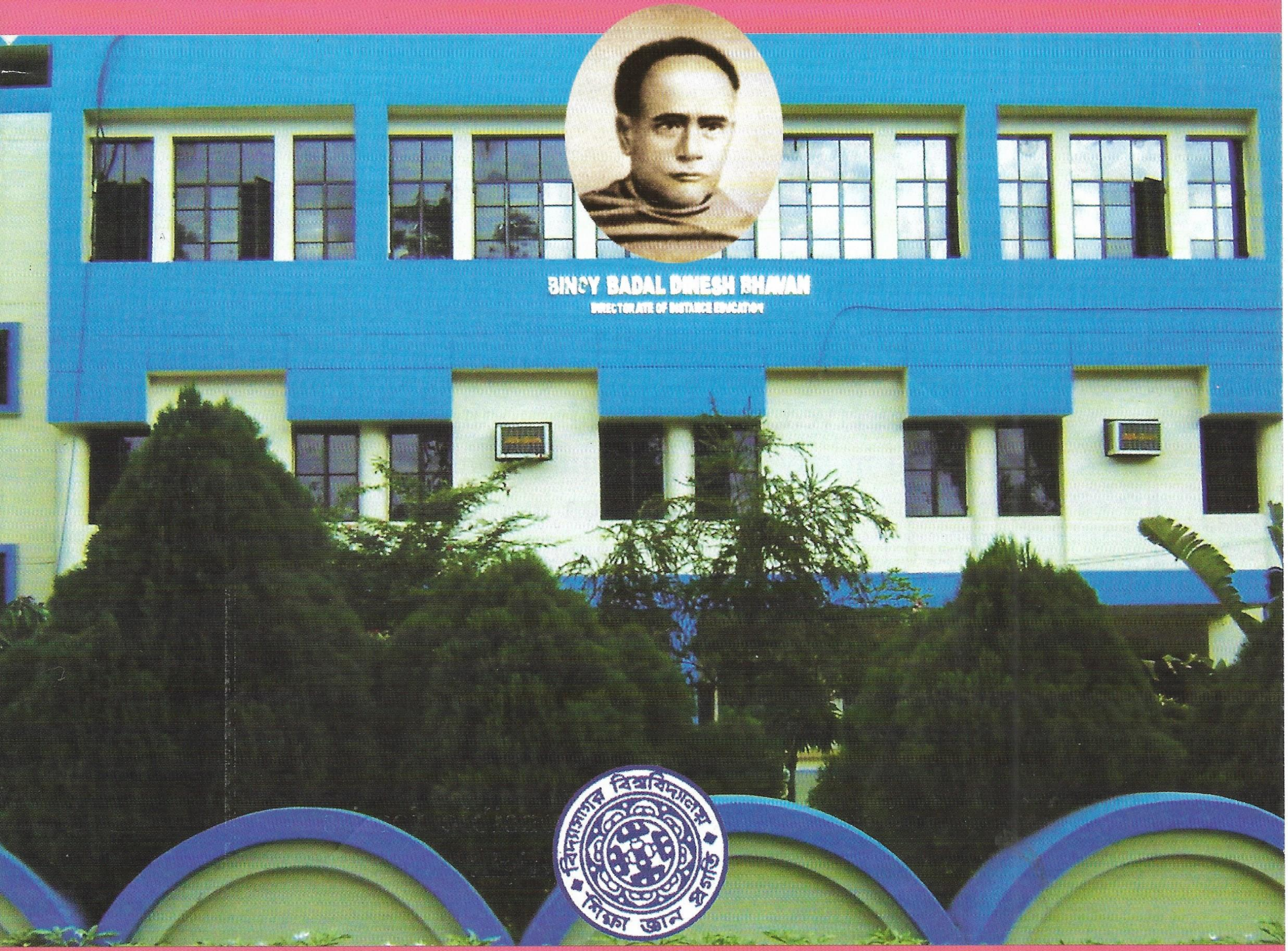
DISTANCE LEARNING MATERIAL



VIDYASAGAR UNIVERSITY

DIRECTORATE OF DISTANCE EDUCATION

MIDNAPORE - 721 102

M. A. / M. Sc. in Geography

PART - I

Paper : V (Practical) : Module No. - IX : Unit - 01, 02, 03 & 04
Paper : V (Practical) : Module No. - X : Unit - 01 & 04

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Module No. - IX ★ Unit – 01, 02, 03 & 04
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M.A. / M. Sc. in Geography

Part - I

Paper -V (Practical)

Contants

PART - I
Paper – V (Practical)
Module – IX : Unit – 01

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Paper-V (Practical)
Module – IX : Unit : 01

GROUND SURVEY AND PHOTO INTERPRETATION

9.1.1 Contour Survey on the basic of levelling by Dumpy Level and Prismatic Compass.

Δ What is survey ?

Surveying is the art of making such measurements as will determine the relative positions of points on the surface.

Δ Objective of survey ?

The primary objective of a survey is the preparation of a map. The plans or maps of area required for various purposes such as planning, design and execution of engineering projects, location of different geological structure, showing the geographical boundaries of districts, states and countries too.

Primary division of survey:

Surveying may be divided into two general classes-

(a) Geodetic

(b) Plane

Δ Classification of surveying :

Broadly the classification of surveying may be based on:

Classification based on nature of the field of surveying		
Sl, no	Name of the survey	Definition
1	**Land**	It is for determining the boundaries and areas of parcels of land, It is also known as property, boundary or cadastral survey,
2	Marine/navigation	It is determine the navigation chart for travel a ship.
3	Astronomic	Astronomic surveys are conducted for the determination of latitude, longitudes, azimuths, local time etc, for various places by observing heavenly bodies such as sun and star.

Classification based on function/ object /purpose of surveying	
Name of the survey	Definition / Concept
Contour	It is establishing the horizontal and vertical position of widely spaced control points using geodetic method.
City	It is for urban planning. These are conducted within the limit of the city. These are required for the purpose of layout of building, street, sewers etc.
Topographic	It is determining topographic features of earth,
Engineering	Specifically for this purposes. 1st is of exploratory nature, the 2nd is to collect adequate data for design and 3rd is to set out work on the ground.
Route	It is primarily for planning, design and execution of highway, railway, canal, pipelines and other linear projects.
Construction	Construction surveys are those type of surveys which are required to est

	points, lines, grades and for staking out engineering works, after the plans been prepared and the structural design has been done.
Geological	These are conducted to determine different strata of the earth's crust for geological studies.
Archaeological	Archaeological surveys have the primary objective of unearthing relics of antiquity.
Mine	Mine surveys are conducted for the exploration of mineral deposits and to guide tunneling and other operations associated with mining.
Satellite	It is conducted to establish intercontinental, interdatum and interisland geodetic ties all the word over by making observations on artificial satellites,
Military	It is conducted for military purposes

Classification based on instrument employed of surveying	
Chain	This is the simplest type of surveying in which only linear measurements are made with a chain or tape and no angular measurements are taken.
Compass	The horizontal angles are measured with the help of a magnetic compass. The linear measurements are also required which are taken with a chain or tape.
Plane-table	The map is prepared in the field itself by determining the direction of various lines making linear measurements and plotting the details on paper using a plane table.
Levelling	This type of survey is used to determine the elevations and relative heights of points with the help of an instrument known as level.
Theodolite	It is primarily used in traversing and triangulation for providing controls. The horizontal and vertical angles are measured with help of theodolite.
Tacheometric	A special type of theodolite known as tacheometer is used to determine horizontal and vertical angles directly.
Photogrammetric	In this types of survey, measurement are made with the help of photographs.
EDM	The linear measurements are made with the help of EDM instruments. In trilateration, all the tree sides of a triangle are measured with EDM instruments.
Total station	Survey was done by Automated.

□ 9.1.2 Contouring

A contour or a contour line is defined as the line of intersection of level surface with the surface of the ground. Thus, every point on a contour line has the same elevation. Therefore, contour line may also be defined as a line joining the points of equal elevation. The shore line of a reservoir with still water represents a contour line of fixed reduced level. As the water level changes, the new shore line represents another contour of a different R.L. The contour lines of an area are presented in a map known as contour map or topographic map. In addition to contour lines, a topographic map includes the features like streams, rivers, reservoirs, valleys, hills, bridges, culverts, roads, fences etc.

When, we doing the surveying the contouring the two types of Instruments are necessary in this arena. This is Dumpy Level other is Prismatic Compass. Now we discuss the basic of Dumpy level and Prismatic Compass

Levelling may be defined as the art of determining the relative heights or elevation of the points or objects on the earth's surface. It deals with measurements in a vertical plane.

Δ Definition of Important Terms

Level Surface:

It is a surface normal to the line of gravity as indicated by a plumb bob. As the earth is an oblique spheroid, a level surface is parallel to the mean spheroidal surface of the earth and it is a curved surface.

Level Line:

A line lying on a level surface is a level line. It is particular to the plumb bob at all points.

Horizontal plane

A plane which is tangential to the level surface at a point is called a horizontal plane through that point. It is therefore, normal to the plumb line at that point.

Horizontal line:

It is a line lying in a horizontal plane.

Vertical line:

At any point, a vertical line is normal to the level surface through that point plumb bob line is a vertical line.

Vertical plane:

A vertical plane is a plane which contains vertical lines.

Vertical angle.

It is an angle between two intersecting lines in a vertical plane.

Datum surface.

It is also called datum plane or only datum and is a plane or a line with reference to which all vertical measurements are taken. Its elevation is zero. In India, originally the datum adopted was the mean sea level at Karachi .at present, the mean sea level at Madras is used.

Elevation.

Elevation is the vertical distance above or below the datum. This is also known as reduced level (R.L.).

Bench mark

A bench mark is a fixed point of reference of known or assumed elevation with respect to which other elevations are calculated. Permanent bench marks are marked on well defined and permanent object such as a parapet wall of culverts, corners of buildings, milestone etc. by government departments such as PWD. For small leveling works, arbitary bench mark on a well defined object may be selected. Temporary bench marks are selected at the end of a day's work. The work is started with reference to this temporary benchmark on the next day.

Line of Collimation

It is the line joining the intersection of cross hairs to the optical centre of the object glass and its continuation. It is the line of sight through the leveling instrument.

Back sight (B.S)

A back sight reading is a staff reading taken on a point of known elevation. It is the first reading taken after the level is set up as on a bench mark or a change point. It is called plus (+) sight.

Fore sight

It is the staff reading denoting the shifting of the level. It is taken on a point whose elevation is to be determined. It is called minus (-) sight.

Intermediate sight (I.S)

All sights taken between the back sight and fore sight are known as intermediate sights. It is the staff reading taken on a point of known elevation.

Change point

It is the point on which reading is taken just before and after shifting the instrument. The means both back sight and fore sight readings are taken on this point. This is also known as a turning point. It should be taken on a firm, well defined object.

Station

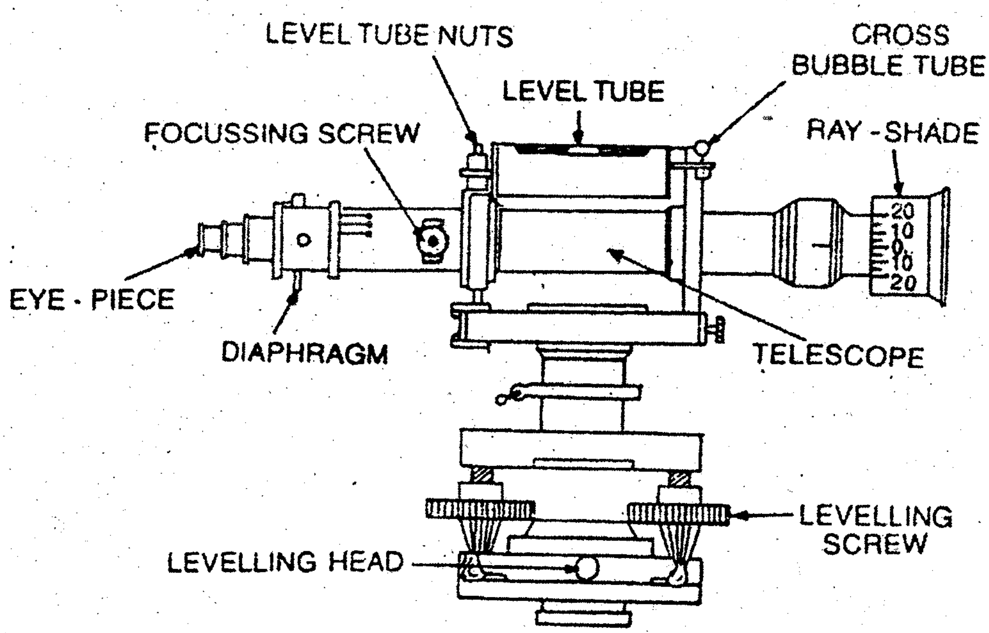
A station is a point whose elevation is to be determined or a point which is to be located at a given elevation. Thus station is a point where the leveling staff is held and not the point where the level is set up.

Height of instrument

It is the reduced level of the line of sight when the leveling instrument is correctly leveled. It is also called height of plane of collimation or simply collimation. The line of colitmation can be revolved in a horizontal plane known as the plane of sight.

□ 9.1.3 Dumpy level

Of the leveling instruments, is the most simple compact and stable. The leveling head consists of a tribrach and a river with three arms each carrying a foot or leveling screw. A telescope is rigidly fixed to its supports fitted to the spindles which are attached to the central hollow of the tribrach. The rotation of the telescope around the vertical axis is regulated by a clamp and slow motion tangential screw. The telescope contains an eye piece, diaphragm, focusing screw, sighting knob and object glass. On the body, two level tubes (long and cross) are fixed in perpendicular direction.



Dumpy Level

Contour interval: The constant vertical distance between two consecutive contour line is called the contour interval. The contour interval is kept constant; otherwise the map will be misleading. The horizontal distance between any two consecutive contour lines is known as the "horizontal equivalent". The horizontal equivalent, for a given contour interval depends on the nature of the ground. The contour interval depends upon the following factors:

i) Time and fund available for field and office work.
ii) Purpose and extent of survey.
iii) Nature of the ground, and
iv) Scale of the map.

The following contour intervals are generally used:

i) for flat agricultural land, calculation of earth work, land leveling etc.0.15 to 0.50,
ii) for location surveys 2 to 3 m, and
iii) for small scale topographic map of hilly area 3m to 25m.

Δ Characteristics of contour lines:

i) All points in contour line have the same elevation

ii) Uniformly spaced contour lines indicate a uniform shape whereas; straight, parallel and equally spaced lines indicate a plane surface.

iii) Widely spaced contour lines indicate a flat ground and closely spaced contour lines indicate steep ground.

iv) A series of closed contours with the higher values indicate a summit or hill

v) A series of closed contours with the higher values outside indicate a depression.

vi) Contour lines cross a ridge or a valley line at right angles.

vii) If the contour lines from U-shaped curves and the higher values of contour are inside the loop, then it indicates a ridge line.

viii) If the contour lines from V shaped curves and the lower values of contour are inside the loop, it indicates a valley line.

ix) Contour lines cannot cross one another or merge on the map expect in case of an over hanging cliff.

x) If several contour lines coincide i.e. the horizontal equivalent is zero then it indicates a vertical cliff

xi) Four sets of contours represent their trend towards opposite side they represent a saddle i. e. a depression between summits. It is a dip in a ridge or the junction of two ridges. Line passing through the saddles and summits give watershed line.

Δ Use of Contours:

I) By inspection of a contour map, information regarding the characters of the terrain is obtained, whether it is flat, undulating or rolling etc.

II) Contour map is very useful for taking up land leveling works.

III) With the help of contour map, suitable site for streams, rivers, reservoirs, valleys, hills, bridges, culverts, roads, railways etc. can be selected.

IV) Total drainage area and capacity of reservoirs can be determined with the help of contour map.

V) Computation of earth work is possible from contour map.

VI) Contour maps are essential for taking up any soil conservation works like terracing, bunding, construction of structures and spillways.

VII) In coastal areas for construction of brackish water fish farm contour map is required to decide about the type of farm to be constructed i. e. tide-fed or pump-fed farm.

VIII) Intervisibility of any two points can be known from the contour map.

IX) From the contour map of agricultural land, most suitable method of irrigation for a particular crop can be decided.

X) Section can easily be drawn from contours.

XI) A route with a given slop can be traced on a contour map.

Δ Methods of contouring:

Two methods are mainly used for contour surveying: (i) Direct Method (ii) Indirect method

I) Direct Method: Direct Method: The method is very accurate, but very slow and tedious. This is suitable for small areas where great accuracy is required.

In the direct method, contours to be plotted are directly traced in the field. Number of points for each contour are found out, plotted are contours are drawn by joining the points. At first a bench mark is established near the site of survey. The level is set in such a position from where maximum number of points can be covered. The height of instruments (H.I. is found out by taking a B. S. on the established B. M. The required staff readings for various contours are calculated. The staff is held at an approximate position and looking through the level, the staff moved up or down to get the desired reading corresponding to a particular contour. The point may be marked with a peg. In a similar manner, all points for this contour are located and pegged. From the same set up of levels, points for as many contours are possible are located. The level is then shifted and a new H. I.

Is found out taking a B.S. on previously surveyed point. New required staff readings corresponding to this H.I. and various contour values are calculated and the process is repeated to located to locate all the contours.

The positions of the contour points may be located either simultaneously or afterwards by suitable methods of surveying like plane table, theodolite or compass traversing. The points can then be plotted on a map and contours can be drawn by joining the points of equal elevation.

Δ Method of RADIAL lines:

If the area is so small that the level set up in a single points in the centre cover the entire area, then this method is most suitable. Radial lines are ranged out from the common centre by using a compass or a theodolite and their positions are fixed by horizontal angles and bearings. Temporary bench marks are fixed both at the centre and near the ends of the radial lines. The contour points are located and pegged by using the method explained earlier. Their distances are measured along the radial lines. They are then plotted and the contours are obtained by joining all the corresponding points.

FIELD BOOK:
Contour Survey by Dumpy level & Prismatic Compass
(Method: Three radial Lines)

Place: University Campus
Ins. No: D.L.-3
P.M.
P.C.-3

Date: 17-12-07
Time: 12.30

Table : 1

Line	Station	Distance in mt.	Staff Reading in mt.			Height of Collimation	Reduced Level in mt.	Remarks
			B.S.	I.S.	F.S.			
O	O	0	1.010			46.610	45.60	Bench marks of Station "O" is 45.60 mt.
	A1	1		1.115			45.50	
	A2	2		1.095			45.52	
	A3	3		1.070			45.54	
	A4	4		1.090			45.52	
	A5	5		1.145			45.47	
A	A	6		1.205			45.41	
	B1	1		1.090			45.52	
	B2	2		1.195			45.42	
	B3	3		1.220			45.39	
	B4	4		1.260			45.35	
	B5	5		1.285			45.33	
B	B	6		1.310			45.30	
	C1	1		1.195			45.42	
	C2	2		1.275			45.34	
	C3	3		1.315			45.30	
	C4	4		1.325			45.29	
	C5	5		1.330			45.28	
C	C	6			1.340		45.27	

[Ground survey by prismatic compass]

Table: 2

Line	Length in mt.	Whole Circle Bearing
OA	6	287^0
OB	6	38^0
OC	6	155^0

Leveling Operations

The equipments for leveling consist of a level (commonly a dumpy level), a tripod, a leveling staff, a tape and a well laid and neatly drawn field book for recording the staff readings, distances and field notes.

Procedure:

i. The instruments are first set up at a convenient height and at a place, from where maximum number of stations can be sighted.
ii. With the help of the bubble tube (s), the instrument is then perfectly leveled by turning the foot screws right in and left out in positions when the telescope is: a) parallel to a line throw two-foot screws and b) perpendicular to it. This operation is successively repeated taking other foot screws until the bubble remains stationary at the centre of the level tube for any position of the telescope.
iii. The telescope is then directed towards the staff held vertically over the station (within or outside the traverse) with a known reduced level (Bench Mark). The eye piece and the object are focussed properly and the staff reading for the middle stadia is taken and the first reading is entered as a back sight reading (BS)
iv. Similarly, the staff readings for all the stations visible are taken successively. The last reading of the set up is entered as a fore sight-reading (FS) while all others as intermediated sight-readings (IS).
v. The instrument is then shifted to some other position(s) from where the readings of the remaining stations (not covered in the first set up) can be taken. After precise leveling of the instruments, the reading is to be taken on the staff held at the last station of the former set up; it is a back sight-reading of course. This station is called a change point (CP).
vi. Following the same procedure staff reading are then taken on the remaining stations.

Δ Computation:
The reduced levels of the stations can be calculated in either of the two common methods one is the (i) collimation method and (ii) the rise and fall method.
i.) The Collimation Method:-

In this, the reduced levels are evaluated by subtracting the staff readings from the corresponding height of collimation. The common rules are ;

a. height of collimation =[Back sight reading + Reduced level of the BM]
b. Reduced level of a station = [Height of collimation – Staff reading (IS or FS)
c. For a new set up, i.e. at change points, new heights of collimation are to be evaluated by the rule,
Height of Collimation of a Change point = [Back Sight Reading +Reduced Level of a Change Point]

Arithmetical checks should b done to avoid any ambiguity and confusion. The common checks are:

$\sum BS \sim \sum FS$ = Last RL ~ First RL .... (i) And $\sum$ (Height of collimation x Number of applications) = $\sum IS + \sum FS + \sum RLs -$ First RL... ....ii)

Procedure of Contour line:

1. At first we draw a line vertically on the paper and indicate it north arrow this line also known as an arbitrary north line.
2. Then with a help of protector "OA" line drawn and length measure according to scale i.e. 1cm to 1mt.
3. similarly "OB" and "OC" line drawn in the same way of "OA"
4. Then all the station marked against three different line and also plotted reduced level on each station.
5. Calculate the difference between maximum and minimum value of reduced level (in the case of table no: 1 show that maximum elevation 45.60mt. and minimum elevation 45.27mt differential reduced level is 0.33 mt.)
6. Now we get minimum three (3) contour then we divided four 4 on differential reduced level is 0.33 mt. The dividing value is 0.09 (round fig.) therefore

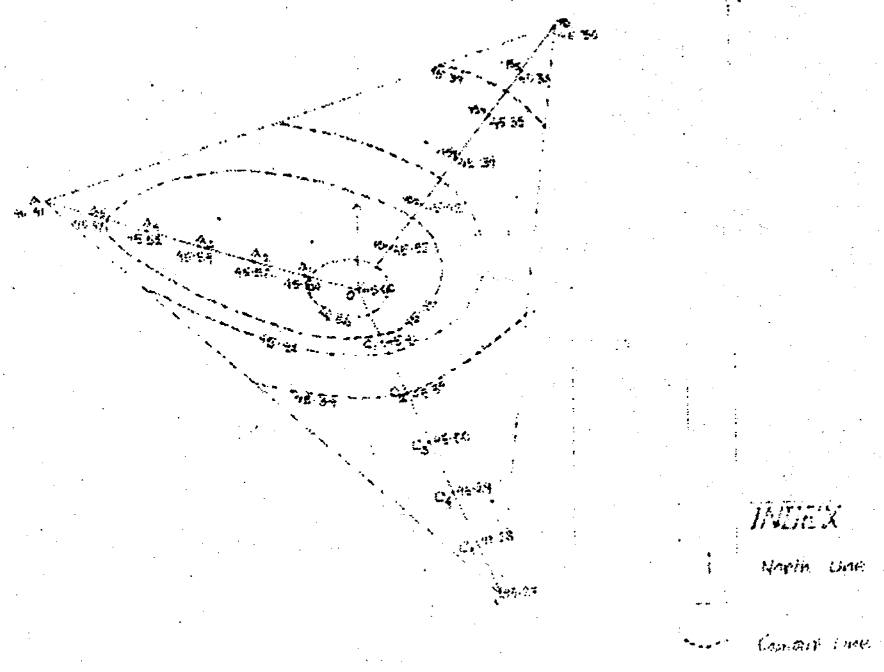
1st contour line is drawn is 45.27+ 0.09 = 45.36 mt.

2nd contour line is drawn is 45.36+ 0.09 = 45.42 mt.

3rd contour line is drawn is 45.42+ 0.09 = 45.51 mt.

7. Here we draw a contour the map.

Contouring Survey by Dumpy Level & Prismaytic Compass



0 **4 mt.**

FIELD BOOK:

Contour Survey by Dumpy level & Prismatic Compass
(Method: Z type)

Place: University Campus **Date: 17-12-07**
Ins. No:- D.L.-3 **Time: 12.30**
P.M.
P.C.-3

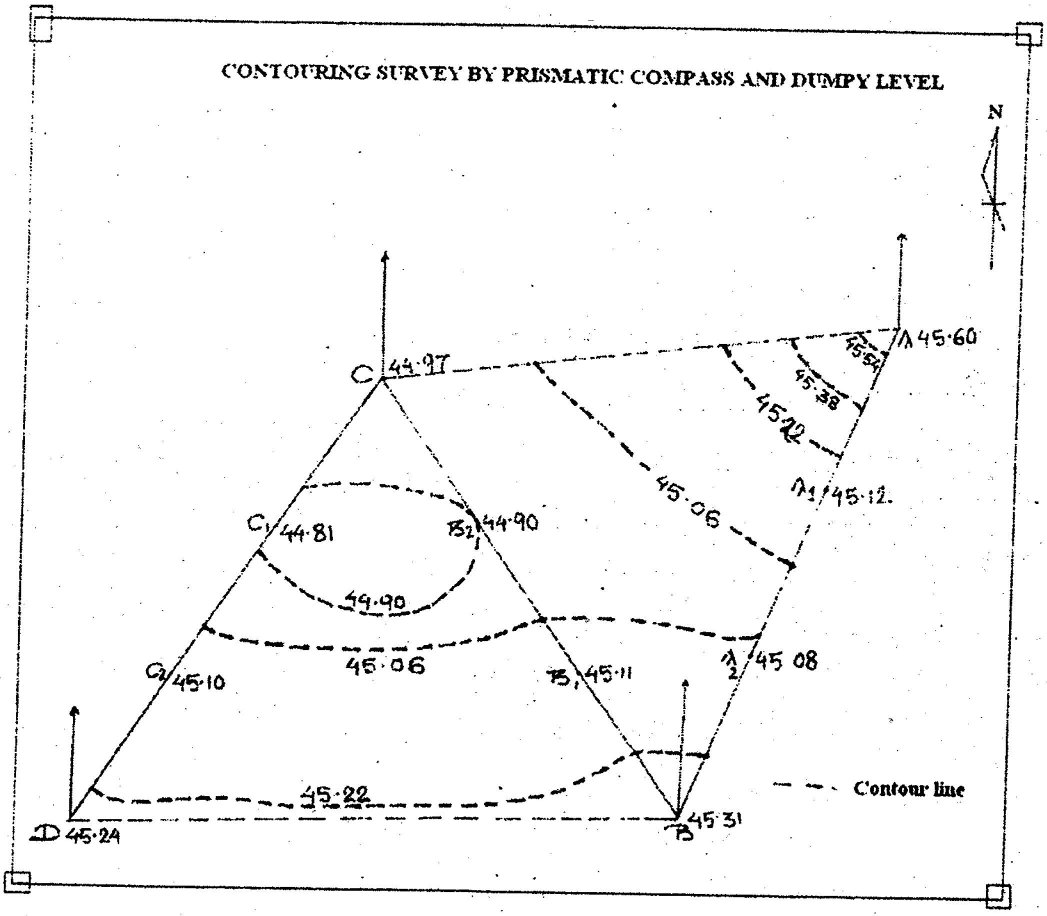
Table: 1

Line	Station	Distance in mt.	Staff Reading in mt.			Height of Collimation (in meter)	Reduced Level in mt.	Remarks
			B.S.	I.S.	F.S.			
A	A	0	1.365			46.95	45.60	Bench marks of Station "A" is 45.60 mt.
	A1	3		1.850			45.10	
	A2	6		1.890			45.06	
B	B	9		1.660			45.29	
	B1	3		1.860			45.09	
	B2	6		2.07			44.88	
C	C	9		2.00			44.95	
	C1	3		2.16			44.79	
	C2	6		1.87			45.08	
D	DS	9			1.725		44.225	

[Ground survey by prismatic compass]

Table: 2

Line	Length in mt.	Whole Circle Bearing
AB	9	203^0
BC	9	$322^0 15''$
CD	9	$214^0 30''$



Model Question :

1. What is contour? What is meant by contour interval and on what factors does it depends?
2. Write in details the characteristics and uses of contours.
3. What are the direct Method of contouring? Write the procedure of direct contouring in details.
4. The page of a level book is shown below. The readings of the cross- marks (x) are missing. Determine the missing reading.

B.S	I.S.	F.S.	Rise	Fall	R. L
X					100
	2.355			X	X
	2.605			X	X
X		1.845	X		99.805
	1.955		0.510		X
	X			0.885	99.430
2.440		3.415		X	98.855
	X			0.210	X
		2.450	0.200		98.845

5 A page of level field book is reproduced below in which some readings are missing (marked by *). Complete the page with all arithmetic checks.

Station	Staff reading in mt.			Rise(+)	Fall (-)	Reduced Level	Remarks
	B.S.	I.S.	F.S.				
A	3.65						
B		*		2.75			
C		2.83					
D		3.64					
E	*						
F		12.41			7.32		
G		4.32					
H		3.00					
I		-6.17					Staff held inverted against ceiling
J	*		*			108.26	
K			*				
∑	17.66				25.93		

Reference :

1. Kanetkar, T.P. and Kulkarni, S.V. 1984. Surveying and Levelling; part one. P.V. Griha prakashan, Pune.
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□ 9.1.4 Traverse Survey by i) Plane Table (Intersection method) ii) Prismatic Compass

PLANE TABLE SURVEY

Δ Introduction:

Plane table surveying is a method of surveying in which the fields work and plotting are done simultaneously. It is therefore, a graphical method of surveying which does not require a field book. In case numbers of objects are to be located on the map, this method can be used in conjunction with triangulation or other methods of surveying. In the triangulation method, the positions of the station are fixed and then plane table surveying is done to locate the features. Also when great accuracy is not required, plane table surveying can be used for small to medium scale mapping. Plane table surveying does not require very costly instruments. But the plane table and other accessories are slightly heavy to carry to the field.

Δ EQUIPMENTS AND ACCESSORIES:

The following equipments and accessories are used for plane table surveying.

1. **Plane Table**: It is essentially a drawing board mounted on a tripod stand. The board is made of well seasoned teak or other good quality wood (Fig.).It is plain, well polished and soft so that drawing papers can be fixed on that drawing pins and lines can be drawn without difficulty. The normal size of the board varies from 50 cm to 60 cm square to rectangle of 75 cm X 60 cm. It is mounted on a tripod, can be revolved on a vertical axis and clamped. Leveling can be done by adjusting the legs of the tripod.
2. **Alidade**: It is a straight edge rular made of brass or teak wood and is about 50cm long. There two types of alidade (i) telescopic and (ii) plane alidade. But, we used plane alidade, this is widely used. It is fitted with sight vanes at both the ends. The eye vane is provided with a narrow silt and the object vane has wider slit in which a central wire is fitted. The alidade is used to sight any object in the plane table surveying and draw a straight line parallel to the line of sight. The leveled edge through which line is drawn is called the fiducial edge.
3. **Trough Compass**: It is used for making the direction on the magnetic meridian on the drawing sheet.
4. **U-fram with plumb bob**: It is used for cenrering the table. Centering is the process of placing the table in a manner such that the point on the paper is exactly vertically over the point on the ground which it represents.
5. **Spirit level**: One spirit level is used to level the table.
6. **Water proof cover**: One water proof cover should be available with the survey team to protect the drawing sheet from rain. Also a survey umbrella may be used.

Drawing materials: The most important drawing materials is the drawing paper. It should be of very good quality and should not shrink or expand with atmospheric changes. As far as possible, it should be carried in a flat position and should never be folded. On very wet climate it is difficult to walk with ordinary drawing sheet. Zinc or celluloid sheet are used in such conditions. The drawing sheet should either be pinned or better clamped with the drawing board. Good quality HB, H and 2H pencils and erasers should be used for drawing.

Δ SETTING UP THE PLANE TABLE:

The following operations are required to be perfomed in setting up the plane table:

1. At first survey stations should be conveniently selected keeping in mind the points mentioned.
2. The table should be set up at one of the selected stations at a convenient height. The height varies according to the surveyor. The legs should be firmly fixed into the ground.
3. The centering of the table should prpoperly is done over the survey station. The pointed end of the upper leg of theU-frog should coincide with the point on the paper and the plumb bob suspended from the lower edge should touch the peg fixed over the station. Centering may also be done approximately by dropping a stone from a point under the table which is directly below the point on the paper. In selecting the first station point on the paper, one should keep in mind the area to be surved. This together with the selection of proper scale will help the surveyor to accommodate the entire area in the drawing sheet, However, very accurate centering is not require for small scale map.

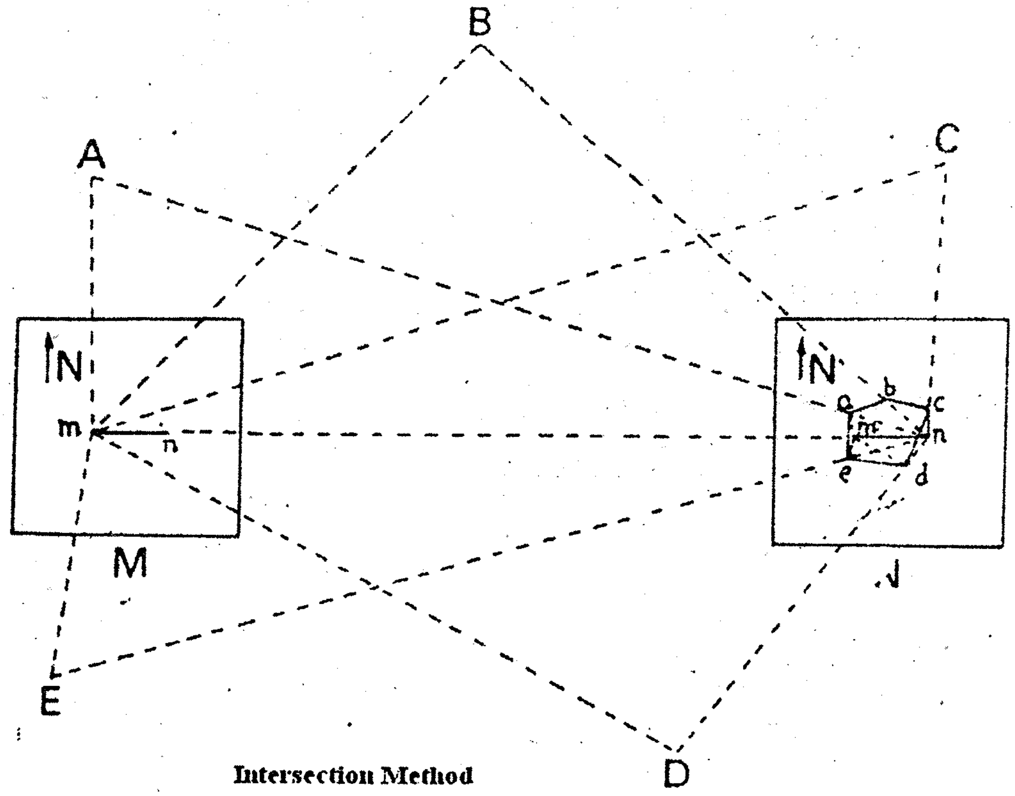
4. The plane table is then leveled. Spirit level is used to check the leveling. At first it is leveled by placing the spirit level parallel to one side and then perpendicular to that side. Initial leveling is done by adjusting the legs of the tripod and final leveling by adjusting the ball and socket joint if provided. However no precise leveling is require for very small scale maps.
5. During the continuation of the survey, whether the table is shifted to a new position, the table should be kept parallel to the previous position. This operation of keeping the plane table parallel to the position it occupied at the previous location is known as orientation. If orientation properly, the lines on the paper will always be parallel to the lines on the ground which they represent. Without orientation, the magnetic meridian at one place will not be parallel to the magnetic meridian at another place and the plotting will not be correct. The orientation can be done either (a) by use of tough compass or (b) by back sighting.
   (a) Orientation by trough compass: As soon as surveying is started, the magnetic meridians is marked at one corner by using the trough compass. When the table is shifted the trough compass is placed along this magnetic meridian. The board is turned till the ends of the magnetic needle are in line with the zeros of the scale. Then the board is clamped in position. In case, there exists local attraction of different magnitudes at different station, this method is not accurate.
   (b) Orientation by back sighting: This is better and more accurate method specially where local attraction is present. Suppose, initially the table was set up at station A and line ab was drawn to represent the line AB on the ground. Now the table is shifted and centered over station B. The alidade is placed along the line ba and sighting is done towards the ranging rod at A. The board is turned till the ranging rod at A is bisected by the line of sight. At that time, the board is clamped taking care to see that the centering is not disturbed.

Δ METHODS OF PLANE TABLE SURVEYING

Although there are four methods of plane table surveying(Radiation, Intersection, Resection, Traversing), our syllabus used only Intersection Method. While in ground capital letters have used to denote the points on the ground and small letters for the corresponding points on the paper.

