
size			
value			
grain/texture			
colour			
orientation			
shape			

**5.0 APPLICATIONS OF GIS**

Now a day, GIS is applied in wide range of fields including geology, hydrogeology, engineering, agriculture, meteorology, developmental planning, socio-economic studies, health studies etc. Some major application areas can be outlined as follows:

- Socio-economic/Government
  - Health infrastructure planning
  - Local government
  - Transportation planning
  - Service planning
  - Urban management
- Defense agencies
  - Target site identification
  - Tactical support planning
  - Mobile command modeling
  - Intelligence data integration
- Commerce and business
  - Market share analysis
  - Insurance
  - Fleet management
  - Direct marketing
  - Target marketing
  - Retail site location
- Utilities
  - Network management
  - Service provision
  - Telecommunications
  - Emergency Repairs
- Environmental Management

- Land fill site selection
- Land cover/Landuse change analysis
- Site suitability analysis
- Pollution monitoring
- Natural Hazard assessment
- Disaster Management
- Resource Management
- Environmental Impact Assessment

## 6.0 ERRORS & ACCURACY IN SPATIAL DATA

It is important to distinguish from the start a difference between **accuracy** and **precision**:

**1) Accuracy** is the degree to which information on a map or in a digital database matches true or accepted values. Accuracy is an issue pertaining to the quality of data and the number of errors contained in a dataset or map. In discussing a GIS database, it is possible to consider horizontal and vertical accuracy with respect to geographic position, as well as attribute, conceptual, and logical accuracy.

- The level of accuracy required for particular applications varies greatly.
- Highly accurate data can be very difficult and costly to produce and compile.

**2) Precision** refers to the level of measurement and exactness of description in a GIS database. Precise locational data may measure position to a fraction of a unit. Precise attribute information may specify the characteristics of features in great detail. It is important to realize, however, that precise data--no matter how carefully measured--may be inaccurate. Surveyors may make mistakes or data may be entered into the database incorrectly.

- The level of precision required for particular applications varies greatly. Engineering projects such as road and utility construction require very precise information measured to the millimeter or tenth of an inch. Demographic analyses of marketing or electoral trends can often make do with less, say to the closest zip code or precinct boundary.
- Highly precise data can be very difficult and costly to collect. Carefully surveyed locations needed by utility companies to record the locations of pumps, wires, pipes and transformers cost \$5-20 per point to collect.

High precision does not indicate high accuracy nor does high accuracy imply high precision. But high accuracy and high precision are both expensive.

Be aware also that GIS practitioners are not always consistent in their use of these terms. Sometimes the terms are used almost interchangeably and this should be guarded against.

Two additional terms are used as well:

1. **Data quality** refers to the relative accuracy and precision of a particular GIS database. These facts are often documented in data quality reports.
2. **Error** encompasses both the imprecision of data and its inaccuracies.

## TYPES OF ERROR

Positional error is often of great concern in GIS, but error can actually effect many different characteristics of the information stored in a database.

### 1. Positional accuracy and precision.

This applies to both horizontal and vertical positions.

Accuracy and precision are a function of the scale at which a map (paper or digital) was created. The mapping standards employed by the United States Geological Survey specify that:

"requirements for meeting horizontal accuracy as 90 per cent of all measurable points must be within 1/30th of an inch for maps at a scale of 1:20,000 or larger, and 1/50th of an inch for maps at scales smaller than 1:20,000."

### 2. Attribute accuracy and precision

The non-spatial data linked to location may also be inaccurate or imprecise. Inaccuracies may result from mistakes of many sorts. Non-spatial data can also vary greatly in precision. Precise attribute information describes phenomena in great detail. For example, a precise description of a person living at a particular address might include gender, age, income, occupation, level of education, and many other characteristics. An imprecise description might include just income, or just gender.

### 3. Conceptual accuracy and precision

GIS depend upon the abstraction and classification of real-world phenomena. The users determines what amount of information is used and how it is classified into appropriate categories. Sometimes users may use inappropriate categories or misclassify information. For example, classifying cities by voting behavior would probably be an ineffective way to study fertility patterns. Failing to classify power lines by voltage would limit the effectiveness of a GIS designed to manage an electric utilities infrastructure. Even if the correct categories are employed, data may be misclassified. A study of drainage systems may involve classifying streams and rivers by "order," that is where a particular drainage channel fits within the overall tributary network. Individual channels may be misclassified if tributaries are miscounted. Yet some studies might not require such a precise categorization of stream order at all. All they may need is the location and names of all stream and rivers, regardless of order.

### 4 Logical accuracy and precision

Information stored in a database can be employed illogically. For example, permission might be given to build a residential subdivision on a floodplain unless the user compares the proposed plat with floodplain maps. Then again, building may be possible on some portions of a floodplain but the user will not know unless variations in flood potential have also been recorded and are used in the comparison. The point is that information stored in a GIS database must be used and compared carefully if it is to yield useful results. GIS systems are typically unable to warn the user if inappropriate comparisons are being made

or if data are being used incorrectly. Some rules for use can be incorporated in GIS designed as "expert systems," but developers still need to make sure that the rules employed match the characteristics of the real-world phenomena they are modeling.

Finally, It would be a mistake to believe that highly accurate and highly precision information is needed for every GIS application. The need for accuracy and precision will vary radically depending on the type of information coded and the level of measurement needed for a particular application. The user must determine what will work. Excessive accuracy and precision is not only costly but can cause considerable details.

## SOURCES OF INACCURACY AND IMPRECISION

There are many sources of error that may affect the quality of a GIS dataset. Some are quite obvious, but others can be difficult to discern. Few of these will be automatically identified by the GIS itself. It is the user's responsibility to prevent them. Particular care should be devoted to checking for errors because GIS are quite capable of lulling the user into a false sense of accuracy and precision unwarranted by the data available. For example, smooth changes in boundaries, contour lines, and the stepped changes of choropleth maps are "elegant misrepresentations" of reality. In fact, these features are often "vague, gradual, or fuzzy" (Burrough 1986). There is an inherent imprecision in cartography that begins with the projection process and its necessary distortion of some of the data (Koeln and others 1994), an imprecision that may continue throughout the GIS process. Recognition of error and importantly what level of error is tolerable and affordable must be acknowledged and accounted for by GIS users.

Burrough (1986) divides sources of error into three main categories:

1. Obvious sources of error.
2. Errors resulting from natural variations or from original measurements.
3. Errors arising through processing.

Generally errors of the first two types are easier to detect than those of the third because errors arising through processing can be quite subtle and may be difficult to identify. Burrough further divided these main groups into several subcategories.

### 1 Obvious Sources of Error

#### *Age of data*

Data sources may simply be too old to be useful or relevant to current GIS projects. Past collection standards may be unknown, non-existent, or not currently acceptable. For instance, John Wesley Powell's nineteenth century survey data of the Grand Canyon lacks the precision of data that can be developed and used today. Additionally, much of the information base may have subsequently changed through erosion, deposition, and other geomorphic processes. Despite the power of GIS, reliance on old data may unknowingly skew, bias, or negate results.

#### *Areal Cover*

Data on a given area may be completely lacking, or only partial levels of information may be available for use in a GIS project. For example, vegetation or soils maps may be incomplete at borders and transition zones and fail to accurately portray reality. Another example is the lack of remote sensing data in certain parts of the world due to almost continuous cloud cover. Uniform, accurate coverage may not be available and the user must decide what level of generalization is necessary, or whether further collection of data is required.

#### *Map Scale*

The ability to show detail in a map is determined by its scale. A map with a scale of 1:1000 can illustrate much [finer points of data](#) than a smaller scale map of 1:250000. Scale restricts type, quantity, and quality of data (Star and Estes 1990). One must match the appropriate scale to the



level of detail required in the project. Enlarging a small scale map does not increase its level of accuracy or detail.

### **Density of Observations**

The number of observations within an area is a guide to data reliability and should be known by the map user. An insufficient number of observations may not provide the level of resolution required to adequately perform spatial analysis and determine the patterns GIS projects seek to resolve or define. A case in point, if the contour line interval on a map is 40 feet, resolution below this level is not accurately possible. Lines on a map are a generalization based on the interval of recorded data, thus the closer the sampling interval, the more accurate the portrayed data.

### **Relevance**

Quite often the desired data regarding a site or area may not exist and "[surrogate](#)" data may have to be used instead. A valid relationship must exist between the surrogate and the phenomenon it is used to study but, even then, error may creep in because the phenomenon is not being measured directly. A local example of the use of surrogate data are habitat studies of the golden-cheeked warblers in the Hill Country. It is very costly (and disturbing to the birds) to inventory these habitats through direct field observation. But the warblers prefer to live in stands of old growth cedar *Juniperus ashei*. These stands can be identified from aerial photographs. The density of *Juniperus ashei* can be used as surrogate measure of the density of warbler habitat. But, of course, some areas of cedar may uninhabited or inhibited to a very high density. These areas will be missed when aerial photographs are used to tabulate habitats.

Another example of surrogate data are electronic signals from remote sensing that are used to estimate vegetation cover, soil types, erosion susceptibility, and many other characteristics. The data is being obtained by an indirect method. Sensors on the satellite do not "see" trees, but only certain digital signatures typical of trees and vegetation. Sometimes these signatures are recorded by satellites even when trees and vegetation are not present (false positives) or not recorded when trees and vegetation are present (false negatives). Due to cost of gathering on site information, surrogate data is often substituted and the user must understand variations may occur and although assumptions may be valid, they may not necessarily be accurate.

### **Format**

Methods of formatting digital information for transmission, storage, and processing may introduce error in the data. Conversion of scale, projection, changing from raster to vector format, and resolution size of pixels are examples of possible areas for format error. Expediency and cost often require data reformation to the "lowest common denominator" for transmission and use by multiple GIS. Multiple conversions from one format to another may create a ratchet effect similar to making copies of copies on a photo copy machine. Additionally, international standards for cartographic data transmission, storage and retrieval are not fully implemented.

### **Accessibility.**

Accessibility to data is not equal. What is open and readily available in one country may be restricted, classified, or unobtainable in another. Prior to the break-up of the former Soviet Union, a common highway map that is taken for granted in this country was considered classified information and unobtainable to most people. Military restrictions, inter-agency rivalry, privacy laws, and economic factors may restrict data availability or the level of accuracy in the data.

### **Cost**

Extensive and reliable data is often quite expensive to obtain or convert. Initiating new collection of data may be too expensive for the benefits gained in a particular GIS project and project managers must balance their desire for accuracy the cost of the information. True accuracy is expensive and may be unaffordable.

## **2. Errors Resulting from Natural Variation or from Original Measurements.**

Although these error sources may not be as obvious, careful checking will reveal their influence on the project data.

### ***Positional accuracy***

Positional accuracy is a measurement of the variance of map features and the true position of the attribute (Antenucci and others 1991, p. 102). It is dependent on the type of data being used or observed. Map makers can accurately place well-defined objects and features such as roads, buildings, boundary lines, and discrete topographical units on maps and in digital systems, whereas less discrete boundaries such as [vegetation or soil type](#) may reflect the estimates of the cartographer. Climate, biomes, relief, soil type, drainage and other features lack sharp boundaries in nature and are subject to interpretation. Faulty or biased field work, [map digitizing errors](#) and conversion, and scanning errors can all result in inaccurate maps for GIS projects.

### ***Accuracy of content***

Maps must be correct and free from bias. Qualitative accuracy refers to the correct labeling and presence of specific features. For example, a pine forest may be incorrectly labeled as a spruce forest, thereby introducing error that may not be known or noticeable to the map or data user. Certain features may be omitted from the map or spatial database through oversight, or by design. Other errors in quantitative accuracy may occur from faulty instrument calibration used to measure specific features such as altitude, soil or water pH, or atmospheric gases. Mistakes made in the field or laboratory may be undetectable in the GIS project unless the user has conflicting or corroborating information available.

### ***Sources of variation in data***

Variations in data may be due to measurement error introduced by faulty observation, biased observers, or by mis-calibrated or inappropriate equipment. For example, one can not expect sub-meter accuracy with a hand-held, non-differential GPS receiver. Likewise, an incorrectly calibrated dissolved oxygen meter would produce incorrect values of oxygen concentration in a stream.

There may also be a natural variation in data being collected, a variation that may not be detected during collection. As an example, salinity in Texas bays and estuaries varies during the year and is dependent upon freshwater influx and evaporation. If one was not aware of this natural variation, incorrect assumptions and decisions could be made, and significant error introduced into the GIS project. In any case if the errors do not lead to unexpected results their detection may be extremely difficult.

## **3. Errors Arising Through Processing**

Processing errors are the most difficult to detect by GIS users and must be specifically looked for and require knowledge of the information and the systems used to process it. These are subtle errors that occur in several ways, and are therefore potentially more insidious, particularly because they can occur in multiple sets of data being manipulated in a GIS project.

### ***Numerical Errors***

Different computers may not have the same capability to perform complex mathematical operations and may produce significantly different results for the same problem. Burrough (1990) cites an example in number squaring that produced 1200% difference. Computer processing errors occur in rounding off operations and are subject to the inherent limits of number manipulation by the processor. Another source of error may from faulty processors, such as the recent mathematical problem identified in Intel's Pentium(tm) chip. In certain calculations, the chip would yield the wrong answer.

A major challenge is the accurate conversion of existing maps to digital form (Muehrcke 1986). Because computers must manipulate data in a digital format, numerical errors in processing can lead to inaccurate results. In any case numerical processing errors are extremely difficult to detect, and perhaps assume a sophistication not present in most GIS workers or project managers.

### ***Errors in Topological Analysis***

Logic errors may cause incorrect manipulation of data and topological analyses (Star and Estes 1990). One must recognize that data is not uniform and is subject to variation. Overlaying multiple layers of maps can result in problems such as [Slivers](#), [Overshoots](#), and [Dangles](#). Variation in accuracy between different map layers may be obscured during processing leading to the creation of "virtual data which may be difficult to detect from real data" (Sample 1994).

### **Classification and Generalization Problems**

For the human mind to comprehend vast amounts of data it must be classified, and in some cases generalized, to be understandable. According to Burrough (1986, pp. 137) about seven divisions of data is ideal and may be retained in human short term memory. Defining class intervals is another problem area. For instance, defining a cause of death in males between 18-25 years old would probably be significantly different in a class interval of 18-40 years old. Data is most accurately displayed and manipulated in small multiples. Defining a reasonable multiple and asking the question "compared to what" is critical (Tufte 1990, pp. 67-79). Classification and [generalization of attributes](#) used in GIS are subject to interpolation error and may introduce irregularities in the data that is hard to detect.