Δ INTERSECTION :

When all the points to be plotted are visible from two stations, then this method can be used. Points are located on the plan by the intersection of rays draw from these two stations. The line joining these two stations is called base line. The length of this base line is only required to measured and other points are located by intersection. The method has the advantage of being able to locate the inaccessible object like points across the river, mountain, peaks etc. Also details can be located by this method in combination with other methods. The following steps are follow step are followed in this method.



Intersection Method

(i) Select two points M and N such that all points to be plotted are visible from both of them.

(ii) Set up the table at M, level it and centre it over M so that a point m is obtained on the paper.

(iii) Using the trough compass, mark the direction of the magnetic meridians on the top corner of the paper.

(iv) With the alidade touching m, sight the ranging rods at N, A, B, C etc. and draw lines along the fiducial edge of the alidade.

(v) Measure MN precisely and draw it two scale along the line drawn by sighting the ranging rod at N. This line mn is the base line.

(vi) Shift the table and place it over N. Level it and centre it so that n is exactly over N on the ground.

(vii) Now orient the table preferably by back sighting. For this purpose, place the alidade along mn and turn the board till the ranging rod at M is sighted. Then clamp it.

(viii) With the alidade touching n, sight the same object A, B, C etc. and draw from m give the position of the points A, B, C etc. as a, b, c etc. on the paper. Join ab, bc, cd, etc. to get the outline of the survey.

Very acute angle of intersection less than 30^0 or very obtuse angle of intersection greater than 120^0 should be avoided.

Δ Sources of Error :

The major sources of error are inaccurate entering; imperfect leveling and incorrect orientation, besides, error may appear (i) If rays do not radiate from or converge at the station point exactly due to wrong fixing of alidade. (ii) In accurate intersection or resection would give wrong point whole plotting due to wrong sighting of the object and (iii) Non vertically of the ranging rods would effect the whole survey process.

Δ Advantages of Plane Table Survey :

1. The plan is drawn by the out-door surveyor himself while the country is before his eye, and therefore, there is no possibility of omitting the necessary measurements.
2. The surveyor can compare plotted work with the actual features of the area.
3. Since the area is in view, contour and irregular objects may be represented accurately.
4. Direct measurements may be almost entirely dispensed with, as the linear and angular dimension are both to obtained by graphical means.
5. Notes of measurements are seldom required and the possibility of mistakes in booking is eliminated.
6. It is particularly useful in magnetic areas where compass may not be used.
7. It is simple and hence cheaper than the theodolite or any other type of survey.
8. It is most suitable for small-scale maps.
9. No great skill is required to produce a satisfactory map and the work may be entrusted to a subordinate.

Δ Disadvantages of Plane Table Survey :

1. Since notes of measurements are not recorded, it is a great inconvenience if the map is required to be reproduced to some different scale.
2. The plane tabling is not intended for very accurate work
3. It is essentially a tropical Instrument.
4. It is most convenient in rainy season and in wet climate
5. Due to heaviness, it is inconvenient to transport
6. Since there are so many accessories, there is every likelihood of these being lost.

☐ 9.1.5 Self-assessment question :

1. What is plane table surveying and when do you recommend it?
2. Make a list of equipments and accessories required for plane table surveying. With the help of sketches explain the working of the alidade and U-fork/U-frame.
3. With the help of a sketch, describe the details of the plane table. How do you set up the plane table and orient it?
4. Explain the steps that are required for conducting the intersection types of plane table surveying. Draw explanatory sketches.
5. Write a short notes on the followings:
   (I) Centering (II) Orientation (II) Trough Compass (IV) U-Frok/Fram with plumb bob (V) Alidade
6. State the advantages and disadvantages of the plane table surveying

☐ 9.1.6 Refferences :

1. Surveying and Levelling part-I- Late T.P. Kanetkar and Prof.S.V. Kulkarni, Pune Vidyarathi Giri Prakashan, Pune-411030
2. Surveying – B. C. Purnia
3. Plane Surveying-Dr. A. M. Chandna
4. Introduction to Soil and Water Conservation Enggeneering- Dr. B. C. Mal, Kalyani Publishers
5. Advance Surveying- Ramesh Gopi. S. Sathikumar

☐ 9.1.7 Traverse Survey by i) Plane Table (Intersection method) ii) Prismatic Compass

Δ Prismatic Compass Survey :

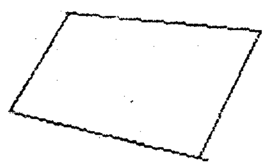
What is Traverse Survey?

A traverse is one in which the framework consists of a series of connected lines (the length and direction of which are measured with chain or tape) is called traverse survey.

A traverse may be classed as a) Closed b) Open

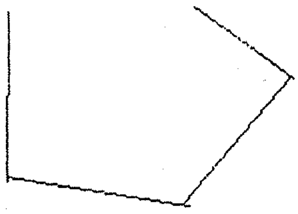
Closed Traverse:

A traverse is said to be closed when a complete circuit is made is called Closed Traverse, Example: Lake, Building area etc.



Open Traverse:

A traverse is said to be open when it does not from a closed polygon. It is most suitable for the survey of a long narrow strip of country i. e. the valley of a river, coastline, road etc.

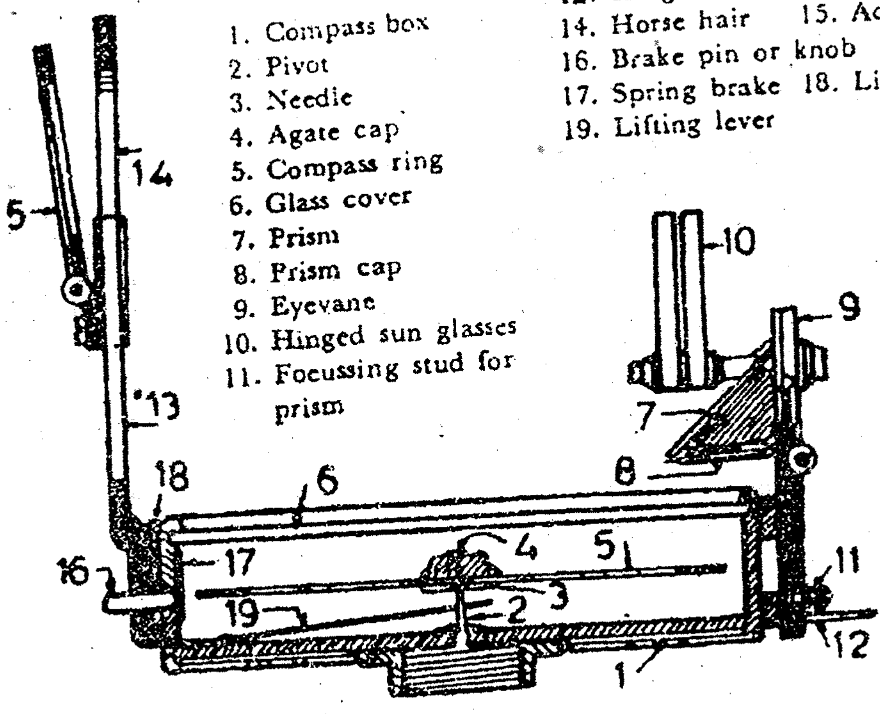


What is triangulhtion survey?

Triangulation is the basic of trigonometrically or geometrical surveys the term 'Triangulation" when used without qualification denotes a system of surveying in which the sides of the various triangles are computed from:-

A) A single line measured directly called the baseline
B) The three angles of each triangle measured accurately with a theodolite.

Prismatic Compass



Equipment

1. 1 Prismatic Compass
2. 4 Ranging Poles.
3. 10 small Pegs.
4. 1 Survey field book
5. Pencil

6. Eraser
7. Tripod
8. Linen Tape (50m)
9. Plumb line
10. Optical Square

Mandatory Pre-Survey Checks

1. Check for compass error.
2. Check for true length of the Chain as this can introduce cumulative errors in measurements.
3. Ensure that you know the current magnetic declination of the area to be surveyed. This is particularly important when going to the field with a forest boundary schedule; as there will always be the need to add to each bearing, the Magnetic Variation or Declination of the area
4. Ensure that the survey is tied to a point or landmark, the **co-ordinates** of which can be obtained. (e.g. A forest Boundary Pillar).
5. Before conducting a survey, it is often recommended that a reconnaissance survey be carried out. This is to ensure inter-visibility between adjacent stations. Although reconnaissance survey may not be obligatory, it is nevertheless a very helpful exercise.

If the survey is to be tied to a pre-existing pillar, a tripod is placed above the pillar and a plumb line made to fall vertically above the pin point of the pillar. In the absence of a plumb line; (a piece of lead with a tapering end hung to the base of the tripod with a thin piece of thread), a piece of stone is placed at the point of convergence of the legs of the tripod just below the compass, and made to drop freely onto the top of the pillar. If the stone falls right on top of the central pin of the pillar, the tripod may be considered as being vertically above the pillar. The Compass is then fitted to the tripod and balanced horizontally with the aid of the spirit level. A ranging pole is then placed as far from the starting point as is convenient and visible, for the bearing of this pole to be taken from the starting point. **Never conduct a survey holding the compass in your hand.** In the absence of a **tripod**, a wooden "peg" (**monopod**) may be cut for use. The length of the monopod is best at breast height of the compass reader. The top of this monopod should be about the size of the base of the compass and made flat for ease of placing the compass on it. Since the monopod cannot be placed conveniently on top the survey pillar, it is fixed directly behind the pillar, with the line of sight passing over the centre of the pillar, usually indicated by a pin. The bearing to the ranging pole is then taken after the compass, resting on the monopod, is levelled. In this case, measurement of the distance should be from the top of the pillar to the ranging pole and not from where the monopod (with compass on it) is positioned.

The tripod or monopod is then moved to the location of the ranging pole and the process repeated. **The compass must always shifted to and be placed directly above the location of the ranging pole whose bearing has just been taken, for the next bearing to be taken.**

Δ IMPORTANT DEFINITIONS:

The Magnetic North (MN):

Our Earth has a magnetic axis inclined to the line of longitude, which divides the earth into two equal parts. This magnetic axis is the property that influences the needle of a compass. When a compass needle is allowed to swing freely and settle, it points to the northern pole of this axis, and the direction so indicated is referred to as the Magnetic North. The magnetic North therefore is the direction of the pole of the earth's magnetic axis from any point on the earth's surface as indicated by the freely suspended needle of a compass. It is important to note that the Magnetic North forms the basis for all angular measurements with surveying instruments. Without it, surveying with the theodolite and compass would not be possible. (See Fig. 2.1)

True North (TN)

The direction indicating the pole of the earth's geographic axis in the Northern Hemisphere All other lines referenced to this are referred to as true north bearings. (See Fig.2.1) The figure below shows the Magnetic North (MN), the True North (TN), the True South, (TS) and the Magnetic South (MS).

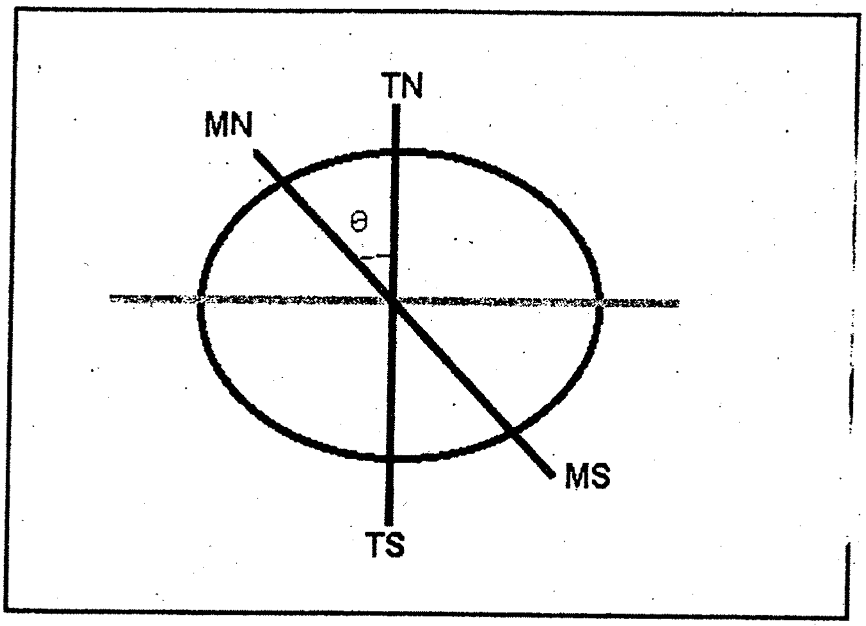


Fig. 2.1 The True North And Magnetic North

The Azimuth:

The Azimuth is the smallest bearing to a point measured Eastward or Westward from a particular reference North. Azimuths may be measured either with reference to the Magnetic North or to the True North and referred to as Magnetic North and True North Azimuths respectively. The azimuth begins from °0 or 360° representing North and runs through 90° East, 180° South, 270° West and back to 360° North.

What is bearing?

The bearing of a line as already started is the horizontal angle, which the lines make with some reference direction or meridian. The reference direction employed in surveying may be

b) True bearing/meridians b) Magnetic bearing/meridians c) arbitrary/assumed bearing. The true meridian is usually employed in geodetic surveys while the magnetic bearing is used in plane surveys.

I) True Bearing:

The points of intersection of the earth's axis and the surface of the earth are known as the north geographical pole and the south geographical pole. The true or geographical meridian passing through a point on the earth surface is the line in which the plane passing through the given point and the north and South Pole intersect the surface of the earth. The direction of true meridians at stations is not parallel but converges to the poles, however, for ordinary small surveys they are assumed to be parallel to each other. The horizontal angle between the true meridian and a line. It is also known as an azimuth

II) Magnetic Bearing:

The direction indicated by a freely suspended and properly balanced magnetic needle unaffected by local attractive forces is called the magnetic north and south line. The angle, which a line makes with the magnetic meridians, is called a magnetic bearing of the line or simply a bearing of the line.

III) Arbitrary Bearing:

For small surveys any convenient direction may be taken as a meridian. It is usually the direction from a survey station to some well-defined permanent object or the first line of a survey. The angle between this meridian and a line is known as an arbitrary or assumed bearing of the line.

BEARINGS:

The mathematical analysis of survey data begins with the reduction of the bearings obtained from the analysis above, to **quadrantal bearings**.(See Fig. 3.1 below)

The next thing to do is to resolve the measured ground distances to their Horizontal and vertical components. We do this by finding the sine and cosine of each quadrantal bearing and multiplying by the measured distance on the ground. The sine of the bearing, multiplied by the distance gives the horizontal X axis value or **Easting Component** often referred to as the DEPARTURE while the cosine of the bearing multiplied by the measured distance gives the Vertical Y axis value or **Northing Component** often designated as the **LATITUDE**.

CALCULATING QUADRANTAL BEARINGS

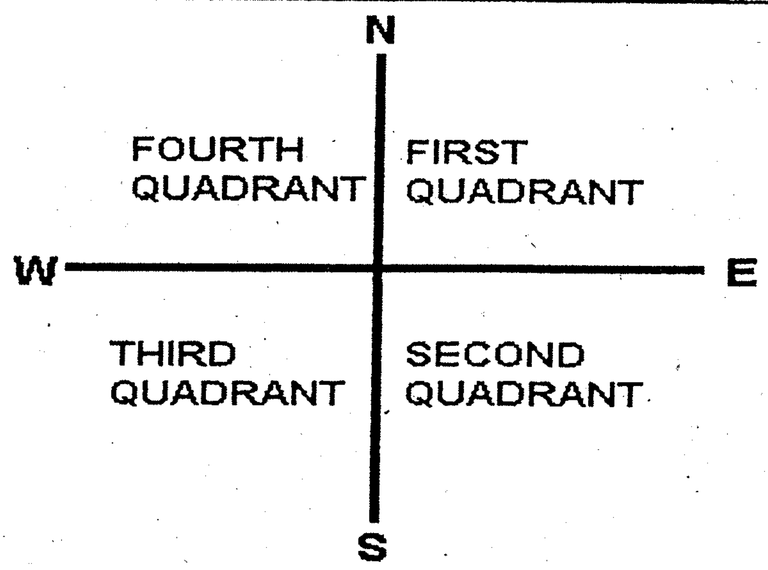


Fig. 3.1 The Cartesian Plane

One very important characteristic to note about quadrantal bearings is that, they are measured relative to the N and S and **NOT** to the **E** and **W** cardinal points. Quadrantal bearings always have a preceding **N** or S followed by **E** or **W** depending on the quadrant in which the bearing falls. **(N=north, S=South, E=East** and **W=West)** (See Fig. 3.1) The primary objective of reducing whole circle bearings to quadrantal bearings is to reduce the bearings to values between 0 and 90 degrees. This facilitates the calculation of sines and cosines which, when multiplied by the distances measured will produce DEPARTURES and LATITUDES respectively.

Angles of the first Quadrant:

Angles equal to or less than 90 degrees retain their values and is placed in the first quadrant. 90-degree angles are referred to as Due East. For example a bearing of 75 degrees is referred to as **N** 75° **E** in quadrantal terms. A bearing of 90° is referred to as DUE EAST.

Angles of the second Quadrant:

Bearings greater than 90°, but less than 180°, are usually subtracted from 180°. The resulting angle is then measured from the South cardinal point. South falls into the second quadrant. 180-degree bearings are referred to as Due South. For example, a bearing of 170° reduced to quadrantal bearings will be (180 °- 170°) = **S** 10° **E.** A bearing of 180° is referred to as DUE SOUTH.

Angles of the third Quadrant:

Bearings greater than 180°, have 180° subtracted from them to produce quadrantal bearings of the third quadrant. The resulting bearings are measured from the south cardinal point and written as S "bearing" W. For example, a whole compass bearing of 196° would be (196° -180°) = **S** 16° **W** in quadrantal terms. A bearing of 270° is referred to as DUE WEST.

Angles of the fourth Quadrant:

Angles greater than 270° fall into the fourth quadrant. To obtain quadrantal bearings of the fourth quadrant, such bearings are subtracted from 360°. For example, a whole compass bearing of 288° would be (360 ° -288°) = **N** 72° **W**. A bearing of 0 ° or 360 ° is referred to as DUE NORTH.

Local Attraction:

This is a term denoting any local influence that causes the magnetic needle to be deflected away from the magnetic meridian for that locality. This causes wrong measurements to be obtained. Measuring both the forward and the back bearing helps to detect local attraction. Some sources of local attraction are: permanently fixed objects of iron, steel and magnetite in the ground. Local attraction includes iron and steel articles about the person. High-tension lines are known to influence the needle of the compass and should be avoided where possible. Generally, the difference between the forward bearing (FB) and the Back Bearing (BB) is equal to **180°**.

The Forward Bearing and Back Bearing:

When the bearing of a line is stated in a direction from an original point to a terminal point, it is known as a forward bearing. The back bearing is opposite in direction, to the forward bearing.

If the difference between the **forward bearing** and the **back bearing** is exactly **180°**, then, the two stations are free from **local attraction.** As an example, consider a survey line along stations **A, B** and **C**. If the forward bearing from **A** to **B** is 95° and the back bearing to **A** from **B** is 275, the difference between the two bearings is exactly **180°** and there will be no reason to suspect any local attraction at stations B and A. If from station **B** the bearing to station **C** is 240 (Forward Bearing) and the back-bearing from station **C** to **B** is 61, the difference between the two bearings will be 179°. Since it is already known that there is no local attraction at stations **A** and **B**, then there is good reason to suspect local attraction at station **C**. To confirm this suspicion a forward bearing is taken to station **A** from station **C**, and a back-bearing taken from **A** to **C.** Since **A** is known to have no local attraction, if the difference between the two bearings is not exactly **180°**, then the presence of local attraction at station C is confirmed.

Magnetic Declination/Variation (MD or MV):

This is the angle the magnetic axis makes with the earth's geographic axis.(angle θ in Figure 12). It is often synonymously referred to as the Magnetic Variation because its value does vary from one point on the earth's surface to the other. The Isogonic chart of Ghana shows this variability across the entire country as at 1958. The magnetic axis oscillates between West and East, over an angle of about 22°. In other words, its maximum deviation from the true North is 11°. In Ghana, it is presently inclined to the west of True North, and is decreasing at the rate of **6.5 minutes of arc per annum (6.5')**. Consequently, the magnetic declination of a particular area is usually subtracted from all magnetic bearings recorded in the field before plotting is done, to reduce the bearings to values that relate to the true north. It is usually very important to critically examine the forest reserve boundary schedule to see whether the bearings refer to the true North or to the magnetic North.

Where the bearings refer to the true North, the magnetic declination of the area in that particular year must be **added to** each bearing before using the schedule in the field.

A PROCEDURE FOR UNDERTAKING PRISMATIC COMPASS SURVEY

1. Collect a Prismatic Compass, a Sighting Pole and possibly a Chain for the Fieldwork. Try not to wear too many **jewellery** or rings as the **metals** can interference with the compass readings.

2 Remember that Compass readings are made along **straight segments** of a boundary. Irregular paths (or boundaries) should therefore be first divided into straight segments before readings are taken. In this example, the straight segments of the boundary have been determined and marked for you.

3 To begin, pick the prismatic compass and locate the Starting Point (station 1). Let your partner move to station 2 with the **sighting pole**. Your partner must then hold the pole upright from the position marked station 2. Take a reading from your location (marked station 1) onto the sighting pole at station 2 and record the azimuth (angles) you get.

4 To verify whether the forward azimuth reading you made is correct, exchange positions with your partner (or preferably let your partner take a back azimuth onto the sighting pole now located at station 1). As a rule, if the **forward azimuth** is greater than 180^0, you should subtract 180 from the forward azimuth to get **the back azimuth** but if the **forward azimuth** is less than 180^0 you should add 180 to it to get the **back azimuth**. With the rule, make a quick check of the forward azimuth you made and record it if it is right. If it is wrong, redo the reading all over.

5 Record the forward azimuth you read earlier. See the next page for an example of how to record the readings on a page in a survey book.

6 Measure the segment of the boundary between station 1 and station 2 and record your answer beside the azimuth reading for this segment. You may use a chain or a tape and remember to take the measurement in feet. In tha absence of a chain or a tape, you may take the measurements by pacing along the boundary and counting the number of paces you make. Generally, a pace taken in a relaxed mood (not running) is about a yard (three feet) for many people. If you will use this method, you should first determine the length of your pace by marking three feet segments on the floor and walk along them for some time.

7 Walk along the boundary segment between station 1 and station 2 and make any other required readings such as resection or intersection then record such measurements on the page you have already opened. Make some sketches if necessary, to portray the features and positions you find in the field. See an example of the entry on the next page.

8 Now go to station 2 and let your partner move with the sighting pole to station 3. Take the forward and backward azimuths as explained above and record only the forward azimuth in your survey book. Check to make any required chain and compass readings along the segment between stations 2 & 3 and then move on to the next segment. Continue with the process in the same manner as described until all stations (or segments) are measured and the measurements recorded in your notebook.

9 Keep your note book entries for you shall use it to plot the shape of land you measure in the field. You will also hand in your note book entries for grading.

BOOKING OF THE FIELD DATA

Traversing involves taking bearings and distances from one station to the other until the last station is encountered. The convention for recording such data is shown in Fig.2.2. The survey book has two parallel lines running through the centre of each page. Booking is usually started from the last page of the book and from the bottom to the top of each page. The stations are represented as triangles enclosing serial numbers or letters specific to each station.

Fig.2.2 is an example of the booking of a closed traverse, which starts at A through B, C, D, E and back to A. The bearing from A to B is recorded at the top of the triangle enclosing A. The distance from A to B is recorded at the base of the Triangle enclosing B. Any feature encountered, such as the footpath shown in dotted line or the stream with an arrow head, is sketched at the point it crosses the survey line. It's distance from the previous station is recorded just below the sketch as shown above.

The Magnetic Declination; (MD), of the area of the survey is recorded at the bottom right hand corner, together with the date of completion of the survey and the Name of the officer conducting the survey.

Interpreting the Note Book entries:

The azimuth from station A to station B was 199° and a distance of 120.37meters.
The azimuth from station B to C was 92° and a distance of 83.8 meters separates B and C.
A path crosses the traverse at 50.2 meters from B
The azimuth from station C to D was 65° and a distance of 40.75 meters separates C and D.
A river crosses the traverse at 30 meters from C.
The azimuth from station D to E was 353° and a distance of 59.83 meters separates D and E.
The azimuth from station E to A was 299° and a distance of 81.8 meters separates E and A.

Survey Data Analysis:

The compass usually measures bearings from the magnetic north in a clockwise direction over a 360 degrees sweep. The first thing to do with these bearings is to correct each of them by finding the difference between the magnetic variation and the bearing of each leg. Because of the inclusion of magnetic declination in this corrective analysis, the corrected bearings are relative to the True North. The bearings so obtained could then be used with the measured distances for graphical plotting. (See the section on **producing a map from the Survey data, below**)

Producing A Plot From The Survey Data:
Producing a plan of the survey from field survey data may be achieved, using one of two methods, namely: **(a) The Graphical Method** and **(b) The Mathematical Method**

The Graphical method:
This is a procedure in which Protractors, Set Squares and Rulers are employed. The accuracy of the graphical method depends largely on the skills of the person employing it; his ability to measure angles or bearings and scale distances accurately. Graphical distribution of the closing error if it does occur again depends on one's skills at handling drawing equipment.

This method is adopted if very high levels of accuracy are not very important and only rough sketches are sufficient. This is not to say however, that when used correctly, reasonably high levels of accuracy cannot be achieved using this method.

Plotting with Bearings And Measured Distances:

Plotting is the translation of the mathematically analysed and corrected survey data into a two dimensional pictorial form on a sheet of paper or any other suitable material. In plotting, Symbols in common use are also considered below.(See Fig. 3.2) When plotting, It is important to look for the longest leg and see how that can be fitted onto the piece of plotting paper. Please take note of where you are going to start and where you will end. Fig. 3.3 is a plot of the data in table1.

FROM	TO	TRUE-NORTH BEARINGS / Forward Bearing	DISTANCE (Meters)
A	B	192° 44'	120.37
B	C	85° 44'	83.80
C	D	58° 44'	40.75
D	E	346° 44'	59.83
E	A'	292° 44'	41.80

Table 3.1 Survey Data

The plot is as shown below: (See Fig. 3.3)

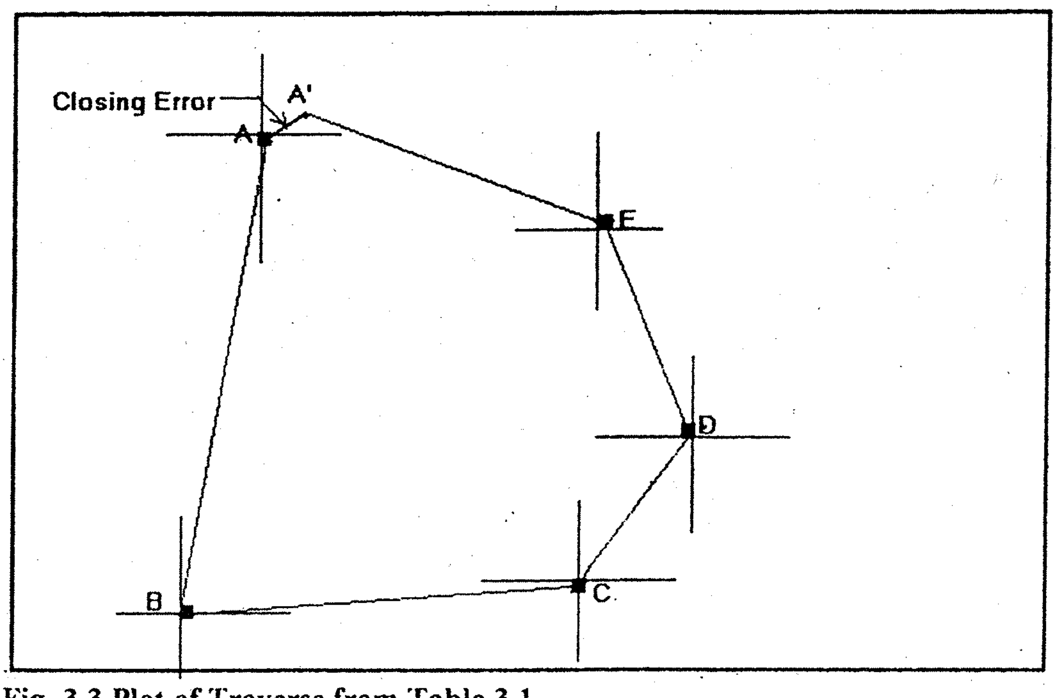


Fig. 3.3 Plot of Traverse from Table 3.1

To produce a graphical plot from the data in table 3.1. a protractor and a ruler are required. At a starting point A, the protractor is placed on A, such that the North-South and West-East intersecting lines meet at A. The angle from A to B (**192°** 44') is read off the protractor and marked with a point. This point is joined to A, and depending on the selected scale, the distance A-B is scaled along the distance between A and the marked point towards B. The protractor is next shifted to the end of the scaled line A-B, which is the position of B and the process repeated for B-C. This process of reading off angles and scaling off distances is continued until the last leg ; E is reached. At E, if the field survey data were expertly measured, there will be no closing error and the bearing from E to A and the scaled distance would perfectly fit the distance between E and the starting point; A. In practice, however, this rarely happens and the result is a **closing error** as shown in figure 3.3. From the above plot, if **EA** does not coincide at **A,** but ends up at **A'** then we have a closing error. Normally, the line **EA** should coincide with **A**. This is usually due to faulty chaining slight errors in taking bearings or plotting inaccuracies. Very skilled hands often eliminate plotting inaccuracies. Where the error consistently persists after a few re-plots, the error of closure is attributed to the latter, and adjustments or error distribution among the various legs will be necessary.

The error is therefore distributed round the traverse by adjusting the length of each leg in proportion to its scaled length from the start of the traverse in a direction parallel to the closing error. The stations will therefore be shifted accordingly until **EA'** coincides with **A**. This is the graphical method defined by Bowditch's rule.

If however, after the first plotting, the line **EA'** coincides with **A**, then we do not have a closing error and the field survey data could be described as meeting acceptable standards.

Adjusting the Traversing Error:

The adjustment of the traverse error is done in conformity with Bowditch's rule which states that the distribution of the closing error should be in proportion to the ratio of the individual legs to the entire length of the traverse. Simply put, longer legs are given larger portions of the error than smaller lengths.

Construct an error-correcting graph as shown in Fig. 3.4 First, the total length of the legs is drawn with the same scale as was used for the plotting. A, B, C. D, A. represent the total perimeter of the survey and the intervals represent the scaled distances between the stations. A perpendicular **AA'**, which is the length of the **Closing Error** is erected at the end of the line.. This is then joined to the other end to form a right angled triangle as shown below in figure 3.4.

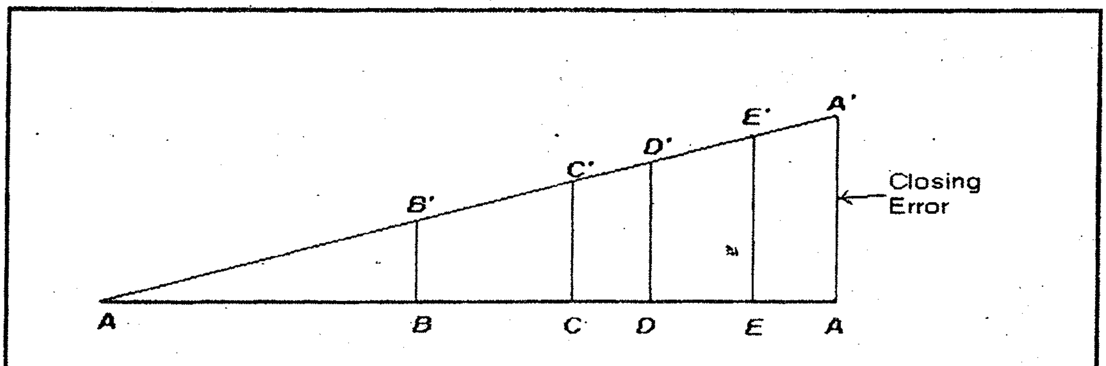


Fig. 3.4 Adjustment of the Closing Error

Other perpendiculars are erected at each station to meet the line A, A' through B' C' D' and E'. The adjustment of the traverse error **AA'** is done by drawing lines from each of the stations parallel to and in the direction of the line joining the gap **AA'**. From the error-correcting graph, the length of the perpendiculars at each station is measured and transferred to the corresponding station on the plot and marked off. The parallel lines are drawn from the corresponding stations and in the direction of the line joining the error of closure. The marked points along the parallel lines are then joined in broken lines to form the adjusted traverse as shown below in Fig. 3.5.

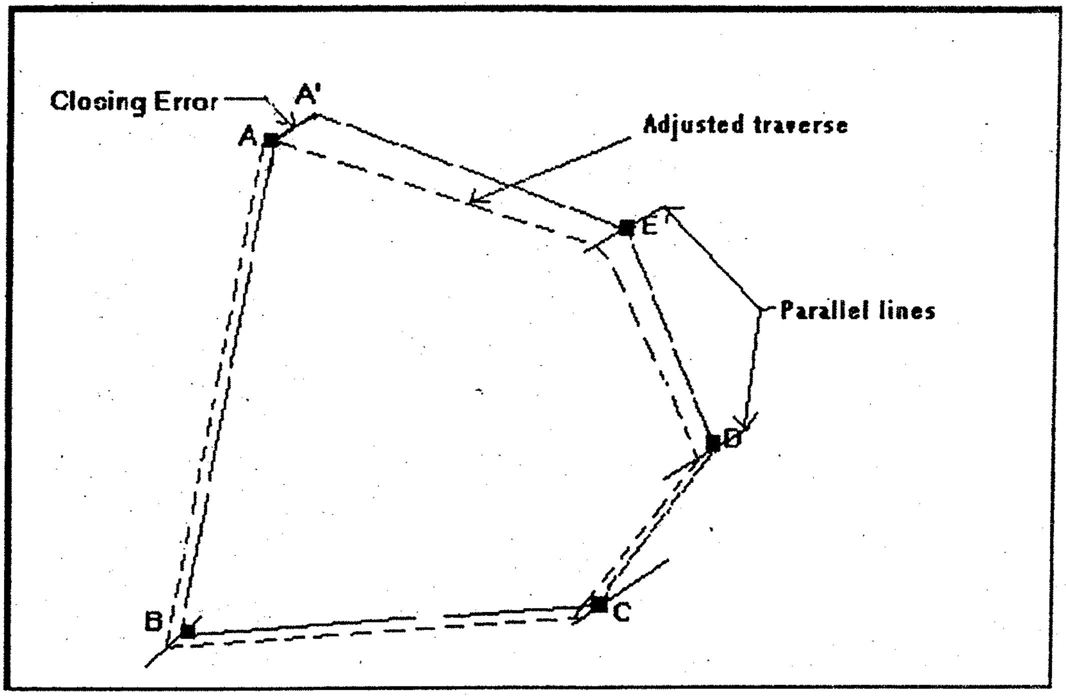


Fig. 3.5 Adjusting the Traverse

The Mathematical (Trigonometric) Method:

This is a procedure where the data is trigonometrically analysed to produce coordinates of the various positions of the Compass or Theodolite in the field for plotting. **This method is very accurate and therefore recommended for use in the processing of plane survey data.**

The mathematical procedure is facilitated by the use of the Gale's Traverse Table, as shown in (Table 3.2). For the sake of presenting all the difficulties associated with this method, a new set of data is tabulated in table3.2. .Bearings and distances between stations are tabulated as shown below and trigonometry employed to compute Partial coordinates in the form of Latitudes and Departures. From this Table, the area of the close traverse may be calculated, in addition to producing Assumed Coordinates for plotting the survey. While the mathematical procedure is considered the most accurate form of survey data analysis, there is no doubt that when large volumes of data are involved, this method can be pose practical problems.

Applying trigonometry, we find the sines and cosines of the quadrantal bearings calculated for each station and multiply by the measured distance on the ground to obtain Departures and Latitudes respectively. The sine of the quadrantal bearing multiplied by the distance gives the partial **Easting (Longitude or Departure) Component** and the cosine of the bearing multiplied by the distance gives the partial **Northing (Latitude) Component**.

Local attraction:

The external disturbing forces which do not permit a freely moving and properly balanced magnetic needle to point to the actual magnetic north and south directions are known as local attraction. Also the deviation of the needle caused by the disturbing forces is called local attraction. The source of disturbance may be magnetic rock, iron or rails, metallic structure, wires carring electric current, chains, arrows, bunch of key, knife etc. Chain, arrows etc. should therefore, be kept away from the compass.

Detection of local attraction and remedied:

Local attraction can be detected by observing both fore bearing and back bearings of the lines at a place. If they differ exactly by 180^0 there is no local attraction at either station provided no other error occurs. But if the difference is not equal to 180^0, local attraction may exist at either or both the stations. The local attraction, once detected may be corrected by using any one of the following methods.

(b) If the F.B. and B.B. of a line differ by 180^0 approximately, the F.B. should be calculated from B.B. and the average of the observed and the calculated F.B. is taken as the corrected F.B. say for example, observe F.B. is 40^0 and B.B. is 221^0, then the calculated F.B. is $40^0 30''$ which is the average of 40^0 and 41^0 is taken as corrected F.B.

(c) In case of a closed traverse, the error due to local attraction may be corrected by using any of the following procedures.

(d) The included angles calculated from the bearing taken at a station affected by local attraction will be corrected as the error is same for all the bearing from a station. Starting from the unaffected line and using these included angles the corrected bearings of the lines are calculated.

(e) At first, error at each station is found out and then starting from an unaffected bearing, the bearings of others lines are corrected by applying corrected bearing to them.

Field Book

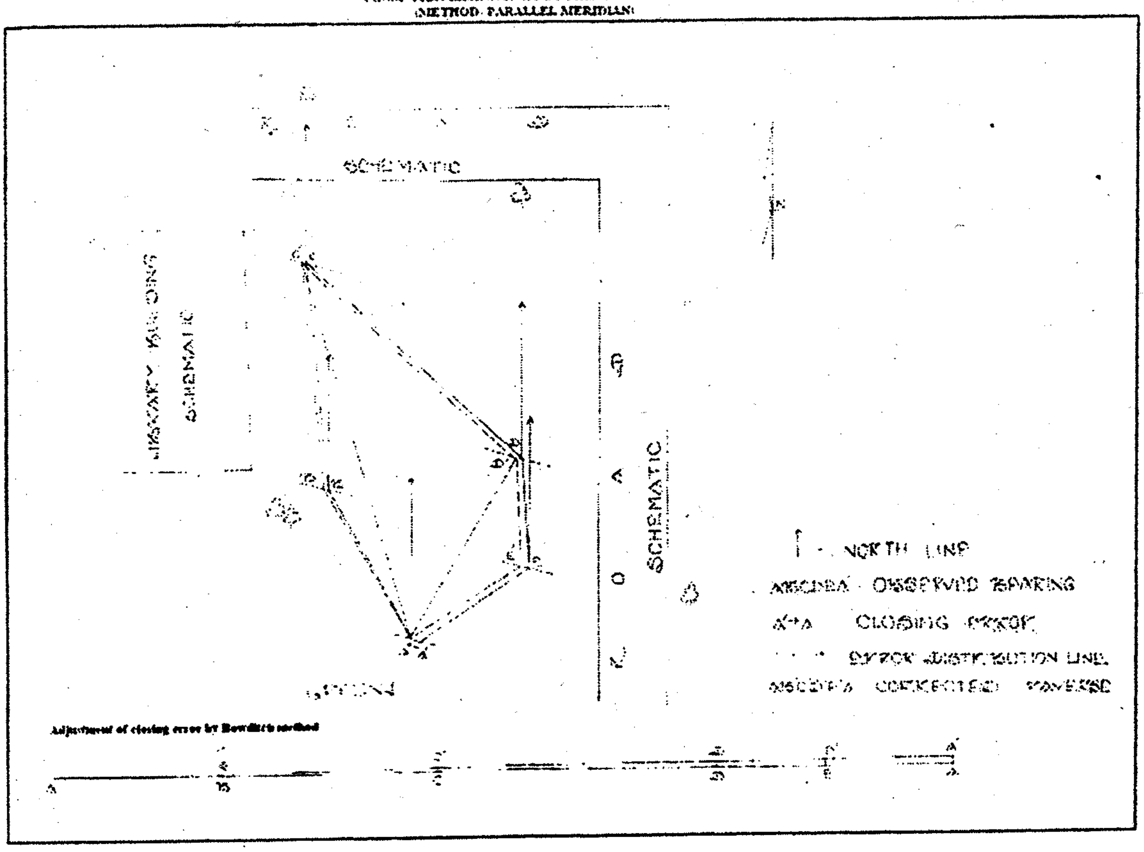
Closed traverse Survey by Prismatic Compass

Place: VU campus — **Date: 19-12-2007**

Ins. No: 2 — **Time: 12:30 P.M.**

Line	Length in mt.	Observed Bearing		Difference (d)	Error= 180-d	e/2	Corrected Bearing		Included Angle	Remarks
		F.B.	B.B.				F.B.	B.B.		
AB	15.5	330°	151°	179°	-1°	-30'	330° 30'	150°30'	89° 45'	I) Survey was done by
BC	20	354° 30'	174°	180° 30'	30'	15'	354° 15'	174°15'	156° 15'	clock wise direction
CD	25.8	132°	311° 30'	179° 30'	-30'	-15	131° 45'	311° 45'	42° 30'	II) All station are
DE	10	177° 30'	355°	177° 30'	2° 30'	1° 15	176° 15'	356°15'	135° 30'	locally attracted
EA	12	240°	60° 30'	1790 30'	-30'	-15'	240°15'	60° 15'	116°	near the Iron pole.

CLOSE TRAVERSE SURVEY BY PRISMATIC COMPASS
(METHOD: PARALLEL MERIDIAN)



9.1.8 Self-assessment question:

1. Write short note on the following:
   (a) Closed Traverse and open traverse (b) Magnetic meridians and true meridians (c) Whole circle bearing and reduced bearing (d) Closing Error (e) Local Attraction
2. Convert the Following whole circle bearing into reduced bearings.
   (i) $50^0 30'$ (ii) $115^0 45''$ (ii) 313^0 (iv) 210^0

3. Convert the Following reduced bearings into whole circle bearing
   (j) N 45^0W (ii) S 15^0W (iii) S45^0E (iv) N 45^0E

4. The bearing of the sides of a closed traverse ABCDEA are as follows. Calculate the interior angles of the traverse.

Side:	AB	BÇ	CD	DE	EA
Fore bearing	50^0	140^0	230^0	275^0	350^0

5. What is local attraction and how to detect it ? What are the methods of correcting the bearing affected by local attraction?

6. In running a closed traverse ABCDEA, the following bearing were obtained. Find out which stations are affected by local attraction. Calculated the included angles and the correct bearings

Line	AB	BC	CD	DE	EA
F.B.	44^0	$115^0 30$	200^0	$280^0 40$	$355^0 15"$
B.B	$220^0 15"$	$298^0 30"$	$18^0 30$	$100^0 40$	$177^0 30$

9.1.9 Reference :

6. Surveying and Levelling part-I- Late T.P. Kanetkar and Prof.S.V. Kulkarni, Pune Vidyarathi Giri Prakashan, Pune-411030
7. Surveying – B. C. Purnia
8. Plane Surveying-Dr. A. M. Chandna
9. Introduction to Soil and Water Conservation Enggeneering- Dr. B. C. Mal, Kalyani Publishers
10. Advance Surveying- Ramesh Gopi. S. Sathikumar

PART-I

Paper – V (Practical)

Module - IX : Unit - 02

Module Structure

- 9.2.1 : Determination of Height by Transit Theodolite (Base Inaccessible)
  - Δ Theodolite
  - Δ Transit Theodolite
- 9.2.2 : Self-assessment Question
- 9.2.3 : Reference

- 9.2.4 : Survey of Road in Study Area by a GPS Handset and Preparation of Road Map
  - Δ GPS - An Introduction
  - Δ What is GPS?
  - Δ GPS Satellites
  - Δ Ground Stations
  - Δ Navigation Message
  - Δ Applications of GPS
- 9.2.5 : Self-assessment Question
- 9.2.6 : Reference

GROUND SURVEY AND PHOTO INTERPRETATION
Paper-V (Practical)
Module – IX
Unit - 02

9.2.1 Determination of Height by Transit Theodolite (Base Inaccessible)

Δ THEODOLITE :

The theodolite is the most intricate and accurate instruments used for measurements of horizontal and vertical angles. It consists of a telescope by means of which distant objects can be sighted. The telescope has two distinct motions one in the horizontal plane and the other in the vertical plane, the former being measured on a graduated horizontal circle by means of a set of verniers, and the later on a graduated vertical circle by two verniers. It can also be used for various other purposes such as laying of horizontal angles, locating points on a line, prolonging survey lines, establishing grades, determining differences in elevation. Etc.

Theodolites are primarily classified as (i) Transit, and (ii) Non-transit :

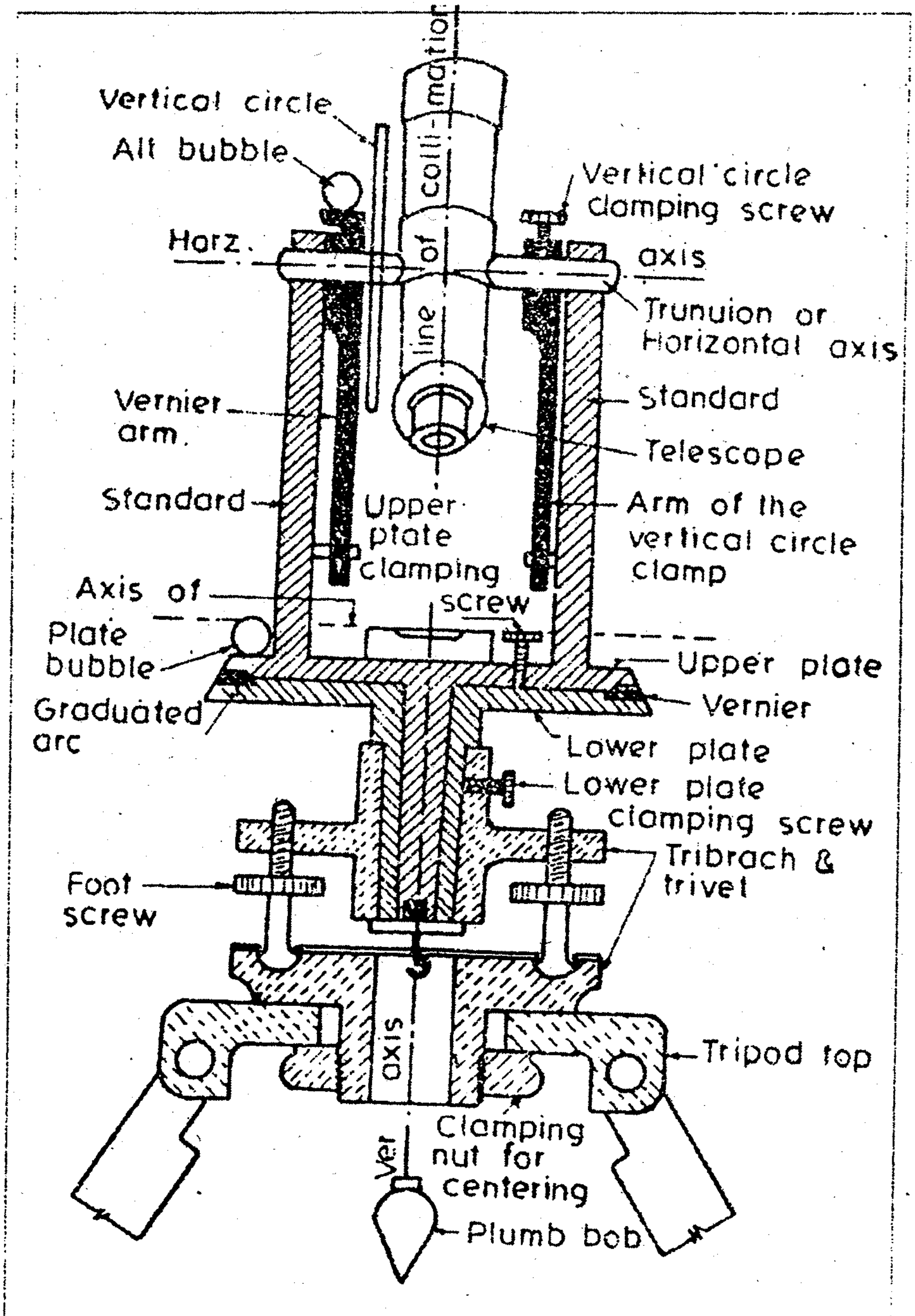
There are three main types, viz. (i) the Transit, (ii) the plain or Y- and (iii) the Everest. A theodolite is called a transit theodolite, when its telescope can be revolved through a complete revolved through a complete revolution about its horizontal axis in a vertical plane..

The first type is transit type is transiting and the other two are non-transiting. The transit type is largely used, while the other two types have now become obsolete.

Theodolite are also classed as (i) vernier Theodolites, and (ii) micrometer theodolite, according as vernier or micrometers are fitted to read the gradually circles.

Δ Transit Theodolite :

It is most intricate instruments by which horizontal and vertical angles can be determined with great precision. The size of it (i.e. the diameter of the graduated circle or the lower plate) varies from 8 to 25 cm. The leveling head consists of two parallel plates (tribrach and trivet) with three arms, each carrying a leveling or foot screw in a ball-socket joint. The lower plate (trivet) has a central aperture through which a plumb bob may be suspended. At the central hollow of the tribrach two spindles with a common vertical axis are fitted-the inner one in attached to the vernier plate while outer one to the scale plate. The scale plate with beveled edge is silvered and graduated from 0^0 to 360^0 in a clock wise direction. It is provided with a clamp and slow motion tangential screw. The upper vernier plate carries two double vernier (VA and VB) fixed at diametrically opposite sides and provided wit6h clamps and slow motion tangential screws and vernier aids. A level tube is attached to the outer surface of the horizontals plates. Two upright standards or A-frames stand upon thew vernier plate to support the trunian axis, at the centre of and at right angle to which telescope is fitted. The telescope contains the eye piece, the objective, the diaphragm, the focusing screw and sighting knobs. A vertical circle firmly attached to the telescope moves with it. It is beveled, silvered and graduated to degrees and minutes. The index bar (T-farme) which is centered on the horizontal axis carries two double venires (VC& VD) at the ends of the index arm and are provided with a clamp and slow motion tangential screw. The clipping arm is provided with a fork; two screws and an altitude bubble tube, the latter is fitted at the top of the frame. Sometimes, a compass is fitted on the Theodolites to note the bearings. The instrument is mounted on a tripod made of solid legs (wood or light steel or aluminum)



Transit Theodolite

To find the height and distance of an object :

Base inaccessible, same vertical plane, Instruments heights same at both station.

On a flat ground (S_1. S_2), PM is the object with inaccessible base. A and B are the two stations at d distance apart such that A, B and M are collinear on the ground. Therefore, the instruments at A and B and the object lie on the same vertical plane. At both the stations, instruments are set up at the same height, h; Therefore DEC represents the common and fixed line of collimation.

Procedure :

i) After proper centering and leveling of the theodolite at A, its height (h) is measured with a tape or a graduated staff.

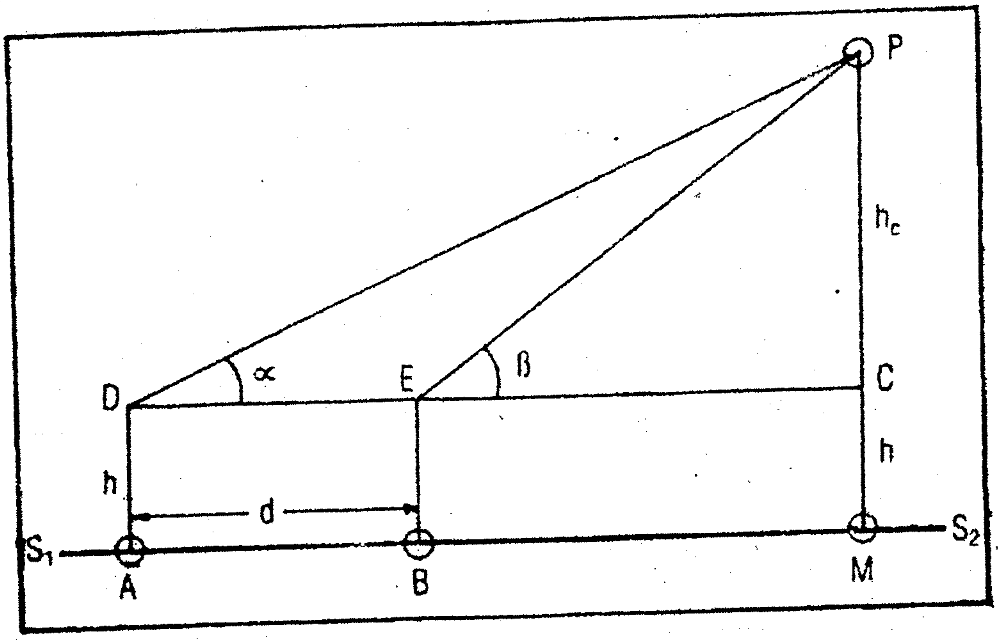
ii) The angle of elevation (α) of the object (P) at A is measured from the observations of the vertical circle readings of the theodolite.

iii) With the horizontal plate fixed, another station of observation (β) is selected on the ground by looking through the telescope.

iv) The distance, AB (d), is measured with a tape.

v) The instruments is then shifted to B, set up at the height, h, carefully centered and leveled and

vi) The angle of elevation (β) of top of the object (P) at B is then measured from the vertical circle readings



Determination of Height and Distance of an object with Inaccessible Base by Theodolite (Same vertical plane)

Field Book :

Determination of angle of elevation by Transit Theodolite

(Method: Base inaccessible)

Place: **VU campus** **Date:12-12-07**

Ins. No:20 Time:12.30P.M.

Instruments at	Object Sighted	Face	Vertical Circle Reading		Mean Angle	Grand Mean Angle	Remarks
			VC	VD			
A	Top of the lamp post	Left	$10^0 25$	$10^0 35$	$10^0 25$	$10^0 30'$	Instrument height in same in A and B station i.e. 2.10mt.
		Right	$10^0 28$	$10^0 32$	$10^0 30$		
B		Left	$15^0 26$	$15^0 32$	$15^0 29$	$15^0 35'$	
		Right	$15^0 40$	$15^0 42$	$10^0 41$		

Computation :

From the above figure

We can say,

AM ∥ DC and AD ∥ BE ∥ MC

Therefore, AD= BE = MC = hand AB = DE = d.

From the Δ PDC is right angle triangle,

DC /PC = Cot α

DC= PC. Cot α ....(i) no equation.

From the Δ PEC is right angle triangle,

EC/PC = Cot β

EC = PC. Cot β ....(ii) no equation.

Here, DEC lie in a same vertical Plane

Therefore, DC-EC= DE or AB

From the equation no (i) and (ii) we get,

PC. Cot α - PC. Cot β = d (distance between AB or DE which is measure by tape)

PC = d /Cot α - Cot β

9.2.2 Self-assessment question :

1. Define Line of Collimation.
2. Define Diaphram
3. What is meant by "Face left" and " Face right"
4. What are the sources of error in Theodolite Survey
5. What is transit theodolite

9.2.3 Reference :

1. Kanetkar, T.P. and Kulkarni, S.V. 1984. Surveying and Levelling; part one. P.V. Griha prakashan, Pune.
2. Hussain, S.K. and Nagraj, M S. 1978. Textbook of surveying. S. Chand & Co. Ltd. New Delhi
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4. Purnmia, B. C. 1989. Surveying. Laxmi Publications, New Delhi.
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8. Gopi, S., Sathikumar, R., and Madhu, N. 2007. Advance Surveying-Total Station, GIS and Remote Sensing. Dorling Kindersley (India) Pvt. Ltd., Licensees of pearson Education in South Asia. New Delhi.

9.2.4 Survey of road in study area by a GPS handset and preparation of road map

Δ <u>GPS - AN INTRODUCTION</u>

The Global Positioning System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS we can make measurements to better than a centimeter. In a sense it is like giving every square meter of the planet a unique address.

GPS receivers have been miniaturized to just a few integrated circuits and so are becoming very economical. And that makes the technology accessible to everyone. These days GPS is finding its way into cars, boars, planes, construction equipments, movie making gears, farm machinery, even laptop computers. Currently GPS is displaying its great utility in busting terrorist hideouts when to missiles.

Soon GPS will become almost as basic as the mobile phones. Indeed, we think it just may become a universal utility.

Δ WHAT IS GPS?

The Global Positioning. System (GPS) is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations. GPS uses these "man-made stars" as reference points to calculate positions accurate to a matter of meters. In fact, with advanced forms of GPS you can make measurements to better than a centimeter! In a sense it's like giving every square meter on the planet a unique address.

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Soon GPS will become almost as basic as the telephone. Indeed, we think it just may become a universal utility. The Global Positioning System (GPS) is a worldwide radio-navigation.system formed from a constellation of 24 satellites and their ground stations. GPS receivers have been miniaturized to just a few integrated circuits and so are becoming very economical. And that makes the technology accessible to virtually everyone.

Δ GPS Satellites :

Name: NAVSTAR

Manufacturer: Rockwell International

Altitude: 10,900 nautical miles

Weight: 1900 lbs. (in orbit)

Size: 17 ft with solar panels extended

Orbital Period: 12 hours

Orbital Plane: 55 degrees to equatorial plane

Planned Lifespan: 7.5 years

Current constellation: 24 Block II production satellites

Future satellites: 21 Block IIrs developed by Martin Marietta.

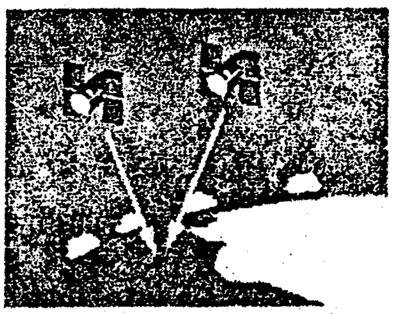
Δ Ground Stations

(Also known as the "Control Segment")

These stations monitor the GPS satellites, checking both their operational health and their exact position in space. The master ground station transmits corrections for the satellite's ephemeris constants and clock offsets back to the satellites themselves. The satellites can then incorporate these updates in the signals they send to GPS receivers.

There are five monitor stations: Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs. There is five monitor stations: Hawaii, Ascension Island, Diego Garcia, Kwajalein, and Colorado Springs.

HOW GPS WORKS ?



Here's how GPS works in five logical steps :

1. The basis of GPS is "triangulation" from satellites.
2. To "triangulate," a GPS receiver measures distance using the travel time of radio signals.
3. To measure travel time, GPS needs very accurate timing, which it achieves with some tricks.
4. Along with distance, you need to know exactly where the satellites are in space. High orbits and careful monitoring are the secret.
5. Finally you must correct for any delays the signal experiences as it travels through the atmosphere.

We'll explain each of these points in the next five sections. We recommend you follow them in order. Remember, science is a step-by-step discipline!

<u>ALGORITHM OF GPS SURVEY</u>

01). We chalked out an area with sufficient ground control points as our area of survey.

02). On a cloudless un-windy day we started our field survey with a GPS handset.

03). The survey instrument (i.e. GPS handset) was turned on and some time is given to receive signals from maximum possible number of satellites (in any case not less than four). Then we set up the datum in the instrument as WGS-84.

04). We choose a water-tank as our first ground control point and noted down its latitude, longitude and north-line shown by the instrument.

05). We choose cultural features like water-tanks, sign-boards beside roads, caveats, important road crossings. cultural shelters and temples at adequate distances separating them as our ground control points and recorded their respective latitudes, longitudes and north-lines sequentially.

06). We traversed in a close track path recording twelve ground control points on our path to come to the same point from where we started.

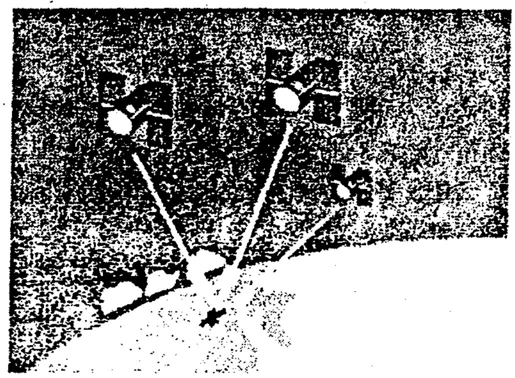
07). We collected an unrectified map of appropriate scale of the area surveyed and then scanned it to the computer for further processing.

08). In the computer we found out the precise location of all the twelve recorded points on the uncorrected map.

09). We inserted the respective latitudes and longitudes of the points on the map thereby geo-correcting it.

10). In this way we prepared a rectified road map with the aid of GPS survey, and its direction shown by the north-line.

Step 1: Triangulating from Satellites



Improbable as it may seem, the whole idea behind GPS is to use satellites in space as reference points for locations here on earth.

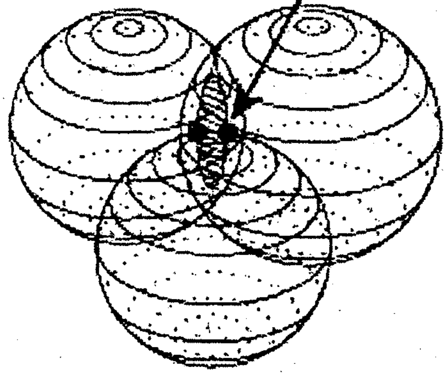
That's right, by very, very accurately measuring our distance from three satellites we can "triangulate" our position anywhere on earth.

Forget for a moment how our receiver measures this distance. We'll get to that later. First consider how distance measurements from three satellites can pinpoint you in space.

The Big Idea Geometrically.

Suppose we measure our distance from a satellite and find it to be 11,000 miles. Knowing that we're 11,000 miles from a particular satellite narrows down all the possible locations

If we then make a measurement from a third satellite and find that we're 13,000 miles from that one, that narrows our position down even farther, to the two points where the 13,000 mile sphere cuts through the circle that's the intersection of the first two spheres.



So by ranging from three satellites we can narrow our position to just two points in space. To decide which one is our true location we could make a fourth measurement. But usually one of the two points is a ridiculous answer (either too far from Earth or an impossible velocity) and can be rejected without a measurement. A fourth measurement does come in very handy for another reason however, but we'll tell you about that later. Next we'll see how the system measures distances to satellites.

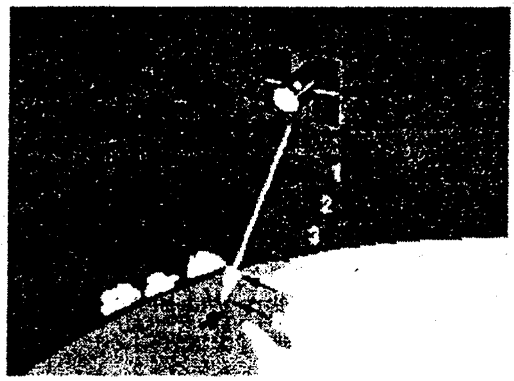
Triangulation???

We're using the word "triangulation" very loosely here because it's a word most people can understand, but purists would not call what GPS does "triangulation" because no angles are involved. It's really "trilateration" or "resection."

In Review : Triangulating

1. Position is calculated from distance measurements (ranges) to satellites.
2. Mathematically we need four satellite ranges to determine exact position.
3. Three ranges are enough if we reject ridiculous answers or use other tricks.

Step 2: Measuring distance from a satellite



We saw in the last section that a position is calculated from distance measurements to at least three satellites. But how can you measure the distance to something that's floating around in space? We do it by timing how long it takes for a signal sent from the satellite to arrive at our receiver.

A Random Code?

The Pseudo Random Code (PRC) is a fundamental part of GPS. Physically it's just a very complicated digital code, or in other words, a complicated sequence of "on" and "off" pulses as shown here:

The signal is so complicated that it almost looks like random electrical noise. Hence the name "Pseudo-Random".
There are several good reasons for that complexity: First, the complex pattern helps make sure that the receiver doesn't accidentally sync up to some other signal. The patterns are so complex that it's highly unlikely that a stray signal will have exactly the same shape.

Since each satellite has its own unique Pseudo-Random Code this complexity also guarantees that the receiver won't accidentally pick up another satellite's signal. So all the satellites can use the same frequency without jamming each other. And it makes it more difficult for a hostile force to jam the system. In fact the Pseudo Random Code gives the DoD a way to control access to the system.

But there's another reason for the complexity of the Pseudo Random Code, a reason that's crucial to making GPS economical.

The codes make it possible to use "information theory" to "amplify" the GPS signal. And that's why GPS receivers don't need big satellite dishes to receive the GPS signals.

We glossed over one point in our goofy Star-Spangled Banner analogy. It assumes that we can guarantee that both the satellite and the receiver start generating their codes at exactly the same time. But how do we make sure everybody is perfectly synced? Stay tuned and see.

In Review : Measuring Distance

1. Distance to a satellite is determined by measuring how long a radio signal takes to reach us from that satellite.

2. To make the measurement we assume that both the satellite and our receiver are generating the same pseudo-random codes at exactly the same time.

3. By comparing how late the satellite's pseudo-random code appears compared to our receiver's code, we determine how long it took to reach us.

4. Multiply that travel time by the speed of light and you've got distance.

GPS Signals in detail

Carriers

The GPS satellites transmit signals on two carrier frequencies. The L1 carrier is 1575.42 MHz and carries both the status message and a pseudo-random code for timing.

The L2 carrier is 1227.60 MHz and is used for the more precise military pseudo-random code.

Pseudo-Random Codes

There are two types of pseudo-random code. The first pseudo-random code is called the C/A (Coarse Acquisition) code. It modulates the L1 carrier. It repeats every 1023 bits and modulates at a 1MHz rate. Each satellite has a unique pseudo-random code. The C/A code is the basis for civilian GPS use.

The second pseudo-random code is called the P (Precise) code. It repeats on a seven-day cycle and modulates both the L1 and L2 carriers at a 10MHz rate. This code is intended for military users and can be encrypted. When it's encrypted its called "Y" code. Since P code is more complicated than C/A it's more difficult for receivers to acquire. That's why many military receivers start by acquiring the C/A code first and then move on to P code.

A Navigation Message

There is a low frequency signal added to the L1 codes that gives information about the satellite's orbits, their clock corrections and other system status.

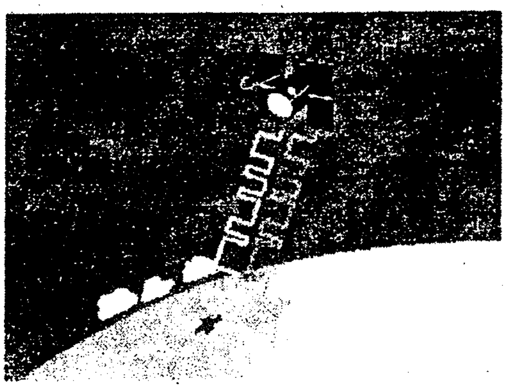
Encrypted GPS

GPS was developed by the Defense Department primarily for military purposes. And even though it's been estimated that there are ten times as many civilian receivers as military ones the system still has considerable military significance.

To that end the military maintains exclusive access to the more accurate "P-code" pseudo random code. It's ten times the frequency of the civilian C/A code (and so potentially much more accurate) and much harder to jam. When it's encrypted it's called "Y-code" and only military receivers with the encryption key can receive it. Because this code is modulated on two carriers, sophisticated games can be played with the frequencies to help eliminate errors caused by the atmosphere.

It almost makes you want to enlist, doesn't it?

Step 3: Getting perfect timing



If measuring the travel time of a radio signal is the key to GPS, then our stop watches had better be darn good, because if their timing is off by just a thousandth of a second, at the speed of light, that translates into almost 200 miles of error!

On the satellite side, timing is almost perfect because they have incredibly precise atomic clocks on board.

But what about our receivers here on the ground?

Remember that both the receivers are essentially an atomic-accuracy clock.

The secret to perfect timing is to make an extra satellite measurement.

That's right, if three perfect measurements can locate a point in 3-dimensional space, then four imperfect measurements can do the same thing.

If you don't have time here's a quick summary :

Extra Measurement Cures Timing Offset

If everything were perfect (i.e. if our receiver's clocks were perfect) then all our satellite ranges would intersect at a single point (which is our position). But with imperfect clocks, a fourth measurement, done as a crosscheck, will NOT intersect with the first three.

So the receiver's computer says "Uh-oh! there is a discrepancy in my measurements. I must not be perfectly synced with universal time."

Since any offset from universal time will affect all of our measurements, the receiver looks for a single correction factor that it can subtract from all its timing measurements that would cause them all to intersect at a single point.

That correction brings the receiver's clock back into sync with universal time, and bingo! - you've got atomic accuracy time right in the palm of your hand.

Once it has that correction it applies to all the rest of its measurements and now we've got precise positioning.

One consequence of this principle is that any decent GPS receiver will need to have at least four channels so that it can make the four measurements simultaneously.

O.k, with the pseudo-random code as a rock solid timing sync pulse, and this extra measurement trick to get us perfectly synced to universal time, we have got everything we need to measure our distance to a satellite in space.

But for the triangulation to work we not only need to know distance, we also need to know exactly where the satellites are.

In the next section we'll see how we accomplish that.

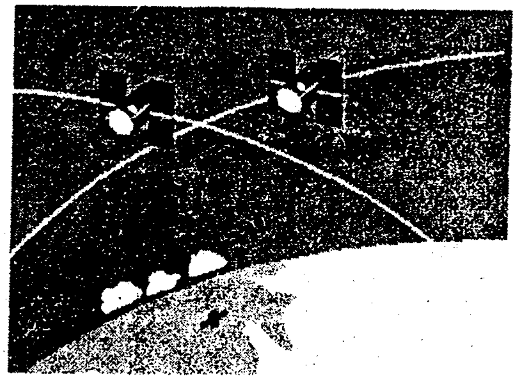
In Review : Getting Perfect Timing

1. Accurate timing is the key to measuring distance to satellites.
2. Satellites are accurate because they have atomic clocks on board.
3. Receiver clocks don't have to be too accurate because an extra satellite range measurement can remove errors.

Atomic Clocks

Atomic clocks don't run on atomic energy. They get the name because they use the oscillations of a particular atom as their "metronome". This form of timing is the most stable and accurate reference man has ever developed.

Step 4 : Knowing where a satellite is in space



Here we've been assuming that we know where the GPS satellites are so we can use them as reference points.

But how do we know exactly where they are? After all they're floating around 11,000 miles up in space.

A high satellite gathers no moss

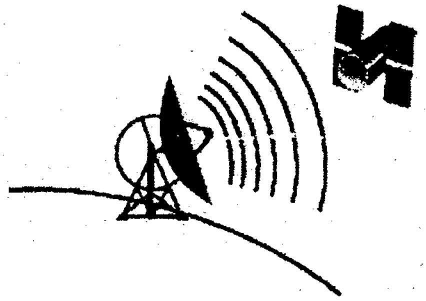
That 11,000 mile altitude is actually a benefit in this case, because something that high is well clear of the atmosphere. And that will mean it will orbit according to very simple mathematics.

The Air Force has injected each GPS satellite into a very precise orbit, according to the GPS master plan.

On the ground all GPS receivers have an almanac programmed into their computers that tells them where in the sky each satellite is, moment by moment.

Constant monitoring adds precision

The basic orbits are quite exact but just to make things perfect the GPS satellites are constantly monitored by the Department of Defense.

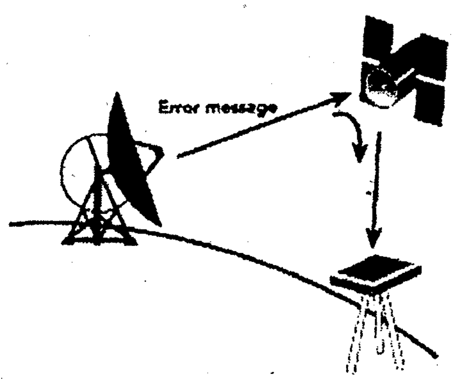


They use very precise radar to check each satellite's exact altitude, position and speed.

The errors they're checking for are called "ephemeris errors" because they affect the satellite's orbit or "ephemeris". These errors are caused by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites.

The errors are usually very slight but if you want great accuracy they must be taken into account.

Getting the message out Once the DoD has measured a satellite's exact position, they relay that information back up to the satellite itself. The satellite then includes this new corrected position information in the timing signals it's broadcasting.



So a GPS signal is more than just pseudo-random code for timing purposes. It also contains a navigation message with ephemeris information as well.

With perfect timing and the satellite's exact position you'd think we'd be ready to make perfect position calculations. But there's trouble afoot. Check out the next section to see what's up.

In Review : Satellite Positions

1. To use the satellites as references for range measurements we need to know exactly where they are.
2. GPS satellites are so high up their orbits are very predictable.
3. Minor variations in their orbits are measured by the Department of Defense.
4. The error information is sent to the satellites, to be transmitted along with the timing signals.

Step 5 : Correcting errors

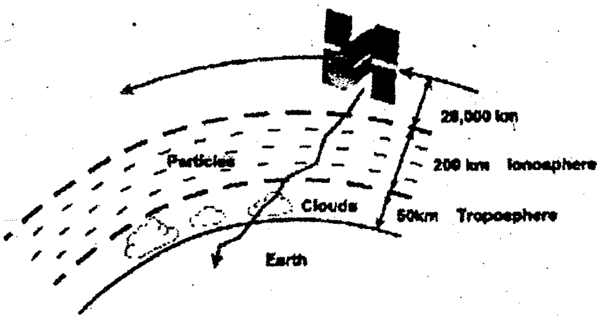
Up to now we've been treating the calculations that go into GPS very abstractly, as if the whole thing were happening in a vacuum. But in the real world there are lots of things that can happen to a GPS signal that will make its life less than mathematically perfect.

To get the most out of the system, a good GPS receiver needs to take a wide variety of possible errors into account. Here's what they've got to deal with.

Rough trip through the atmosphere

First, one of the preambles we've been using throughout this course is not exactly true. We've been saying that you calculate distance to a satellite by multiplying a signal's travel time by the speed of light. But the speed of light is only constant in a vacuum.