### **Digitizing and Geocoding Errors**

Processing errors occur during other phases of data manipulation such as digitizing and geocoding, overlay and boundary intersections, and errors from rasterizing a vector map. Physiological errors of the operator by involuntary muscle contractions may result in [spikes](#), [switchbacks](#), [polygonal knots](#), and [loops](#). Errors associated with damaged source maps, [operator error while digitizing](#), and bias can be checked by comparing original maps with digitized versions. Other errors are more elusive.

## **7.0 REMOTE SENSING**

(source : <http://www.gisdevelopment.net/tutorials/tuman008.htm>)

### **An Introduction**

Remote Sensing is the science and art of acquiring information (spectral, spatial, temporal) about material objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation. Without direct contact, some means of transferring information through space must be utilised. In remote sensing, information transfer is accomplished by use of electromagnetic radiation (EMR). EMR is a form of energy that reveals its presence by the observable effects it produces when it strikes the matter. EMR is considered to span the spectrum of wavelengths from 10-10 mm to cosmic rays up to 1010 mm, the broadcast wavelengths, which extend from 0.30-15 mm.

### **Types**

1. In respect to the type of Energy Resources:
  - Passive Remote Sensing: Makes use of sensors that detect the reflected or emitted electromagnetic radiation from natural sources.
  - Active remote Sensing: Makes use of sensors that detect reflected responses from objects that are irradiated from artificially-generated energy sources, such as radar.
2. In respect to Wavelength Regions: Remote Sensing is classified into three types in respect to the wavelength regions
  1. Visible and Reflective Infrared Remote Sensing.
  2. Thermal Infrared Remote Sensing.
  3. Microwave Remote Sensing.

### **Some Interesting Links :**

- [Remote Sensing](#)  
An Overview of Remote Sensing

- Remote Sensing of the Global Environment  
An Article by David J. Schneider, Michigan Technological University
- The Concept of Remote Sensing  
Historical & Technical Perspectives of Remote Sensing
- RS Introduction and History  
An Article from Earth Observatory, NASA
- The philosophical underpinnings of remote sensing  
The Philosophy behind Remote Sensing can perhaps....- An Article by GDSPDS
- GOES 3.9um Channel Tutorial  
An excellent tutorial on Thermal Remote Sensing

### **Bands Used in Remote Sensing**

Emission of EMR (Electro-Magnetic Radiation) from gases is due to atoms and molecules in the gas. Atoms consist of a positively charged nucleus surrounded by orbiting electrons, which have discrete energy states. Transition of electrons from one energy state to the other leads to emission of radiation at discrete wavelengths. The resulting spectrum is called line spectrum. Molecules possess rotational and vibrational energy states. Transition between which leads to emission of radiation in a band spectrum. The wavelengths, which are emitted by atoms/molecules, are also the ones, which are absorbed by them. Emission from solids and liquids occurs when they are heated and results in a continuous spectrum. This is called thermal emission and it is an important source of EMR from the viewpoint of remote sensing.

The **Electro-Magnetic Radiation** (EMR), which is reflected or emitted from an object, is the usual source of Remote Sensing data. However, any medium, such as gravity or magnetic fields, can be used in remote sensing.

Remote Sensing Technology makes use of the wide range Electro-Magnetic Spectrum (EMS) from a very short wave "Gamma Ray" to a very long 'Radio Wave'.

Wavelength regions of electro-magnetic radiation have different names ranging from Gamma ray, X-ray, Ultraviolet (UV), Visible light, Infrared (IR) to Radio Wave, in order from the shorter wavelengths.

The optical wavelength region, an important region for remote sensing applications, is further subdivided as follows:

<b>Name</b>	<b>Wavelength (mm)</b>
Optical wavelength	0.30-15.0
Reflective	0.38-3.00
1. Portion Visible	0.38-0.72
2. Near IR	0.72-1.30
3. Middle IR	1.30-3.00
Far IR (Thermal, Emissive)	7.00-15.0

Microwave region (1mm to 1m) is another portion of EM spectrum that is frequently used to gather valuable remote sensing information.

### **Spectral Characteristics vis-à-vis different systems.**

The sunlight transmission through the atmosphere is effected by absorption and scattering of atmospheric molecules and aerosols. This reduction of the sunlight's intensity is called extinction. The interrelationship between energy sources and atmospheric absorption characteristics is shown in Figure 3

- Figure 3(a) shows the spectral distribution of the energy emitted by the sun (black body at 58000 K and by earth features black body at 3000 K). These two curve represent the most common sources of energy used in remote sensing.
- Figure 3(b) shows the spectral regions in which the atmosphere blocks the energy are shaded. Remote-sensing data acquisition is limited to the unblocked spectral regions called atmospheric windows.
- Figure 3(c) shows that the spectral sensitivity range of the eye (the 'visible' range) coincides with an 'atmospheric window' and the peak level of energy from the sun.
- Figure 3 (d) shows the example of atmospheric transmission characteristics and notes some of the important 'atmospheric windows'. An 'atmospheric window' is a portion of Electro-magnetic spectrum in which the radiation passing through the atmosphere is not significantly altered by reflection, or absorption, or scattered by atmospheric constituents. Some useful atmospheric windows are given in the table.

The important point to note from the figures is the interaction and the interdependence between the primary sources of Electro-magnetic energy, the atmospheric windows through which source energy may be transmitted to and from the earth's surface features, and the spectral sensitivity of the sensors available to detect and record the energy. One cannot select the sensors to be used in any given remote-sensing task arbitrarily; one must instead consider

1. the available spectral sensitivity of the sensors,
2. the presence or absence of atmospheric windows in the spectral range(s) in which one wishes to sense, and
3. the source, magnitude, and spectral composition of the energy available in these ranges.

Ultimately, however, the choice of spectral range of the sensor must be based on the manner in which the energy interacts with the features under investigation.

### **Energy Interactions, Spectral Reflectance and Colour Readability in Satellite Imagery**

All matter is composed of atoms and molecules with particular compositions. Therefore, matter will emit or absorb electro-magnetic radiation on a particular wavelength with respect to the inner state. All matter reflects, absorbs, penetrates and emits Electro-magnetic radiation in a unique way. Electro-magnetic radiation through the atmosphere to and from matters on the earth's surface are reflected, scattered, diffracted, refracted, absorbed, transmitted and dispersed. For example, the reason why a leaf looks green is that the chlorophyll absorbs blue and red spectra and reflects the green. The unique characteristics of matter are called spectral characteristics.

#### **Energy Interactions**

When electro-magnetic energy is incident on any given earth surface feature, three fundamental energy interactions with the feature are possible. See Figure 4

#### **Spectral Reflectance & Colour Readability**

Two points about the above given relationship (expressed in the form of equation) should be noted.

1. The proportions of energy reflected, absorbed, and transmitted will vary for different earth features, depending upon their material type and conditions. These differences permit us to distinguish different features on an image.
2. The wavelength dependency means that, even within a given feature type, the proportion of reflected, absorbed, and transmitted energy will vary at different wavelengths.

Thus, two features may be distinguishable in one spectral range and be very different on another wavelength band. Within the visible portion of the spectrum, these spectral variations result in the visual effect called COLOUR. For example we call blue objects 'blue' when they reflect highly in the 'green' spectral region, and so on. Thus the eye uses spectral variations in the magnitude of reflected energy to discriminate between various objects.



A graph of the spectral reflectance of an object as a function of wavelength is called a spectral reflectance curve. The configuration of spectral reflectance curves provides insight characteristics of an object and has a strong influence on the choice of wavelength region(s) in which remote sensing data are acquired for a particular application. This is illustrated in figure 5, which shows highly generalized spectral reflectance curves of deciduous and coniferous trees. (In the discussion, we use the terms deciduous and coniferous somewhat loosely, referring to broad-leaved trees, such as Oak and Maple, as deciduous and to needle-bearing trees, such as pine and spruce, as coniferous.) It should be noted that the curve for each of these object types is plotted as a 'ribbon' (or 'envelope') of values, not as a single line. This is because spectral reflectances vary somewhat within a given material class. That is, the spectral reflectance of one deciduous tree species and another will never be identical. Nor will the spectral reflectance of trees of the same species ever be exactly equal.

Figure 6 shows the typical spectral reflectance curves for three basic types of earth feature:

- Green vegetation
- Soil
- Water.

The lines in this figure represent average reflectance curves compiled by measuring large sample features. It should be noted how distinctive the curves are for each feature. In general, the configuration of these curves is an indicator of the type and condition of the features to which they apply. Although the reflectance of individual features will vary considerably above and below the average, these curves demonstrate some fundamental points concerning spectral reflectance.

#### **Colour Discrimination based on Wavelengths of Spectral Reflectances.**

(IRS-IA/IB LISS I and LISSII\*)

<b>Band</b>	<b>wavelength (<math>\mu\text{m}</math>)</b>	<b>Principal</b>
1	0.45-0.52	Sensitive to sedimentation, deciduous/coniferous forest cover discrimination, soil vegetation differentiation
2	0.52-0.59	Green reflectance by healthy vegetation, vegetation vigour, rock-soil discrimination, turbidity and bathymetry in shallow waters
3	0.62-0.68	Sensitive to chlorophyll absorption: plant species discrimination, differentiation of soil and geological boundary
4	0.77-0.86	Sensitive to green biomass and moisture in vegetation, land and water contrast, landform/geomorphic studies.

\*Spatial Resolution of Linear imaging self scanning (LISS): LISS-I (72.5 m) and LISS-II (36.25m)

#### **Electro-Magnetic Remote Sensing of Earth's Resources — Process & Elements**

##### **Major Components of Remote Sensing Technology:**

The following are major components of Remote sensing System:

1. Energy Source
  1. Passive System: sun, irradiance from earth's materials;
  2. Active System: irradiance from artificially generated energy sources such as radar.
1. Platforms:(Vehicle to carry the sensor) (truck, aircraft, space shuttle, satellite, etc.)
2. Sensors:(Device to detect electro-magnetic radiation) (camera, scanner, etc.)
3. Detectors: (Handling signal data) (photographic, digital, etc.)
4. Processing:(Handling Signal data) (photographic, digital etc.)

5. Institutionalisation: (Organisation for execution at all stages of remote-sensing technology: international and national organisations, centres, universities, etc.).

### Platforms

The vehicles or carriers for remote sensors are called the platforms. Typical platforms are satellites and aircraft, but they can also include radio-controlled aeroplanes, balloons kits for low altitude remote sensing, as well as ladder trucks or 'cherry pickers' for ground investigations. The key factor for the selection of a platform is the altitude that determines the ground resolution and which is also dependent on the instantaneous field of view (IFOV) of the sensor on board the platform.

Salient feature of some important satellite platforms.

Features	Landsat1,2,3	Landsat 4,5	SPOT	IRS-IA	IRS-IC
Natre	Sun Sys	Sun Sys	Sun Sys	Sun Sys	Sun Sys
Altitude (km)	919	705	832	904	817
Orbital period (minutes)	103.3	99	101	103.2	101.35
inclination (degrees)	99	98.2	98.7	99	98.69
Temporal resolution (days)	18	16	26	22	24
Revolutions	251	233	369	307	341
Equatorial crossing (AM)	09.30	09.30	10.30	10.00	10.30
Sensors	RBV,MSS	MSS,TM	HRV	LISS-I,LISS-II	LISS-III,PAN,WIFS

**SENSORS**

<p align="center"><b><u>ACTIVE SENSORS</u></b> (Detect the reflected or emitted electromagnetic radiation from natural sources.)</p>	<p align="center"><b><u>PASSIVE SENSORS</u></b> (Detect reflected responses from objects that are irradiated from artificially-generated energy sources such as radar.)</p>
<p>Passive Non-Scanning</p> <p><u>Non-Imaging.</u> (They are a type of profile recorder, ex. Microwave Radiometer. Magnetic sensor.Gravimeter.Fourier Spectrometer.</p> <p><u>Imaging.</u> (Example of this are the cameras which can be: Monochrome, Natural Colour, Infrared etc.)</p> <p>Scanning</p> <p><u>Imaging.</u> Image Plane scanning.Ex. TV CameraSolid scanner.Object Plane scanning.Ex. Optical Mechanical ScannerMicrowave radiometer.</p>	<p>Active Non-Scanning</p> <p><u>Non-Imaging.</u> (They are a type of profile recorder, ex. Microwave Radiometer.Microwave Altimeter.Laser Water Depth Meter.Laser Distance Meter.</p> <p>Scanning</p> <p><u>Imaging.</u> (It is a radar ex. Object Plane scanning:</p> <p>Real Aperture Radar. Synthetic Aperture Radar.</p> <p>Image Plane Scanning: Passive Phased Array Radar.</p>

**Resolution**

In general resolution is defined as the ability of an entire remote-sensing system, including lens antennae, display, exposure, processing, and other factors, to render a sharply defined image. Resolution of a remote-sensing is of different types.

1. Spectral Resolution: of a remote sensing instrument (sensor) is determined by the band-widths of the Electro-magnetic radiation of the channels used. High spectral resolution, thus, is achieved by narrow bandwidths width, collectively, are likely to provide a more accurate spectral signature for discrete objects than broad bandwidth.
2. Radiometric Resolution: is determined by the number of discrete levels into which signals may be divided.
3. Spatial Resolution: in terms of the geometric properties of the imaging system, is usually described as the instantaneous field of view (IFOV). The IFOV is defined as the maximum angle of view in which a sensor can effectively detect electro-magnetic energy.
4. Temporal Resolution: is related to the repetitive coverage of the ground by the remote-sensing system. The temporal resolution of Landsat 4/5 is sixteen days.

**An Ideal Remote Sensing System**

Having introduced some basic concepts, we now have the necessary elements to conceptualize an ideal remote sensing system. In doing so, we can then appreciate some of the problems encountered in the design and application of the various real remote-sensing systems examined in subsequent chapters.

The basic components of an ideal remote-sensing system are shown in figure 8. These include the following components.

- A uniform energy source. This source will provide energy over all wavelengths, at a constant, known, high level of output, irrespective of time and place.

- A non-interfering atmosphere. This will be an atmosphere that will not modify the energy from the source in any manner, whether that energy is on its way to earth's surface or coming from it. Again, ideally this will hold irrespective of wavelength, time, place, and sensing altitude involved.
- A series of unique energy/matter interaction at the earth's surface. These interactions will generate reflected and/or emitted signals that are not only selective in respect to wavelengths, but also are known, invariant, and unique to each and every earth surface feature type and subtype of interest.
- A super sensor. This will be a sensor, highly sensitive to all wavelengths, yielding spatially detailed data on the absolute brightness (or radiance) from a scene (a function of wavelength), throughout the spectrum. This super sensor will be simple and reliable, require, virtually no power or space, and be accurate and economical to operate.
- A real-time data handling system. In this system, the instant the radiance versus wavelength response over a terrain element is generated, it will be processed into an interpretable format and recognized as being unique to the particular terrain element from which it comes. This processing will be performed nearly instantaneously (real time), providing timely information. Because of the consistent nature of the energy/matter interactions, there will be no need for reference data in the analytical procedure. The derived data will provide insight into the physical-chemical-biological state of each feature of interest.
- Multiple data users. These people will have comprehensive knowledge of both their respective disciplines and of remote-sensing data acquisition and analysis techniques. The same set of data will become various forms of information for different users, because of their vast knowledge about the particular earth resources being used.

Unfortunately, an ideal remote-sensing system, as described above, does not exist. Real remote-sensing systems fall short of the ideal at virtually every point in the sequence outlined.

### **Remote Sensing Satellites**

A satellite with remote sensors to observe the earth is called a remote-sensing satellite, or earth observation satellite. Remote-Sensing Satellites are characterised by their altitude, orbit and sensor.

#### **TRIOS Series (1960-1965)**

The Television and Infrared Observation Satellites.

**NOAA** It is the first generation of National Oceanic and Atmospheric Administration satellites and was as the first operation operational remote sensing satellite system.

The third generation NOAA satellites are also successfully used for vegetation monitoring, apart from meteorological monitoring. It is equipped with Advanced Very High Resolution Radiometer (AVHRR) sensors, and is established at an altitude of 850 km. In polar orbit.

**GMS** Geo-synchronous meteorological satellite. It is established at an altitude of 36,000 km, and its main purpose is meteorological observations

**Landsat** is established at an altitude of 700 Kms is a polar orbit and is used mainly for land area observation.

Other remote sensing satellite series in operations are: **SPOT, MOS, JERS, ESR, RADARSAT, IRS** etc.

**Some Interesting Links :**

## 8.0 FCC

**False color** (or **false colour**) refers to a group of [color rendering methods](#) used to display images in color which were recorded in the [visible](#) or non-visible parts of the [electromagnetic spectrum](#). A **false-color image** is an image that depicts an object in [colors](#) that differ from those a [photograph](#) (a "**true-color**" image) would show.

In addition, variants of *false color* such as **pseudocolor** ([see discussion](#)), **density slicing** ([see discussion](#)), and **choropleths** ([see discussion](#)) are used for [information visualization](#) of either data gathered by a single grayscale channel or data not depicting parts of the electromagnetic spectrum (e.g. elevation in relief maps or tissue types in [magnetic resonance imaging](#)).

### Keys of Satellite Image Interpretation

Recognizing targets is the key to interpretation and information extraction. Observing the differences between targets and their backgrounds involves comparing different targets based on any, or all, of the visual elements of **tone, shape, size, pattern, texture, shadow, and association**. Visual interpretation using these elements is often a part of our daily lives, whether we are conscious of it or not. Examining satellite images on the weather report, or following high speed chases by views from a helicopter are all familiar examples of visual image interpretation. Identifying targets in remotely sensed images based on these visual elements allows us to further interpret and analyze. The nature of each of these interpretation elements is described below, along with an image example of each.



**Tone** refers to the relative brightness or colour of objects in an image. Generally, tone is the fundamental element for distinguishing between different targets or features. Variations in tone also allows the elements of shape, texture, and pattern of objects to be distinguished.





**Shape** refers to the general form, structure, or outline of individual objects. Shape can be a very distinctive clue for interpretation. Straight edge shapes typically represent urban or agricultural (field) targets, while natural features, such as forest edges, are generally more irregular in shape, except where man has created a road or clear cuts. Farm or crop land irrigated by rotating sprinkler systems would appear as circular shapes.



**Size** of objects in an image is a function of scale. It is important to assess the size of a target relative to other objects in a scene, as well as the absolute size, to aid in the interpretation of that target. A quick approximation of target size can direct interpretation to an appropriate result more quickly. For example, if an interpreter had to distinguish zones of land use, and had identified an area with a number of buildings in it, large buildings such as factories or warehouses would suggest commercial property, whereas small buildings would indicate residential use.



**Pattern** refers to the spatial arrangement of visibly discernible objects. Typically an orderly repetition of similar tones and textures will produce a distinctive and ultimately recognizable pattern. Orchards with evenly spaced trees, and urban streets with regularly spaced houses are good examples of pattern.



**Texture** refers to the arrangement and frequency of tonal variation in particular areas of an image. Rough textures would consist of a mottled tone where the grey levels change abruptly in a small area, whereas smooth textures would have very little tonal variation. Smooth textures are most often the result of uniform, even surfaces, such as fields, asphalt, or grasslands. A target with a rough surface and irregular structure, such as a forest canopy, results in a rough textured appearance. Texture is one of the most important elements for distinguishing features in radar imagery.



**Shadow** is also helpful in interpretation as it may provide an idea of the profile and relative height of a target or targets which may make identification easier. However, shadows can also reduce or eliminate interpretation in their area of influence, since targets within shadows are much less (or not at all) discernible from their surroundings. Shadow is also useful for enhancing or identifying topography and landforms, particularly in radar imagery.

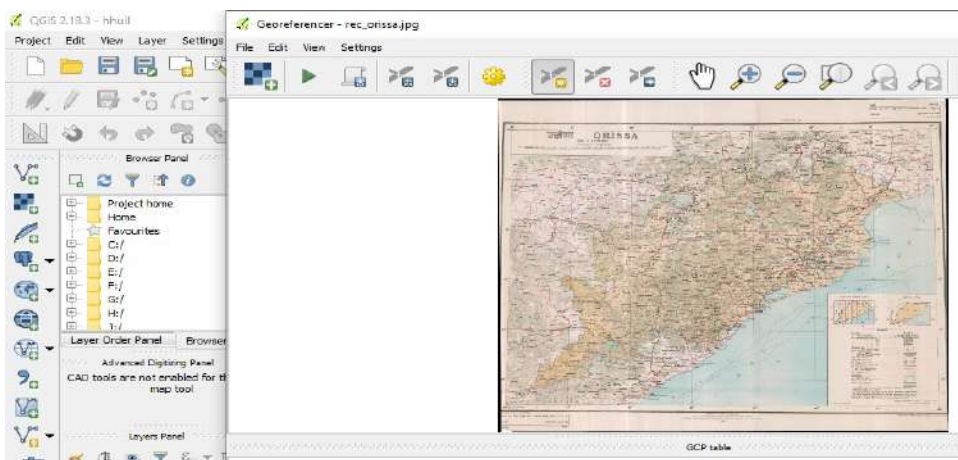
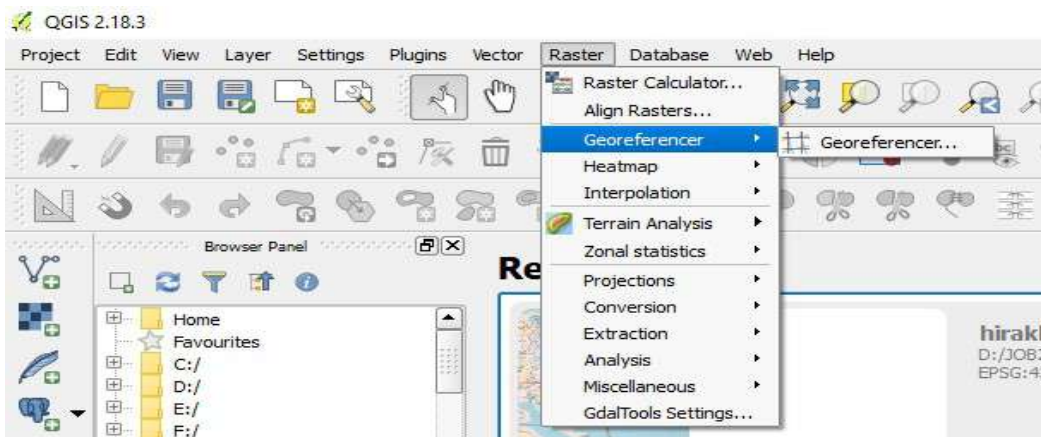


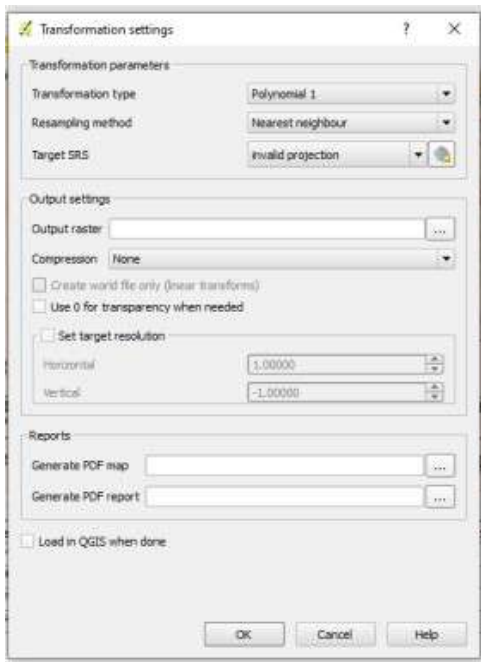
**Association** takes into account the relationship between other recognizable objects or features in proximity to the target of interest. The identification of features that one would expect to associate with other features may provide information to facilitate identification. In the example given above, commercial properties may be associated with proximity to major transportation routes, whereas residential areas would be associated with schools, playgrounds, and sports fields. In our example, a lake is associated with boats, a marina, and adjacent recreational land.

## 9.0 HANDS ON IN QGIS

### Georeferencing

- Open QGIS
- Go to Layer Menu
- Add Raster Layer
- Open Odisha.jpg file provided to you
- Now Odisha raster image will be displayed in view area
- Then Go to Raster Menu
- Select Georeferencer
- A new Georeferencer Window will open
- In this window, Go to Open Raster (top left most button)
- The Odisha map (raster will be added to this window)
- Go to Add GCP point button
- Then add GCP points at the known coordinate locations on this Odisha map and input the longitude (X) and latitude (Y) values for at least four such known locations
- Once done with, then Click on Start Georeferencing Button on the top 2<sup>nd</sup> left in button bar
- A Dialog Box will appear and enter the output raster file (Odisha\_Geo) name and click OK
- The output Georeferenced raster map of Odisha i.e. Odisha\_Geo.jpg will be added to view





- Start Georeferencing of Odisha Map
- In the Georeferenced Odisha Map, Find the coordinates of Bhubaneswar, Sambalpur, Raurkela, Puri, Baleswar
- Find the distances of all other places from Bhubaneswar and prepare a table.

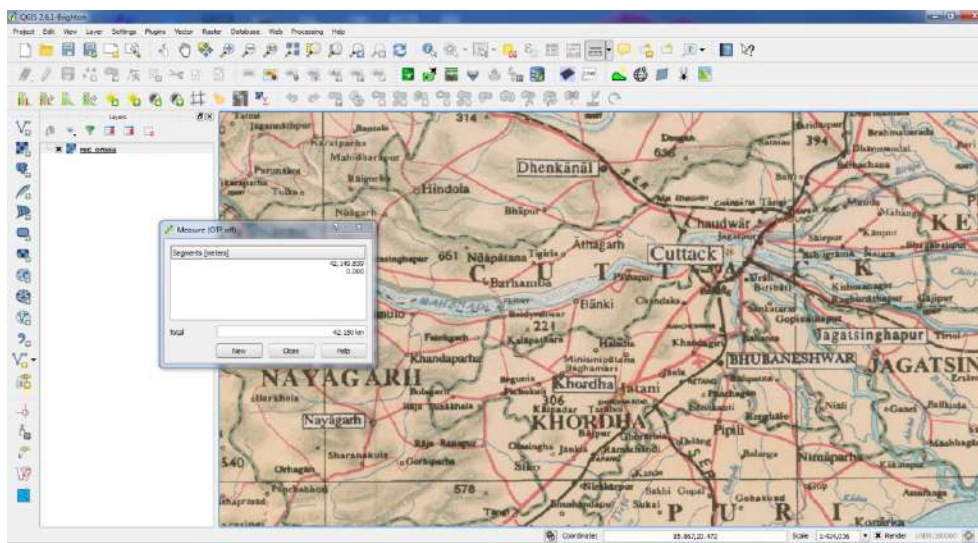
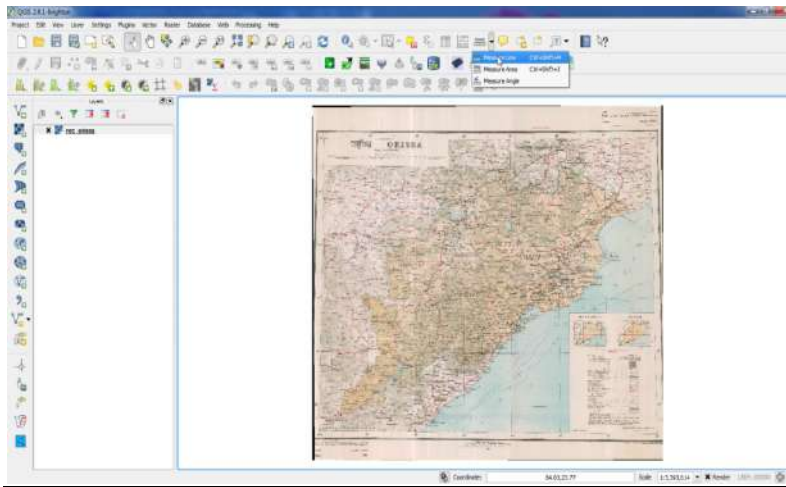
Sl	Place	Longitude	Lattitude	Distance from Bhubaneswar
1	Bhubaneswar			
2	Sambalpur			
3	Raurkela			
6	Puri			
7	Baleswar			