As a GPS signal passes through the charged particles of the ionosphere and then through the water vapor in the troposphere it gets slowed down a bit, and this creates the same kind of error as bad clocks.

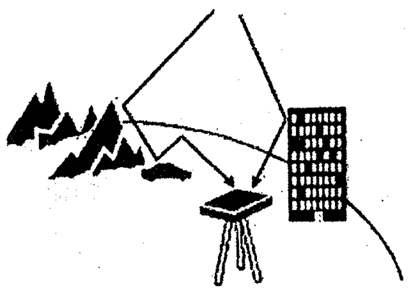


There are a couple of ways to minimize this kind of error. For one thing we can predict what a typical delay might be on a typical day. This is called modeling and it helps but, of course, atmospheric conditions are rarely exactly typical.

Another way to get a handle on these atmosphere-induced errors is to compare the relative speeds of two different signals. This "dual frequency" measurement is very sophisticated and is only possible with advanced receivers.

Rough trip on the ground

Trouble for the GPS signal doesn't end when it gets down to the ground. The signal may bounce off various local obstructions before it gets to our receiver.



This is called multipath error and is similar to the ghosting you might see on a TV. Good receivers use sophisticated signal rejection techniques to minimize this problem.

Problems at the satellite

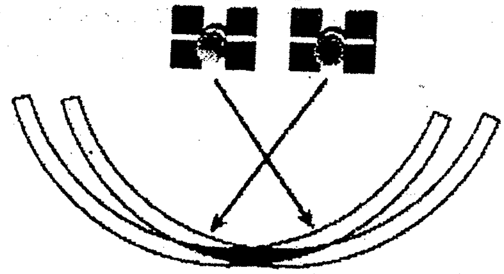
Even though the satellites are very sophisticated they do account for some tiny errors in the system. The atomic clocks they use are very, very precise but they're not perfect. Minute discrepancies can occur, and these translate into travel time measurement errors.
And even though the satellites' positions are constantly monitored, they can't be watched every second. So slight position or "ephemeris" errors can sneak in between monitoring times.

Some angles are better than others

Basic geometry itself can magnify these other errors with a principle called "Geometric Dilution of Precision" or GDOP. It sounds complicated but the principle is quite simple.

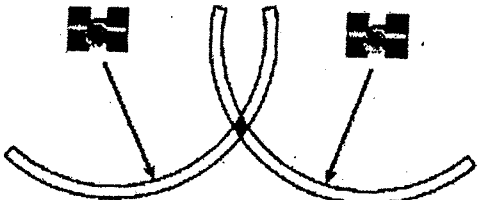
There are usually more satellites available than a receiver needs to fix a position, so the receiver picks a few and ignores the rest.

If it picks satellites that are close together in the sky the intersecting circles that define a position will cross at very shallow angles. That increases the gray area or error margin around a position.



At close angles
the box gets bigger

If it picks satellites that are widely separated the circles intersect at almost right angles and that minimizes the error region.



We're somewhere
in this box.

Good receivers determine which satellites will give the lowest GDOP.

Intentional Errors!

As hard as it may be to believe, the same government that spent $12 Billion to develop the most accurate navigation system in the world is intentionally degrading its accuracy. The policy is called "Selective Availability" or "SA" and the idea behind it is to make sure that no hostile force or terrorist group can use GPS to make accurate weapons.

Basically the DoD introduces some "noise" into the satellite's clock data which, in turn, adds noise (or inaccuracy) into position calculations. The DoD may also be sending slightly erroneous orbital data to the satellites, which they transmit back to receivers on the ground as part of a status message.

Together these factors make SA the biggest single source of inaccuracy in the system. Military receivers use a decryption key to remove the SA errors and so they're much more accurate.

The bottom line

Fortunately all of these inaccuracies still don't add up to much of an error. And a form of GPS called "Differential GPS" can significantly reduce these problems. We'll cover this type of GPS later.

In Review: Correcting Errors

1. The earth's ionosphere and atmosphere cause delays in the GPS signal that translate into position errors.

2. Some errors can be factored out using mathematics and modeling.
3. The configuration of the satellites in the sky can magnify other errors.
4. Differential GPS can eliminate almost all error.

Δ Applications of GPS :

(1) Mapping With Satellite Images : The satellite images are now-a-days, widely employed for a large number of mapping projects including Topographic Surveys and Thematic Mapping. The original image data suffers from a number of geometric distortions due to variation in altitude, attitude etc. of the satellite at the time of imaging. Therefore, this data needs some pre-processing in order to bring back the geometric fidelity. Usually, a number of GCPs (points whose co-ordinates with respect to a mapping reference system are known and whose image co-ordinates are observable) are utilised for implementing the corrections on the image data. From landsat data to IRS data with resolution of 80-30 mts, the extraction of GCPs were done using topographic Maps on 1:50,000 scale. With the enhanced spatial resolution of 10 m from SPOT and 6 m from IRS 1C. the extraction of co-ordinates of GCPs from topographic maps is undesirable considering the desired level of accuracy. Therefore, there is a need to obtain the GCPs from ground survey methods providing accuracies compatible with the spatial resolution of the image data.

Here, the GPS technology plays a significant role. At least three GPS receiveers can be utilised in differential mode to provide the locational co-ordinates of the point of observation with an accuracy of 2-3 meters.

The GPS technology also can be utilised to determine the position of an orbiting earth resource satellite like SPOT/IRS etc at any instant. This can be of immense use in geometric treatment of images at the time of swath modelling.

(2) Topographic Mapping : The GPS technology can be utilised in topographic mapping for provision of Ground Control points.

(3) Cadastral Surveying : Cadastral Maps are large scale maps on scales varying between 1:500 to 1:8,000 depicting property boundary lines. Conventionally, the survey for this is carried out by ground survey methods using theodolites or EDM (Electro-magnetic Distance Measurement) instruments. The aerial photogrammetric techniques are also used now a days with limited groundcontrol points from cited ground survey methods. The GPS technology here offers an efficient tool for directly suveying on the ground. Also, this can be utilised for control provision for aerial photogrammetric methods. This is the trend for the future generation.

(4) Town Planning & Engineering Surveys

(5) GEODESY, GPS SURVEYING. Expert has 30 years experience in the geodetic data collection and processing required to determine the precise location of points on the earth's surface. For the past 16 years, he has been using the GPS to achieve these results. He has also utilized the GPS for precise navigation, using the differential processing technique to tag data with a time and location.

(6) HYDROGRAPHIC SURVEYING. Expert's experience includes the mapping of the ocean bottom, using various positioning techniques and sonar ranging to measure depths.

(7) PHOTOGRAMMETRIC SURVEYING. Expert has three years experience as the Chief of the National Ocean Surveys Coastal Mapping Division. In this position, his work has included the mapping of the nation's airports and coastlines, as well as developing photogrammetric applications in the surveying and mapping of the ocean floor. He also pioneered GPS controlled aerial mapping

(8) GIS Applications : GPS is a powerful tool to support a GIS (Geographic Information System). Its role is enumerated below:

- It contributes to a uniform basic geometric frame, for example a co-ordinate system, a digital map or a digital terrain model.
- It contributes to the geometric location of objects that enter the GIS. For example streets, buildings, power lines, property boundaries etc.
- It allows GIS to be taken out into the field with GPS direct entry.

Depending on accuracy requirements GPS provides continuous position information for all scales of interest. Therefore, integration of GPS technology with GIS is the state of the art

GPS Receiver Basic Use :

Once the receiver is initialized and set-up, the most useful and immediate function is to save the current position as a waypoint.

Saving Current Position as a Waypoint:

To save the current position as a named or numbered waypoint you must access the function for your unit that does this. On many of the Garmin units, the "MARK" button is specifically for this purpose. Other units may access a menu first where "Create Waypoint" or some other related option is available. Usually, the current position coordinates are then displayed and can be edited if you choose to create a waypoint that is not the current location. If you are saving the current position, you then proceed with the menu choices to name and save the waypoint. With many units available, the waypoint will automatically be assigned a sequential number that can be changed to a name of your choosing. This is so a waypoint can be saved quickly and the name noted. You can go back later and rename it if you choose or you can rename it as you are saving it initially. The naming process is usually simple using the up and down arrows of your keypad to choose various letters and the left and right arrows being used to move to the different characters. This process will be adequately described in the user's manual.

GOTO

Once a location has been saved as a waypoint, the next obvious activity will be to navigate to that waypoint when you are away from it. In almost all GPS units this is called the "GOTO" function.

A classic example would be if you were going hiking or camping and acquired a position fix at your camp and named it something like "GERMIN" & **CAMP399**". Try and use something descriptive enough so as not to be confused with other names. In our example, we put the month and year at the end of the name so we will know more about it.

It is important for you to understand that you will get confusing headings and distances using the GOTO, if you don't get more that about ½ mile away first. If you activate the GOTO right after saving the waypoint and are essentially in the same location, you are very likely to get indications that it is .2 to .3 miles away. This is primarily due to Selected Availability errors, but may be confusing if you don't understand the problem.

When you activate the GOTO, the receiver will then go into the navigation mode and you will have on your display any of a number of "Navigation Screens" available. There are options to select various Navigation Screens and a default one can usually be established in Set-up. The main types of screens available are:

Highway - This screen looks like a highway and shows the direction you are progressing toward the destination. You will have values displayed for Heading, Distance, and Speed.

CDI - Course Deviation Indicator: This has a horizontal graph usually towards the bottom of the screen with the center representing being on course. If you deviate to the left or right, a pointer or vertical line will indicate that you are to the left or right of course and a numeric value will usually indicate by how much. This screen also has values displayed for Heading, Distance, and Speed.

Compass Card - This display shows a set of compass values with a pointer indicating what direction you are traveling. This screen also has values displayed for Heading, Distance, and Speed.

There is some variety in Navigation Screens, but the essential information on Bearing, Heading, Distance and Speed are always displayed.

It is important to understand the difference between Bearing and Heading when navigating to a waypoint.

Bearing - This is the compass heading (When Magnetic North is in Set-up) to the waypoint.

Heading - This is the direction you are traveling.

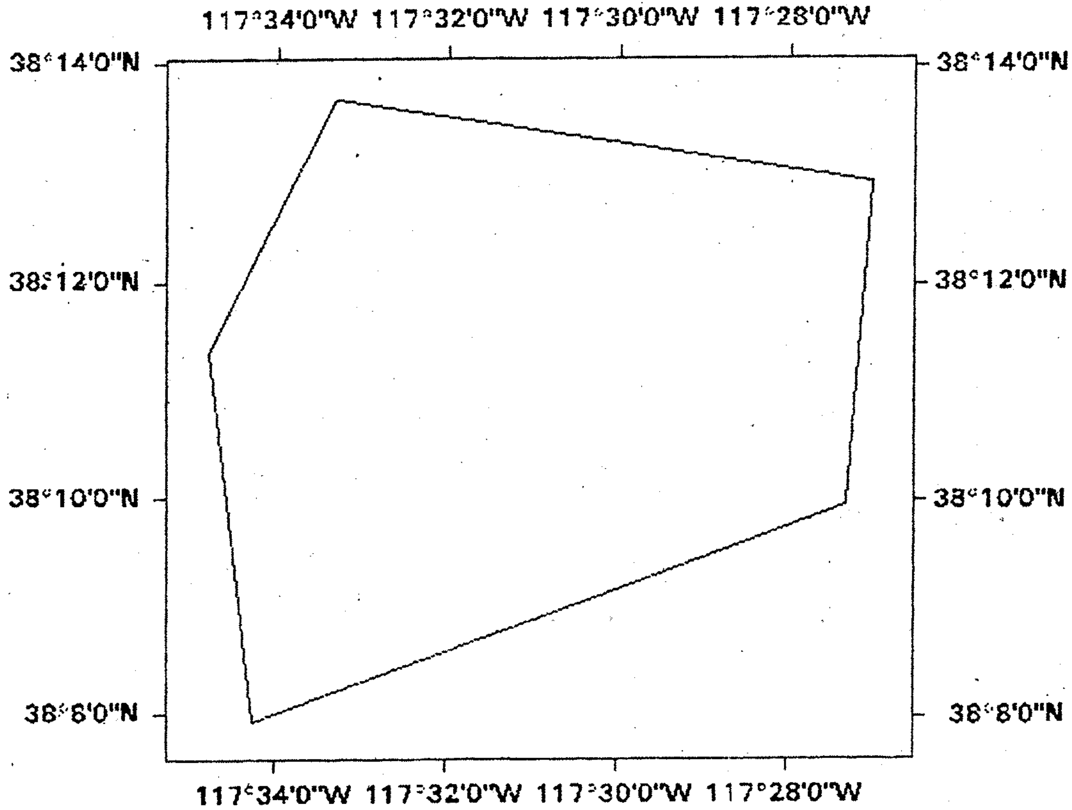
Ideally if terrain were not a consideration, the Heading would be the same as the Bearing.

Field Book

Closed Traverse Survey By GPS

Sl. No	Way Point	Latitude	Longitude	Remarks
1	30	**39°13'41.92" N**	**117°33' 18.54"W**	
2	31	**39°12'56.82" N**	**117°27'01.99"W**	
3	32	**38°9'56.68" N**	**117°27' 19.29"W**	
4	33	**38° 7'57.07" N**	**117°34'17.54"W**	
5	34	**38°11'20.35" N**	**117°34' 48.74"W**	

CLOSE TRAVERSE SURVEY BY GPS



□ 9.2.5 Self-assessment question

1. What is GPS
2. Write down name of the Control Segments of GPS
3. How GPS does it works?
4. Discuss of algorithms of GPS Survey
5. Discuss how GPS works in five logical Step.
6. Why do you need differential GPS
7. Discuss how does differential GPS works
8. Discuss what are the Mode of application in GPS Survey
9. Put a tick marks (√) against correct answer
   - i) GPS Satellites normally placed at an altitude of 36000 km
   - ii) GPS Satellites normally placed at an inclination angle of 55^0
   - iii) Differential GPS takes cares of the intentional degradation by DoD, USA
   - iv) GPS P code is converted to Y code in ' Selective Availability'

□ **9.2.6 Reference** :

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Paper - V

Geography-Practical : Study Material

Module-IX : Unit-03

Ground Survey and Aerial Photo Interpretation

Structure

PART-I
Paper-V (Practical)
Module-IX : Unit-03

Ground Survey and Aerial Photo Interpretation

□ 5.9.3.1 INTRODUCTION

Photogrammetry is the science and technology of obtaining spatial measurements and other geometrically reliable derived products from photographs. Photogrammetric analysis procedures can range from obtaining approximate distances, areas, and elevations using hardcopy photographic products, unsophisticated equipment, and simple geometric concepts to generating precise digital elevation models (DEMs), orthophotos, thematic GIS data, and other derived products through the use of digital raster images and relatively sophisticated analytical techniques.

We use the terms *digital* and *softcopy* photogrammetry interchangeably to refer to any photogrammetric operation involving the use of digital raster photographic image data rather than hardcopy images. Digital photogrammetry is changing rapidly and forms the basis for most current photogrammetric operations. However, the same basic geometric principles apply to traditional hardcopy (analog) and softcopy (digital) procedures. In fact! it is often easier to visualize and understand these principles in a hardcopy, context and then extend them to the softcopy environment. This is the approach we adopt in this discussion. We also stress *aerial* photogrammetric techniques and procedures, but the same general principles hold for *space-based* operations.

Historically, the most common use of photogrammetry has been to produce hardcopy topographic maps. Today, photogrammetric procedures are used extensively to produce a range of GIS data products such as precise raster image backdrops for vector data and digital elevation models. Thematic data (in three dimensions) can also be extracted directly from photographs for inclusion in a GIS.

□ 5.9.3.2 OBJECTIVES

In this unit, we introduce only the most basic aspects of the broad subject of photogrammetry. Our objective is to provide the student with a fundamental understanding of how hardcopy photographs can be used to measure and map earth surface features and how softcopy systems work conceptually. The following photogrammetric activities will be discussed in this unit.

Determining the scale of a vertical photograph and estimating horizontal ground distances from measurements made on a vertical photograph. The scale of a photograph expresses the mathematical relationship between a distance measured on the photo and the corresponding horizontal distance measured in a ground coordinate system. Unlike maps, which have a single constant scale, aerial photographs have a range of scales that vary in proportion to the elevation of the terrain involved. Once the scale of a photograph is known at any particular elevation, ground distances at that elevation can be readily estimated from corresponding photo distance measurements.

Using area measurements made on a vertical photograph to determine the equivalent areas in a ground coordinate system. Computing ground areas from corresponding photo area measurement is simply an extension of the above concept of scale. The only difference is that whereas ground distances and photo distances vary linearly, ground areas and photo areas vary as the square of the scale.

Quantifying the effects of relief displacement on vertical aerial photographs. Again unlike maps, aerial photographs in general do not show the true plan or top view of objects. The images of the tops of objects appearing in a photograph are displaced from the images of their bases. This is known as *relief displacement* and causes any object standing above the terrain to "lean away" from the principal point of a photograph radially. Relief displacement, like scale variation, precludes the use of aerial photographs directly as maps. However, reliable ground measurements and maps can be obtained. from vertical photographs if photo measurements are analyzed with due regard for scale variations and relief displacement.

Determination of object heights from relief displacement measurements. While relief displacement is usually thought of as an image distortion that must be dealt with, it can also be used to estimate the heights of objects appearing on a photograph. As we later illustrate, the magnitude of relief displacement depends on the flying height, the distance from the photo principal point to the feature, and the height of the feature. Because these factors are geometrically related, we can measure an object's relief displacement and radial position on a photograph and thereby determine the height of the object. This technique provides limited accuracy but is useful in applications where only approximate object heights are needed.

Determination of object heights and terrain elevations by measurement of image parallax. The previous operations are performed using vertical photos individually. Many photogrammetric operations involve analyzing images in the area of overlap of a stereo pair. Within this area, we have two views of the same terrain, taken from different vantage points. Between these two views, the relative positions of features lying closer to the camera (at higher elevation) will change more from photo to photo than the positions of features farther from the camera (at, lower elevation). This change in relative position is called *parallax.* It em be measured on overlapping photographs and used to determine object heights and terrain elevations.

Mapping with aerial photographs. As mentioned previously, "mapping" from aerial photographs can take on numerous forms and can employ either hardcopy or softcopy approaches. Traditionally, topographic maps have been produced from hardcopy stereo pairs in a device called a *stereo-plotter.* With this type of instrument, the photographs are mounted in special projectors that can be mutually oriented to precisely correspond to the angular tilts present when the photographs were taken. Once oriented properly, the projectors recreate an accurate model of the terrain that, when viewed stereoscopically, can be used to plot a planimetric map having no relief distortions. In addition. topographic contours can be plotted on the map and the height of vertical features appearing in the model can be determined.

☐ KEY WORDS

Photogrammetry, Aerial Photos, Films, Aerial Cameras, Stereoscopy, Image Parallax.

☐ 5.9.3.3 ADVANTAGES : AERIAL PHOTOGRAPHY OVER ON-THE-GROUND OBSERVATIONS

One of the most common, versatile, and economical forms of remote sensing is aerial photography. The basic advantages aerial photography affords over on-the-ground observation include:

1. **Improved vantage point.** Aerial photography gives a bird's-eye view of large areas, enabling us to see earth surface features in their spatial context. In short, aerial photography permits us to look at the "big picture" in which objects of interest reside. It is often difficult, if not impossible, to obtain this view of the environment through on-the-ground observation. With aerial photography, we also see the "whole picture" in that *all* observable earth surface features are recorded simultaneously. Completely different information might be extracted by different people looking at a photograph. The hydrologist might concentrate on surface water bodies, the geologist on bedrock structure, the agriculturalist on soil or crop type, and so on.
2. **Capability to stop action.** Unlike the human eye, photographs can give us a "stop action" view of dynamic conditions. For example, aerial photographs are very useful in studying dynamic phenomena such as floods, moving wildlife populations, traffic, oil spills, and forest fires.
3. **Permanent recording.** Aerial photographs are virtually permanent records of existing conditions. As such, these records can be studied at leisure, under office rather than field conditions. A single image can be studied by a large number of users. Air photos can also be conveniently compared against similar data acquired at previous times, so that changes over time can be monitored easily.
4. **Broadened spectral sensitivity.** Film can "see" and record over a wavelength range about twice as broad as that of the human eye (0.3 to 0.9 μm versus 0.4 to 0.7 μm). With photography, invisible UV and near-IR energy can be detected and subsequently recorded in the form of a visible image; hence film can see certain phenomena the eye cannot.
5. **Increased spatial resolution and geometric fidelity.** With the proper selection of camera, film, and flight parameters, we are able to record more spatial detail on a photograph than we can see with the unaided eye. This detail becomes available to us by viewing photographs under magnification. With proper ground reference data, we can also obtain accurate measurements of positions, distances, directions, areas, heights, volumes, and slopes from airphotos. In fact, most planimetric and topographic maps are currently produced using measurements extracted from airphotos.

□ 5.9.3.4 Tools and Equipments used in Aerial Survey

1> Aircraft
2> Air camera fitted in the plane with vertical axis,
3> Altimeter,
4> Filter (yellow, which eliminates the effects of fog and ultraviolet radiation).

The cameras to be used in such surveys are, of different sizes and focal lenses, through which air photos 9" x 9" to. 6" x 6" sizes are obtained. In India, *RC5*, *RC8*, and *Eagle IX* cameras are used.

The lenses used in the camera, are of the following types according to the angles of coverage and the focal length:

Narrow Angle 60° - (longer focal length)
Normal Angle 60° - 75°
Wide Angle 75° - 100°
Super wide angle 100° - (shorter focal length)

For air survey, the dry weather is good because in the rainy season the clouds accelerate reflection due to which clear images are not obtained. The noon with scorching sun, and the misty morning are also not favourable for air photography, therefore, same periods between morning and noon, and noon and evening are best for the purpose.

◻ 5.9.3.5 Types of Air Photographs

According to the position of the axis of the camera, the air photos may be grouped as fallows :
(i) Vertical, (ii) horizontal, (iii) oblique (iv) convergent, and (v) trimetrogon.

In the first case, the axis after camera is vertically adjusted to take the photographs; in spite of all possible precautions, it is difficult to get completely vertical aero photograph. This is why up to 2° inclination of the axis; all photographs are grouped in this category. The areas covered through vertical air photos are often square in shape at the uniform plane. The horizontal air photos are also called as Terrestrial air photos. In the production of such air photos, the axis of the camera is horizontally adjusted. In the oblique air photos, the adjustment of the axis of the camera ranges from the vertical to angular position. The areas covered by oblique air photos assume the shape of a trapezium. The convergent air photos are also oblique, but an area is simultaneously photographed by two cameras. In trimetrogon air photos, three cameras are used simultaneously amongst which the central camera is -vertical, and the other two are adjusted to oblique position.

In addition, on the basis of the films used in the cameras, the air photographs are classified as Black and While, Infra-red and Coloured.

Δ Some defined terms associated with Aerial Photographs and Aerial Photographic Surveys

1. ***Central Projection:*** Photo images are drawn through aeroplanes on central Projection, because the rays of the different objects pass through the optical centre (also known as perspective centre) of the lenses.

2. ***Fiducial Mark:*** In the interior of the camera, some marks (+ or - or I) are made on the four comers or in the centre of the four sides, which are transferred on the air photos; these marks are known as *fiducial marks.* The point of intersection made by joining the opposite marks is located in the centre, which is known as the principal point *(pp)* of the photograph. The corresponding point of the land is known as principal land point.

3. ***Tilt:*** The inclination of the *axis* of the camera between vertical and angular position is known as tilt. This tilt may correspond to the direction of flight – known as X inclination and when it is perpendicular to the direction of flight called Y inclination.

4. ***Overlap:*** The image of every part of the earth is continuously extended into more than two adjoining air photographs. Such extended parts are known as overlaps. These are of two types: i) end lap or overlap in the direction of flights are 60% or more. *ii)* Lateral overlap which is generally from 20% to 30%. These overlaps are of special significance in air photo interpretation as well as in the construction of maps based on such air photos. Three dimensional models are associated with such overlapping parts; Lateral overlaps are helpful in joining two adjoining strips or in their systematic arrangements, because lateral, control points are identified in such overlapping parts.

5. *Air-base:* The distance between two adjoining exposure stations marked along the route *of* the flight, is known as air base. All exposure stations are located vertically over the principal points or respective inter connected air photographs.

6. *Conjugate Principal Point:* The image of the principal point of every aerial, photograph is extended into the back and front strips of air photos; such a point is known as conjugate principal point.

The average distance between both the conjugate principal points of the principal points of an aerial photograph, is known as *Photo-base.*

7. *Iso-centre:* If the photograph is not vertical then the mid point of the line joining its plumb and the axial point of the camera is known as Iso-centre *(I)*. In fact, all calculations made in reference to this point, are correct. But its determination is difficult and on the approximately vertical photographs, its distance is negligible so the principal point is used for calculation.

8. *Crab:* During aerial survey, when there is lack of adjustment between position of the camera and the route line of the flight, the air base of the margins of the air photos or the flight line may not, be parallel, and such a situation is known as *crab*.

9. *Flying Altitude:* The altitude of the aeroplane from the datum during aerial surveys is called flying altitude, and the height above the photographic plane is known as flying height.

10. *Radial Displacement:* All objects, whether situated vertically or horizontally on the earth surface arc projected horizontally on the air photograph, and in proportion to the height of the objects radially located to the centre. This is known as radial displacement.

□ 5.9.3.6 GEOMETRIC ELEMENTS OF VERTICAL PHOTOGRAPH

Assuming the size of a paper print positive (or film positive) is equal to that of the negative, positive image position can be depicted diagrammatically in front of the lens in a plane located at a distance *'f'*.

The x and y coordinate positions of image points are referenced with respect to axes formed by straight lines joining the opposite fiducial marks recorded on the positive. The x axis is arbitrarily assigned to the fiducial axis most nearly coincident with the line of flight and is taken as positive in the forward direction of flight. The positive y axis is located 90° counter clockwise from the positive x axis. The photo coordinate origin, 'O' can be assumed to coincide exactly with the principal point, The intersection of the lens optical axis and the film plane. The point where the prolongation of the optical axis of the camera intersects the terrain is referred to as the ground principal point.

The xy photo coordinate of a point are the perpendicular distances from the xy coordinate axes. Points to the right of the y axis have positive x coordinates and points to the left have negative x coordinate. Similarly points above the x axis have positive y coordinates and those below have negative y coordinates.

Photo coordinate generally measured by Triangular engineer's scale or metric scale, coordinate digitizer, mono and stereo comparator. In soft copy photogrammetric operations, individual points in a photograph are referenced by their row and column coordinates in the digital raster representation of the image. The relationship between the row and column coordinate system and the cameras fiducial axis coordinate system is determined through the development of a mathematical coordinate transformation between the two systems.

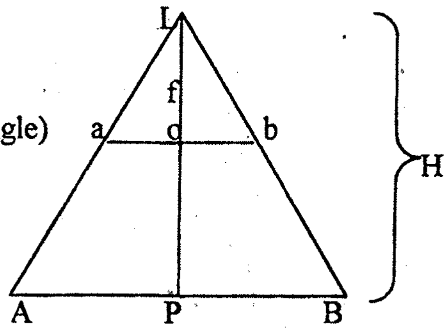
The errors associated with photocoordinate measurement are camera lens distortions, atmospheric refraction, earth curvature, and failure of the fiducial axes to intersect at the principal point, and shrinkage or expansion of the photographic material.

Δ SCALE OF AERIAL PHOTOGRAPH

The scale of aerial photograph is determined with the help of camera focal length (f) and the height of the aeroplane above datum (H) of the aerial photograph.

In the diagram below the geometry of aerial photograph is shown here triangle Loa and triangle LPA are similar triangle because –

<Loa = <LPA = 90^0
<aLo = <ALP
And <Lao = <LAP (corresponding angle)



Therefore:

$$\frac{La}{LA},\ \frac{ao}{AP} \text{ and } \frac{Lo}{LP} = \frac{f}{H} = S$$

$$S = \frac{f}{H} \quad \text{(PROVED)}$$

The scale of aerial photograph is directly proportional to the focal length of camera and inversely proportional to the height of aeroplane from datum of air photo which means if the height of aeroplane from datum of air photo is constant, with increasing focal length of camera the size of object on aerial photograph will increases. If the focal length of camera remains constant the size of object on aerial photograph will be larger with decreasing flying altitude and smaller with increasing flying altitude.

We can also determine the focal length of camera (f) and the height of aeroplane from the datum of aerial photograph (H) from the equation $S = \frac{f}{H}$ if the Scale of aerial photograph is known

$$H = \frac{f}{S} \quad \text{or} \quad f = S \times H.$$

Problem-I: f=12cm, h_1=30,000m, h_2=20,000m, S=?

$H_{avg} = \frac{30,000+20,000}{2}$ m

=25,000m

=2,500,000cm.

$$\frac{1}{S} = \frac{f}{H}$$

$S = \frac{H}{f} = \frac{2,500,000cm}{12cm}$

=208333.3cm

=210,000cm (approx.)

Scale = 1:210,000 (approx.)

Problem-II: Assume that two road intersection shown on a photograph can be located on 1:25000 scale topographical map the measured distance between the intersection is 47.2mm on the map and 94.3 mm on the photograph what is the scale of the photograph? At that scale what is the length of a fence line that measures 42.9mm on the photograph?

The scale of topographical map :- 1:25,000
1mm = 25000 mm = 25m
1mm map distance represents 25m ground distance
47.2 mm map distance represents (47.2x25) ground distance
= 1180m
=1.18Km
the ground distance between the intersection is 1.18km.
the distance on photograph is 94.3mm

94.3 mm photo distance represents 1.18km ground distance
94.3 mm photo distance represents 180000mm ground distance
1mm photo distance represents $\frac{1180000}{94.3}$ mm ground distance

=12513.25557
=12,500(approx.)
scale = 1:12,500 (approx.)
The scale of the photograph is 1:12,500 (approx)

1mm photo distance represents 12513.26mm ground distance.
42.9 mm photo distance represents (12513.26 x 42.9)mm
=536818.8540 mm
=536.82m
At that line the length of fence line is photograph 536.82m which is measured 42.9mm on the photograph.

Problem-III: A camera equipped with a 152mm focal length lens (f) is used to take a vertical photograph from a flying height of 2780m (H) above msl. If the terrain is flat and located at an elevation of 500m (h) what is the scale of the photograph?
Focal length of camera (f) = 152mm
Flying height = 2780mAbove msl.
The elevation of terrain from msl.(h_2) = 500m
Flying height above datum(H) = 2780-500 = 2240m

$S = \frac{H}{f} = \frac{2280000mm}{152mm} = 15000$

the scale of the photograph is 1:15000

Problem-IV: Assume a vertical photograph was taken at a flying height 5000m above m.s.l. using a camera with 152mm focal length.

a) Determine the photo scale at point a and b which lie at an elevation of 1200m and 1960m.

b) What ground distance corresponds a 20.1mm photo distance measured on photography?

Focal length of camera (f) = 152mm

At point a

Flying height above msl. (h_1) = 1200m

Flying height above datum (H) = (5000-1200)m

=3800m

$$S = \frac{H}{f} = \frac{3800000}{152}$$

=25000

scale at point a =1:25000

At point b:

elevation of b from m.s.i.(h_2) = 1960m

flying height above datum (H) (5000-1960)=3040m

$$S = \frac{H}{F} = \frac{3040,000}{152}$$

=20,000

Scale at point b =1:20,000

The air photo scale at point a is 1:25000 and at point b is 1:20,000

b) $$\frac{1}{S_{avg}} = \frac{f}{H - h_{avg}}$$

$$H_{avg} = \frac{1200 + 1960}{2} = 1580m$$

$H-h_{avg}$ = (5000-1580)m

=3420m

=3420,000mm

$$S_{avg} = \frac{3420,000mm}{152mm}$$

=22500 = 1:22500

1mm photo distance represents 22,500mm ground distance

20.1 mm photo distance represents (22500 x 20.1)

=452,250mm

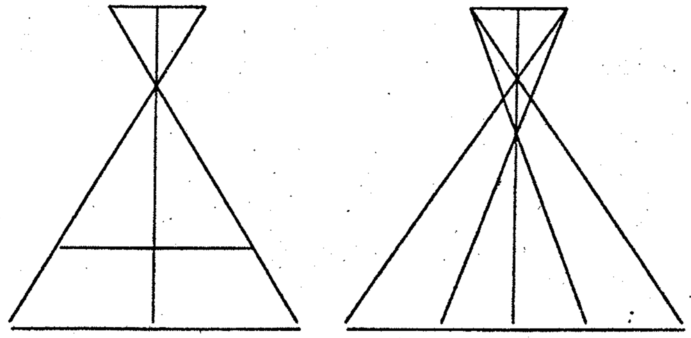
=452.25m

452.25m ground distance corresponds 20.1mm photo distance measured on photograph.

∆ GROUND COVERAGE OF AERIAL PHOTOGRAPH

The ground area coverage of a photograph is among other things a function of camera format size, and the ground coverage of photography obtained with any given format is a function of focal length and flying height above ground.

For a constant flying height the width of The ground area coverage of a photo varies inversely with the focal length consequently photos taken with shorter focal length lenses have the large area coverage than do those taken with larger focal length. For any given focal length lens the width of the ground area covered by photo varies directly with flying height above terrain with image scale varying inversely with flying height.



a) Variable flying height   b) Variable focal length

Area Measurement on Aerial Photograph: The process of measuring areas using aerial photographs can take on many forms. Simply shaped like area of a rectangular field or a circular stadium can be measured easily from their length and width and radius respectively but the area of a irregularly shaped feature can be measured by following methods.

1. <u>Dot Grid</u>: Transparent grid overlay consisting of line forming squires of unit area and dots uniformly spaced inside the squire. From the knowledge of the dot density of the grid the photo area of the region can be computed.
2. <u>Planimeter</u>: This instrument is used to measure the area with irregularly shaped boundary on hard copy photograph by moving the tracing point round the boundary of the area and taking readings from a graduated drum.
3. <u>Vector Digitization</u>: When Photographs are available in soft copy format with proper geo-coding, a closed polygon is created by digitizing the boundary of the area and area is written in the data table automatically.

∆ BASIC NEGATIVE TO POSITIVE PHOTOGRAPHIC SEQUENCE

Many photographic procedures, particularly black and white techniques, employ a two-phase negative-to-positive sequence. In this process, the "negative" and "positive" materials are typically film and paper prints. Each of these materials consists of a light-sensitive photographic *emulsion* coated onto a *base*.

In black and white film and print paper, the coated emulsion consists of a thin layer of light-sensitive silver halide crystals, or grains, held in place by a solidified gelatin. Paper is the base material for paper prints. Various plastics are used for film bases. When exposed to light, the silver halide crystals within an emulsion undergo a photochemical reaction forming an invisible *latent image*. Upon treatment with suitable agents in the *development process*, these exposed silver salts are reduced to silver grains that appear black, forming a visible image.

When processed, the film crystals exposed to light are reduced to silver. The number of crystals reduced at any point on the film is proportional to the exposure at that point. Those areas on the negative that were not exposed are clear after processing because crystals in these areas are dissolved as part of the development process. Those areas of the film that were exposed become various shades of gray, depending on the amount of exposure. Hence a "negative" image of reversed tonal rendition is produced. Next the negative is illuminated and reprojected through an enlarger lens so that it is focused on print paper, again forming a latent image. When processed, the paper print produces dark areas where light was transmitted through the negative and light areas where the illuminating light was decreased by the negative. The final result is a realistic rendering of the original scene whose size is determined by the enlarger setup. In the two-phase process of creating the final image, the negative provides an image of reversed geometry (left for right and top for bottom) and reversed brightness (light for dark and dark for light). The positive image gives a second reversal and, thus, true relative scene geometry and brightness.

Most aerial photographic paper prints are produced using the negative-to-positive sequence and a *contact printing procedure*. Here, the film is exposed and processed as usual, resulting in a negative of reversed scene geometry and brightness. The negative is then placed in emulsion-to-emulsion contact with print paper. Light is passed through the negative, thereby exposing the print paper. When processed, the image on the print is a positive representation of the original ground scene at the size of the negative.

Positive images need not be printed on print paper. For example, transparent positives are often made on plastic-based or glass-based emulsions. These types of images are referred to as *diapositives* or *transparencies.*

Δ BLACK AND WHITE FILMS AND SPECTRAL SENSITIVITY

Black and white aerial photographs are normally made with either *panchromatic* film or *infrared-sensitive* film. Panchromatic film has long been the "standard" film type for aerial photography. The spectral sensitivity of panchromatic film extends over the UV and the visible portions of the spectrum. Infrared-sensitive film is sensitive not only to UV and visible energy but also to near-IR energy.

It is of interest to note what determines the "boundaries" of the spectral sensitivity of black-and white film materials. As indicated in Section 2.1, we can photograph over a range of about 0.3 to 0.9 *μm*.The *0.9-μm* limit stems from the photochemical instability of emulsion materials that are sensitive beyond this wavelength. (Certain films used for scientific experimentation are sensitive out to about 1.2 *μm*, and form the only exception to this rule. These films are not commonly available and typically require long exposure times, making them Unsuitable for aerial photography.)