- Put the Coordinates on Google Earth and Check these locations.
- Take a screenshot/clipping of Google map with these Points.
- Send the google map and the table to the email id:

lusinayak28591@gmail.com

## Distance Measurement

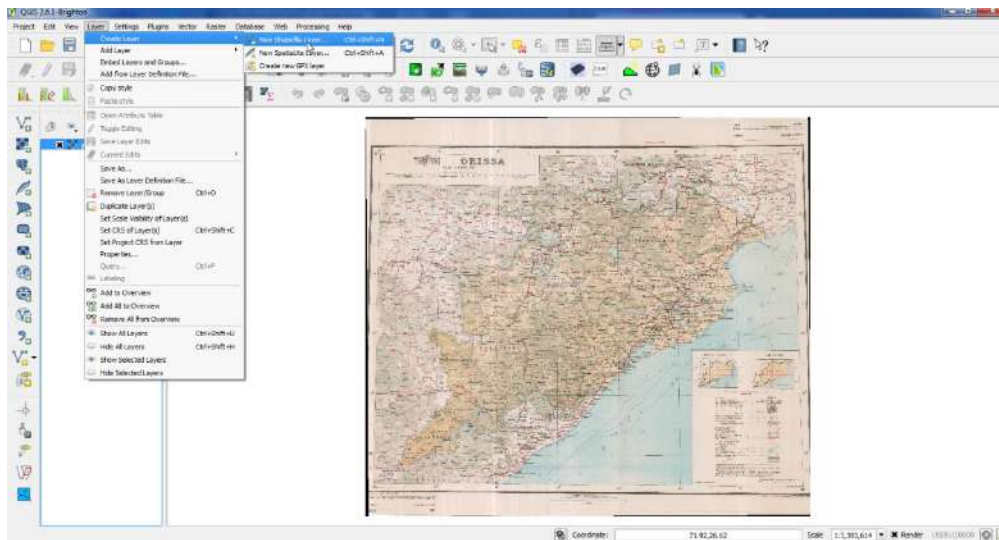
- Open QGIS
- Go to Layer Menu
- Add Raster Layer
- Open Odisha.jpg file provided to you
- Now Odisha raster image will be displayed in view area
- Then Go to Toolbar
- Select Measurement Toolbar
- Choose what you want a measure: a distance (Measure Line), a surface area (Measure Area) or an angle (Measure Angle). The Measure window will open
- Put your Cursor in the map image and click on the starting point
- Draw a line: left Clicking will create a node and right clicking will mark the end point. At Area you can create a multiple angled shape. In the measure window you can read the distance.
- Click on close in the Measure window (otherwise the line, area or angle will stay in the map image)



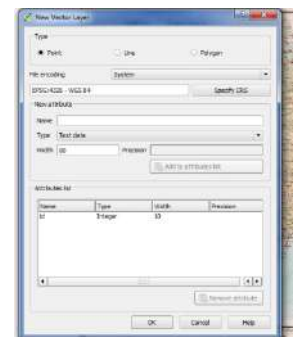


**Point Layer Creation for Towns on Odisha Map**

- Open QGIS
- Go to Layer Menu
- Select *Layer > New > New Shape file Layer* to create the new empty layer for your vector feature
- You will be prompted to confirm the Coordinate Reference System for the layer. By default, the Coordinate Reference System for the project is used
- Click on the *Capture Points* button
- Click points at your chosen location, and choose a name for each point feature
- Click on *Toggle editing* to save the vector point layer

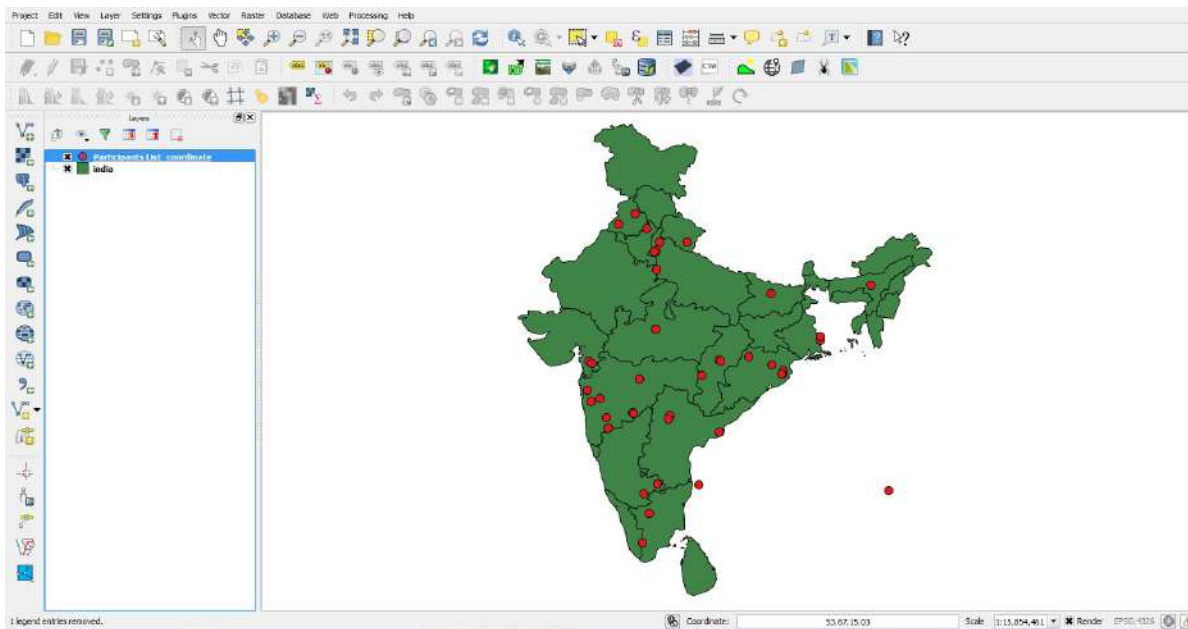


- The **Type of feature** you are tracing - point, line or polygon
- The **Name of the Attribute** you are tracing
- The **Type** of the Attribute - eg. Text, Whole Number
- The **Width** of the field for the Attribute. Select *Add to Attribute list*
- The **Shapefile Name** to save the layer as

**Point Layer Creation from Excel file of Coordinates of Participants**

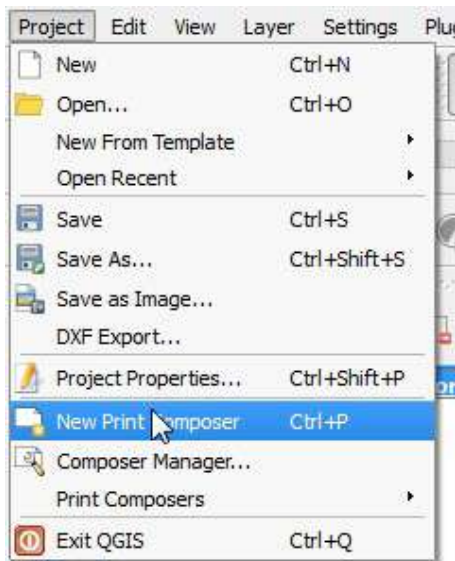


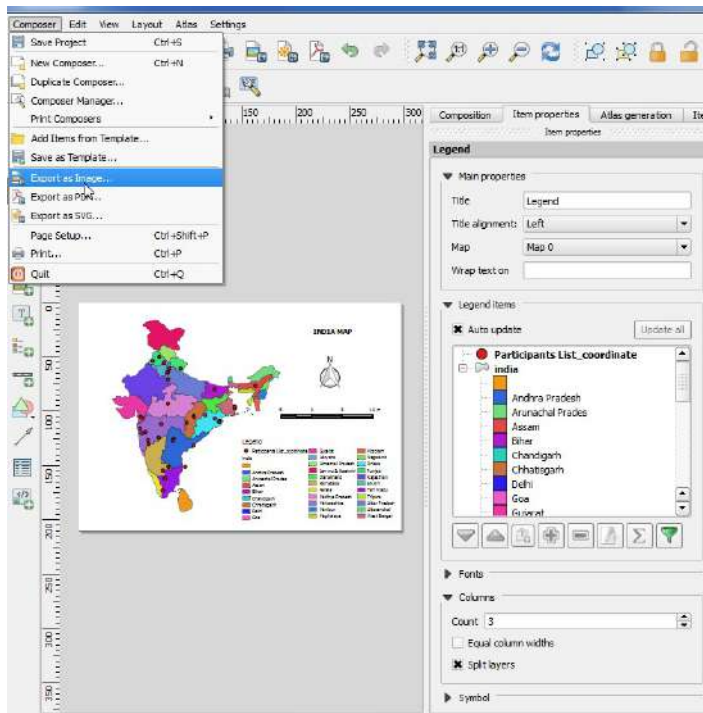
- Open Excel File
- Go to office Button
- Then Save as your File Format in Text (Tab Delimited) > Then Save
- Open QGIS
- Go to Layer Menu > Add Layer > Add Delimited Text Layer > Then Browse > Add Your Text Layer
- Then File Format Select In (Custom delimiters)
- "X" field is Longitude and "Y" Field is Latitude > Then OK.



### Map Layout Composition

- Open QGIS
- Go to Project Menu
- Then Select "New Print Composer" > Add Composer title > Then OK
- Select Your Layout Menu > Add Map
- Once the Add Map button is active, hold the left mouse button and drag a rectangle where you want to insert the map.
- Let us adjust the zoom level for the given map. Click on the Item Properties tab and enter 15000000 for Scale value.
- Add Label > Enter Your Title Name
- Add Image > Click on Item Properties tab and enter Search directories > Select your North Arrow > Then Add
- Then Add Scale bar
- Add Legend
- Then Go to Composer Menu > Export as Image







# Photogrammetry

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- The method of determining the shapes, sizes and position of objects using photographs.
- based on the possibility of optically projecting the terrain onto a flat surface



# Use of photogrammetry

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- Determining spatial information
  - Distance
  - Elevation
  - Area
  - Volume
  - Cross -section
- Construction of topographical map



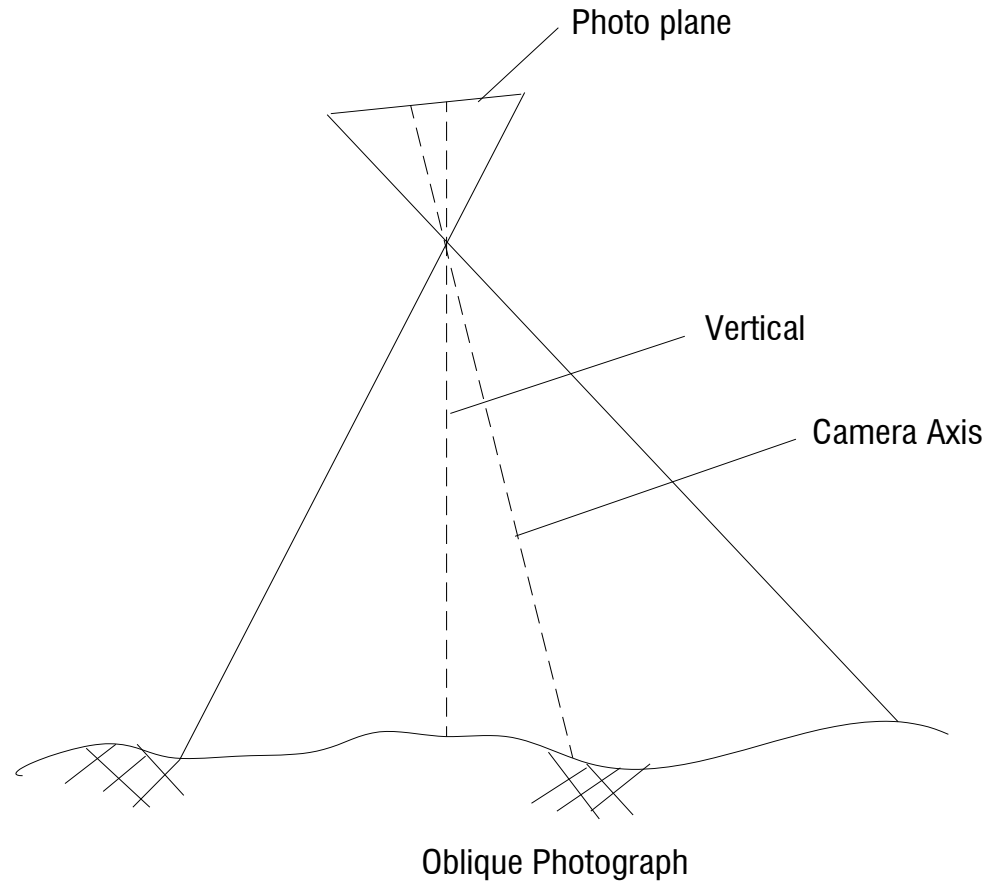
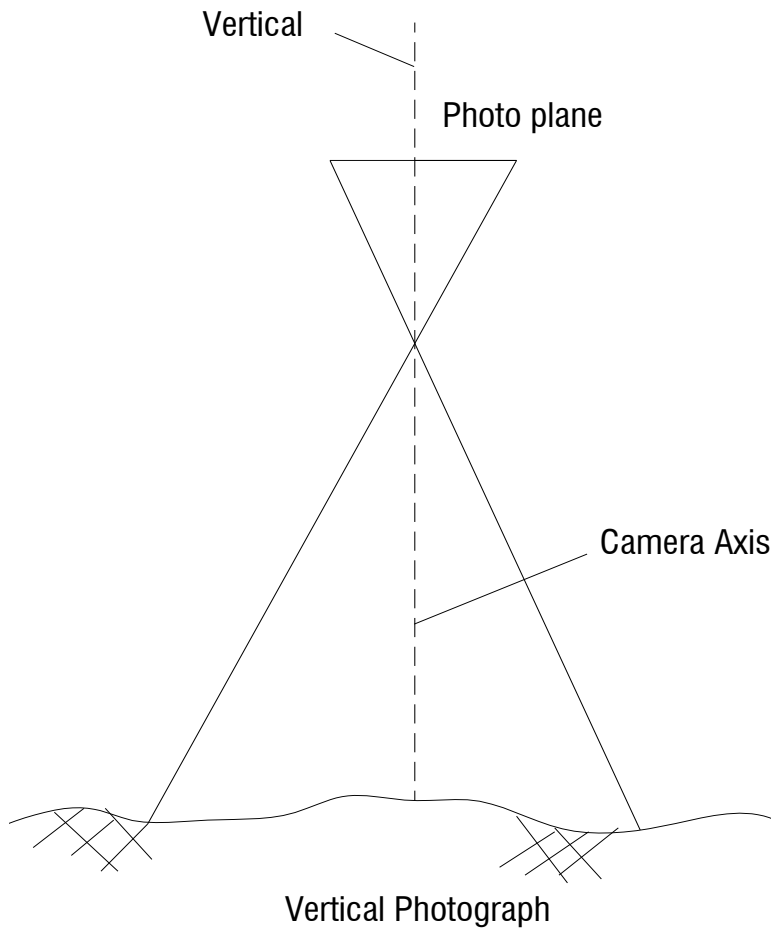


# Two types photogrammetry

---

- **Aerial:** photograph taken from air
  
- **Terrestrial:** photograph taken on or near the ground

# Two types of photographs



# Vertical photograph





# Oblique photograph





# Advantage of aerial photograph

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- Speed of coverage of an area
- Ease of obtaining topography in inaccessible area
- Freedom from possible omission of data in the field
- The tremendous amount of detail shown



# History of photogrammetry

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- 1851 --- produced the first camera
- 1858 --- aerial photograph began from balloons and measurement on photographs
- 1875 – produced the first aerial camera
- 1888 --- ground photography began
- 1901 --- introduced stereoscopic principle of measurement
- World War II gave rise to a new development of aerial photographs



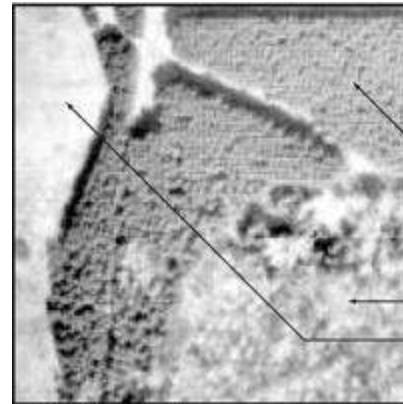
# What information can I find on an air photo?