In comparison between panchromatic and black and white IR aerial photographs we can see that healthy, green vegetation reflects much more sunlight in the near IR than in the visible part of the spectrum; therefore, it appears lighter in tone on black and white infrared photographs than on panchromatic photographs. Note, for example, presence of water and wet soils in the fields can be seen more distinctly in the black and white IR photograph. Water and wet soils typically have a much darker tone in black and white IR photographs than in panchromatic photographs because sunlight reflection from water and wet soils in the near IR is considerably less than in the visible part of the electromagnetic spectrum.

The *0.3-μm* limit to photography is determined by something other than film sensitivity. In fact, virtually all photographic emulsions are sensitive in this UV portion of the spectrum. The problem with photographing at wavelengths shorter than about 0.4 *μm* is twofold: (1) the atmosphere absorbs or scatters much of this energy and (2) glass camera lenses absorb such energy. But photographs can be acquired in the *0.3-to-0.4-μm* range if extremes of altitude and unfavorable atmospheric conditions are avoided. Furthermore, some improvement in image quality is realized if quartz camera lenses are used.

An interesting application of UV photography in zoological research and management shows that when panchromatic and UV aerial photographs taken simultaneously of harp seals *(Pagophilus groelandicus)* on the snow and ice surface of the Gulf of St. Lawrence, adult harp seals are dark in color and appear in both the panchromatic image and the UV image. In contrast to the adults, infant harp seals have coats that appear white to the eye. Hence, they are nearly invisible on a snow and ice background in panchromatic imagery. In the UV portion of the spectrum, the snow and ice background is still highly reflective but the "white" seal coats, which are very strong absorbers of UV energy, photograph black. Thus, both the adults and their young offspring can be detected on the UV image. This characteristic enables reliable monitoring of the change in population of this animal, which cannot be done practically over large areas using any other means. The same technique can be used to inventory other "white" objects, such as polar bears, arctic foxes, and hares on show-covered surfaces (Lavigne, 1976).

To date, the applications of aerial UV photography have been limited in number, due primarily to strong atmospheric scattering of UV energy. A notable exception is the use of UV photography in monitoring oil films on water (Vizy, 1974). Minute traces of floating oil, often invisible on other types of photography, can be detected in UV photography. (The use of aerial photography to study oil spills is illustrated in Section 4.9.)

Δ COLOR FILMS

Although black and white panchromatic film has long been the standard film type for aerial photography, many remote sensing applications currently involve the use of color film. The major advantage to the use of color is the fact that the human eye can discriminate many more shades of color than it can tones of gray. As we illustrate in subsequent chapters, this capability is essential in many applications of air photo interpretation. In the remainder of this section we present the basics of how color film works. To do this, we must first consider the way in which human color vision works.

Δ Color-Mixing Processes

The detailed psychophysical mechanisms by which we see color are still not fully understood, yet it is generally held that the human brain receives color impulses from the eye via three separate light receptors in the retina. These receptors respond to blue, green, and red light, respectively. What color we associate with a particular object depends on the particular amounts of blue, green, and red it reflects. That is, we physiologically mix impulses from the retina's blue receptor with those from the green and red receptors. Added together, these three impulses result in the perception of a single color for any given object.

A change in the relative quantity of blue, green, or red light coming from the object changes the color we associate with it. In short, we perceive all colors by synthesizing relative amounts of just three.

Blue, green, and red are termed *additive primaries.* When projecting blue, green, and red light in partial superimposition, where all three beams overlap, the visual effect is white because all three of the eyes' receptor systems are stimulated equally. Hence, white light can be thought of as the mixture of blue, green, and red light. Various combinations of the three additive primaries can be used to produce other colors. As illustrated, when red light and green light are mixed, yellow light is produced. Mixture of blue and red light results in the production of magenta light (bluish-red). Mixing blue and green results in cyan light (bluish-green).

Yellow, magenta, and cyan are known as the *complementary colors,* or *complements,* of blue, green, and red light. Note that the complementary color for any given primary color results from mixing the remaining two primaries.

Like the eye, color television and computer monitors operate on the principle of additive color mixing through use of blue, green, and red dots (or vertical lines) on the picture screen. When viewed at a distance, the light from the closely spaced screen elements forms a continuous color image.

Whereas color television simulates different colors through *additive* mixture of blue, green, and red *lights,* color photography is based on the principle of *subtractive* color mixture using superimposed yellow, magenta, and cyan *dyes*. These three dye colors are termed the *subtractive primaries*, and each result from subtracting one of the additive primaries from white light. That is, yellow dye absorbs the blue component of white light. Magenta dye absorbs the green component of white light. Cyan dye absorbs the red component-of white light.

The subtractive color-mixing process may be illustrated by three circular filters being held in front of a source of white light. The filters contain yellow, magenta, and cyan dye. The yellow dye absorbs blue light from the white background and transmits green and red. The magenta dye absorbs green light and transmits blue and red. The cyan dye absorbs red light and transmits blue and green. The superimposition of magenta and cyan dyes results in the passage of only blue light from the background. This comes about since the magenta dye absorbs the green component of the white background and the cyan dye absorbs the red component. Superimposition of the yellow and cyan dyes results in the perception of green. Likewise, superimposition of yellow and magenta dyes results in the perception of red. Where all three dyes overlap, all light from the white background is absorbed and black results.

In color photography, various proportions of yellow, magenta, and cyan dye are superimposed to control the proportionate amount of blue, green. and red light that reaches the eye. Hence, the subtractive mixture of yellow, magenta, and cyan dyes on a photograph is used to control the additive mixture of blue, green, and red light reaching the eye of the observer. To accomplish this, color film is manutactured with three emulsion layers that are sensitive to blue, green, and red light but contain yellow, magenta, and cyan dye after processing.

Δ Structure and Spectral Sensitivity of Color Film

Spectral sensitivity of color film may be discussed in the following manner. The top film layer is sensitive to blue light, the second layer to green and blue light, and the third to red and blue light. Because these bottom two layers have blue sensitivity as well as the desired green and red sensitivities, a blue-absorbing filter layer is introduced between the first and second photosensitive layers. This filter layer blocks the passage of blue light beyond the blue-sensitive layer. This effectively results in selective sensitization of each of the film layers to the blue, green, and red primary colors. The yellow (blue-absorbing) filter layer has no permanent effect on the appearance of the film because it is dissolved during processing.

From the standpoint of spectral sensitivity, the three layers of color film can be thought of as three black and white silver halide emulsions. Again, the colors physically present in each of these layers after the film is processed are *not* blue, green, and red. Rather, after processing, the blue-sensitive layer contains yellow dye, the green-sensitive layer contains magenta dye, and the red-sensitive layer contains cyan dye. The amount of dye introduced, in each layer is inversely related to the intensity of the corresponding primary light present in the scene photographed. When viewed in composite, the dye layers produce the visual sensation of the original scene.

The manners in which the three dye layers of color film operate that correspond to scene reflectance in four spectral bands: blue, green, red, and near IR. During exposure, the blue sensitive layer is activated by the blue light, the green sensitive layer is activated by the green light, and the red-sensitive layer is activated by the red light, if layer is activated by the near IR energy then the film is not sensitive to near-IR energy. During processing, dyes are introduced into each sensitivity layer in *inverse* proportion to the intensity of light recorded in each layer. Hence the more intense the exposure of the blue layer to blue light, the less yellow dye is introduced in the image and the more magenta and cyan dyes are introduced. For "blue light, the yellow dye layer is clear and the other two layers contain magenta and cyan dyes. Likewise, green exposure results in the introduction of yellow and cyan dyes, and red exposure results in the introduction of yellow and magenta dyes. When the developed image is viewed with a white light

source, we perceive the colors in the original scene through the subtractive process.
Where a blue object was present in the scene, the magenta dye subtracts the green component of the white light, the cyan dye subtracts the red component, and the image appears blue. Green and red are produced in an analogous fashion. Other colors are produced in accordance with the proportions of blue, green, and red present in the original scene.

5.9.3.7 AERIAL CAMERAS

One of the very first box cameras made for commercial purpose was developed for Louis Daguerre in France by Samuel F.B. Morse. While modern cameras are much more sophisticated than simple box cameras, they nevertheless share certain fundamental characteristics.

Δ The Simple Camera

The cameras used in the early days of photography were often no more than a light-tight box with a pinhole at one end and the light-sensitive material to be exposed positioned against the opposite end. The amount of exposure of the film was controlled by varying the time the pinhole was allowed to pass light. Often, exposure times were in hours because of the low sensitivity of the photographic materials available and the limited light-gathering capability of the pinhole design. In time, the pinhole camera was replaced by the simple lens camera, shown in Figure. By replacing the pinhole with a lens, it became possible to enlarge the hole through which light rays from an object were collected to form an image, thereby allowing more light to reach the film in a given amount of time. In addition to the lens, an adjustable *diaphragm* and an adjustable *shutter* were introduced. The diaphragm controls the diameter of the lens opening during film exposure, and the shutter controls the duration of exposure.

Δ Single-Lens Mapping (Metric) Camera

Single-lens metric cameras obtain most of the aerial photography used to map the planimetric (x,y) location of features and to derive topographic (contour) maps. These *cartographic* cameras are calibrated to provide the highest geometric and radiometric quality aerial photography. They usually consist of a camera body, lens cone assembly, shutter, film feed and uptake motorized transport assembly at the film plane, and an aircraft-mounting platform. Filter(s) placed in front of the lens determine the wavelengths of light that are allowed to illuminate the film plane.

In the United States, Federal Aviation Administration (FAA) approval is required to cut a hole in an airplane's fuselage to accommodate an aerial camera. If two aerial cameras are mounted in the aircraft (Figure 4-7 d), it is possible to expose two types of emulsions at the same time (e.g., color and color-infrared) by synchronizing the camera shutter release mechanisms.

The lens cone assembly is the most important part of the camera. It usually consists of a single, expensive *multiple-element lens* that projects undistorted images of the real world onto the film plane. The multiple-element lens is focused at infinity because the aircraft typically flies at thousands of meters above-ground-level during data collection. Metric mapping cameras use various lenses with different angular fields of view, depending on the mission requirements. *Narrow* camera lenses have an angular field of view of < 60°, *normal* 60° - 75°, *wide-angle* 75° - 100°, and *super-wide-angle* > 100°. The wider the angular field of view, the greater the amount of Earth recorded on the film at a given altitude above-ground-level. The higher the altitude, the greater the amount of Earth recorded on the film by each lens. These relationships are summarized in Figure 4-8.

An *intervalometer* is used to expose the photographic film at specific intervals of time (dependent upon the aircraft altitude above-ground-level and speed) that will result in the proper amount of end lap to be obtained for overlapping (stereoscopic) coverage.

Aerial cameras usually expose film that is 24 cm (9.5 in.) wide in rolls and more than 100 to 500 ft in length, depending upon the thickness of the film. Individual exposures are typically 9 x 9 in. (23 x 23 cm). At the instant of exposure, the film is held in place against a flat platen surface located at the focal plane. Vacuum pressure is applied to the film via the platen just prior to the instant of exposure to remove any bubbles, bumps, *or* irregularities in the unexposed film. After exposure, the vacuum is released and the drive mechanism moves the exposed film onto the take-up reel in preparation for the next exposure.

Depending on the velocity of the aircraft and the aircraft altitude above ground-level *(h)*, the film might be advanced slightly during exposure to compensate for image motion. Special-purpose *image motion compensation* (IMC) magazines move the film across the focal plane anywhere from 0 to 64 mm per second. Correction is achieved by shifting the platen pressure plate with the film attached via vacuum in the flight direction in accordance with a velocity-to-height ratio (v / h) and the focal length of the lens. This greatly increases the quality of the aerial photography.

Most modern metric cameras provide detailed *image annotation* around the 9 x 9 in. image area of the film. For example, numerous types of ancillary information are displayed around the perimeter of the vertical aerial photograph. A programmable light-emitting diode inside the camera exposed text information onto the film. Important information present includes: 1) a grayscale step wedge used to determine if a proper exposure has been obtained, 2) a note pad where the aerial photographer can enter mission critical notes in pencil if necessary, 3) altimeter, 4) white cross-hair fiducial marks, 5) clock, 6) lens cone serial number, 7) focal length in mm, 8) *project* frame number, 9) mission, name and date, and 10) navigation data (not visible).

Sometimes we analyze aerial photographs that are many years old. Having detailed image annotation information is critical to successful information extraction, especially if sophisticated photogrammetric instruments have to be calibrated or if the photography will be used in computer soft copy photograrmmetry applications.

A Multiple-Lens (Multiple band) Camera

More information can usually be obtained about the environment from a study of photographs taken simultaneously in several regions (bands) of the electromagnetic spectrum than from photographs taken in any single band. When conducting multiband spectral reconnaissance (Colwell, 1997), each of the cameras simultaneously records photographs of the same geographic area, but using different film and/or filter combinations. For example, a four-camera Hasselblad 70mm configuration, by carefully selecting the film and filter combinations, specific wavelengths of light reflected from the scene can be recorded by each of the cameras.

Multiple-band aerial photography provides different information recorded in the individual blue, green, red, and near-infrared photographs. A natural-looking color composite of these photographs can be produced by simultaneously projecting blue light through the blue photograph onto a screen, green, light through the green photograph, and red light through the red photograph. A color-infrared color composite could be created by simultaneously projecting blue light through the green photograph, green light through the red photograph, and red light through the near-infrared photograph.

Δ Panoramic Camera

A panoramic camera uses a rotating lens (or prism) to produce a narrow strip of imagery *perpendicular* to the flight line. Each of these long, narrow exposures will typically be vertical in the center and more oblique toward the ends. A panoramic camera intended for low-altitude use will typically pan across the flight line from one horizon to the other, giving rise to a 180° field of view in the resulting air photo. Panoramic cameras are very common in military photoreconnaissance, but much less so in the civilian world. Because the panoramic images are produced by dynamic motion during the exposure, the resulting air photo does not have a rigid geometry like that resulting from a standard frame camera. Nevertheless, types of measuring and mapping are done from panoramic imagery by organizations with the required systems and capabilities (Hooper and Gustafson, 1983).

Δ Digital Camera

A high-quality digital camera uses an area array of solid-state charge-coupled-device (CCD) detectors. The detectors are arranged in a matrix format with 1524 columns and 1024 rows. Digital cameras also utilize a lens with its associated diaphragm to control the *f/stop*, the shutter to control the length of exposure, and a focusing device. However, the major difference is that instead of using film, a CCD area array is located at the film plane. The lens focuses the light from the outside world onto the bank of detectors. The photons of light illuminating each of the detectors cause an electrical charge to be produced that is directly related to the amount of incident radiant energy. This analog signal is then typically sampled electronically and converted into a digital brightness value ranging from 8-bit (values from 0 - 255) to 10-bit (values from 0 to 1023). The brightness values obtained from the analog-to-digital (A-to-D) conversion may be stored within the camera in computer memory or on small flash cards that can be read by standard computer systems. The charge-coupled-devices are actually more sensitive to spectral reflectance changes in the scene than the silver halide crystals used in conventional photography.

Digital cameras can also produce color images. Inside the camera there is a small blue, green, and red filter wheel (or a dichroic grate). At the instant of exposure, the camera rapidly records three versions of the scene using the three filters. The result is one image based solely on blue light reflected from the terrain, another based on only green light reflected from the terrain, and a final image produced only from reflected red light. The three individual black-and-white images can be color-composited together using additive color theory to produce a natural-looking color photograph. It is also possible to make the detectors sensitive to near-infrared light.

One of the drawbacks of using certain types of digital cameras for aerial remote sensing is that it is necessary to register the three individual images using digital image processing techniques. Unlike terrestrial photography, where the photographer is normally holding the camera very still during the exposure, the aircraft is moving during the acquisition of digital aerial photography. This causes each successive exposure (e.g., blue, green, and red) to be acquired from a slightly different vantage point, which may amount to hundreds of feet in a fast-moving aircraft. Thus, the geographic area recorded on each of the individual images is different and even the common geographic area among the three images is not automatically registered.

In addition to the registration problem, there is also the issue of spatial resolution. Light (1996) found that to replicate the spatial resolution of standard 9 x 9 in. metric aerial cameras and high-quality aerial film, a digital camera would require approximately 20,000 rows by 20,000 columns of detectors.

Color photography in certain digital cameras would require three banks of 20,000 by 20,000 detectors. Currently, the highest quality digital cameras available to the general public have about 2,000 by 3,000 picture elements (pixels), and these digital cameras are very expensive. Fortunately, the cost of digital cameras continues to decline. It is likely that digital cameras will be heavily used in remote sensing of the environment in the future once the image registration issue is resolved and there are 20,000 by 20,000 pixel CCD camera systems.

Δ Miscellaneous Cameras

There are a variety of relatively simple, inexpensive cameras used both commercially and in a research mode that-provide high-quality aerial photography. For example, extensive use is made of 35-mm. cameras, mounted inside a plane or handheld by the scientist to obtain aerial photography of small research areas (Warner et al., 1996). Such systems can provide excellent, inexpensive aerial photography if properly mounted, exposed, and processed.

Δ FILM EXPOSURE

The exposure at any point on a photographic film depends on several factors, including the scene brightness, the diameter of the camera lens opening, the exposure time. and the camera lens focal length. In this section, we describe the interrelationships among these factors. We also describe various geometric factors influencing film exposure.

The design and function of modem adjustable cameras is conceptually identical to that of the early simple lens camera. To obtain sharp, properly exposed photographs with such systems. they must be focused and the proper exposure settings must be made. We shall describe each of these operations separately.

Δ Focus

Three parameters are involved in focusing a camera: the focal length of the camera lens, *f*, the distance between the lens and the object to be photographed, *o*, and the distance between the lens and the image plane, *i*. The focal length of a lens is the distance from the lens at which parallel light rays are focused to a point. (Light rays coming from an object at an infinite distance are parallel.) When a camera is properly focused, the relationship among the focal length, object distance, and image distance is

$$\frac{1}{f} = \frac{1}{o} + \frac{1}{i}$$

Since f is a constant for any given lens, as object distance o for a scene changes. image distance i must change. This is done by moving the camera lens with respect to the film plane. When focused on an object at a discrete distance, a camera can image over a range just beyond and in front of this distance with acceptable focus. This range is commonly referred to as the *depth of field*.

In aerial photography the object distances involved are effectively infinite. Hence the $1/o$ term in above equation goes to zero and i must equal f. Thus, *most* aerial cameras are manufactured with their film plane precisely located at a *fixed* distance f from their lens.

Exposure The exposure at any point in the film focal plane of a camera is determined by the irradiance at that point multiplied by the exposure time, expressed by -

$$E = \frac{sd^2t}{4f^2}$$

where

E = film exposure, J mm^{-2}
s = scene brightness, J mm^{-2} sec^{-1}
d = diameter of lens opening, mm
t = exposure time, sec
f = lens focal length, mm

It can be seen from above equation that, for a given camera and scene, the exposure reaching a film can be varied by changing the camera shutter speed t and/or the diameter of the lens opening d. Various combinations of d and t will yield equivalent exposures.

[The internationally accepted symbol for exposure is H. To avoid confusion with the use of this symbol for flying height, we use E to represent "exposure" in our discussion of photographic systems. Elsewhere, E is used as the internationally accepted symbol for "irradiance"].

The diameter of the lens opening of a camera is determined by adjusting the diaphragm to a particular *aperture setting*, or *f-stop*. This is defined by

$$F = \text{f-stop} = \frac{\text{lens focal length}}{\text{lens opening diameter}} = \frac{f}{d}$$

As can be seen in above equation as the f-stop number increases, the diameter of the lens opening decreases and, accordingly, the film exposure decreases. Because the *area* of the lens opening varies as the square of the diameter, the change in exposure with f-stop is proportionate to the square root of the f-stop. Shutter speeds are normally established in sequential multiples of 2 (1/125 sec, 1/250 sec, 1/500 sec, 1/1000 sec, . . .). Thus, f-stops vary as the square root of 2 (f/1.4, f/2, f/2.8, f/4, . . .). Note that when the value of the f-stop is 2, it is written as *f*/2.

The interplay between f-stops and shutter speeds is well known to photographers. For constant exposure, an incremental change in shutter speed setting must be accompanied by an incremental change in f-stop setting. For example, the exposure obtained at 1/500 sec and f/1.4 could also be obtained at 1/250 sec and *f*/2. Short exposure times allow one to "stop action" and prevent blurring when photographing moving objects (or when the camera is moving, as in the case of aerial photography). Large lens-opening diameters (small f-stop numbers) allow more light to reach the film and are useful under low light conditions. Small lens-opening diameters (large f-stop numbers) yield greater depth of field. The f-stop corresponding to the largest lens opening diameter is called the "lens speed." The larger the lens-opening diameter (smaller f-stop number), the "faster" the lens is.

Using f-stops, the equation for exposure can be simplified to – $E = \frac{st}{4F^2}$ *where* F = f-stop = f/d.

Above equation is a convenient means of summarizing the interrelationship among film exposure, scene brightness, exposure time, and f-stop. This relationship may be used in lieu of the first one to determine various f-stop and shutter speed settings that result in identical film exposures.

Numerical Problem-I

A film in a camera with a 40-mm-focal-length lens is properly exposed with a lens opening diameter of 5 mm and an exposure time of 1/125 sec (condition 1). If the lens opening is increased to 10 mm and the scene brightness does not change, what exposure time should be used to maintain proper exposure (condition 2)?

Solution

We wish to maintain the same exposure for conditions 1 and 2. Hence,

$$E_1 = \frac{s_1 (d_1)^2 t_1}{4(f_1)^2} - \frac{s_2 (d_2)^2 t_2}{4(f_2)^2} = E_2$$

Canceling constants, we obtain

$$(d_1)^2 t_1 = (d_2)^2 t_2$$

or $$t_2 = \frac{(d_1)^2 t_1}{(d_2)^2} = \frac{5^2}{10^2} \cdot \frac{1}{125} = \frac{1}{500} \text{ sec.}$$

Numerical Problem-II

A film is properly exposed when the lens aperture setting is f/8 and the exposure time is 1/125 sec (condition 1). If the lens aperture setting is changed to *f*/4, and the scene brightness does not change, what exposure time should be used to yield a proper film exposure (condition 2)? (Note that this is simply a restatement of the condition of the above problem).

Solution

We wish to maintain the *same exposure* for conditions 1 and 2. With the scene brightness the same in each case,

$$E_1 = \frac{s_1 t_1}{4(F_1)^2} = \frac{s_2 t_2}{4(F_2)^2} = E_2$$

Canceling constants,

$$\frac{t_1}{(F_1)^2} = \frac{t_2}{(F_2)^2}$$

and $$t_2 = \frac{t_1 (F_2)^2}{(F_1)^2} = \frac{1}{125} \cdot \frac{4^2}{8^2} = \frac{1}{500} \text{ sec.}$$

5.9.3.8 FUNDAMENTALS OF HUMAN STEREOSCOPY

Stereoscopy is the science of perceiving depth using two eyes. When a human being's two eyes *(binocular vision)* are focused on a certain point, the optical axes of the eyes converge on that point, forming a *parallactic angle* (Ø). The nearer the object, the greater the parallactic angle. For example, the optical axes of the left and right eyes are separated by the *eye base* or *interpupillary distance.* The eye base of the average adult is between 63 and 69 mm (approximately 2.5 to 2.76 in.). When the eyes are focused on point A, the optical axes converge, forming parallactic angle $Ø_a$ Similarly, when looking at point B, the optical axes converge, forming parallactic angle $Ø_b$. The brain has learned to associate distances with corresponding parallactic angles, and gives the viewer the visual and mental impression that object A is closer than object B. This is the basis of *depth percepton.* If both objects were exactly the same distance from the viewer, then $Ø_a = Ø_b$ and the viewer would perceive them as being the same distance away.

When we walk outside, the maximum distance at which distinct stereoscopic depth perception is possible is approximately 1000 m for the average adult. Beyond that distance, parallactic angles are extremely small, and changes in parallactic angle necessary for depth perception may not be discerned. This is why humans have trouble determining whether one house is behind another house, or one car is behind another car when these objects are thousands of meters away from us. Conversely, if we could somehow stretch our eyes - to be a meter or even hundreds of meters apart, then we would be able to resolve much more subtle differences in parallactic angles and determine which objects are closer to us over much greater distances. Such *hyperstereoscopy* depth perception would be ideal for hunting and sports activities, but it would require a substantial modification of the human head. Fortunately, there is a simple method that we can use to obtain a hyperstereoscopy condition when collecting and interpreting stereoscopic aerial photography.

Δ Stereoscopy Applied to Aerial Photography

Overlapping aerial photography (usually 60 percent endlap) obtained at exposure stations along a flight line contain stereoscopic parallax. The exposure stations are separated by large distances. Nevertheless, it is possible to let our eyes view the photographs as if our eyes were present at the two exposure stations at the instant of exposure. This results in a *hyperstereoscopy* condition that allows us to view the terrain in three dimensions. We normally view the stereoscopic aerial photography using a lens or mirror stereoscope with magnifying lenses. These instruments enhance the three-dimensional nature of the stereoscopic model. There are other stereoscopic viewing alternatives.

Δ Methods of Stereoscopic Viewing

The photointerpreter can view the vertically exaggerated stereoscopic model of the 60 percent endlap area of two successive aerial photographs using one of four methods: 1) keeping the lines of sight parallel with the aid of a stereo scope, 2) keeping the lines of sight parallel without the aid of a stereoscope, 3) crossing the eyes and reversing the order of the stereoscopic images, or 4) using anaglyphic or polarizing glasses.

The vast majority of image analysts prefer to use a simple lens pocket stereoscope or mirror stereoscope that assists the eyes in keeping parallel lines of sight and in addition, usually magnifies the photographs. This produces some eye strain. It is suggested that novice interpreters only view photographs in stereo for 10 to 15 minutes at a time in the beginning while the eyes become accustomed to using a stereoscope.

Some people are adept at forcing their eyes to remain parallel and thus do not need to use a stereoscope. They simply situate the overlapping portion of two stereo photographs adjacent to one another, position their head approximately 8 in. from the photographs, and then let their eyes relax as if they were looking at infinity. Gradually, the mind will fuse the two stereoscopic images into a third image directly in the middle of the two stereo photos. This is a good skill to acquire since one can then easily view stereoscopic photographs without a stereoscope whenever the need arises. It is particularly useful when conducting fieldwork. However, this is unnatural for the eyes and may be uncomfortable and cause eye strain.

Some image analysts are able to reverse the order of the stereo photographs and then fixate on a point directly in front of the photos. This causes the eyes to cross. This produces a true stereoscopic impression, but it is very strenuous on the eyes and is not recommended.

Another way of making sure that the left and right eyes view distinct images is to use *anaglyphic* or *polarizing* glasses in conjunction with specially prepared image materials. It is possible to produce aerial photography where the left image is depicted in shades of blue and the right image is projected in shades of red. The analyst then wears anaglyphic glasses with blue (left) and red (right) lenses: The mind fuses the two views and creates a three-dimensional scene. Similarly, it is possible to view the left and right photographs through specially prepared polarizing glasses that accomplish the same goal. .

Δ LENS AND MIRROR STEREOSCOPES AND STEREO CAMERAS

The *stereoscope* is a binocular viewing system specially developed to analyze terrestrial stereoscopic photographs *(not* aerial photographs). It was invented by the English physicist Charles Wheatstone in 1833, although he did not describe it publicly until 1838. Wheatstone used a pair of mirrors, one before each eye, oriented at 45° to allow pictures placed at either side to be fused by the eyes, as shown in Figure 6-15a. David Brewster invented an alternative stereoscopic system using lenses in 1849. The pictures were smaller, but they were enlarged by the lenses. This became the parlor stereoscope so popular during the 1800s and early 1900s for viewing specially prepared stereoscopic photographs.

Throughout most of the 1800s, stereo photographs were obtained by taking one exposure and then picking up the camera on a tripod and moving it a certain distance to the left or right and taking another picture. This introduced stereoscopic parallax between the two photographs. For example, consider the 1899 stereogram of the Salt Lake Temple, in Salt Lake City, Utah. A wealth of historical information about the temple is available when the stereopair is viewed using a stereoscope.

Stereoscopic photographs may also be acquired using special stereoscopic cameras that contain two identical lenses that are situated 60 to 70 mm apart (2.36" - 2.75") that take two photographs of the scene at exactly the same time. The cameras obtain photographs of objects from slightly different vantage points, introducing stereoscopic parallax.

The development of the concept of stereoscopic photographs and the invention of stereoscopic cameras allowed people to view marvelous stereoscopic views of local and foreign landscapes in three dimensions as if they were really at the location. There continues to be significant interest in the collection of stereoscopic photography by the public. The National Stereoscopic Association promotes the study and collection of stereo graphs, stereo cameras, and related materials and publishes *Stereo World*.

Δ Viewing Stereoscopic Aerial Photographs

The same stereoscopic principles used in the original stereoscopes are used in our current photogrammetric stereoscopes. The simple *pocket lens stereoscope* consists of two convex lenses mounted on a rigid metal or plastic frame. The distance between the lenses can be varied to accommodate various eye bases (interpupillary distances). The 'special lenses help keep the viewer's lines of sight parallel and also magnify the photography. The proper method of arranging stereoscopic photographs for analysis using a pocket lens stereoscope is demonstrated. First, the principal point and conjugate principal points are located (PP and CPP, respectively) on each photograph. A line is then drawn through them on each photograph. This is the line of flight previously discussed. The flightlines on each of the photographs are oriented so that they form a continuous line (i.e., they become *collinear).* The analyst then slides one of the photographs left or right so that a portion of the stereoscopic overlap area is visible. Then, the stereoscope is placed above the overlap area and stereoscopic viewing takes place. The common overlap area of a pair of 9 x 9-in. aerial photographs taken with 60 percent overlap is about 5.4 in. that can be viewed in stereo. Unfortunately, when the photographs are aligned for stereovision using the pocket stereoscope, not all of the 5.4 in. of the stereo model can be seen at one time. When this occurs, the interpreter can gently lift up the edge of the top photograph to see what is underneath.

A *mirror stereoscope* permits the entire stereoscopic model of the two overlapping aerial photographs to be viewed. Mirror stereoscopes often have magnification options (e.g., 2x, 3x, 6x) available that greatly increase the interpreter's ability to magnify and interpret fine detail in the stereo model. For example, a more sophisticated and expensive mirror stereoscope with zoom magnification is more useful. This configuration allows the image analyst to view stereoscopically successive overlapping aerial photographs on a roll of film without having to cut the roll of film. Still more sophisticated instruments, based on the camera-lucida principle, allow the analyst to view stereoscopic imagery while simultaneously viewing a map in superposition. This is commonly called a *zoom-transfer-scope* and is often used to transfer information interpreted from aerial photography onto a map base. Digital stereoscopic zoom-transfer-scopes are now available worldwide.

Δ PSEUDOSCOPY

In stereoscopic viewing, it is important to orient the photos so that the left and right eyes see the left and right photos, respectively. If the photos are viewed "in reverse, a *pseudoscopic view* results in which ups and downs are reversed: e.g., valleys appear as ridges and hills appear as depressions. This can be advantageous for certain work such as tracing drainage patterns. but normally the correct stereoscopic view, is desired.

When interpreting imagery with substantial shadows, it is a good practice to orient the imagery so that the shadows fall toward the image interpreter. This keeps the analyst away from experiencing *pseudoscopic illusion* where low points appear high and vice versa. For example, it is difficult to interpret the photograph of the forest and wetland with the shadows falling away from the viewer. Please turn the page around 180° and see how difficult it is to interpret correctly. Unfortunately, most aerial photography of the northern hemisphere is obtained during the leaf-off spring months when the Sun casts shadows northward. This can be quite disconcerting The solution is to reorient the photographs so that south is at the top. Unfortunately, if we have to make a photomap or orthophotomap of the study area, it is cartographic convention to orient the map with north at the top. This can then cause some problems when laypersons interpret the photomap because they do not know about pseudoscopic illusion.

Δ RELIEF DISPLACEMENT ON VERTICAL AERIAL PHOTOGRAPH

The image of any object lying above or below the horizontal plane passing through the elevation of the principal point is displaced on a truly vertical aerial photograph from its true planimetric location. The relief displacement is outward, from the principle point for objects whose elevation is above the local datum and inward to the principal points for objects whose elevation is below the datum. The direction of relief displacement is radial from principle point of photograph.

Characteristics of displacement:

1) The amount of relief displacement (d) is directly proportional to the difference in elevation between the top of the object whose image is displaced and the local datum. Greater the height of the object (h) above the local datum greater is the displacement.

2) (d) is directly proportional to the radial distance (r) between the top of the object and the principal point i.e. further the object from p.p. greater is the displacement.

3) Inversely proportional to the attitude (H) of the camera above the local datum. Therefore we can achieve a reduction in relief displacement of an object by increasing the flying height.

Measurement of height based on relief displacement (from single photograph): From the diagram below, assuming LP as the flying height (H) and AB as the object height (h), we find that -
[The equivalent distance projected to datum: d=D, r=R, h=H].

Here LPC and ABC are similar triangle.

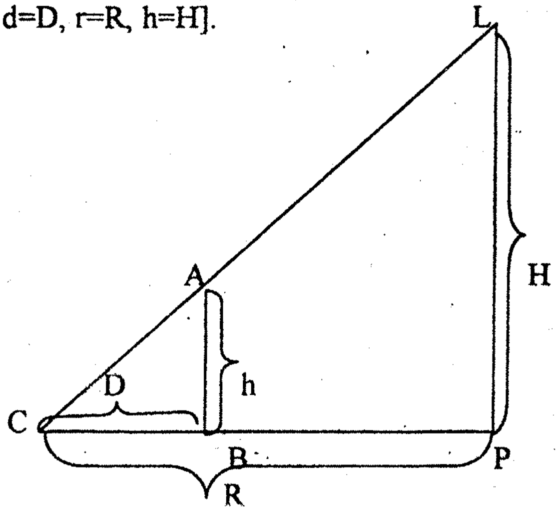
So $\frac{h}{H} = \frac{D}{R}$

Or, $h = \frac{D \times H}{R}$

Or, $R = \frac{DH}{h}$

or, $D = \frac{Rh}{H}$

Or, $H = \frac{Rh}{D}$



Therefore we can compute the height of an object from its relief displacement characteristics on a single vertical aerial photograph. It is important that both the top and bottom of the object are clearly visible and being measured and that the base is on level terrain.

Flying height (H) = 2978.5 ft.
Radial displacement from the p.p. to the top of the object (R) = 2.23 in.
Displacement (D) = 0.129 in.
Compute the height of the object (h) =?

$\frac{h}{H} = \frac{D}{R}$

$h = \frac{DH}{R} = \frac{2978.5 \times 12 \times .129}{2.23}$

=172.2988 ft.

=172.30 ft.
Height of the object h = 172.30 ft.

Assume that the relief displacement of the tower is 2.01mm and the radial distance from the centre of photo to the top of tower 56.43mm if the flying height 1220m above the base of tower. Find the height of the tower.

D = 2.01mm
R = 56.43mm
H = 1220m
h = ?

$$h = \frac{D \times H}{R}$$

$$= \frac{1220 \times 100 \times 2.01}{56.43}$$

=43.45m
height of the object h is 43.45m

In addition to calculate object height, magnitude of relief displacement can be used to correct the image position of terrain on photo. Keep in mind that terrain point in areas of varied relief that terrain point in areas of varied relief exhibit relief displacement as to vertical object.

Assume the R_a is 63.84mm R_b is 62.65mm flying height (H) = 1220m above datum. Point (a) is 152m above datum and (b) is 168m below datum. Find the radial distance and direction one must lay of from point a and b to plot point a' and b'.

H = 1220m, R_a = 63.84mm, h_a = 152m, D_a = ?

$$\frac{h}{H} = \frac{D}{R}$$

$$\text{Or, } \frac{152}{1220} = \frac{D}{63.84} \text{ or } D = \frac{152 \times 63.84}{1220}$$

=7.95mm (inward to p.p)

H = 1220m R_b = 62.65mm, h_b = 168mm, D_a = ?

$$\frac{168}{122000} = \frac{D}{62.65} \text{ or } D = \frac{62.65 \times 168}{122000}$$

or, D = 8.63mm (outward from p.p.)

Height measurement based on shadow length:

The height of an object (h) may be computed by measuring the shadow cast (L).

Note that the tangent of an angle (a) would be equal to opposite side (h) over the adjacent side, which is shadow length (L) Therefore $\tan a = \frac{h}{L} =$ or $h = L \tan a$

The sun's elevation angle (a) above the local horizon can be predicted using a solar ephemeras table this requires knowledge of the approximate geographic co-ordinate (Lat. and Long. of the side and the acquisition date and time of day)

Problem-I. The height of an object is 172.75 ft. it cast the shadow length on photograph that is 0.241 inch. The scale of the photograph is 1:5957. Find out the tangent of angle (a).

1 inch map distance represents 5957 inch ground distance or 496.421ft
0.24 inch map distance represents (496.42 x 0.241)ft = 119.64ft
shadow length (L) = 119.64 ft,
height of object (h) = 172.75 inch

$$\tan a = \frac{h}{L} = \frac{172.75 \text{ ft.}}{119.64 \text{ ft.}}$$

=1.44 – Ans.

Δ IMAGE PARALLAX AND DETERMINATION OF HEIGHT

The term parallax refers to the apparent change in relative position of a stationary objects caused by a change in viewing position.