A15183-37 (September 1955)  
Chinchaga River, Alberta

## Shape

"U"-shaped oxbow lakes



A26458-82 (May 1984)  
CFB Uplands  
Ottawa, Ontario

## Pattern

Plantation forest

Natural forest

Open field

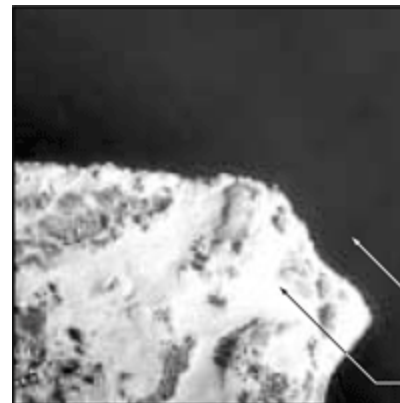


A28411-345 (May 1999)  
Highway 401 & Dufferin  
Toronto, Ontario

## Size

Residential street

Multi-lane highway



A26999-20 (August 1986)  
Sandbanks Provincial Park  
Picton, Ontario

## Tone/Color

Water

Sand

# What information .....



## Shadow

High-rise building  
(long shadow)

Low-rise building  
(short shadow)

A27773-86 (July 1991)  
Notre Dame Ouest & Autoroute Bonaventure  
Montréal, Quebec



## Texture

Calm water (smooth)

Forest (rough)

A22288-4 (July 1971)  
Lake Louise, Alberta



## Association /Site

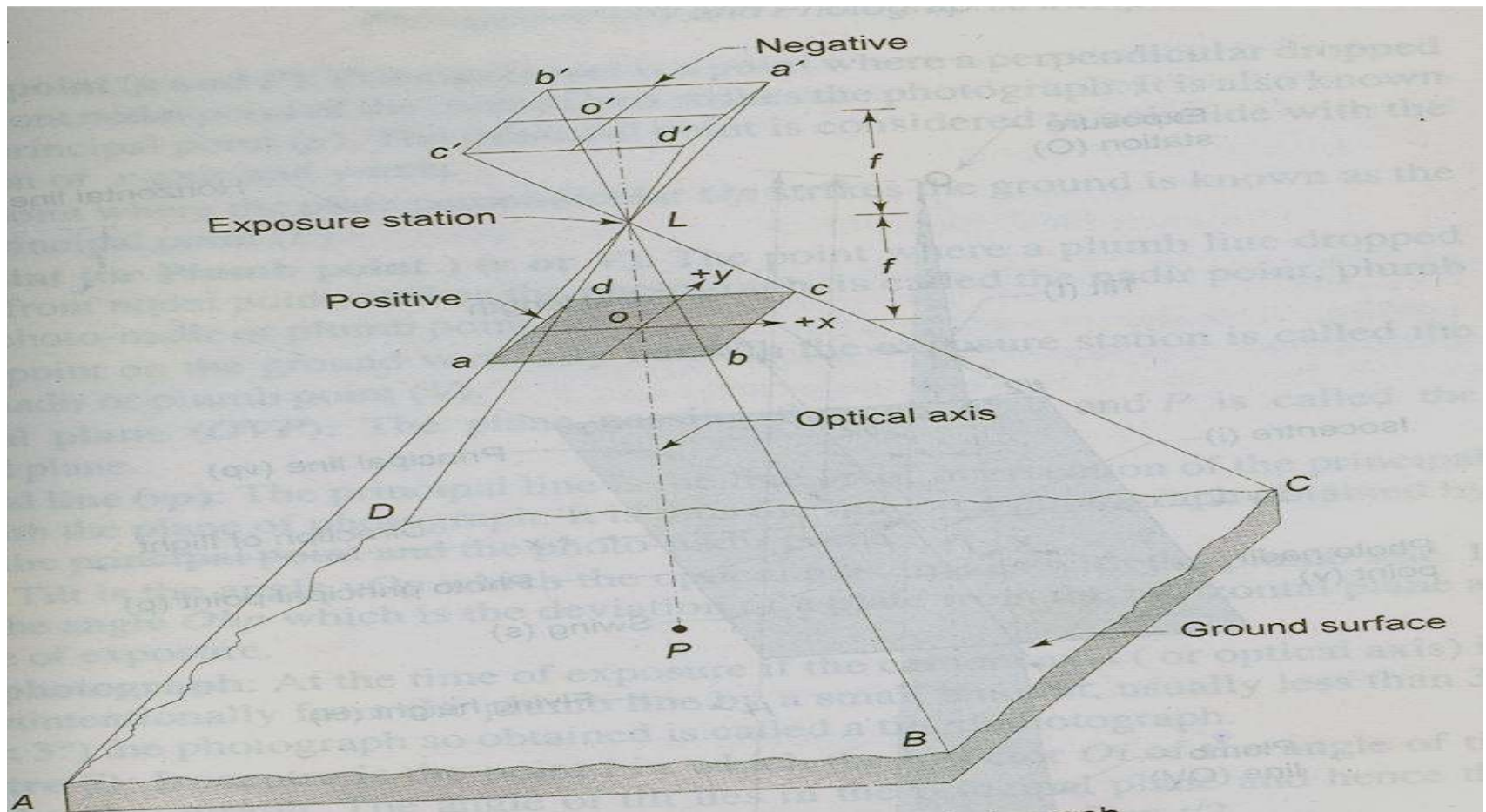
Dry-dock for ships

Railway access

Water

A27949-186 (July 1993)  
Esquimalt Harbour, British Columbia

# Aerial Photogrammetry





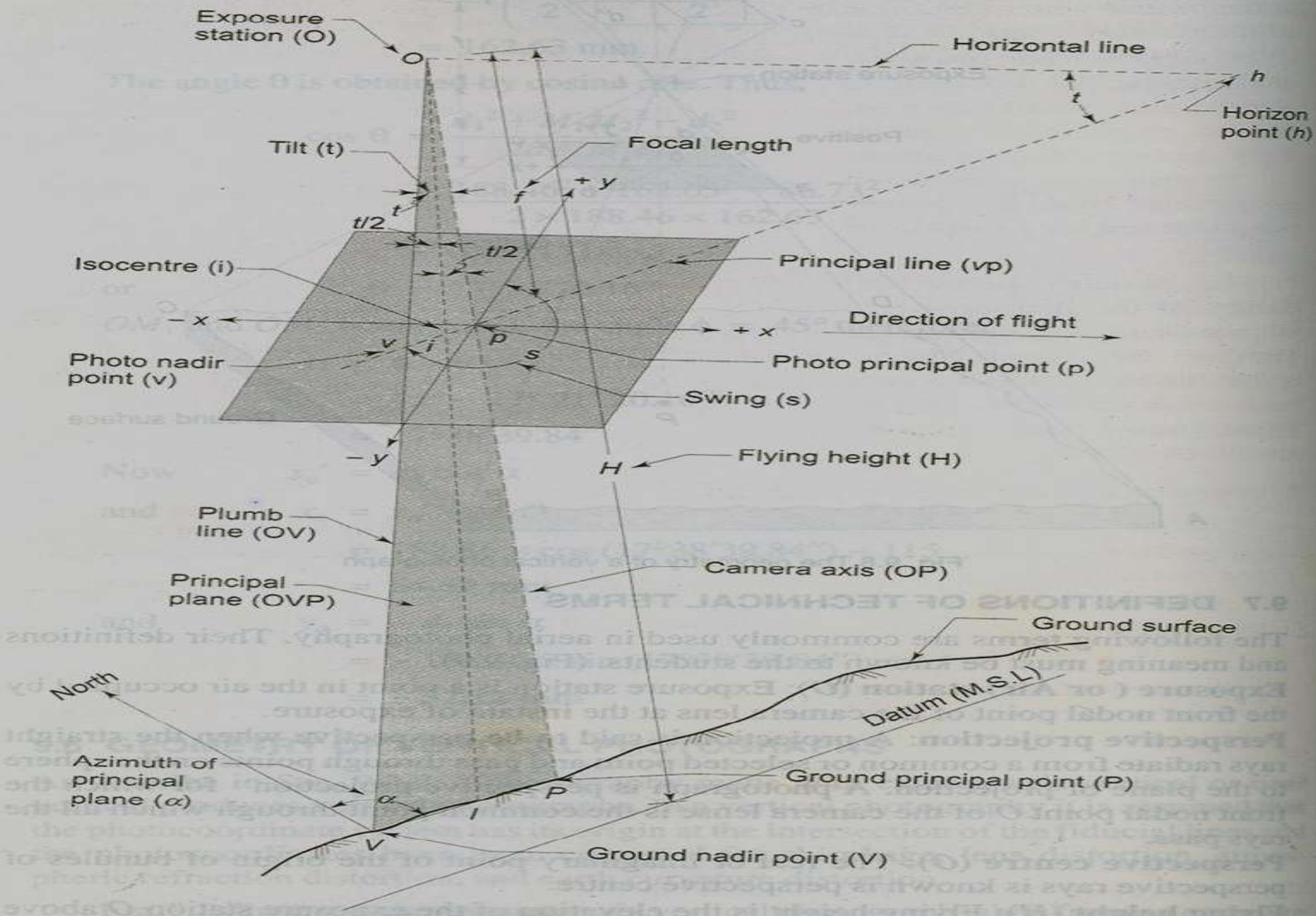
# Definition of technical terms

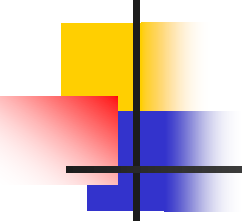
---

- **Exposure (or Air) Station (O)** is a point in the air occupied by the front nodal point of the camera lens at instant of exposure.
- **Perspective projection:** a projection is said to be perspective when the straight rays radiate from the common or selected point and pass thorough points on the sphere to the plane of projection.
- **Perspective Center (O):** the real or imaginary point of the origin of bundles of perspective rays is known as perspective center.
- **Flying height (H):** is the elevation of the exposure station O above mean sea level.
- **Line of flight:** a line which represents the track of an aircraft on an existing map

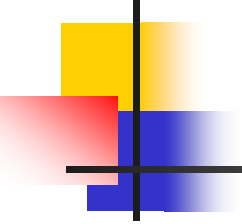


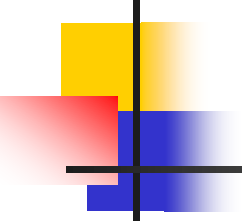
# Technical terms in Figure



- 
- 
- **Focal Length (f):** The distance from the front nodal point of the lens to the plane of the photograph
  - **Principal point (p and P):** principal point is a point where a perpendicular dropped from the front nodal point of the camera lens strikes the photograph.
  - **Nadir point (plumb point)(v or V) :** The point where a plumb line dropped from the front nodal point, strikes the photograph
  - **Principal line (vp) :** is the line of intersection of the principal plane with the plane of photograph.



- 
- 
- **Tilt (t):** Tilt is the angle  $vOp$  which the optical axis makes with the plumb line.
  - **Tilted photograph :** At the time of exposure if the camera axis (or optical axis) is tilted intentionally from the plumb line by a small amount usually less than  $3^\circ$
  - **Isocenter (i):** is the point  $i$  in which the bisector  $Oi$  of the angle of tilt meets the photograph.
  - **Swing(s):** The horizontal angle measured clockwise in the plane of the photograph from the positive  $y$ -axis to the plumb point is known as the swing.

- 
- 
- **Azimuth of the principal plane ( $\alpha$ )** : is the clockwise horizontal angle  $\alpha$  measured about the ground-nadir point from the ground survey north meridian to the principal plane of the photograph.
  - **Horizon Point (h)**: the point of intersection of the principal line  $vip$  produced with the horizontal line  $Oh$  through the exposure station  $O$ , is known as the horizon point.

# Scale of a vertical photograph—flat area

$$S = \frac{ab}{AB}$$

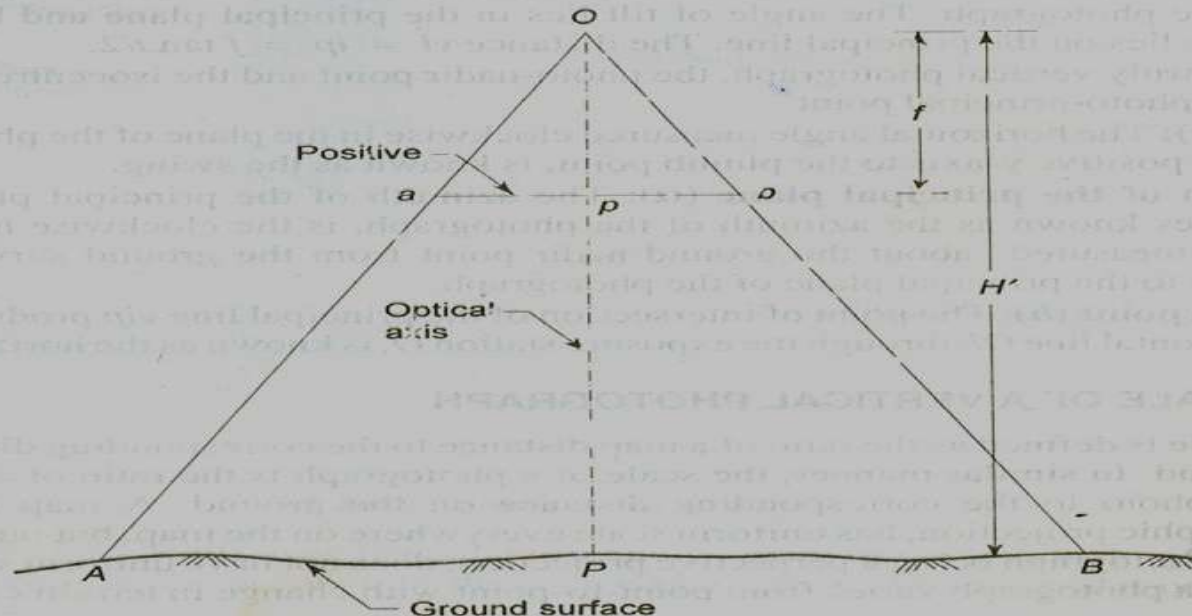
From the similar  $\Delta^s Oab$  and  $OAB$ , we get:

$$\frac{ab}{AB} = \frac{Op}{OP} = \frac{f}{H'}$$

or 
$$S = \frac{f}{H'}$$

Where  $f$  = focal length of the aerial camera

$H'$  = flying height above the ground



# Image Displacement

Consider similar triangle  $vbO$  &  $EBO$

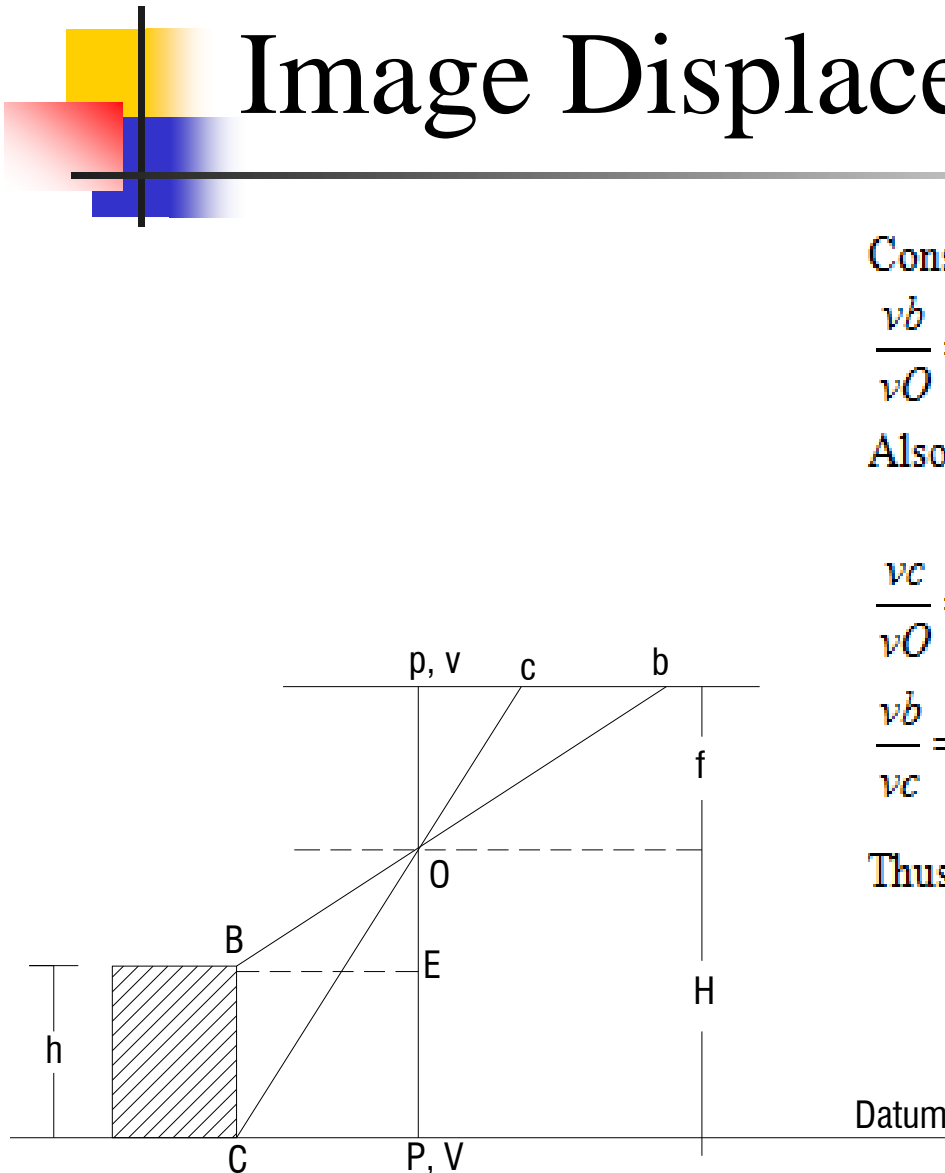
$$\frac{vb}{vO} = \frac{EB}{EO} \Leftrightarrow \frac{vb}{f} = \frac{EB}{H-h}$$

Also from similar triangles  $vcO$  &  $VCO$

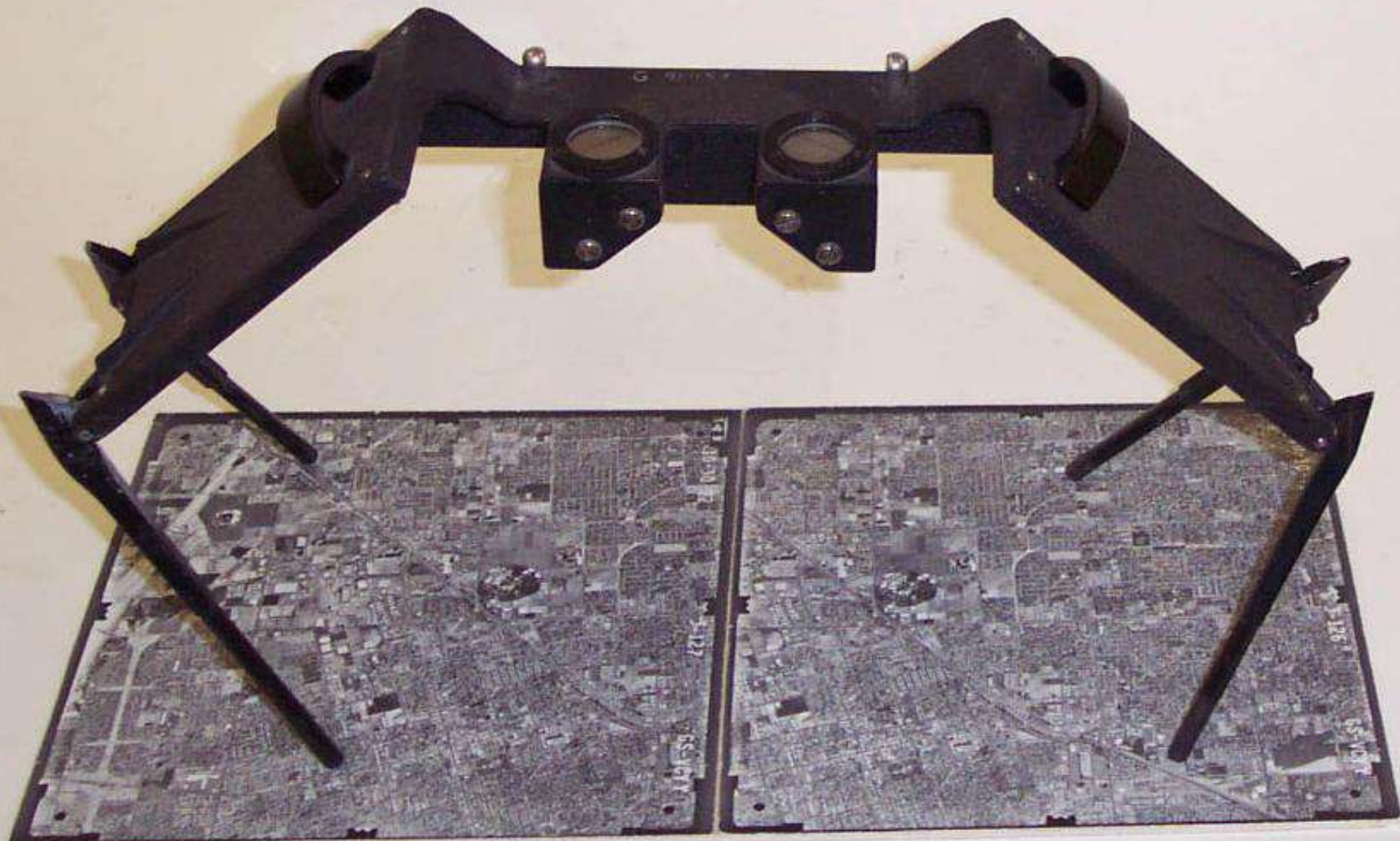
$$\frac{vc}{vO} = \frac{VC}{VO} \Leftrightarrow \frac{vc}{f} = \frac{VC}{H} = \frac{EB}{H}$$

$$\frac{vb}{vc} = \frac{H}{H-h} = \frac{vb}{vb-bc} \Rightarrow \frac{vb}{bc} = \frac{H}{h} \Rightarrow bc = \frac{h}{H} vb$$

Thus, the distortion due to height  $BC = bc = \frac{h}{H} vb$



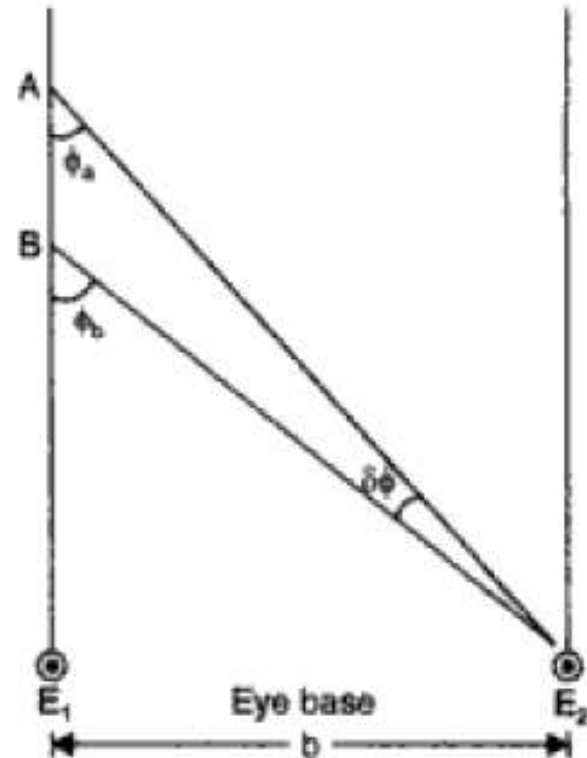
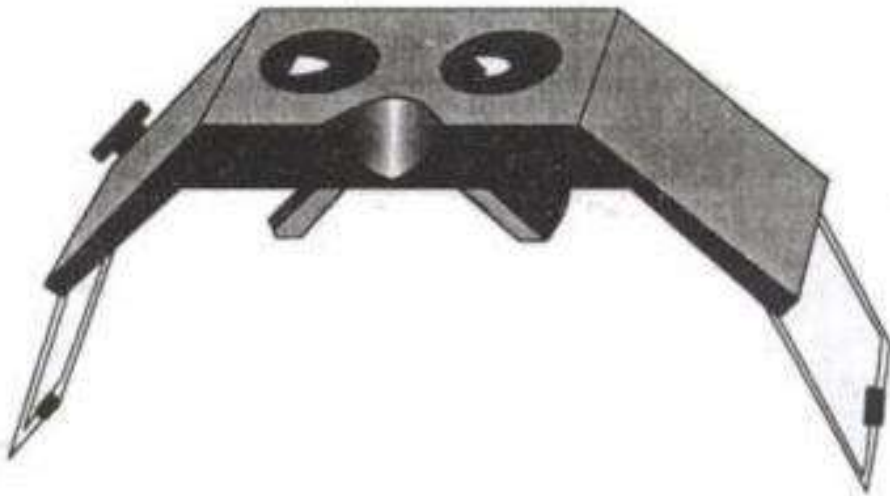
# Mirror Stereoscope





# Stereoscopic Vision

- Overlapping photographs  $\rightarrow$  3D view





# The impression of depth is caused by:

---

- Relative apparent size of near and far objects
- Effects of light and shade
- Viewing of an object simultaneously by two eyes which is separated in space →  
**principle of stereoscopic vision**



# Parallax

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- The algebraic difference of the distances of two images of a ground point from their perspective principal point, measured parallel to the air base.
- Parallax heighting is the process of finding the height of objects from stereo-pair of photographs that have no tilt and are taken from the same flying height.

# Determination of height of object

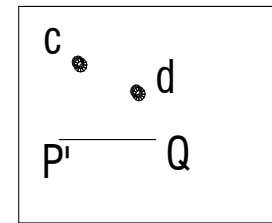
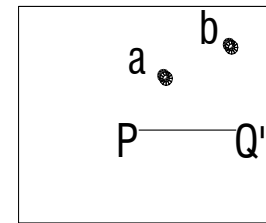
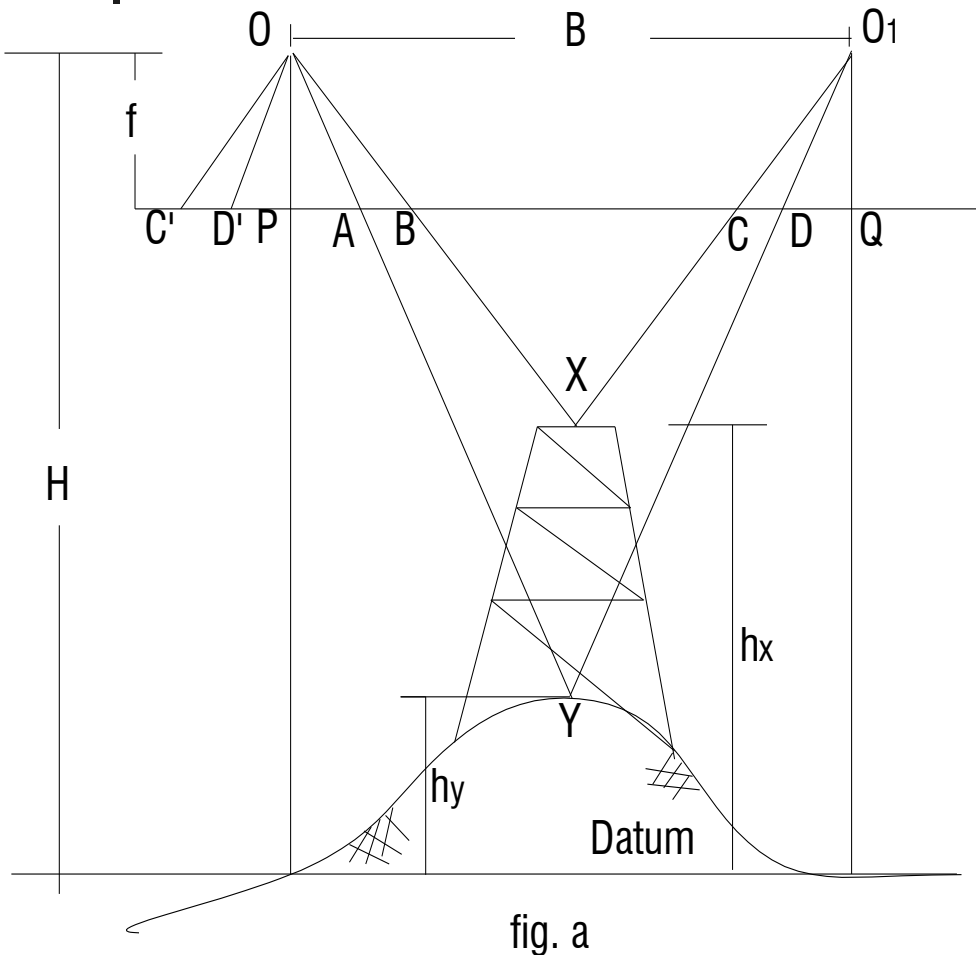


fig. b

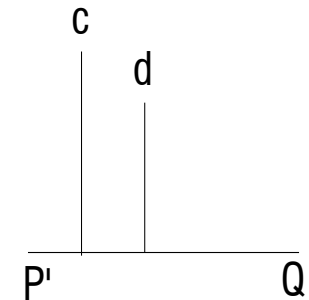
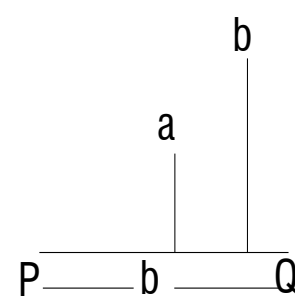


fig. c

- The parallax of X has magnitude of PB – (-CQ) when distances are measured positive to the right. Parallax of Y is PA – (-DQ).