This phenomenon is observable when one looks at objects through a side window of a moving vehicle with the moving window objects at a relatively greater distance from the window appear to move very little in contrast objects close to the window appear to move through a much greater distance.

In the same way terrain features close to an aircraft (i.e. higher elevation) will appear to move relatively greater distance than the lower elevation features when the point of view changes between successive exposure. These relative displacements form the basis for three-dimensional viewing of overlapping photographs. In addition they can be measured and used to compute the elevations of terrain points.

OBJECT HEIGHT MEASUREMENT FROM PARALLAX DIFFERENCES

C_1, C_2 – Exposure stations
B – Air base
b_p – Photo base
H – Flying altitude
f – Focal length of the camera
a – Top of the object
b – Bottom of the object
h_a – Height of the top of the object.
h_b – Height of the bottom of the object.
P_a – Parallax of the top of the object
P_b – Parallax of the bottom of the object.
ΔP – Difference in parallax
Δh – Difference in elevatio..

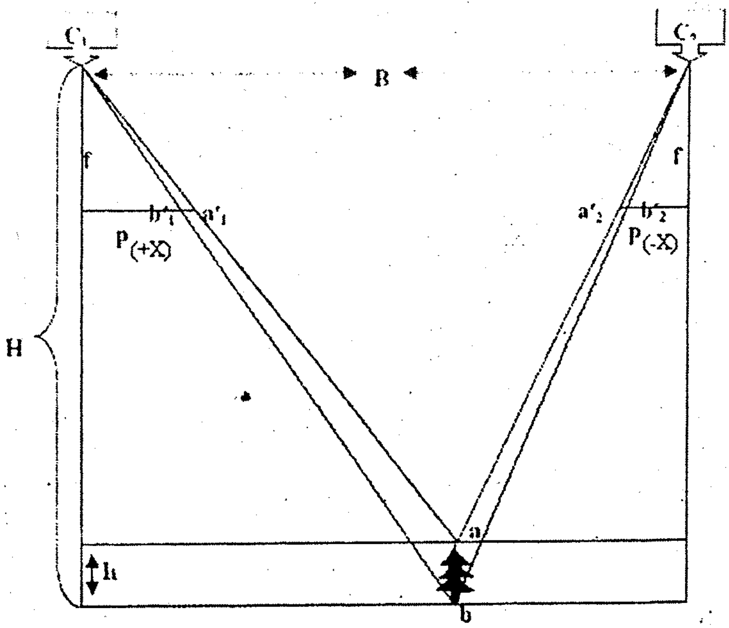
<u>Height of Individual object.</u>

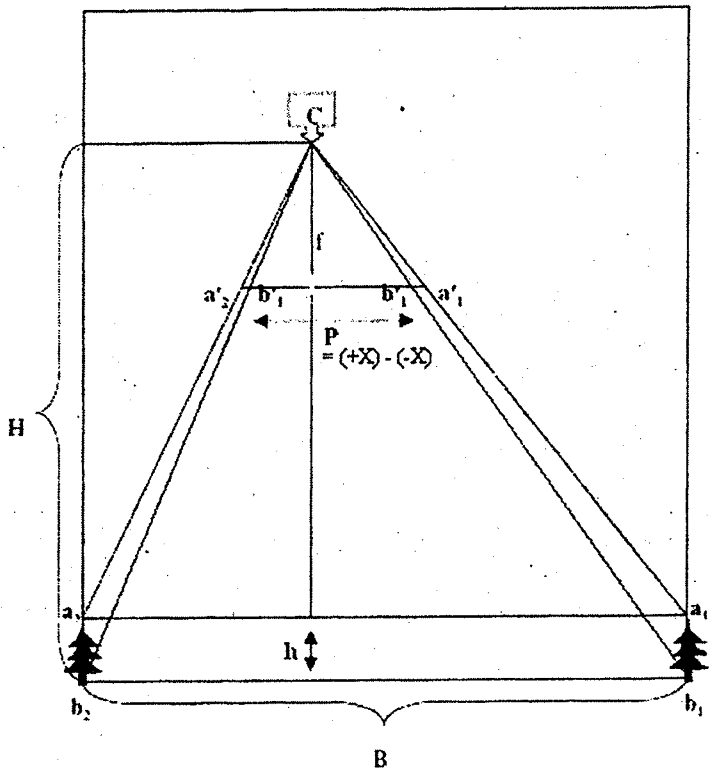
Considering similar triangle **$Ca'_1a'_2$ & Ca_1a_2** –

$(H\text{-}h_a) / B = f / P_a$
or $P_a = Bf / (H\text{-}h_a)$ ---------- Eq-1.
or $(H\text{-}h_a) = Bf / P_a$
or $h_a = H - (Bf / P_a)$ -------- Eq-2.

Similarly considering similar triangle **$Cb'_1b'_2$ & Cb_1b_2** –

$(H\text{-}h_b) / B = f / P_b$
or $P_b = Bf / (H\text{-}h_b)$ ---------- Eq-3.
or $(H\text{-}h_b) = Bf / P_b$
or $h_b = H - (Bf / P_b)$ -------- Eq-4.





DIFFERENCE IN ELEVATION BETWEEN TOP (A) & BOTTOM (B) OF THE OBJECT

From Eq 1. & Eq-3.

$$P_a - P_b = Bf / (H-h_a) - Bf / (H-h_b)$$

$$\text{or } \Delta P = Bf (H-h_b) - Bf(H-h_a) / (H-h_a)(H-h_b)$$

$$\text{or } \Delta P = Bf (\not{H} - h_b - \not{H} + h_a) / (H-h_a)(H-h_b)$$

$$\text{or } \Delta P = Bf / (H-h_a) \times (h_a-h_b) / (H-h_b)$$

$$\text{or } \Delta P = P_a \times (h_a-h_b) / (H-h_b) \text{ ------------------ Eq-5.}$$

$$\text{or } \Delta P = P_a \times \Delta h / (H-h_b) \qquad [\text{ since } P_a = Bf / (H-h_a) - \text{Eq-1. and } \Delta h = (h_a-h_b)]$$

$$\Delta h = \Delta P.\ (H-h_b) / P_a \text{ ------------------------- Eq-6.}$$

Assuming that B is located at datum ie, $h_b = 0$.

$$h_a = \Delta P.\ H / P_a \text{ ----------------------------- Eq-7.}$$

If the height of many features are needed in an area where the ground is approximately level,. The photo base b_p can be utilized as the parallax of the ground point. In this case the Eq-7. can be modified to –

$$h_a = \Delta P.\ H / b_p + \Delta P \text{ or } \Delta P.\ H / b_p \text{ ------ Eq-8.}$$

ΔP can be eliminated from the denominator, as its value is very small compared to b_p.

5.9.3.9 UNIT SUMMARY

From the above discussion we may come into the conclusion that aerial photography has been the historical backbone of remote sensing due to its general availability, geometric integrity, versatility, and economy. With aerial photography, we also see the "whole picture" in that *all* observable earth surface features are recorded simultaneously. Aerial photographs are also very useful in studying dynamic phenomena such as floods, moving wildlife populations, traffic, oil spills, and forest fires. With photography, invisible UV and near-IR energy can be detected and subsequently recorded in the form of a visible image; hence film can see certain phenomena the eye cannot. In fact, most planimetric and topographic maps are currently produced using measurements extracted from airphotos. Photogrammetric analysis procedures can enable us measuring approximate distances, areas, and elevations using hardcopy photographic products, unsophisticated equipment like stereoscope and parallax bar, and simple geometric concepts of height and distance measurement.

However, as with any other sensing system, aerial photography has certain limitations and requirements. Airphotos are often difficult to obtain, handle, store, calibrate, and interpret. Current technological trends seem to indicate that more and more inherently digital recording systems will be used in many applications where aerial photographs have traditionally been employed.

As we have seen in this unit, photogrammetry is a very large and rapidly changing subject. Historically, most photogrammetric operations were analog in nature, involving the physical projection and measurement of hardcopy images with the aid of precise optical or mechanical equipment. Today mathematical models using softcopy data are common. Most softcopy systems are also amenable to the analysis of many different types of digital image data (e.g., airborne digital camera data, satellite data). With links to various GIS and image processing software, softcopy workstations often represent highly integrated systems for spatial data capture manipulation, analysis, storage, display, and output.

5.9.3.10 SELF-ASSESSMENT QUESTIONS

1. A camera equipped with a 155mm focal length lens (f) is used to take a vertical photograph from a flying height of 3050m (H) above msl. If the terrain is flat and located at an elevation of 800m (h) what is the scale of the photograph? (10)

2. Prepare a map showing four distinct physiographic / cultural features using a tracing sheet by observation of the given aerial photo stereo-pair under a mirror stereoscope and compute the area under natural vegetation/agricultural land (any one) and total length of roads/streams (any one) assuming the scale of the photograph 1:20,000. (10+5+5)

3. Compute the difference in elevation of point A & B marked on the given aerial photograph with the help of a parallax bar. Where focal length of the camera is 160mm, and flying altitude of the aircraft above ground 1600m. (10)

4. The relief displacement of a lamppost is 2.11mm and the radial distance from the centre of photo to the top of tower 56.53mm if the flying height 1300m above the base of tower. Find the height of the post. (10)

5. A film in a camera with a 65-mm-focal-length lens is properly exposed with a lens opening diameter of 5 mm and an exposure time of 1/125 sec (condition 1). If the lens opening is increased to 10 mm and the scene brightness does not change, what exposure time should be used to maintain proper exposure (condition 2)? (10)

6. Find out the number of air photo required to cover an area of 30 km × 20 km Where focal length of the camera is 152.4mm, photo size 230mm×230mm and desired photo scale is 1:30000, end lap 60% and side lap 30%. (10)

5.9.3.11 SUGGESTED FURTHER READINGS

1. *Wolf Paul R. & Dewitt Bon A.(2004) Elements of photogrammetry with applications in GIS.3rd Ed. McGraw-Hill Publication(Asia).*
2. *Lillesand T. M. & Kiefer R. W. (2002), Remote Sensing and Image Interpretation. 5th Ed. John Wiley, New York.*
3. *Lo C.P. & Yeung Albert K.W. (2002) Concept and Techniques of Geographic Information System 1st Ed. Prentice Hall, New Delhi.*
4. *Jensen J.R. (2000) Remote Sensing of the Environment- An Earth Resource Perspective, Pearson Education, Singapore.*
5. *Singh.R.L. (1979) Elements of practical geography, Kalyani Publishers, New Delhi.*

PART-I

Paper - V (Practical) :: Module - IX :: Unit - 04

MODULE STRUCTURE

Paper –V (Practical) :: Module – IX
Unit – 04

GROUND SURVEY AND AERIAL PHOTO INTERPRETATION

1. **Air Photo Interpretation; shape, size, pattern, tone, texture, shadows and site.**
2. **Monoscopic and stereoscopic Interpretation of airphotos for geomorphic land use features.**

■ 9.4.0 OBJECTIVES

After a through understanding of this first part of this unit and completion of the laboratory exercise, you will be able to :

1. List the seven basic principles of photo interpretation and give one example of how each principle is used to help identify objects on aerial photographs.
2. Give an example of how each of the nine photo interpretation techniques or aids can be used to help identify and quantify objects on aerial photographs.
3. Using words and schematic diagrams, explain how additive color enhancement work.
4. List four advantages and one disadvantage of the use of additive color enhancement techniques.
5. Describe how shadowless photography is obtained and list two benefits of this type of photography to the photo interpreter.

■ 9.4.1 INTRODUCTION

Whereas photogrammetry deals with measurements and the production of maps from aerial photographs, photo interpretation is defined by the American Society of Photogrammetry (1966) as "the act of examining photographic images for the purpose of identifying objects and judging their significance." The skilled photo interpreter is able to recognize features on aerial photographs and to make inferences about the environment by consciously or subconsciously synthesizing a few or perhaps all of the principles of photo interpretation. This skill is developed through long hours of practice with photos, coupled with ground visitations to check the accuracy of the interpretations. In addition,' the expert interpreter must have a good background in the earth sciences particularly geology, geomorphology, hydrology, soils, and the biological sciences, including plant ecology. Thus, the photo interpreter is first a geologist, an engineer, a forester, or other type of resources manager, who has learned the skills of photo interpretation as an aid in her or his discipline. Photo interpretation, therefore, is merely a means to an end and not an end in itself. A photo interpreter is also a detective of sorts. This means that the image contains many clues that the interpreter must first see and then combine with firsthand knowledge to form some sort of conclusion about the object being viewed. This is done by the use of one or more of the *basic principles* of photo interpretation. The seven basic principles of photo interpretation are discussed as follows.

9.4.2 ABSOLUTE AND RELATIVE SIZE

By relative size we mean the size of an unknown object in relation to the size of a known object (Figure 9.1.1).The photo on the left is a residential-industrial area with the houses ***relatively*** smaller than the apartment buildings below A. Even larger buildings in the vicinity of B indicate warehouses or possibly a small complex of industrial buildings. The photo on the right is an agricultural area of a much smaller scale than the photo at the left as indicated by the small farm buildings at C. The

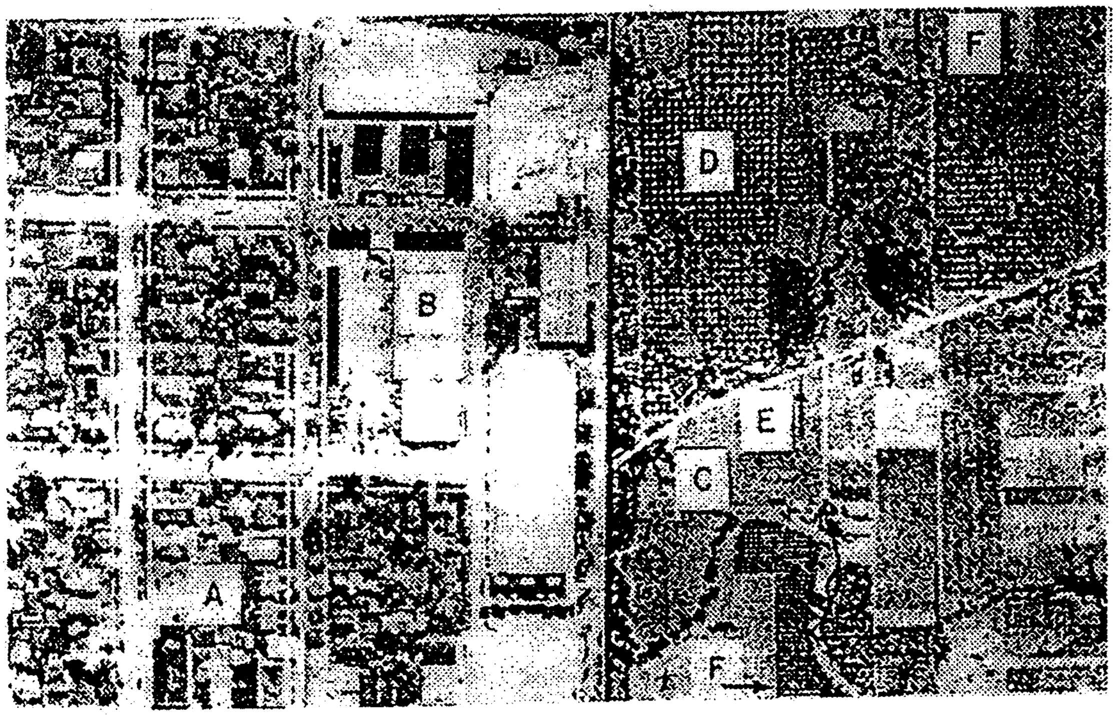


Figure 19.1 Relative and absolute size help to identify objects. See text for more detail.

Figure 9.1.1

orchard at D has very large tree crowns, being nearly as wide as the two-lane highway at E. They are probably large apple or walnut trees. However, at F the trees are much smaller, indicating an orchard of dwarf fruit trees or perhaps filberts. They are planted too close together to be interpreted as just young trees that will grow to the size as those at D. Thus, we should be able to separate cars from buses and trucks, mature trees from young trees, and single-dwelling houses from apartment buildings based on relative size. Absolute size is also important; therefore, a thorough understanding of photo scale is essential in any size analysis. At the larger scales more detail can be seen, which might otherwise go undetected. On the other hand, smaller-scale photography will place large features of the surface within their regional environment and make comparisons with objects of known size easier..

■ 9.4.3 SHAPE

Many objects can be recognized by their two-dimensional shape on a single aerial photograph (Figure 9.1.2), or from three-dimensional views of stereoscopic models.

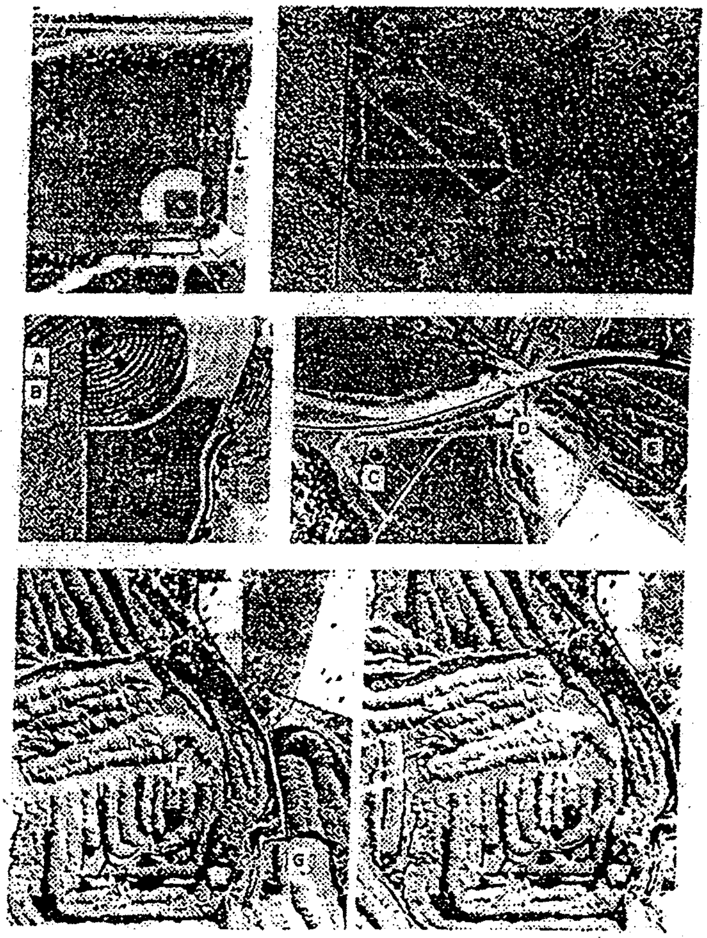


Figure 9.1.2 *Shape is an important factor in the identification of many objects. See text for more detail.*

Railroads may appear as narrow bands with smooth, gradual curves and level grades as compared with wider superhighways that have sharper curves and steeper grades. Secondary roads may be relatively narrow and with very sharp curves and even steeper grades. The interpreter must learn to identify objects on the photograph by their shape as viewed from above as compared with, the shapes he or she is 'accustomed to viewing on a horizontal plane while on the ground. Tilt and topographic displacement may lead to the wrong interpretation particularly near the edges of a photograph.

In Figure 9.1.2 there are several familiar shapes and some not so familiar shapes. See if you can identify them before reading further. In the upper left comer is either a baseball or softball diamond. If we know the *absolute* dimensions of the base paths, we would know which kind of diamond it is.

In the upper right corner is the familiar shape of the runways of an airport except that there are no buildings or airplanes. Therefore, it must be a temporary airstrip used by planes when spraying agricultural or forestland with fertilizer or pesticides.

At center left is a drive-in movie. On the original photo the movie screen can be seen at A and the projection booth can be seen at B.

At center right is a sewage plant at C and a highway bridge at D going over railroad tracks at E. The main highway has long, gradual curves as compared to secondary roads with sharper curves. The railroad is straight here, but if it curved, it would be more gradual than the highway.

The stereogram at the bottom shows tailings from a placer mine. You can see dredges at F and G. Clear (dark) water can be distinguished from the muddy water near the dredges by *tone* differences. This photo was taken in 1937, before environmental problems were considered.

■ 9.4.4 SHADOW

Shadows, when correctly interpreted, can be extremely useful (Figure 9.1.3). They give valuable clues as to profile shapes and relative sizes of objects such as bridge structures, towers, or trees. On the other hand, shadows often obscure important detail that one may wish to see. The best stereo view is obtained when shadows fall toward the interpreter; otherwise, pseudostereo may be the result. Interpreters should be aware that the radial displacement of objects with height may result in a situation where the objects themselves may obscure their own shadows. Thus, shadows should be analyzed in relation to the principal point, or nadir.

Without the shadow of the bridge in the upper photo in Figure 9.1.3 it would still be obvious that it is a bridge, but without the shadow it would be impossible to guess the type of superstructure of this bridge. We can also conclude from the tree shadows that they are hardwoods without their leaves, indicating winter photography.

Figure 9.1.3 In some situations where good shadows exist, they can be very helpful to the photo interpreter, enabling one to get an idea of the profile of an object (such as the structure of the bridge in the upper photograph and the trees in the lower photograph).

In the bottom photo we have conifer (Douglas-fir) shadows at A as indicated by their conical profiles. At B are rounded shadows of hardwoods, again without their leaves. This could be either a spring or fall photo since many hardwoods still have their leaves. It is probably a fall photo as indicated by the different tone of trees at C and D as they change to autumn colors.

■ 9.4.5 TONE OR COLOR

On black-and-white photographs, tone varies from black to white with various shades of gray in between. On color photography, hue (color), saturation, and brightness all contribute to the interpreter's ability to differentiate objects. It is believed that an interpreter can distinguish at least 100 times more variations of color on color photography than shades of gray on black-and-white photography. Tone is also described in terms of pattern, such as uniform, mottled, banded, or scabbed, and in terms of boundary sharpness, such as sharp, distinct, gradual, or fuzzy (Figure 9.1.4).

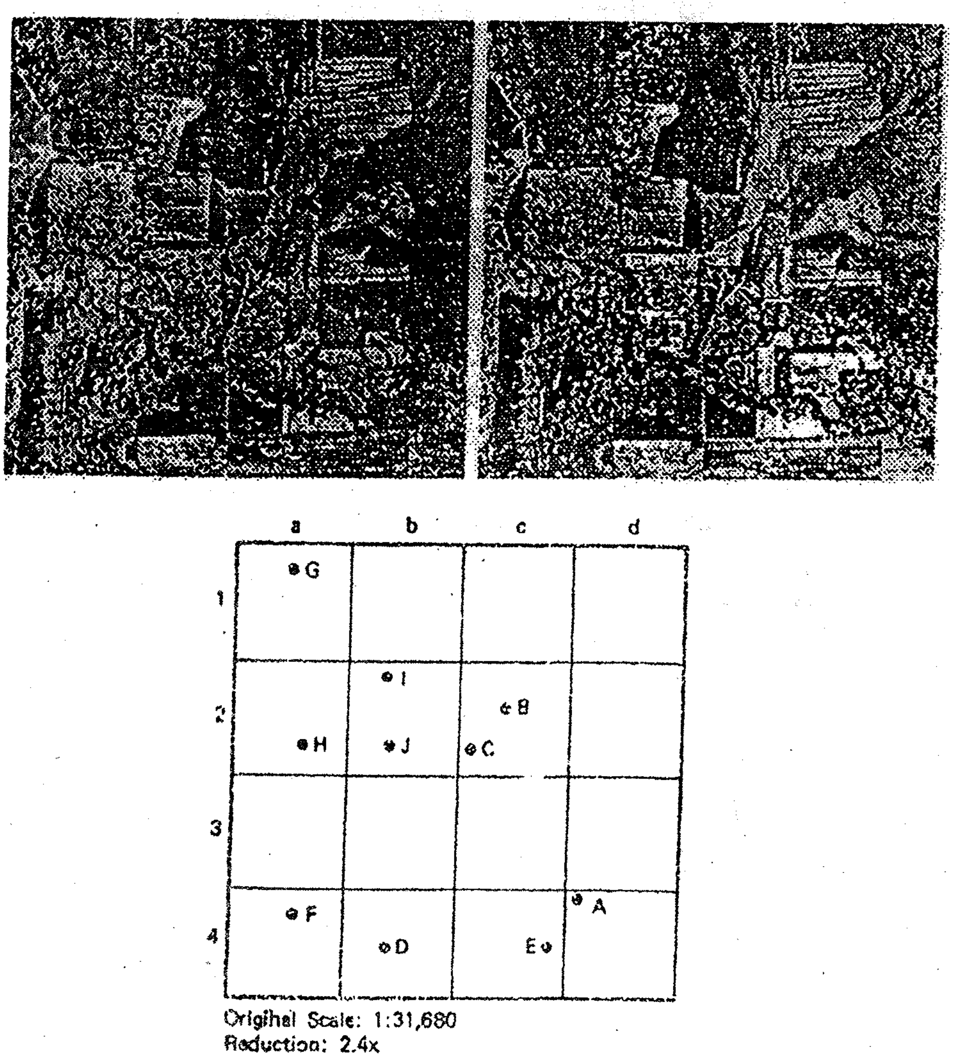


Figure 9.1.4. Photographic tone is measured in shades of gray with white at A, light gray at B, dull gray at C, and dark gray or black at D. Tone may also have distinctive patterns, such as uniform at E, mottled at F, banded at G, and scabbed at H. Boundary sharpness is distinct at I and graduall or fuzzy at J. Notice the banded tones at 2b due to plowing. A typical V-shaped gully in till is shown at 3a and 4a. (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

One of the major factors affecting tone is soil moisture content and vegetation (Figure 9.1.5). Variation due to soil moisture alone is illustrated at 1 ab and 2 ab, while the variation in 3 abcd and 4 abcd is due to both vegetation and soil moisture. Tonal variation caused by vegetation and soil moisture are correlated because of the effect of moisture on the vegetation.

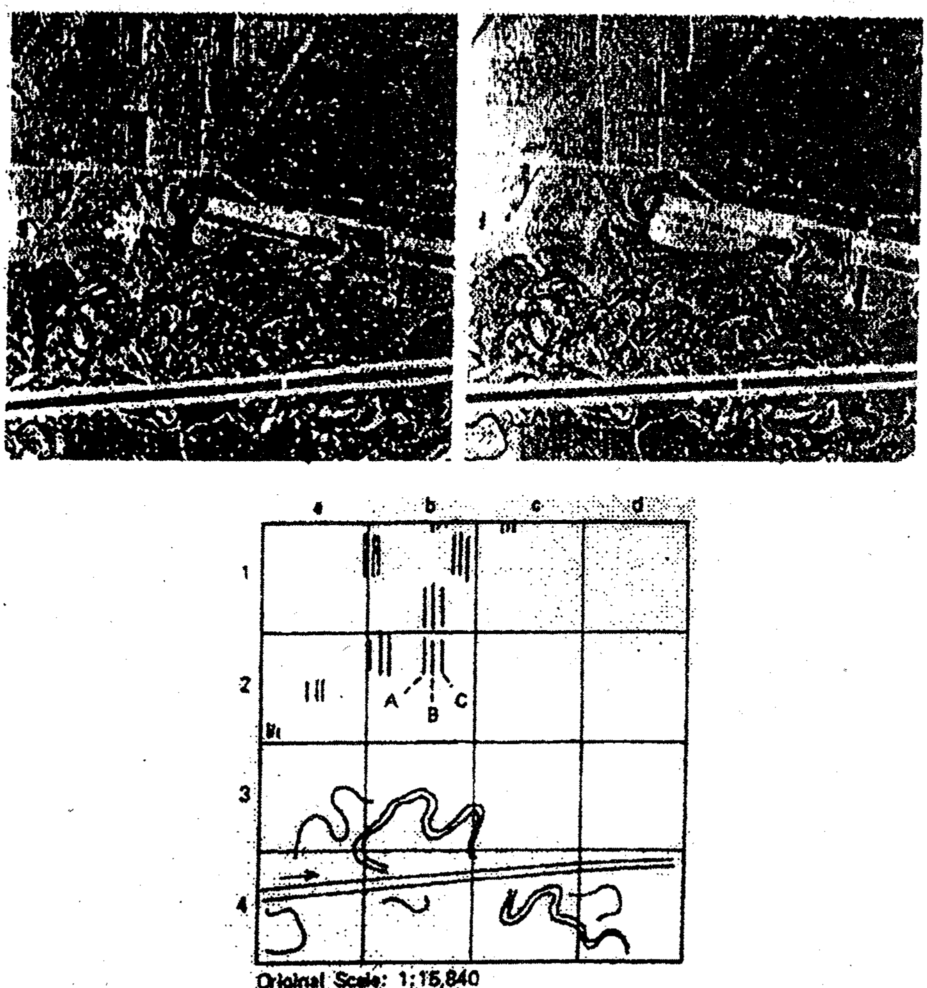


Figure 9.1.5. Variation in tone due to differences in soil moisture. The area was irrigated at different times, with the earliest at A and the most recent at C. A straight man-made canal is visible near the bottom of the stereogram, illustrating a sharp tone boundary. (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

Both tone and hue are relative and vary within, as well as between, photographs of similar objects. This results from differences in exposure settings at the time of photography and differences in developing and printing. Tone also varies with the season of the year and the position of the sun in relation to the camera. Some water bodies may show up as white where the sun's reflection is high, but other water bodies on the same photo may be black where there is no reflection at all.

9.4.6 TEXTURE

Texture is the result of tonal changes that define a characteristic arrangement of tones. Texture ranges from smooth or fine to coarse. For example, in color Plate V *(left)* the texture ranges from very fine to very coarse as we go from A to E *(upper)*. The *very fine* texture at A is a stand of dense red alder all about the same height and with the tree crowns all grown together. At B we have a dense young stand of Douglas-fir poles that exhibit *a fine* texture. The stand of small Douglas-fir sawtimber at C is of *medium* texture. At D is a coarse-textured stand of mature sawtimber and at E is a very coarse stand of old-growth Douglas-fir. As stands of timber become older, there is more variation in height and density, which adds to the texture. The light pink at F is grass (without height) and the darker pink at G is brush intermingled with hardwoods and some conifer. The black at E *(lower)* is the result of a recently burned clear-cut.

■ 9.4.7 PATTERN

Pattern is the spatial arrangement of objects. Patterns can be man-made or natural. In general, man-made patterns can be distinguished from natural ones. Humans usually create well-defined geometric patterns made up of smooth curves and straight lines such as cities, highways, power lines, clear-cuts, farmers' fields, and orchards (Figure 9.1.6). Natural patterns are not nearly as uniform. For example, changes in vegetation patterns that follow long and straight lines are usually indicative of adjoining property ownership lines that follow the rectangular Public Land Survey System (Section 9.2.2). Vegetation changes within a singular ownership do not typically follow straight lines with the exception of agricultural fields. Both man-made and natural patterns are evident in Figures 9.1.7 and 9.1.8

■ 9.4.8 LOCATION, ASSOCIATION, AND CONVERGENCE OF EVIDENCE

Some authors list location, association, and convergence of evidence as separate principles, but they are all very closely related and are combined for our discussion. Sometimes individual features of objects on the ground cannot be identified by themselves, but when studied in association with each other, their identification becomes apparent.

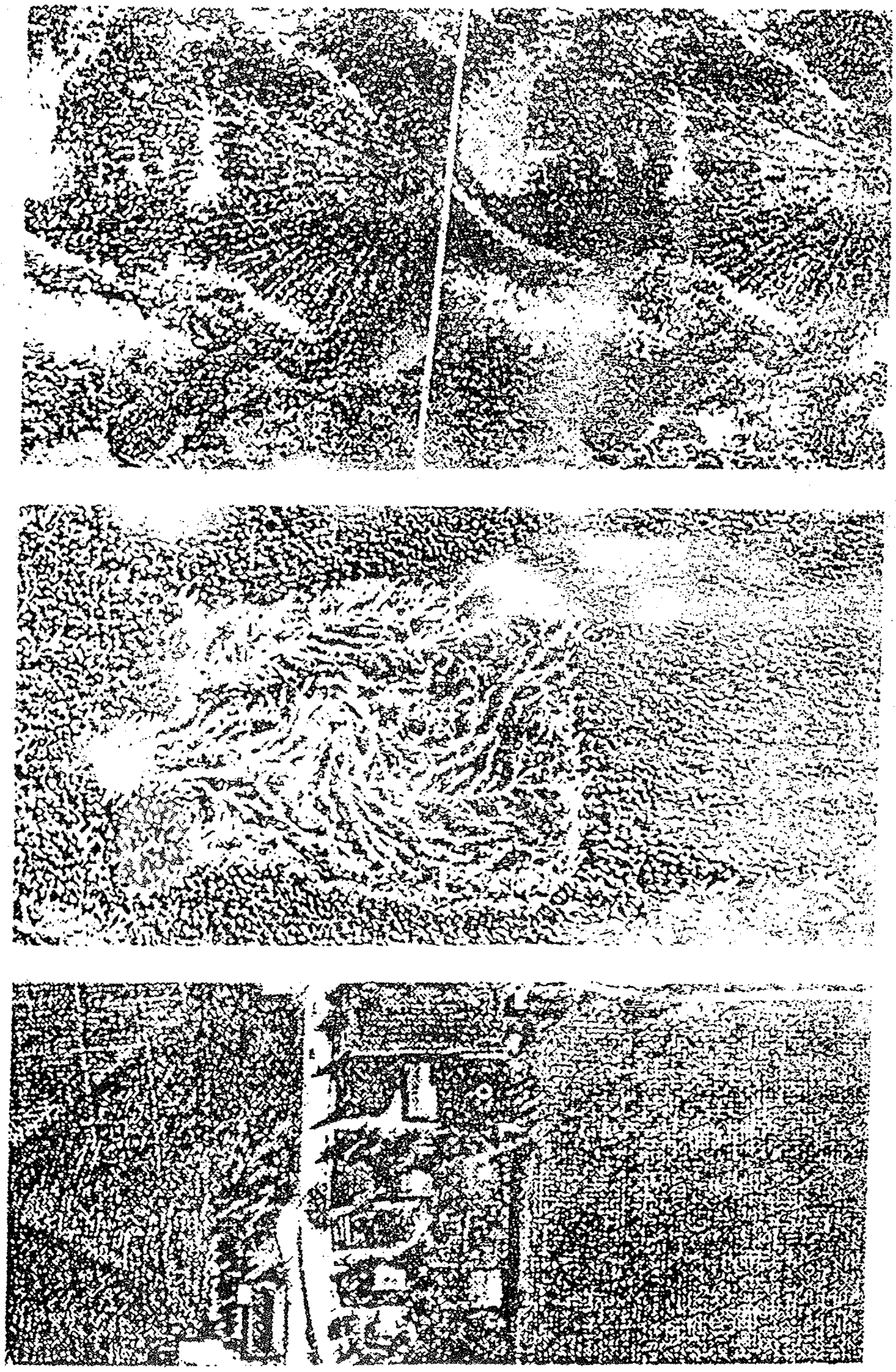


Figure 9.1.6. Typical forestry and agricultural patterns. The top stereogram indicates that a thinning has been accomplished by cable logging. (Courtesy of Illinois Photographic Service) The centre photo shows a clear-cut that was logged by tractors. The bottom photo shows poles an a series of wires for hope on the right and a recently harvested held of any on the left.

Association, or convergence of evidence, is askill developed by the interpreter, which involves a reasoning process that uses all the principles of interpretation to relate an object to its surroundings. In forestry, biological association is particularly important in making type maps. One would expect to find cottonwood located along moist drainage bottoms and not on dry ridge tops, and a smooth area in the middle of a wilderness area is more apt to be a lake than a farmer's plowed field.

Figure 9.1.7 Stereogram for photo interpretation. Agricultural land is at A, forested land is at F, and brush is at the question mark. There is an improved road between 3 and 4 with a cut between 2 and 3. What is at 6? It can be identified using the principles of location, association, and the convergence of evidence. See text for answer. (Courtesy U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station.)

What is located at area 6 on the stereogram of Figure 9.1.7 Using your stereo-scope and the convergence-of-evidence principle, you should be able to identify the object. Try it before reading further.

The object has a very light tone, indicating a nonvegetated area. Could it be a rock or gravel pit? Probably not rock would be hauled out on the lower side and there is no road here. Is it a garbage dump? This is a possibility, but it is more likely to be a sawdust pile from an old lumber mill located close by Notice the log pond by the mill. There is another mill on the stereogram with its sawdust storage or disposal area at O.

There are several man-made patterns in Figure 9.1.8. Use your stereoscope and see if you can identify objects labeled A through J before you read the answers that follow:

■ 9.4.9 LOCATION

A Primary sewage treatment plant (aeration bubbles)

B Clarifier (thickener)

C Sewage spill basin

D Railroad cars for wood chips

E Parking area

F Log piles

G Transformer (power lines are visible on the original stereogram)

H Saw mill

I Wood chip pile

J Logs chained together for shore protection

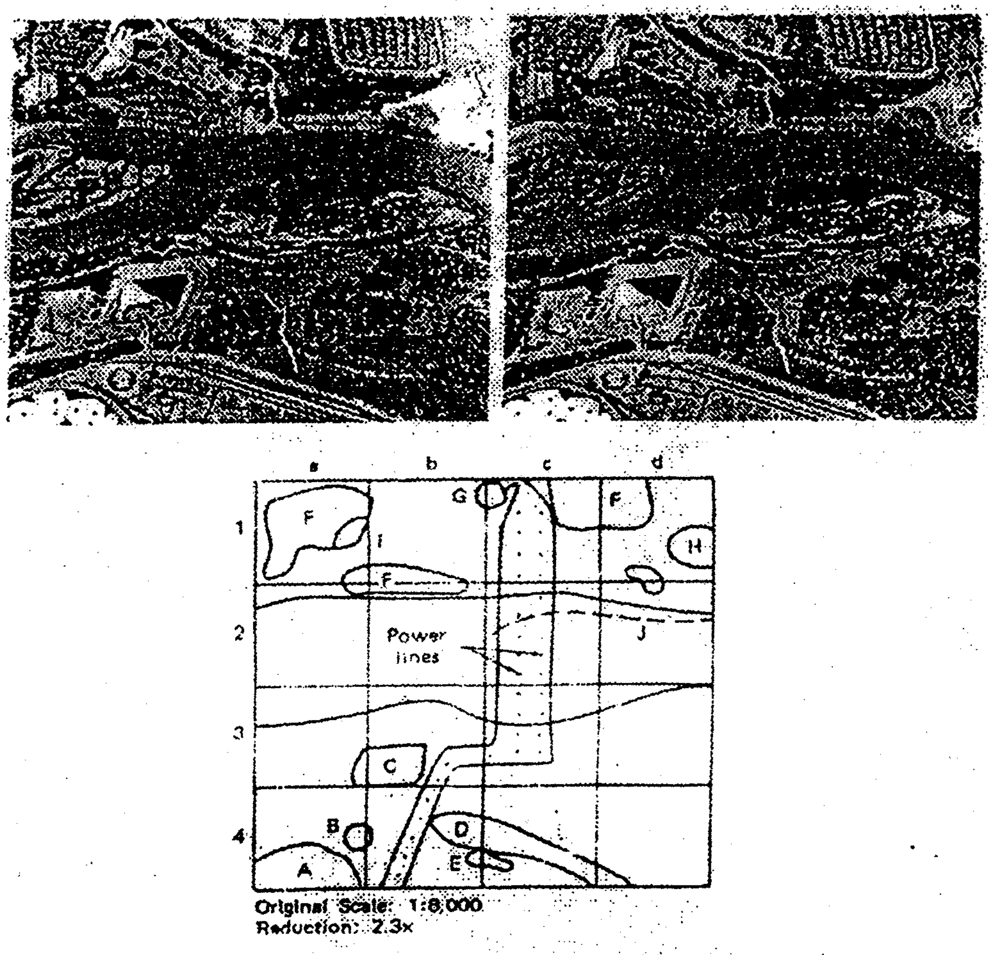


Figure 9.1.8. There are several natural and man-made patterns on this stereogram. Use your stereoscope and try to identify objects labeled A through J before you read what they are in the text.

One note of caution should be mentioned here. It is often the case that an interpreter will be given photos with lines drawn on them (or on overlays to be placed over the photos). The interpreter will then be asked to make interpretations about the lines on the photos. An example of this would be in defining land-use practices and whether they follow a property line. It is important that the photos be viewed with-out the lines present, as these drawn lines can lead to a suggestion of what may or may not he there For example, an interpreter viewing a slighly meandering natural vegetation line could be convinced it is straight and man-made if a predrawn line has been placed over the image along the edge of the vegetation line.

9.4.9 TECHNIQUES AND AIDS FOR PHOTO INTERPRETATION

There are several techniques and aids available to the photo interpreter. Some of the more important ones include (1) stereoscopic examination, (2) sample stereograms, (3) magnification, (4) interpretation keys, (5) photo measurements, (6) conversion tables, (7) statistical analysis, (8) templates, (9) multiband color enhancement, (10) density slicing, and (11) a whole series of techniques requiring the use of computers and sophisticated equipment such as digital image analysis and microdensitometry. These techniques are beyond the scope of this book.

9.4.9.1 STEREOSCOPIC EXAMINATION

Even though stereoscopic examination of aerial photography has been used for photo interpretation for decades, it continues to be an extremely useful and simple technique. Three-dimensional viewing is essential for certain interpretation tasks (the analysis of land forms and drainage patterns, for example). More detail can be observed stereoscopically than by monocular viewing. Stereoscopic viewing also allows the measurement of height, which is often very helpful. A 260-foot tree photographed on the California coast would certainly indicate redwood and not some other species in the same area.

9.4.9.2 STEREOGRAMS

Stereograms are used in many disciplines. Stereograms of all kinds have been developed of known features to give the photo interpreter something to compare unknown features with. Identification of different forest cover types is a common use of stereograms. For maximum value, stereograms should be on the same type of film and at approximately the same scale as the photos being interpreted.

9.4.9.3 MAGNIFICATION

All pocket stereoscopes and mirror stereoscopes with binocular magnification attachments provide valuable magnification of the imagery. Most pocket stereo-scopes are 2-power but some are 4-power. Binocular attachments for mirror stereo-scopes usually range from about 3- to 10- or even 30-power. Even though there is no theoretical limit to the amount of optical enlargement possible, there are some definite practical limits.

For much photography the grain of the film becomes quite noticeable and bother-some at 4 to 6 magnification. Color positive transparencies, however, can be viewed on a light table at much higher magnifications without the film Grain problem.

Another practical limitation to the amount of magnification that is helpful is that you cannot see something that is not there. That is, there is no advantage in magni-fying beyond the limits of resolution of a given film. This is not only true of optical magnification by stereoscopes but also of enlargements.

9.4.9.4 INTERPRETATION KEYS

Photo interpretation keys offer valuable aid to the photo interpreter, especially the beginning interpreter. There are two types: selective and dichotomous. *Selective keys* are comparative. The interpreter simply matches the features of the key with the features of what he or she is looking at. These keys can be in the form of written descriptions, tables, stereograms, or a combination.

Dichotomous keys, sometimes called elimination keys, require the interpreter to make step-by-step decisions from the general to the specific. Good dichotomous keys are difficult to make and are frequently difficult to use. One wrong decision along the way usually leads to an incorrect identification. However, wrong decisions usually occur near the end of the process, when a decision must be made between two similar characteristics. Examples of photo interpretation keys are (1) military such as types of aircraft, warships, or defense installations; (2) land use such as urban, suburban, industrial, agriculture; and (3) cover-type—such as forest cover types or range condition classes.

9.4.9.5 PHOTO MEASUREMENTS

Measurement in both vertical and horizontal planes is not only helpful but 'some-times necessary in photo interpretation work. Besides photo measurements already discussed, the forester makes detailed measurements of tree crown diameters, tree and stand heights, and percent crown closure to estimate the volume of timber in a given area.

9.4.9.6 CONVERSION TABLES

Frequently a photo interpreter wants to determine something that cannot be mea-sured directly on an aerial photograph. For example, in timber-type mapping, the average diameter of the tree stems must be known, but it cannot be measured directly. However, conversion tables have been developed to convert measurable variables such as tree height, crown diameter, and percent crown closure to close approximation of stem diameter. Similar tables are available for basal areas and timber volumes for a wide variety of tree species.

9.4.9.7 STATISTICAL ANALYSIS

The tables mentioned in the previous section were developed using a technique called regression analysis. Double sampling with regression is another technique that can be used by the photo interpreter. Suppose a forester wished to know how many live tree seedlings remain on an area that was planted a few years ago, but he or she cannot see all the trees on the photographs because of brush problems. The forester can count the trees that are visible on selected plots on the aerial photos and make similar counts on a subsample of ground plots. The forester uses this information in a double sampling with regression technique to adjust the photo counts for the unseen trees to estimate the number of trees on all the plots and on the total acreage. The same technique can be used by the range man-ager, recreation specialist, or wildlife census taker.

9.4.9.8 TEMPLATES

There are a variety of templates available to the photo interpreter in the form of transparent overlays that are placed over one or both photos of a stereoscopic pair. Most templates are designed to help take measurements such as parallax for height measurement, length scales and wedges for distance measurement, dot grids for area measurement, density scales for percent crown closure, protractors to measure angles and direction, and slope scales. Most templates are designed to fit a particular photo scale, but some can be used for several scales.

9.4.9.9 LABORATORY EXERCISE

The emphasis of this laboratory exercise is to provide a learning experience for general aerial photo interpretation. For several reasons you are not expected to get all the answers correct. You may not be familiar with the objects to identify—a golf course, for example. When it comes to trees, just identify them as to hardwoods (deciduous) or conifers and perhaps thinned or unthinned. Hardwoods, except for oak and a few other species, are generally lighter in tone than conifers, which have *sharp-pointed* crowns, as compared with rounded crowned hardwoods.

You are given 95 locations on one monogram and nine stereograms (by grid cells) to identify. Some objects or areas cover more than one grid cell, requiring different combinations of grid cell locations as follows:

1. A single grid cell; i.e., A:26
2. A point or line where the grid line cross = A/B:25 or A/B:25/26
3. Several grid cells; i.e., A-C:27-29
4. A long-narrow object; i.e., A:25 to I:25

You will need at least a 2x stereoscope for the stereograms. A magnifying lens might also be helpful. The answers presented were obtained by the authors' interpretation, with a familiarity of the general areas, using the original aerial photographs. We realize that some resolution will be lost during the transfer from the photos to the book, which may make small items very difficult to interpret accurately. However, after completing the exercise, if you look at the answers in Appendix F and then re-examine the stereograms, knowing the answers will show you what experienced interpreters can identify on good aerial photography even at relatively small scales.

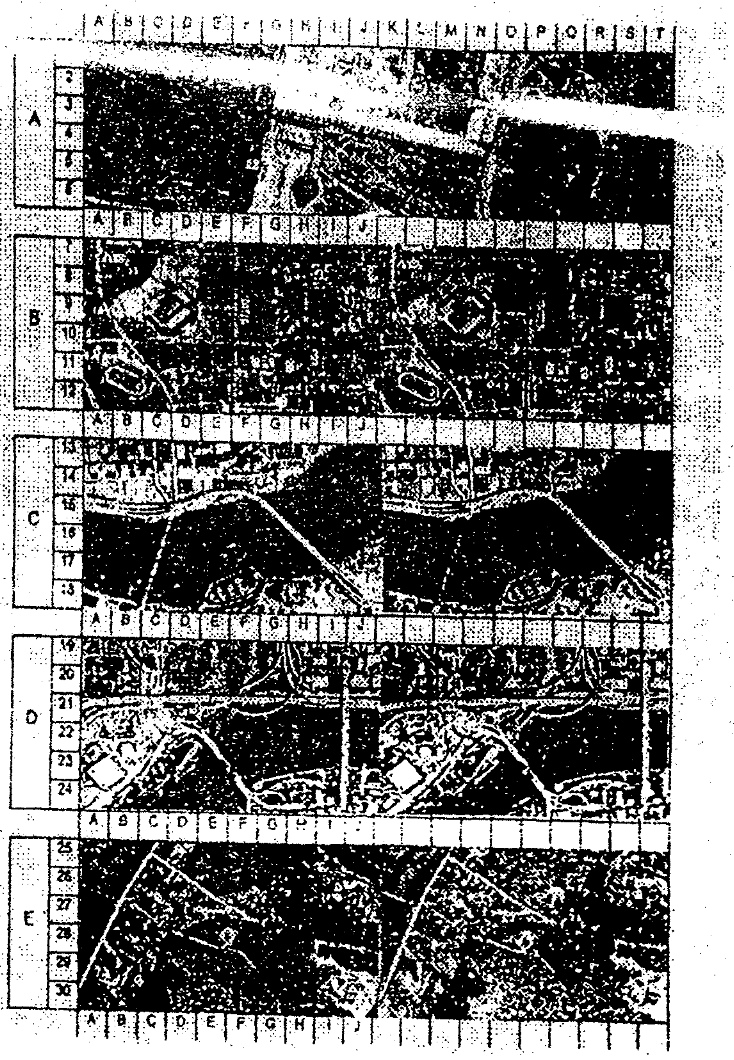


Figure 9.1.9. Stereograms for laboratory exercise. (Courtesy of Gordon Wilkinson, WAC Corporation.)

Stereogram B

1. C–D:9	6. G:11*	11. F–H:7
2. B–C:10	7. E:9	
3. A–B:11–12	8. G–J:7–12	
4. F–G:10	9. G–H:8–9	
5. E:7*	10. G–H:9–10	

Stereogram C

1. F–J:15–18	3. B–F:17–18	5. B–F:16–17
2. C–D:15–BC18	4. I–J:17–18	

Stereogram D

1. I–J:19–24	4. A–B:23–24
2. E–F:23	5. A–B:21–22
3. D:19–20	6. E–F:24

Stereogram E

1. A–B:28–29 and J:[illegible]	3. J:26	5. G–H:28–29
2. H–I:25	4. H–I:27	6. E–F:29–30

*Size or relative size (length) of base paths does not work here because they can not be measured. The large one at E:7 is actually a low fence. The baseball fence is much further out.

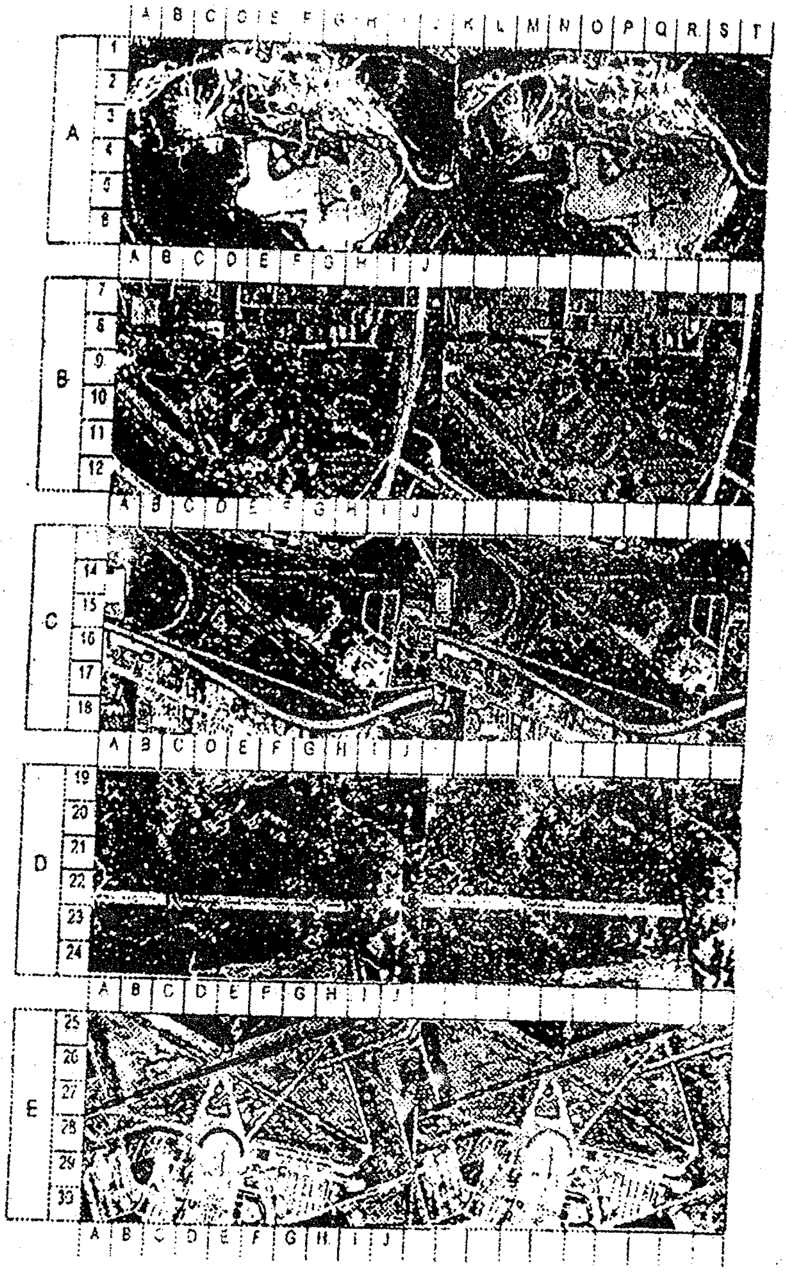


Figure 9.1.10. Stereograms for laboratory exercise. (Courtesy of Gordon Wilkinson. WAC Corporation.)

Monogram A in Figure 9.1.9 a is at a scale of about 1:7,000. Stereogram B in the same figure has a scale of 1:12,000. All remaining stereograms (Figures 9.1.9 and 9.1.10) are at a scale of 1:20,000, except for Stereogram E (Figure 9.1.10), which is at an approximate scale of 1:30,000.

A careful completion of this exercise and a re-examination of the stereograms, knowin the answers, might take a few hours, depending on your diligence and skill. It is recommended that you review the seven principles of photo interpretation before attempting this exercise. Your instructor may wish you to list the principles used for each identification.

Stereogram A

1. A–J:1–6
2. A–D:4–6
3. B–I:4–6
4. I–J:1–3
5. E–F:3
6. F:3
7. F–G:2–3
8. B–D:1
9. B:1
10. J:1
11. G:1

Stereogram B

1. A–J:7–12
2. B–C:9–10
3. B–C:9–10 and B–F:9
4. F:9–10
5. G:10
6. F:8
7. F:8
8. G–H:8–9
9. F:9
10. D:10–11
11. H:8
12. A–I:7–8
13. A–C:7

Stereogram C

1. H–J:15–17
2. J:16
3. I:15
4. I:15
5. I–J:13
6. H–I:16
7. B:13 to J:18
8. A:15 to G:18 to J:17
9. I:18 (curved)
10. A:15, J:18
11. J:18
12. B:14–15
13. G:16
14. B–D:17–18
15. G:14

Stereogram D

1. A:22 to J:22
2. A:22
3. G–H:24
4. F–F:23

Stereogram E

1. A–J:25–30
2. A:27 to I:25
3. B:25 to I:28
4. F:28 to H:25
5. D–E:28
6. E:28
7. E:28
8. B–C:28
9. E–30
10. D:29
11. E:29

■ 9.4.10 SELF ASSESSMENT QUESTIONS

1. For each of the following principles of photo interpretation, give one or more examples of how each principle is used in aerial photo interpretation: (a) absolute and relative size, (b) shape, (c) shadow, (d) tone or color, (e) texture, (f) pattern, and (g) location, association, and convergence of evidence. Try to think of examples that are not in the book.
2. Give one or more examples of the practical use of each of the following techniques or aids to photo interpretation: (a) stereoscopic examination, (b) stereo-grams, (c) magnification, (d) interpretation keys, (e) photo measurements, (f) templates, (g) conversion tables, (h) statistical analysis, and (i) multiband color enhancement. Try to think of examples not in the book.
3. Draw a schematic diagram showing the viewing situation as used in additive color enhancement and explain how the system works.
4. List four advantages and one disadvantage of the use of additive color enhancement techniques.
5. How is shadowless photography obtained, and what are two advantages of this technique?

■ 9.4.11 REFERENCE

American Society of Photogrammetry. 1966. *Manual of Photogrammetry*. Falls Church, Va.: American Society of Photogrammetry.

Keser, N. 1976. *Interpretation of Landforms from Aerial Photographs*. Research Division, British Columbia Forest Service, Victoria, British Columbia, Canada.

Yost, E., and S. Wenderoth. 1967. "Multispectral Color Aerial Photography." *Photogrammetric Engineering*, 33(9):1020-1031.

2. Monoscopic and stereoscopic Interpretation of airphotos for geomorphic land use features.

■ 9.4.12 OBJECTIVES

After a through understanding of this second part of the unit you will be able to :

1. Define the term "landform" in a way that it is independent of geographic location.
2. List seven pattern elements that the photo interpreter uses to identify and categorize landforms
3. Identify on either schematic diagrams or aerial photographs the seven drainage patterns shown and state the probable cause or significance of each pattern.
4. Calculate the drainage density, stream frequency, and relative infiltration of a given drainage from either a schematic diagram or an aerial photograph.
5. Draw schematic diagrams of cross sections of three different gully types and state what each gully type indicates in terms of soil texture, cohesiveness, and the general slopes involved.

■9.4.13 LANDFORMS

The term "landform" can have a variety of meanings, depending on the specific discipline involved. The geologist may describe landform in terms of surface characteristics that yield evidence as to the geologic structure of features of the Earth's crust and may use such terms as faults, joints, domes, and basins. The geologist is interested in landform for academic reasons as well as for specific purposes - mining, engineering, and petroleum exploration, for example.

The soil scientist is more interested in studying landform for the purpose of identifying parent soil material, soil texture, potential fertility, soil moisture, soil drainage, and erodability.

The civil engineer would be more interested in studying landform to gain information about soil or rock-bearing strength, drainage patterns, the location of road-building materials, and potential erosion hazards.

Landscape architects and outdoor recreation specialists think more in terms of the visual impact, and use terms like valleys, mountains, cliffs, or floodplains.

The hydrologist studies landform to analyze water movement. The city and regional planner studies landform for land-use planning and zoning purposes.

The forester, being a combination ecologist, geologist, soil scientist, and engineer, must study landform to obtain clues to the physical and chemical characteristics of the soil as well as the visual significance of a particular surface feature or combination of features. The logging engineer is particularly concerned with potential landslides and how to manage or avoid them in conjunction with logging road construction and other tree-harvesting operations.

An ideal landform classification should allow specific distinctions in landform regardless of their geographic distribution. With this in mind, Way (1973) defined the term landform" as terrain features formed by natural processes, which have definable composition and range of physical and visual characteristics that occur wherever the landform, is found."

V9.4.14 RECOGNITION OF LANDFORM

There are seven basic pattern elements that the photo interpreter can use to identify and categorize landforms and landscapes.

1. Topography
2. Drainage patterns
3. Drainage texture
4. Gully types
5. Photo tone and photo texture
6. Vegetational patterns
7. Land-use patterns

9.4.15 TOPOGRAPHY

The most obvious characteristic of any landform is its three-dimensional shape, easily analyzed in a stereoscopic model. Thus, the interpreter can quickly determine if the topography is relatively flat or steep, whether the hills are rounded or sharp, and so on. Just this much information gives the geologist or soil scientist a good clue as to the soil characteristics if he or she knows a little about the specific geographic area being examined.

An important point to remember when analyzing topography is the effect of vertical exaggeration, as discussed in Chapter 6. Because slope is so important when analyzing landform, it is very important that the interpreter make allowance for vertical exaggeration. As an aid to the interpreter, Table 9.1 shows the conversion of true slopes from slopes estimated on aerial photos for two different exaggeration factors. In critical situations the true slope can be measured.

TABLE 9.1 True Slopes Based on Estimated Slopes for Two Vertical Exaggeration Factors

Estimated Slope (Degrees)		True Slope
Exaggeration Factor 2.5	Exaggeration Factor 3.5	Degrees
5	7	2
10	14	4
15	20	6
20	26	8
24	32	10
34	43	15
42	52	20
49	58	25
55	64	30
60	68	35
64	71	40
68	74	45
72	76	50
77	81	60
81	84	70
86	87	80
90	90	90

■ 9.4.16 DRAINAGE PATTERNS

Drainage patterns, which are closely related to topography and rainfall, are the most important characteristics for the classification of landforms. Dr. R.A. van Zuidam (1972), of the International Institute for Aerial Survey and Earth Sciences, Enschede, The Netherlands, says the following about drainage patterns:

Stream erosion produces many types of valleys, most of which exhibit topographic features revealing the lithology, the conditions of erosion and the geomorphological history of the area during erosion. The drainage system which develops on a regional surface is controlled by the slope of the surface, the types and attitudes of the underlying rocks, and the climatic conditions.

Drainage patterns, which are easily visible on aerial photographs reflect, to varying degrees, the lithology and structure of a region. Except for climatic controls, drainage Z-1 lithology drainage an area of stratified rock depends mainly on the type, distribution, and attitude of the surface rocks, the arrangement of zones or lines of weakness such as bedding planes, joints and faults, and the shape and trend of local folds.

Dr. Van Zuidam defines a drainage pattern as "an aggregate of drainageways in an area, egardless of whether or not they are occupied by permanent streams" and a stream pattern as "the design formed by a single drainageway."

An analysis of topography and drainage patterns gives the trained geologist-photo interpreter much information about the underlying geologic structure, parent soil material, and erodability of a particular area in question. In this chapter we consider seven specific drainage patterns. In addition, there are many other combinations or modifications of these basic seven patterns.

1. Dendritic
2. Parallel
3. Trellis
4. Rectangular
5. Radial
6. Deranged
7. Internal

Dendritic. The dendritic pattern (Figure 9.2.1) is the most common and is characterized by a treelike, branching system where the branches (tributaries) join the stem (main stream) at acute angles. This drainage system indicates homogeneous rock and soil materials with little or no structural control. Soft sedimentary rocks, volcanic tuff, and dissected deposits of thick glacial till typify the dendritic pattern.

Parallel. Parallel drainage systems (Figure 9.2.2) generally develop on gentle to moderate, uniform slopes whose main collector streams may indicate a fault or fracture. The tributaries characteristically join the main stream at about the same angle. There are many transitions possible between this pattern and the dendritic and trellis types.

Trellis. Trellis drainage patterns (Figure 9.2.3) are modified dendritic forms where secondary streams occur at right angles to the main stream with the tertiary streams at right angles to the secondary streams. This type of pattern is typical of tributaries eroded in belts of tightly folded sedimentary rock.

Rectangular. Rectangular drainage patterns (Figure 9.2.4) are also modifications of the dendritic form, but the secondary streams joining the main stream are more at right angles. This pattern lacks the orderly repetitive quality of the trellis pattern and the right angles are slightly acute. Rectangular patterns frequently reflect the regional pattern of intersecting joint systems or a set of joints with cross belts of bedrock at a high angle. These patterns are often formed in slate, schist, or in resistive sandstone in arid climates, or in sandstone in humid climates where little soil profile has developed.

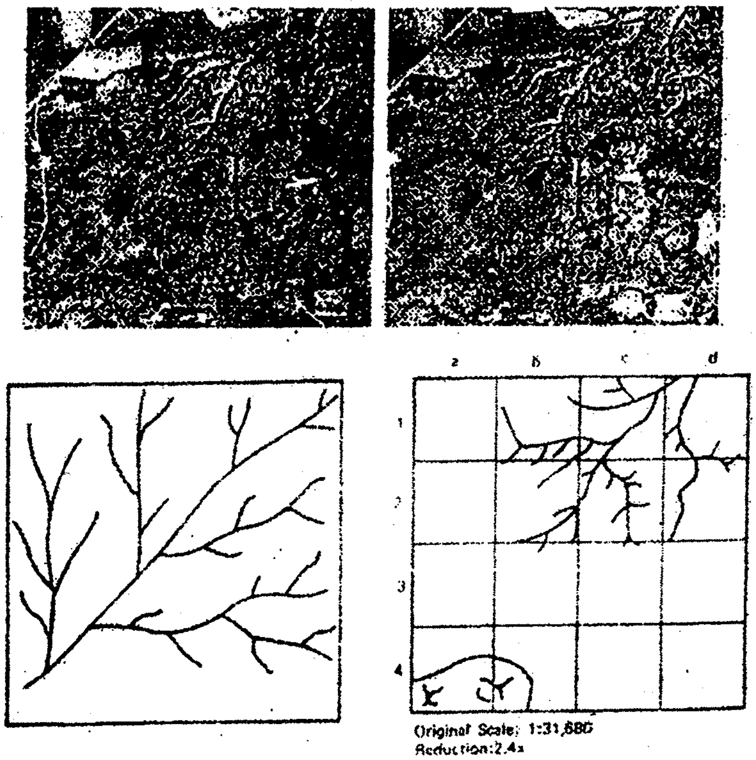


Figure 9.2.1. Dendritic drainage patterns: stereogram (*top*) drawing from stereogram (*bottom right*), and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

Radial. **The radial** drainage pattern (Figure 9.2.5) is characteristic of volcanos **and** other domelike **landforms. It is characterized** by a circular network of stream channels flowing away from a central high point.

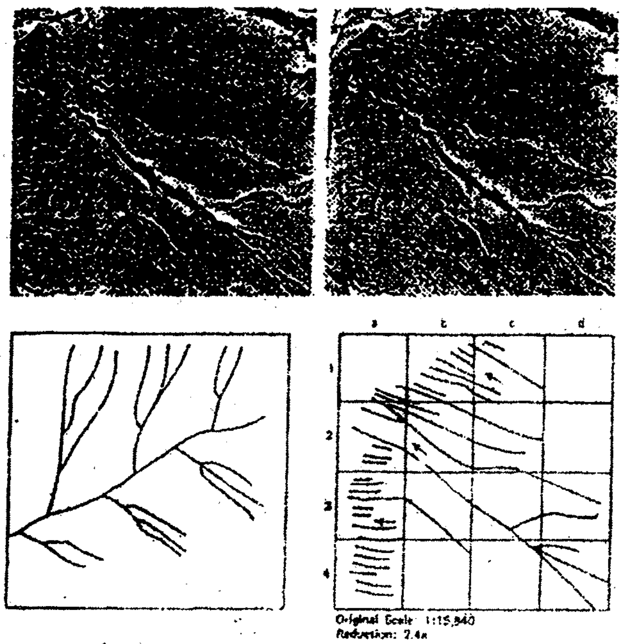


Figure 9.2.2. Parallel drainage patterns: stereogram (*top*), drawing from stereogram (*bottom right*), and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

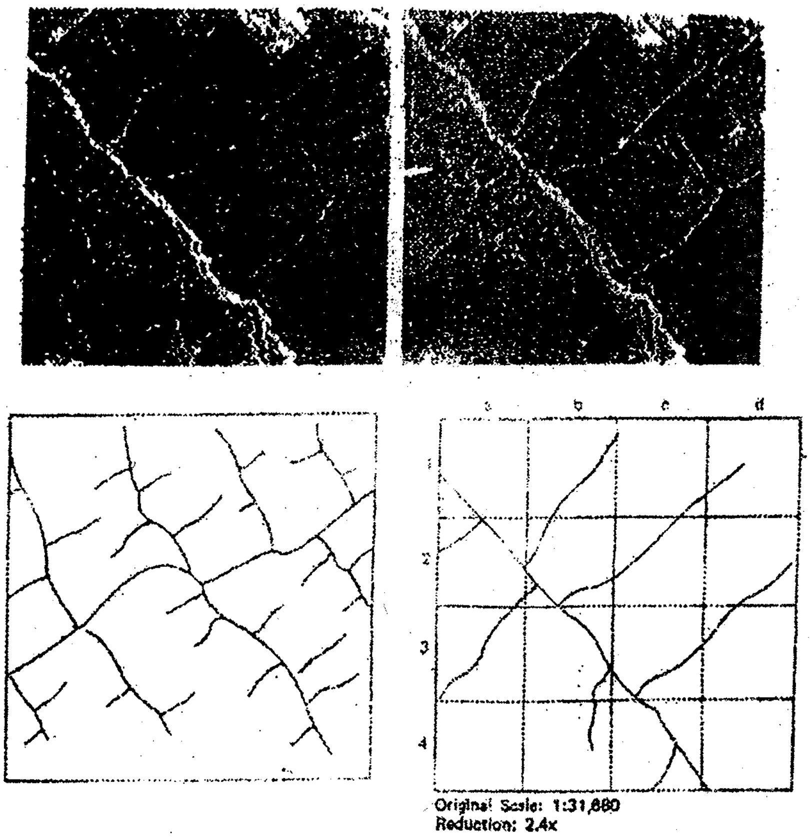


Figure 9.2.3. Trellis drainage patterns: stereogram (*top*), drawing from stereogram (*bottom right*), and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

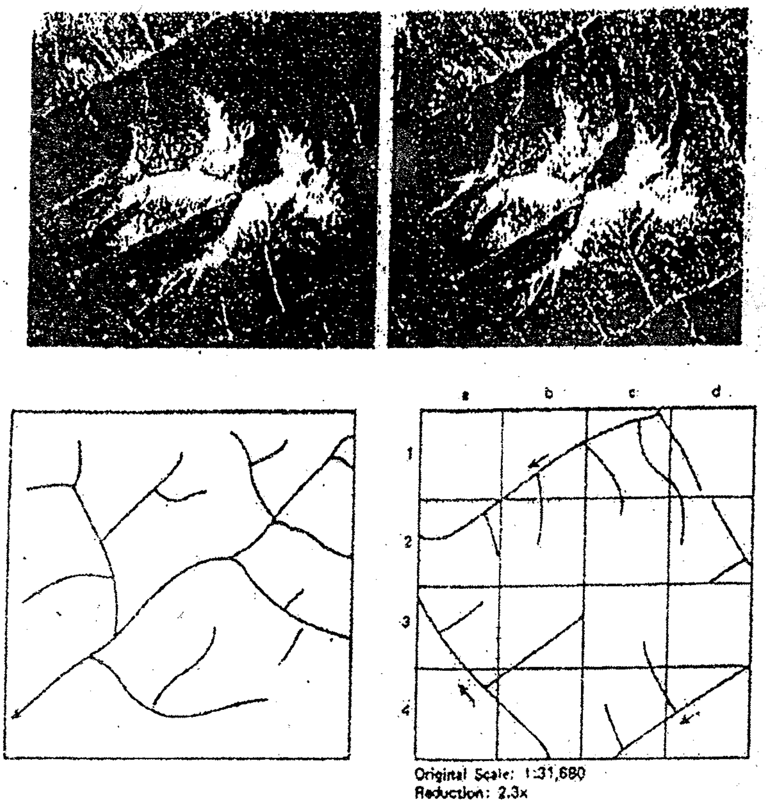


Figure 9.2.4. Rectangular drainage patterns: stereogram (*top*) drawing from stereogram (*bottom right*), and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

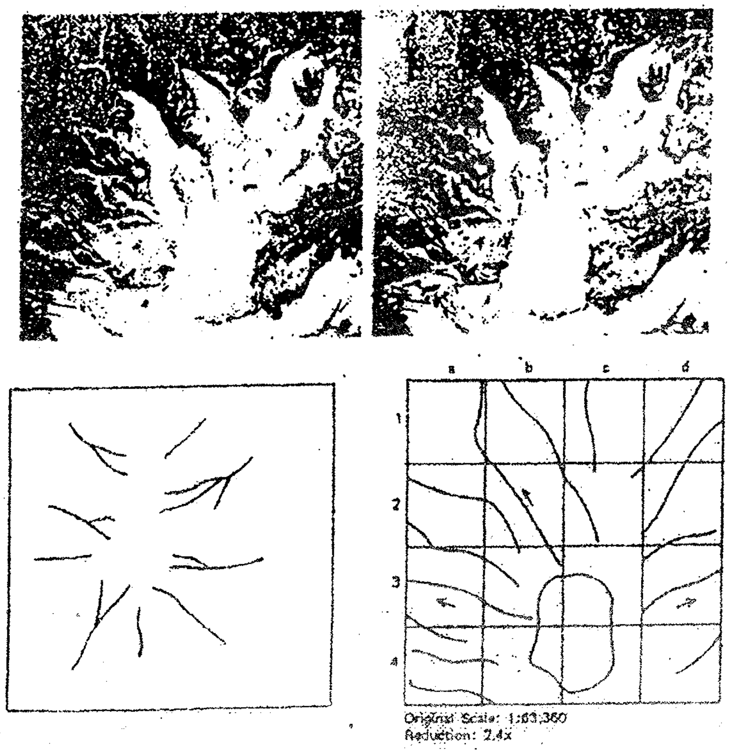


Figure 9.2.5. Radial drainage patterns: stereogram (*top*), drawing from stereogram (*bottom right*), and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

Deranged. The deranged pattern (Figure 9.2.6) is nonintegrated and is characterized by swamps, bogs, small ponds or lakes, and meandering streams. This usually indicates a young landform with low topographic profile, high water table, and poor drainage.

Internal. This is really not a drainage system that has a definite pattern; in fact, it is best described as having no pattern at all. In some areas, this is referred to as a ***braided stream system***. It is the result of highly permeable material with underground drainage channels and is sometimes characterized by sinkholes.

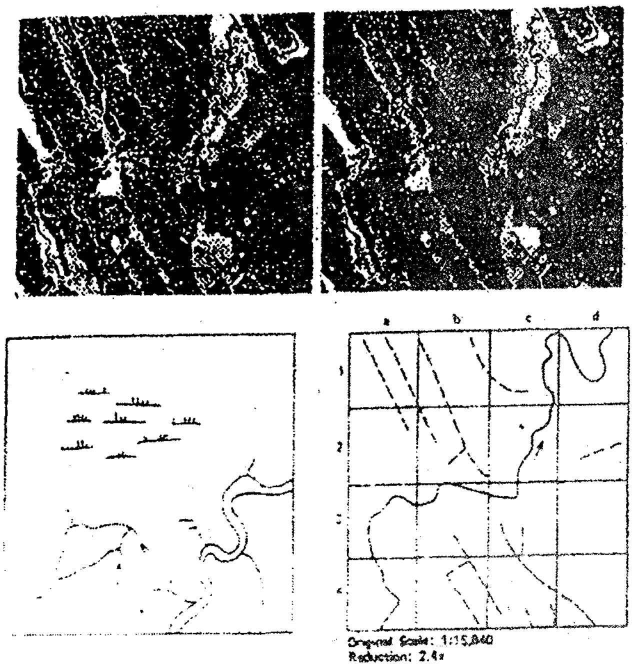


Figure [illegible] Deranged drainage patterns: stereogram (*top*), drawing from stereogram (*bottom right*) and a classical drawing (*bottom left*). (From N. Keser, 1976, aerial photos from [illegible] and Mapping Branch, Government of British Columbia.)