Triangles OD'A and YOO<sub>1</sub> are similar:

$$\frac{OO_1}{D'A} = \frac{H - h_y}{f}$$

$$\Delta p = Px - Py$$

Triangles OD'A and XO<sub>1</sub>O are similar:

$$\frac{OO_1}{C'B} = \frac{H - h_x}{f}$$

$$hx = H - \frac{Bf}{Px}$$

$$hy = H - \frac{Bf}{Py}$$

$$\Rightarrow D'A = P_y = \frac{fB}{H - h_y} \text{ (Parallax of Y)}$$

$$\Rightarrow C'B = P_x = \frac{fB}{H - h_x} \text{ (Parallax of X)}$$

$$\Delta h = Bf \frac{(Px - Py)}{PxPy}$$

$$\text{In general, } P = \frac{fB}{H - h} = \text{Parallax} = \text{Scale} * B$$

$$\Delta h = \frac{Bf \Delta P}{Py(Py + \Delta P)}$$

Let  $P_x - P_y = dP$

$$dP = fB \left[ \frac{1}{H - h_x} - \frac{1}{H - h_y} \right]$$

$$= fB \left[ \frac{h_x - h_y}{(H - h_x)(H - h_y)} \right], \quad h_x - h_y = dh$$

$$= P_x \frac{dh}{H - h_y}$$

$$dh = dp \left[ \frac{H - h_y}{P_x} \right] = \text{difference in level between X and Y}$$

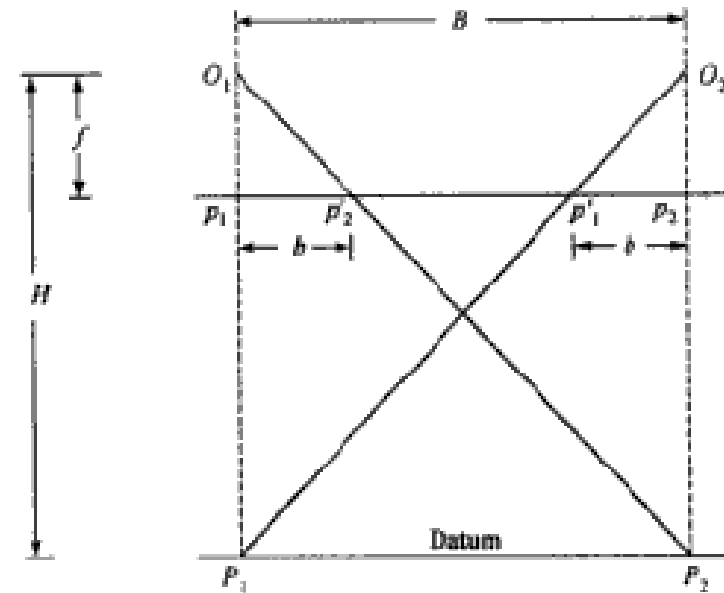
$$dh = dp \frac{H}{P_x} \quad \text{Ignoring } h_y, \text{ since } h_y \ll H$$

$$dh = dp H \left[ \frac{H - h_x}{fB} \right] \quad \text{Ignoring } h_x$$

$$dh = dp \frac{H^2}{fB}$$

If  $h_y = 0, P_y = b_m$

$$\Delta h = \frac{H b_m \Delta P}{b_m(b_m + \Delta P)} \quad dh = \frac{dp H}{b_m + dp}$$



$$p_1 p_2' = b_1 \quad b_m = \frac{b_1 + b_2}{2}$$

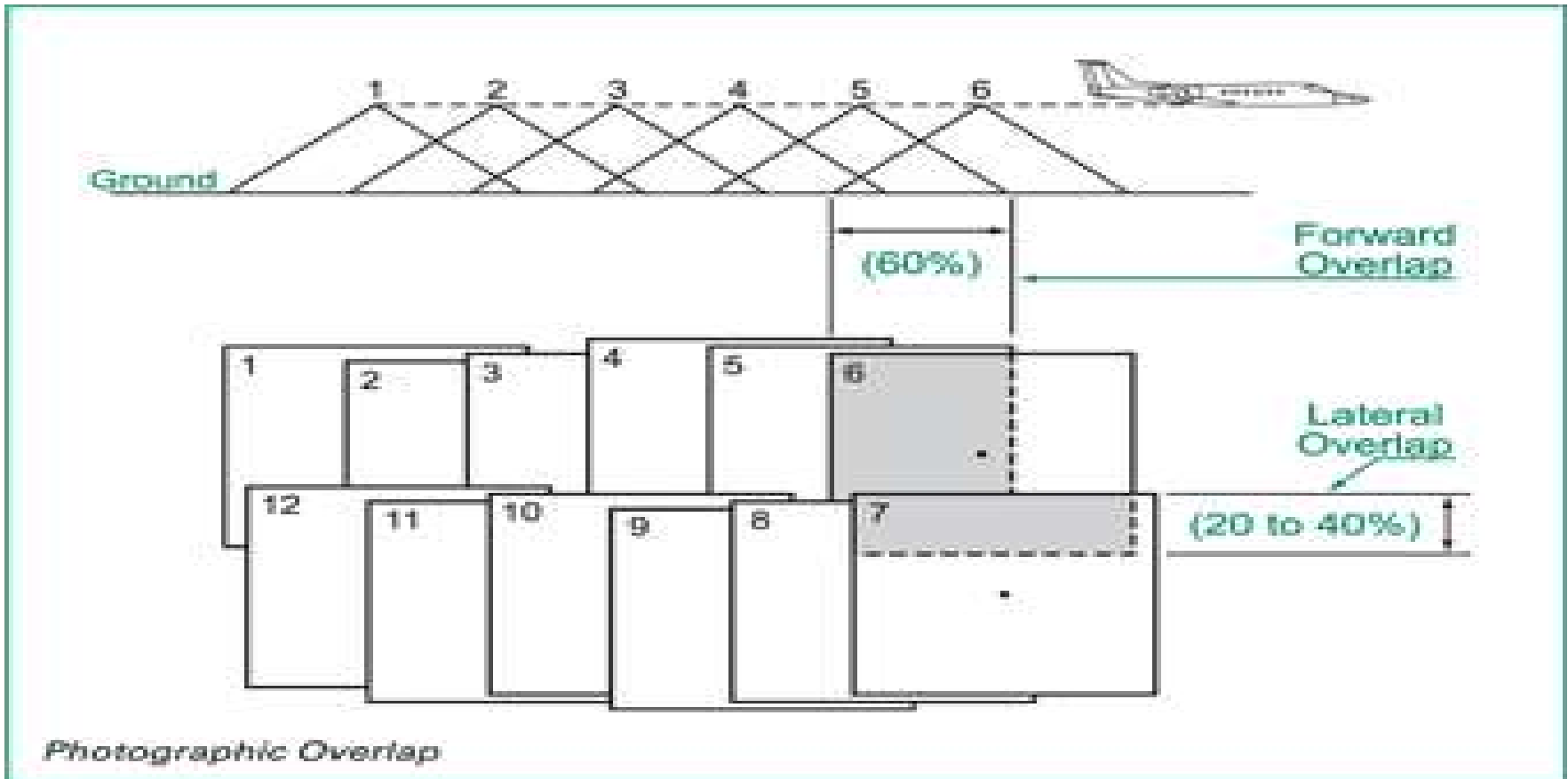
$$p_1' p_2 = b_2$$

$$\frac{f}{H} = \frac{b_m}{B} \rightarrow fB = H b_m$$



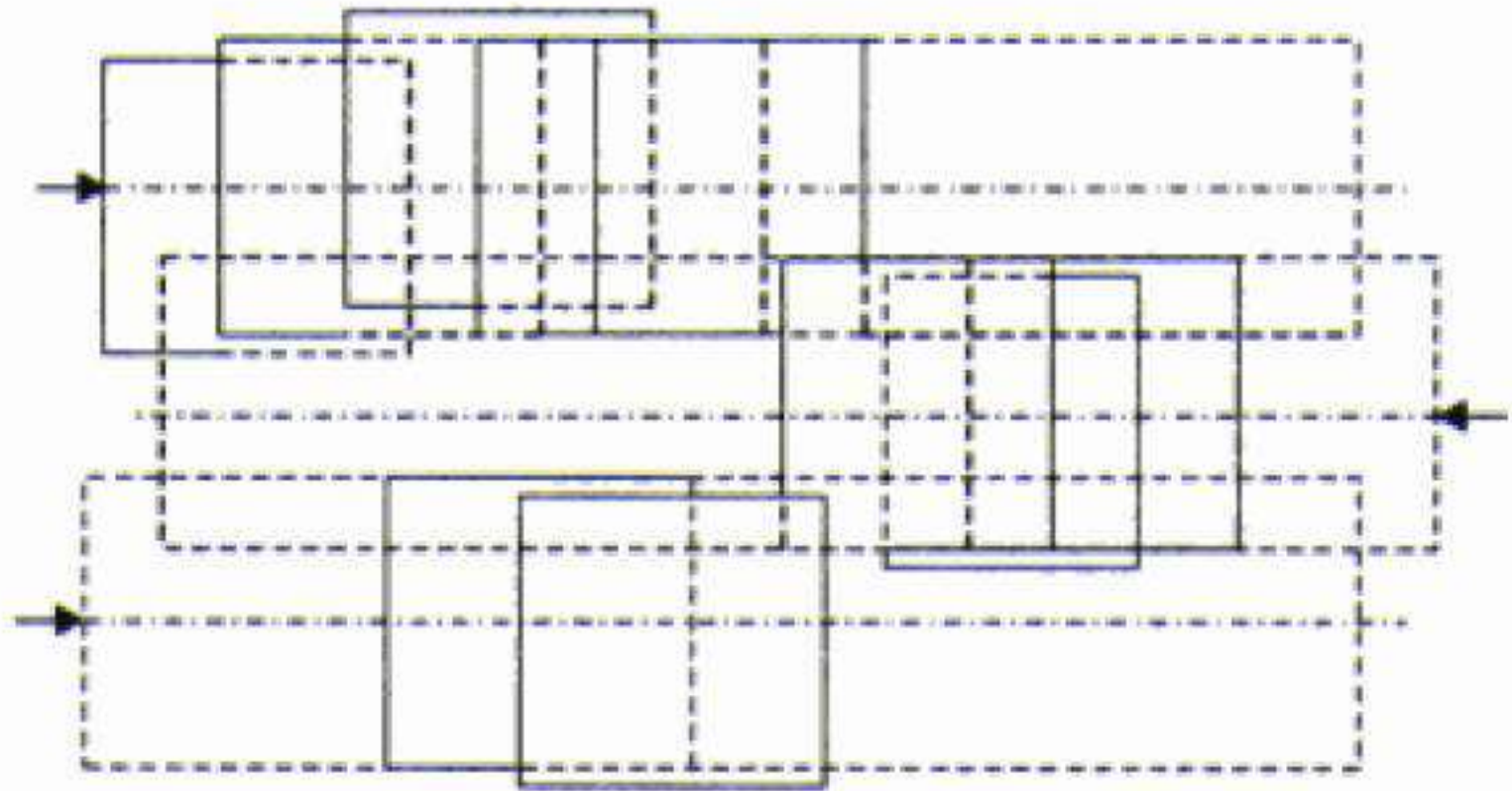
# Flight Planning

In order to obtain stereo pairs, every part of the ground to be surveyed must be photographed at least twice.





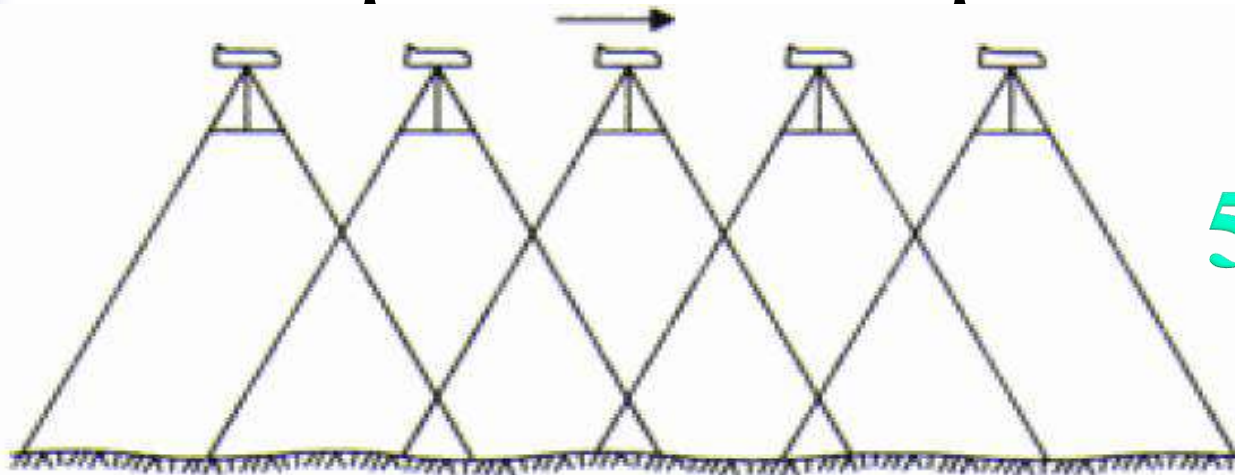
# Flight lines



(a) Flight lines

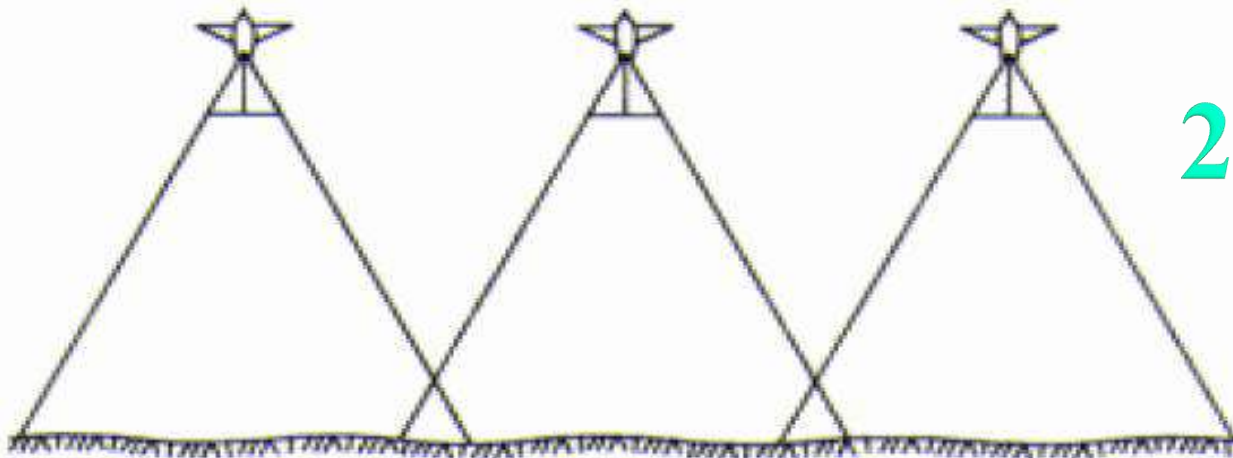


# Overlap and side lap



(b) Overlap in direction of flights

55 -65%

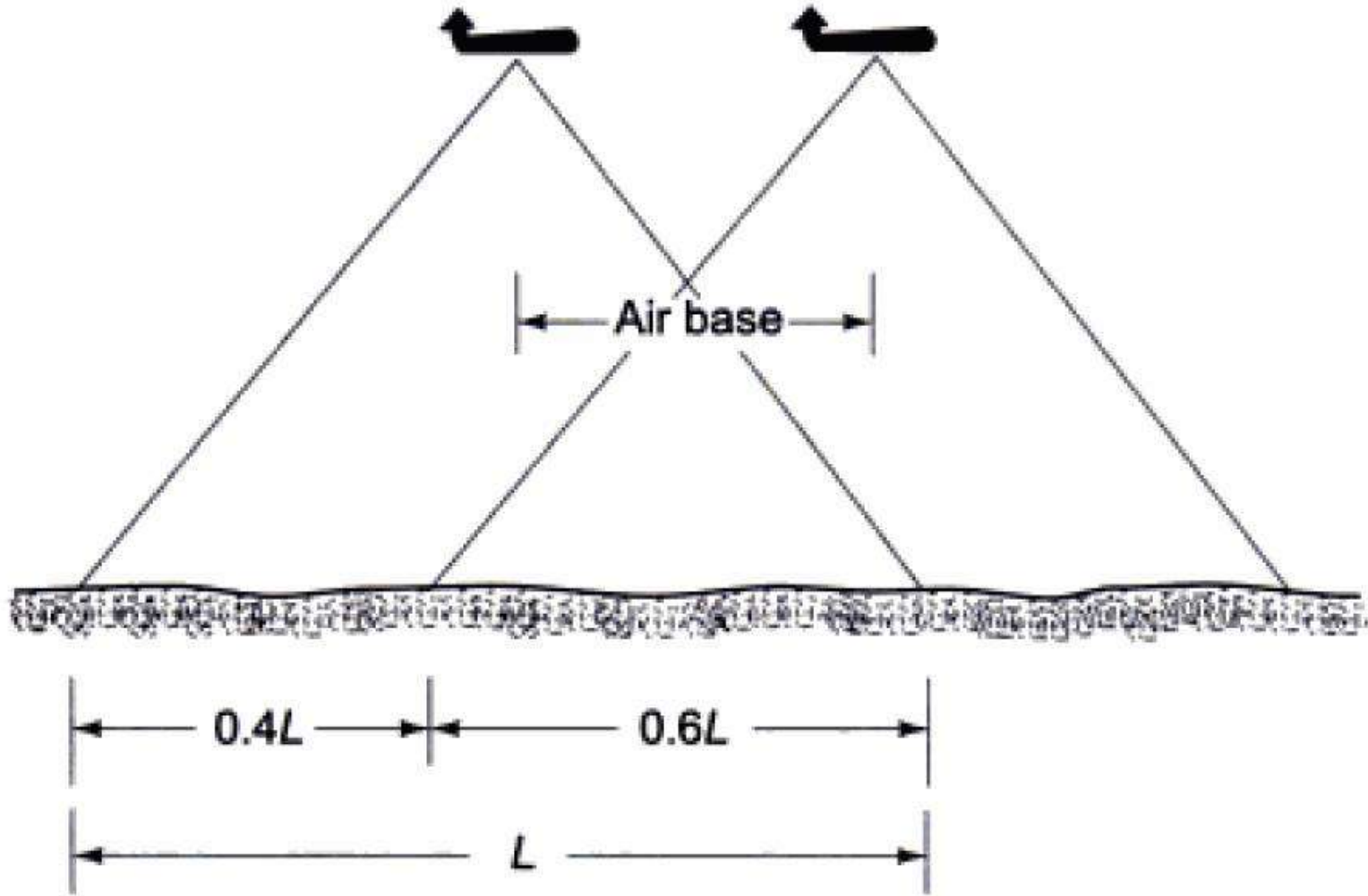


(c) Side lap between flight lines

20 -40%



# Air Base



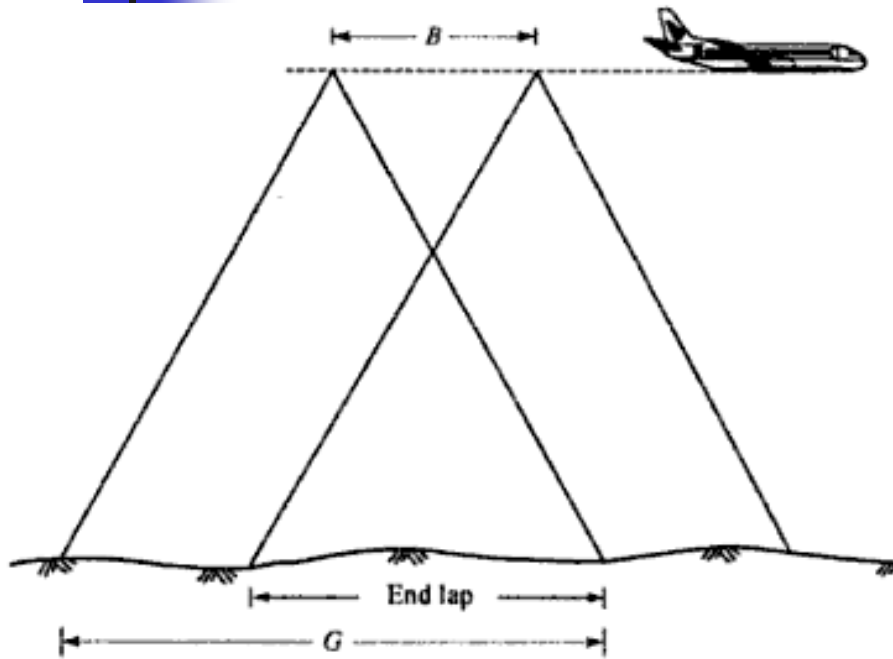


# Photograph Required

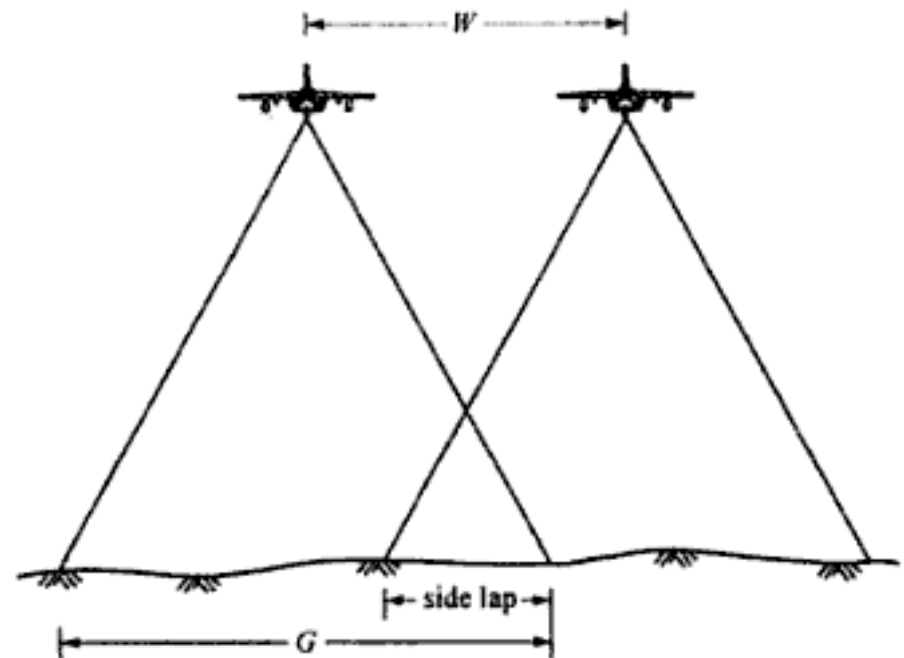
---

- $L_p$  = length of the photograph in cms in the direction of flight
- $L_g$  = Net ground distance corresponding to  $L_p$
- $W_p$  = width of photograph in cms at right angles to the direction of flight
- $W_g$  = Net ground distance corresponding to  $W_p$
- $OL$  = %longitudinal overlap
- $Ow$  = % of side overlap
- $S$  = scale of photograph
- $A_p$  = Net area of the ground in each photograph
- $A_g$  = Total area land to be photographed
- $N$  = Numbers of photographs required

# Overlaps Formula



$$E_{\%} = \left( \frac{G - B}{G} \right) 100$$



$$S_{\%} = \left( \frac{G - W}{G} \right) 100$$





# Total Number of photograph

---

Then  $Lg = SLp(1 - O_L)$   
 $Wg = SWp(1 - O_w)$

Theoretical spacing of flight strips =  $W_G$

Theoretical No of strips,  $K = \frac{\text{width of the area}}{W_G}$

Actual Number of strips =  $K+1$  (one strip being added to cover the sides)

Theoretical no of photographs per strips,  $M = \frac{\text{length of the area}}{Lg}$

Actual no of photograph per strip, =  $M+1$

Actual no of photographs for complete coverage of the area =  $N = (K+1)(M+1)$

**Interval between Exposures**

=  $\frac{3600Lg}{V}$  Where  $V$  = speed of the aircraft in Km/hr,  $Lg$  = distance traveled by the airplane between exposures

**Example 1:** In pair of overlapping vertical photographs the mean distances between two principal points lying on the datum is 6.385 cm. the flying height of the aircraft at the time of photography, was 580 m above datum. Determine the difference of parallel for top and bottom of a tower of height 115 m having base in the datum surface. The focal length of the camera is 150 mm.

**Solution:**

$$B = (b/f)H = (6.385 \times 580 / 15) = 246.89 \text{ m}$$

Parallax is given by :

$$P = (Bf)/(H - h)$$

For the bottom of the tower,  $h = 0$ . Hence

$$P_T = (246.89 \times 150 / (580 - 115)) = 79.64 \text{ mm}$$

$$P_B = (246.89 \times 150 / 580) = 63.85 \text{ mm}$$

The difference of parallax is given by

$$\Delta p = P_T - P_B = 79.64 - 63.85 = 15.79 \text{ mm}$$

The result can be checked

$$\Delta h = h_T - h_B = (H \Delta p) / (bm + \Delta p)$$

$$= (580 \times 15.79) / (63.85 + 15.79) = 115 \text{ m ( the given value)}$$

**Example 2: An area 40 km in the north-south direction and 36 km in the east-west direction, it to be photogrammetrically surveyed. For this, aerial photography is to be made with the following data:**

- i) Photograph size = 20 cm x 20 cm**
- ii) Average scale of photographs = 1:15000**
- iii) Averaged elevation of the terrain (h) = 450 m**
- iv) End lap = 60%**
- v) Side lap = 30%**
- vi) Ground speed of the aircraft = 220km/hr**
- vii) Focal length of the camera = 30 cm**

**Calculate the following data:**

- a) Flying height of the aircraft**
- b) Number of photographs in each flight (i.e. strip)**
- c) Number of flights (i.e. strips)**
- d) Total Number of photographs**
- e) Spacing of flight lines**
- f) Ground distance between exposures**
- g) Exposure interval**

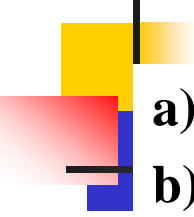


# Solution

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Given that

- $S = 1/15000$
- $f = 30 \text{ cm}$
- $L_p = 20 \text{ cm}$
- $W_p = 20 \text{ cm}$
- $L_o = 40 \text{ km}$
- $W_o = 36 \text{ km}$
- $H = 450 \text{ m}$
- $E = 60\%$
- $S = 30\%$



**a)**  $S = f/(H - h) \rightarrow H = (f/S) + h = 4950 \text{ m}$

**b)** Number of photograph for each flight / Strip

$$N_1 = (L_o/L) + 1$$

$$L = L_p(1-E)/S = 20(1-0.6) \times 15000/100 = 1200 \text{ m}$$

$$N_1 = (40 \times 1000/1200) + 1 = 34.3 = 35$$

**c)** Number of flights or strips

$$N_2 = (W_o/W) + 1$$

$$W = L_p(1-\text{Side lap})/S = 20(1-0.3) \times 15000/100 = 2100 \text{ m}$$

$$N_2 = (30 \times 1000/2100) + 1 = 18.1 = 19$$

**d)** Total number of photographs

$$N = N_1 \times N_2 = 35 \times 19 = 665$$

**e)** Spacing between flights  $d = (W_o/(N_2-1)) = 2000 \text{ m}$

**f)** Ground distance between exposure is  $L = 1200 \text{ m}$

**g)** Exposure interval

$$t = L/V = (1200 \times 3600 / (220 \times 1000)) = 19.6 \text{ sec}$$