■ 9.4.17 DRAINAGE TEXTURE

Drainage texture as contrasted to photo texture, refers to the number and spacing of drainages (With or without permanent streams Drainage texture can be classified as fine, medium, or coarse, as illustrated in Figure 9.2 for the dendritic pattern. Drainage pattern and texture are important to the photo interpreter because they reveal valuable claues as to the geologic structure of the landform and the permeability of the soil mantle that we call internal drainage.

Way (1973) defined fine-texture drainage patterns as those with average spacing between the main stream and the first-order tributanes as averaging 400 feet or less. Fine-texture pattern usually

indicate high levels of surface runoff, impervious bedrock, and soils of low permeability.

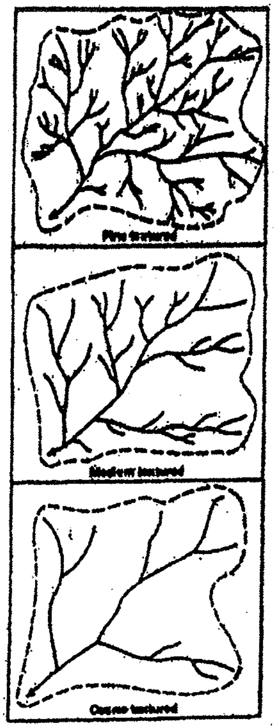


Figure9.2.7.Examples of fine-, medium-, and coarse-textured dendritic patterns. The original PSR was 20,000 reduced in this illustration to 30,000.

Medium-textured drainage patterns have average first-order tributary spacings of from about 400 to 3200 feet. Coarse-textured patterns have spacings greater than 3200 feet. Medium-textured patterns are associated with medium levels of runoff and soils with mixtures of fine and coarse textures. Coarse-textured patterns typify more resistant bedrock that weathers to form coarse, permeable soils with relatively little runoff.

Drainage texture can be quantified by drainage density, steam frequency, and infiltration. These quantifications should be considered as only relative measures because they change between regions due to different climates and, if the values are determined from aerial photos, the results change with changes in photo scale. The tendency is to calculate a greater drainage density on larger-scale photography because the smaller drainages are more easily identified.

■ 9.4.18 DRAINAGE DENSITY

Drainage density is an expression of rainfall, infiltration capacity, and the underlying geologic structures, and can be quantified by the following formula:

$$D_d = \frac{\Sigma^L}{A}$$

Where :

D_d = drainage density in lineal feet per acre

A = area of a given basin in acres

Σ^L = the sum of the lengths of all streams in a given basin in feet

When using the above formula and data taken from aerial photographs, one must using account for the photo scale. From what we have previously learned in the chapters on scale and area, we can easily derive the following:

$$D_d = \frac{[PD(PSR)]/12}{[(PSR/12)^2/43{,}560](DC/DI)} = \frac{PD(522{,}720)}{PSR}\left[\frac{DI}{DC}\right]$$

Where:

PD = sum of the drainage lengths as measured in on the photo PSR = photo scale reciprocal

DC = dot count

DI = dot intensity of dot grid (dots per sq. in.)

For this formula to be valid it must give the same answer, regardless of the photo scale, for example. Let's use the coarse-textured pattern in Figure 9.2.7 for our example and assume the following values:

PSR = 20,000

PD = 10.5 in.

DC = 584

DI = 100

$$D_d = \left[\frac{10.5(522{,}720)}{20{,}000}\right]\left[\frac{100}{584}\right] = 47.0 \text{ feet/acre}$$

Now let us assume the same drainage and a PSR of 10,000. Using this scale photo, the measured PD would be 2 times 10.5, or 21 in., and the dot count would be $(2)^2$ times 584, or 2336 dots. We get:

$$D_d = \left[\frac{21(522{,}720)}{10{,}000}\right]\left[\frac{100}{2336}\right] = 47.0 \text{ feet/acre}$$

In a similar manner we calculate drainage densities of 98 and 153 feet/acre for the medium and fine drainage patterns of Figure 9.2.7. Thus, the drainage densities for coarse-, medium-, and fine-drainage textures as defined by Way (1968, 1973) are approximately 50, 100, and 150 feet/acre.

Ray and Fisher (1960) reported on preliminary data—too meager to allow a complete geologic analysis—from which several interesting observations were apparent. They observed that coarsegrained instrusive rock types show low drainage densities and that fine-grained clastic sedimentary rocks show relatively high drainage densities, despite the different geographic locations of the samples. For example, on 1:20,000-scale photography they found that shale formations had drainage densities of about 60 (medium texture) and sandstone and granite formations had drainage densities of 10 and 12 feet of drainage per acre, respectively (coarse texture).

They also found that the scale of photos used had an influence on calculated drainage densities. This was easily explained since the ability to see small drainage rills obviously decreases as the photo scale becomes smaller. They further found this relationship to be linear and suggested a simple conversion factor to permit equating
suggested densities determined from different scales of photography.

■ 9.4.19 STREAM FREQUENCY

Stream frequency is the number of drainage ways within a drainage basin per unit area of land and can be expressed by

$$F = \frac{N}{A} = \frac{N(6,272,640)}{(PSR)^2}\left[\frac{DI}{DC}\right]$$

Where:

F = drainageway frequency per acre

N = total number of drainage ways in the drainage basin

A = drainage basin area in acres

and the other symbology is as previously defined.

For example, if we assume that N is 8 in the same example as used for calculating drainage density (Figure 9.2.7, corase texture), we get:

$$F = \frac{8(6,272,640)}{(20,000)^2}\left[\frac{100}{584}\right] = 0.021$$

Relative Infiltration. Relative infiltration (RI) is the product of drainage density and drainage frequency. Using the data from the last two examples we get :

$$RI = (D_d)(F) = (47.0)(0.021) = 0.99$$

For the medium- and fine-textured patterns of Figure 9.2.7 we get relative infiltrations of 7.62 and 36.69, respectively. Remember that these are relative values to be compared with each other as to water infiltration into the soil mantle.

Despite the fact that drainage density varies with geologic type and climatic and vegetational condition, its still provides information as to fluvial erosion and the accessibility of an area. Of more importances is the fact that poor land management can lead to additional erosion and increased drainage densities These changes over time can be detected on aerial photography that provides permanent records

■ 9.4.20 GULLY TYPES

The type of gully formed in a given area can tell the soil scientist much about soil cohesiveness and texture Gullies are formed by runoff that collects and erodes through the surface soils. These gullies adapt well-known cross-sectional shapes, depending on the composition and cohesiveness of the soil. In Figure 9.2.8 we have three typical gully cross sections that are characteristic of different soil textures and cohesiveness

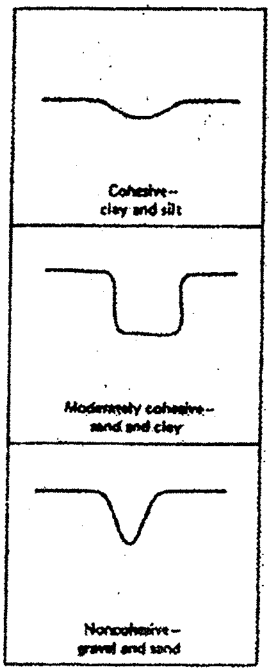
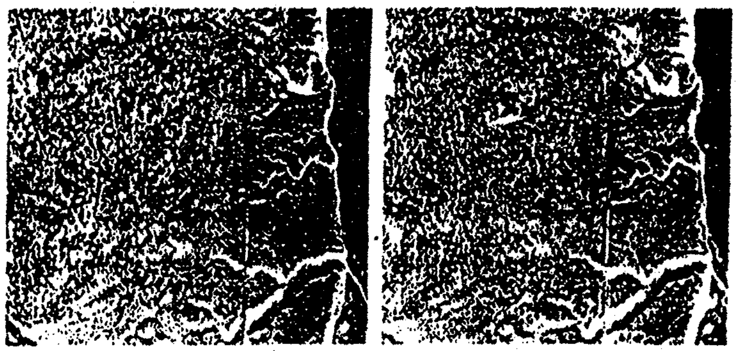


Figure 9.2.8 Characteristic gully profiles found in cohesive, moderately cohesive, and noncohesive soil types.

The cross section in Figure 9.2.8 *(top)* is typical in areas of gradual uniform slopes where the soil consists of clays and silty clays with relatively high cohesiveness. This gully type is usually found in lakebeds marine terraces, or other areas of high clay content (Figure 9.2.9).



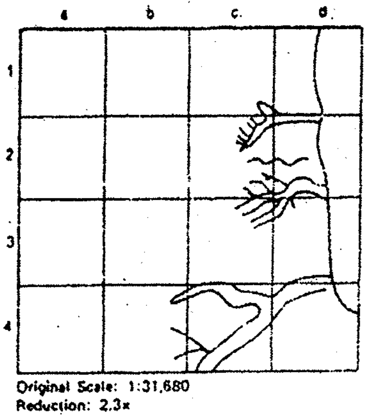


Figure 9.2.9. Gullies formed in sitty soil material. (From N. Keser. 1976. aerial pho-tos photos from Surveys and Mapping Branch, Government of British Columbia.)

Figure 9.2.8 *(middle)* is typical of moderately cohesive soil, consisting of sand, clay, and silt. (Figure 9.2.10). This gully type is usually found on moderate slopes of coastal plains and bedrock areas.

Figure 9.2.8 *(bottom)* is typical of the noncohesive, semigranular soils (sands and gravels) usually found in terraces and outwash plains where slopes are usually steep to very steep (Figure 9.2.11).

■ 9.4.21 TONE AND TEXTURE

Photographic tone refers to the various shades of gray from black to white (Figure 9.1.4) and photographic texture refers to the coarseness or fineness of a group of objects. Tone indicates surface characteristics and is influenced by soil type, soil moisture, and vegetation types (Figure 9.1.5). In general, the darker tones indicate relative high soil moisture content and associated high organic matter, which are often indicators of poor drainage and little leaching. The lighter tones are associated with dry areas with little organic matter and well-leached soils. Medium or gray tones usually indicate soils with good soil profiles and adequate organic content. Very light tones (white) usually indicate barren areas such as exposed sand, gravel, or salt deposits, and, of course, snow and ice.

In glaciated areas we frequently find light and dark tones randomly mixed. This is known as mottling (Figure 9.1.4). Sometimes in old lakebeds, floodplains, or out-washes, light and dark tones are alternately banded. This is a result of interbedded sedimentary formations and is described as a banded appearance (Figure 9.2.12).

Since there is so much tonal variation between different photographs taken and developed under different conditions and between different seasons of the year, photographic tone should be considered as relative, and therefore should be compared within stereoscopic pairs, or at least within individual photographic missions.

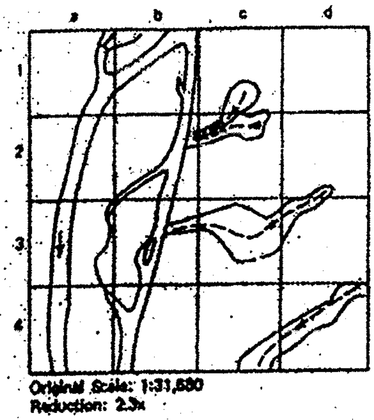
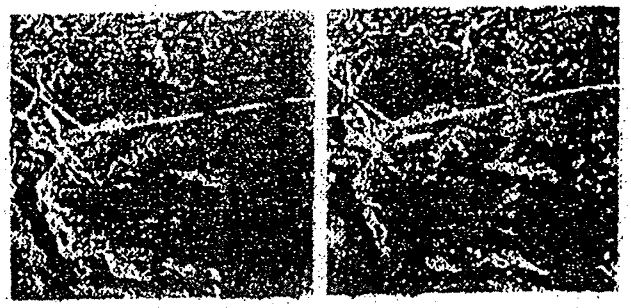


Figure 9.2.10. Gullies formed in moderately cohesive soil material. (From N. Keser 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

■ 9.4.22 VEGETATION PATTERNS

Vegetation frequently prohibits the photo interpreter from viewing the ground, but its mere presence or absence provides a useful clue as to the soil conditions below as to texture, permeability, and moisture availability. Because of different vegetative cover associated with different geographic regions, local experience is absolutely necessary for an accurate assessment of what different vegetational patterns indicate.



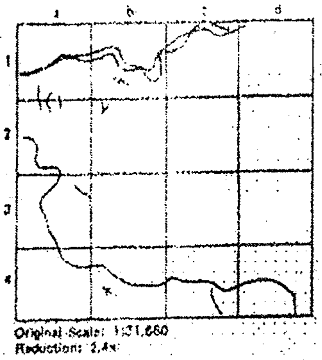


Figure 9.2.11. Gullies formed in noncohesive sand and gravel. (From N. Keser, 1976, aerial photos from Surveys and Mapping Branch, Government of British Columbia.)

Figure 9.2.12. Distinct banding indicates interbedded sedimentary rock. Frequently there is vegetation in the dark bands, but not in the light bands as a result of soil moisture differences. Photos from Surveys and Mapping Branch, Government of British Columbia.

■ 9.4.23 LAND-USE PATTERNS

Land-use patterns are man-made alterations of the landscape, and are valuable clues as to soil conditions. Man-made patterns are conspicuous because they usually consist of straight lines or other regular configurations. The location of transportation routes, cities, farms, and industrial complexes gives valuable clues as to the land surface and subsurface conditions. Winding roads indicate steep or hilly topography. Railroads must be located where grades are minimal and can be separated from roads since their curves must be gradual. Farm locations avoid poorly drained areas as well as rocky or other locations of poor or shallow soils. Cities and industrial areas are often located in certain areas because of transportation routes. Unfortunately, these areas are frequently of high-quality farmlands, but fortunately some of the better residential areas are developing in the foothills surrounding the cities and occupy the less valuable agricultural land.

Conclusion : After reading this two part and doing the laboratory exercise you will be able to interpret the aerial photo properly.

9.4.24 SELF ASSESSMENT QUESTIONS

1. Write a definition for the term "landform" in such a way that it is independent of specific geographic location.
2. List seven pattern elements used by the photo interpreter to identify and categorize landforms.
3. Identify and name each of the drainage patterns in Figure 9.2.13.
4. Calculate the drainage density, stream frequency, and relative infiltration for the drainage patterns shown in Figure 9.2.13 that has the dashed line around it and classify the drainage density as to fine, medium, or coarse. Assume a 30,000 MSR and consider only the area within the dashed lines.
5. Draw a schematic diagram of the cross section of three gully types and state what each gully type indicates as to soil texture, cohesiveness, and the general slops.
6. Carefully examine Figure 9.2.14. what does the vegetation tell you about the annual rainfall of this area? What does the cross-sectional gully shape tell you about the soil cohestveness in the cleared agriculture areas? What does the presence of farm ponds constructed on sidehills tell you about soil permeability in this area? Why is the tone of one pond very light and the other very dark?
7. Carefully examine Figure 9.2.15. What does the vegetation tell you about the annual rainfall of this area? What does the cross-sectional gully shape of the tributaries to the main stream tell you about soil cohesiveness? What does the light tone of the creek in the floodplain and the tributary gully shapes tell you about the erodability of the soil?

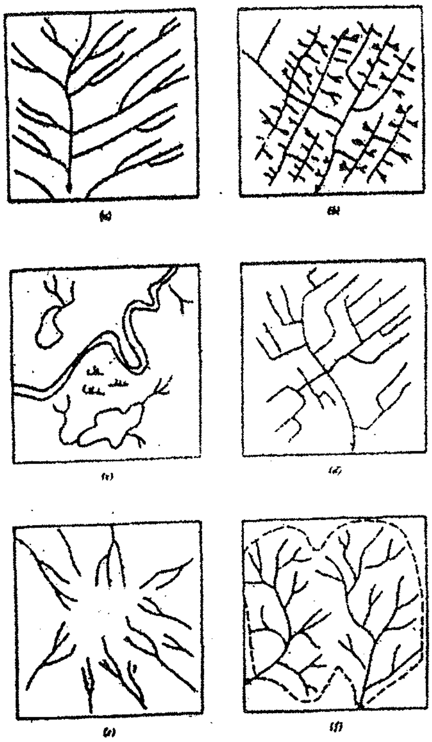


Figure 9.2.13. Drainage patterns for Questions 3 and 4.

Figure 9.2.14. Stereogram for Question 7. (Courtesy of Illinois Photographic Service).

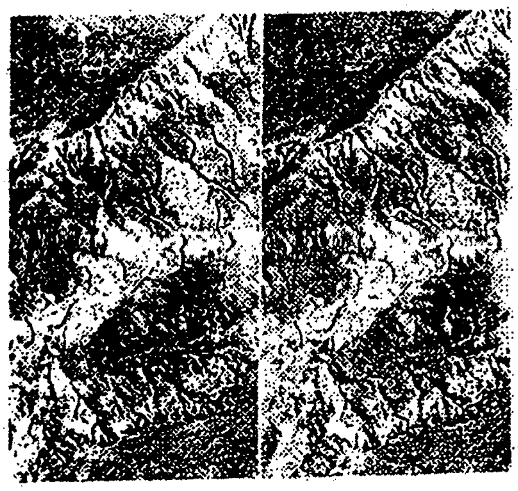


Figure 9.2.15. Stereogram for Question 7 (Courtesy of Illinois Photographic Service).

■ 9.4.25 REFERENCES

Keser, N. 1976. *Interpretation of Landrorms from Aerial Photographs*. Research Division, British Columbia Forest Service, Victoria, British Columbia, Canada.

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PART-I

Paper-V : Module-X

Unit-01

Module Structure

- 10.1.1 Sampling and Summarizing Geographical Data : Types of Sampling Methods, Estimates from Sample
- 10.1.1.1 Sampling
- 10.1.1.2 Types of Sampling Method
- 10.1.1.3 Estimate from Sample
- 10.1.1.4 Summarizing Geographical Data
- 10.1.2 Measuring Inequality-Lorenz Curve
- 10.1.3 Analysis of Combination : Weaver's Combination Index

Paper-V : Module-X
Unit-01

1. **Sampling and summarizing geographical data: Types of sampling methods, Estimates from sample**
2. **Measuring inequality – Lorenz Curve**
3. **Analysis of combination : Weaver's Combination Index**

■ 10.1.1 SAMPLING AND SUMMARIZING GEOGRAPHICAL DATA: TYPES OF SAMPLING METHODS, ESTIMATES FROM SAMPLE

■ 10.1.1.1 SAMPLING

In many studies, it is not possible to collect the information for each and every unit of a large number of observations, because of lack of resources, time and trained personnel etc. The larger group of observations required for a study is known as the universe or population of the study. In statistics, the word population has a technical meaning which may have nothing to do with people. The universe or population can be finite or infinite. In finite universe the number of items is certain, but in case of an infinite universe, the number of items is infinite, i.e. we cannot have any idea about the total number of items. The population of a city, the number of workers in a factory and the like are examples of finite universes, whereas the number of stars in the sky, the slope of the land at point of locations on a map (there being an infinite number of points on a map), throwing of a dice etc. are examples of infinite universes. A part of the population selected as its representative is called the sample and the process of such selection is known as sampling.

Sampling design forms a basis for sample survey. A sample design is a definite plan for obtaining a sample from a given population. One must plan how a sample should be selected and of what size such a sample would be. The characteristics of a good sample design may be stated as under:

(i) Sample design must result in a truly representative sample.
(ii) Sample design must be such which results in a small sampling error.
(iii) Sample design must be viable in the context of funds available for the research study.
(iv) Sample design must be such so that systematic bias can be controlled in a better way.
(v) Sample should be such that the result of the sample study can be applied for the universe with a reasonable level of confidence.

It is worth to note that a good sampling is dependent on both sampling design and sampling frame. Sampling frame denotes sampling units by which the sample is selected. The sampling frame used for enumeration of the population in a census is often a list of households. Similarly, a telephone directory would be a sampling frame if the true population were all a town's telephone subscribers.

■ 10.1.1.2 TYPES OF SAMPLING METHOD

The various methods of sampling can be grouped under two broad heads: **probability sampling (also known as random sampling) and non-probability (or non-random) sampling**.

Probability sampling methods are those in which every item in the universe has equal change or probability of being chosen for the sample. This implies that the selection of sample items is independent of the person making the study. This method is useful only when items in the populations are fairly homogeneous.

Non-probability sampling methods are those which do not provide every item in the universe with a known chance of being included in the sample. The selection process is partially subjective.

Some of important sampling methods that are popularly used:

A. NON-PROBABILITY SAMPLING METHODS

- (i) **Judgement Sampling,**
- (ii) **Convenience Sampling and**
- (iii) **Quota Sampling.**

B. PROBABILITY SAMPLING METHODS

- (a) **Simple or Unrestricted Random Sampling**
- (b) **Restricted Random Sampling**
    - *(i) Stratified Sampling*
    - *(ii) Systematic Sampling*
    - *(iii) Cluster Sampling*

A. NON-PROBABILITY SAMPLING METHODS

(i) Judgement Sampling

In this method of sampling the choice of sampling items depends exclusively on the judgement of the investigator. He purposely selects such items which he feels, are representative of the true conditions of the universe. This is also called **purposive sampling**.

For example, if a sample of 10 students is to be selected from a class of sixty for analyzing the food habits of students, the investigator would select 10 students who, in his opinion, are representative of the class.

The bias and prejudice of the investigator have enough scope to work and influence the selection.

(ii) Convenience Sampling

A convenience sample is obtained by selecting 'convenient' population units. In this method the sampling is done neither by probability nor by judgement but by convenience. A sample obtained from readily available lists such as automobile registrations, telephone directories etc. is a convenience sample and not a random sample even if the sample is drawn at random from the lists. If a person is to submit a project report on labour management relations in textile industry and he takes a textile mill close to his office and interviews some people over here, he is following the convenience sampling method. Convenience samples are prone to bias by their very nature and they are unsatisfactory. However, convenience sampling is often used for making pilot studies.

(iii) Quota Sampling

It is a type of judgement sampling and is perhaps the most commonly-used sampling technique in non-probability category. In a quota sample, quotas are set up according to some specified characteristics such as so many in each of several income groups, so many in each age, and so on. Each interviewer is then told to interview a certain number of persons which constitute his quota. Within the quota, the selection of sample items depends on personal judgement. For example, in a radio listening survey, the interviewers may be told to interview 500 people living in a certain area and that out of every 100 persons 60 are to be housewives, 25 farmers and 15 children under the age of 15. Within these quotas the interviewer is free to select the people to be interviewed. Because of the risk of personal prejudice and bias entering the process of selection, the quota sampling is used infrequently. However, quota sampling is often used in public opinion studies. It occasionally provides satisfactory results if the interviewers are carefully trained to select the representative persons.

B. PROBABILITY SAMPLING METHODS

(a) Simple Random Sampling

It can be achieved by **lottery method** or by consultation of **random numbers table**.

The units of observation in a sampling can differ being points, areas or lines.

Consequently sampling may be (i) Point Random Sampling, (ii) Area Random Sampling, (iii) Line Random Sampling.

(i). Point Random sampling

It is very much facilitated by the use of random numbers table prepared by Tippet, Kendall, Smith, Fisher, Lindley and Miller. A page of one of them is given (Table 1). A random numbers table is such arrangement of numbers in which randomness has been ensured by some method. Any number on any page is either taken from any row, column or from any diagonal to constitute the random sample numbers. In a practical exercise of sampling, first time the numbers of the population are assigned a serial number and then the set of chosen random numbers is considered as the numbers of the members in the population to be selected in the sample. If the total number of observation is between 10 and 99 two adjoining columns of the random numbers have to be taken. In case it is more than 99 but less than 1000 three adjoining columns have to be taken and so on. For example, if the sampling frame contains 88 observations, two columns in the table (Table-I) have to be taken and numbers more than 88 have to be rejected. The numbers which we can read from the table are 20, 74, 22, 45, 44, 16, 04, 32, 03, 62, 61, 01, 27 and so on. If it is required to select 10 random numbers, the list will contain the numbers, viz.20, 74, 22, 45, 44, 16, 04, 32, 03, 62.

(ii) Area Random sampling

The procedure of area random sampling is slightly different from the simple random sampling. By using a grid (or quadrat) overlay on a map a population of coordinate points can be generated. By using a random numbers table a set of points may be selected as random sample of all the points. The **areas around the sample points** may be considered as **sample areas**. If the grid numbers are between 1 and 99, the procedure for area random sampling is to choose any four columns of a random numbers table. From these four random numbers sample points can be chosen by assigning two consecutive columns to the x-coordinate and next two columns to the. y- coordinate. As an example, for a hypothetical map of settlements in Fig 1, there are 10 rows and 10 columns and their serial numbers (given arbitrarily) range from 45 to 55 and from 25 to 35. We shall start at the bottom right-hand corner of theTable-1, and work up the right hand two columns to the top, then down the next two columns, up the next again, and so on. The first 10 pairs of digits within the grid range of 25- 34 for x-coordinate are set out in the left hand column of Table-2. The reading off of random numbers is continued to obtain same number of digits within the grid range of 45-54 for y-coordinate and are set out in the right hand column of Table-2.

Table-1

Random Sampling Numbers

20	17	42	28	23	17	59	66	38	61	02	10	86	10	51	55	92	52
74	49	04	49	03	04	10	33	53	70	11	54	48	63	94	60	94	49
94	70	49	31	38	67	23	42	29	65	40	88	78	71	37	18	48	64
22	15	78	15	69	84	32	52	32	54	15	12	54	02	01	37	38	37
93	29	12	18	27	30	30	55	91	87	50	57	58	51	49	36	12	53
45	04	77	97	36	14	99	45	52	95	69	85	03	83	51	87	85	56
44	91	99	49	89	39	94	60	48	49	06	77	64	72	59	26	08	51
16	23	91	02	19	96	47	59	89	65	27	84	30	92	63	37	26	24
04	50	65	04	65	65	82	42	70	51	55	04	61	47	88	83	99	34
32	70	17	72	03	61	66	26	24	71	22	77	88	33	17	78	08	92
03	64	59	07	42	95	81	39	06	41	20	81	92	34	51	90	39	08
62	49	00	90	67	86	93	48	31	83	19	07	67	68	49	03	27	47
61	00	95	86	98	36	14	03	48	88	51	07	33	40	06	86	33	76
89	03	90	49	28	74	21	04	09	96	60	45	22	03	52	80	01	79
01	72	33	85	52	40	60	07	06	71	89	27	14	29	55	24	85	79
27	56	49	79	34	34	32	22	60	53	91	17	33	26	44	70	93	14
49	05	74	48	10	55	35	25	24	28	20	22	35	66	66	34	26	35
49	74	37	25	97	26	33	94	42	23	01	28	59	58	92	69	03	66
20	26	22	43	88	08	19	85	08	12	47	65	65	63	56	07	97	85
48	87	77	96	43	39	76	93	08	79	22	18	54	55	93	75	97	26
08	72	87	46	75	73	00	11	27	07	05	20	30	85	22	21	04	67
95	97	98	62	17	27	31	42	64	71	46	22	32	75	19	32	20	99
37	99	57	31	70	40	46	55	46	12	24	32	36	74	69	20	72	10
05	79	58	37	85	33	75	18	88	71	23	44	54	28	00	48	96	23
55	85	63	42	00	79	91	22	29	01	41	39	51	40	36	65	26	11
67	28	96	25	68	36	24	72	03	85	49	24	05	69	64	86	08	19
85	86	94	78	32	59	51	82	86	43	73	84	45	60	89	57	06	87
40	10	60	09	05	88	78	44	63	13	58	25	37	11	18	47	75	62
94	55	89	48	90	80	77	80	26	89	87	44	23	74	66	20	20	19
11	63	77	77	23	20	33	62	62	19	29	03	94	15	56	37	14	09
64	00	26	04	54	55	38	57	94	62	68	40	26	04	24	25	03	61
50	94	13	23	78	41	60	58	10	60	88	46	30	21	45	98	70	96
66	98	37	96	44	13	45	05	34	59	75	85	48	97	27	19	17	85
66	91	42	83	60	77	90	91	60	90	79	62	57	66	72	28	08	70
33	58	12	18	02	07	19	40	21	29	39	45	90	42	58	84	85	43
52	49	40	16	72	40	73	05	50	90	02	04	98	24	05	30	27	25
74	98	93	99	78	30	79	47	96	92	45	58	40	37	89	76	84	41
50	26	54	30	01	88	69	57	54	45	69	88	23	21	05	69	93	44
49	46	61	89	33	79	96	84	28	34	19	35	28	73	39	59	56	34
19	65	13	44	78	39	73	88	62	03	36	00	25	96	86	76	67	90
64	17	47	67	87	59	81	40	72	61	14	00	28	28	55	86	23	38
18	43	97	37	68	97	56	56	57	95	01	88	11	89	48	07	42	60
65	58	60	87	51	09	96	61	15	53	66	81	66	88	44	75	37	01
79	90	31	00	91	14	85	65	31	75	43	15	45	93	64	78	34	53
07	23	00	15	59	05	16	09	94	42	20	40	63	76	65	67	34	11
90	08	14	24	01	51	95	46	30	32	33	19	00	14	19	28	40	51
53	82	62	02	21	82	34	13	41	03	12	85	65	30	00	97	56	30
98	17	26	15	04	50	76	25	20	33	54	84	39	31	23	33	59	64
08	91	12	44	82	40	30	62	45	50	64	54	65	17	89	25	59	44
37	21	46	77	84	87	67	39	85	54	97	37	33	41	11	74	90	50

After Lindley and Miller (1953)

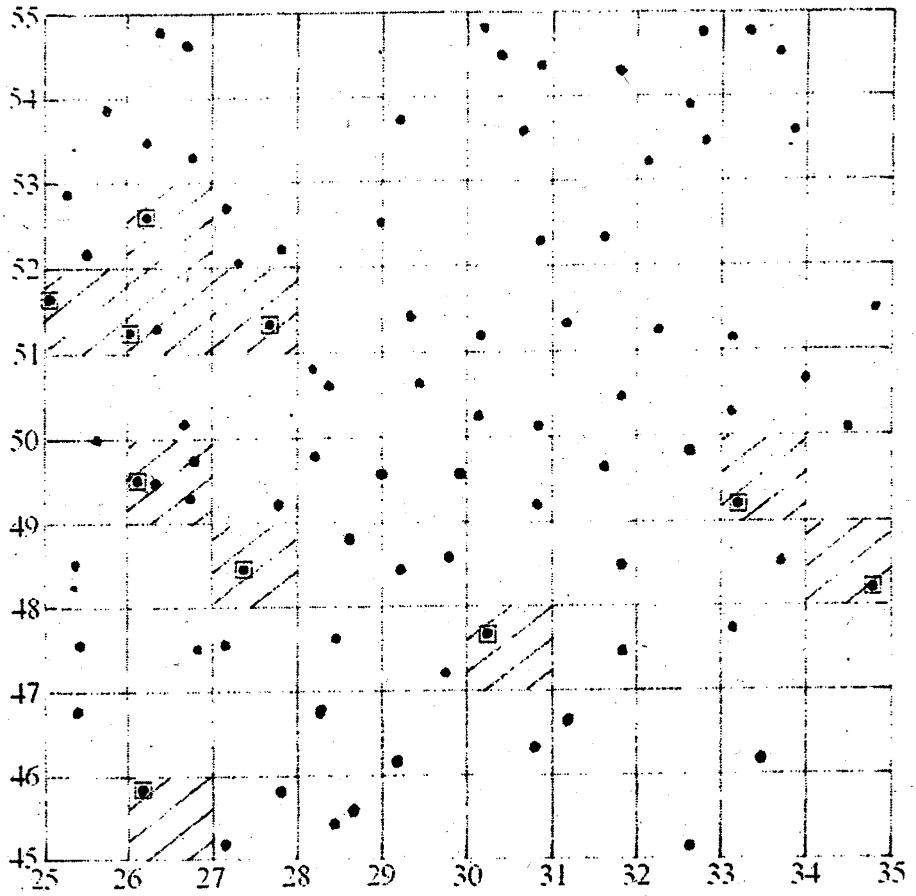

Fig. 1 Area Random Sampling

Table-2: Ten randomly selected grid reference

30	47
34	48
25	51
26	49
26	51
27	51
33	49
26	52
26	45
27	48

We now have 10 four-figure grid references, beginning with 30 47 and these determine the grid squares in which our sample points are located. It should be mentioned that the observational points need not coincide with the chosen grid points. In such cases one can take the nearest observational point from the grid point lying in the north-east quadrat as the member of the sample. When a patch of land is the unit of observation, we may also choose the whole grid (quadrat) on the north-east (or other) direction of the grid point as sample area. Another important aspect in area random sampling is to decide on the size of the grid (quadrat) area. The rule of thumb is that the proper size of a quadrat can be approximately as twice the size of the mean area per point.

Once the point or area sample has been built up, conventional methods are used to measure the characteristics of the sample. For example, with a study of agricultural land use, 25 points from a sample of n- 50 occurring on grassland would give a result of 50 percent grassland in the area sampled. Thus area random sampling can be fruitfully used to study the land use/ land cover pattern of an area.

(iv)Line Random Sampling

Just like area sampling, line sampling can be done for the information presented on area basis. A line with either easting or northing or a transect (line across) on a grid map forms a sample line (Fig. 2). Along this line the chosen characteristics are measured and these values provide sample data.

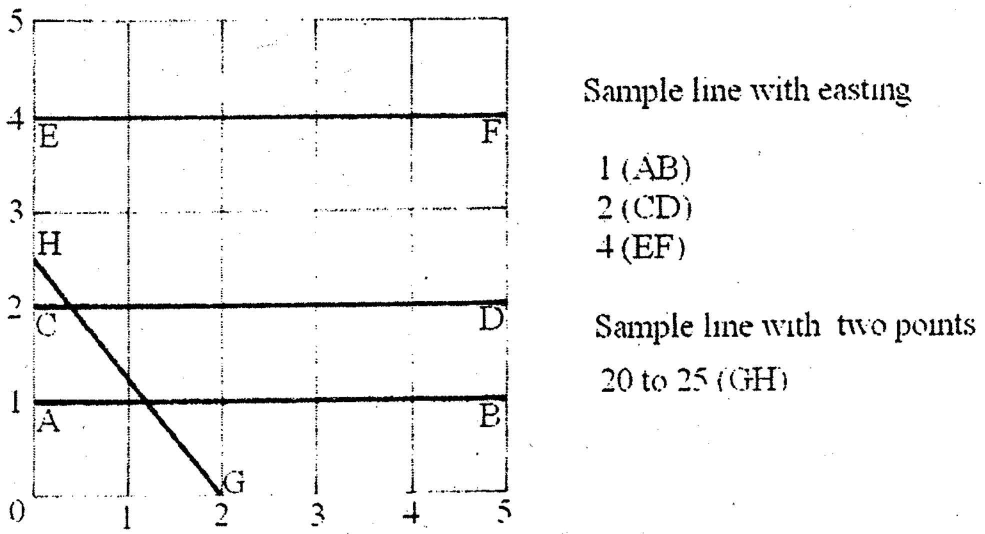

Fig. 2 Line Random Sampling

(b) Restricted random sampling

(i) Stratified Sampling

Under this method the universe is first subdivided (or stratified) into groups which are mutually exclusive and include all items in the universe and then a simple random sample in chosen independently from each group. It is worth to note that a random sample is good only when there are not marked differences in the population. On the contrary when the population is composed of highly varied observations stratified random sampling is practised to achieve a balanced representation.

Stratified sampling may be of **proportional or disproportional** type. In proportional stratified sampling the number of items drawn from each stratum is proportional to the sizes of the strata. For example, if we want a sample size of 30 out of the size of population of 8000 having 3 stratums- N_1= 4000, N_2 =2400 and N_3 = 1600 population, the desired proportional sample may be obtained in the following manner:

Stratum N_1, Sample size= (4000 ÷ 8000) × 30=15
Stratum N_2, Sample size = (2400 ÷ 8000) × 30 = 9

Stratum N_3, Sample size= $(1600 \div 8000) \times 30 = 6$

In disproportional stratified sampling an equal number of cases are taken from each stratum regardless of how the stratum is represented in the universe. Thus in the above example, a sample size of 10 is to be taken from each stratum. In practice disproportional sampling is common when sampling from a highly variable universe.

(ii) Systematic Sampling

A systematic sample is formed by selecting one unit at random and additional units at evenly spaced intervals (i.e. K)

K = N / n, where K =Sampling interval
N=Universe size
n = Sample size

For N= 96 and n=10, the value of K comes out to be 96/10=9.6 or 10. In a systematic sampling of 96 students having roll numbers 1 to 96, the first student between 1 and K (1 & 10) will be selected at random. Let the first student comes out to be fifth. The sample would consist of the following roll numbers: 5,15,25,35,45,55,65,75,85,95.

(iii) Multi-stage Sampling or Cluster Sampling

Under this method, the random selection is made of primary, intermediate and final units from a given population. For example, if we take a sample of 150 towns from the state of West Bengal, the steps adopted are:

First stage- Division of the state into a number of districts and selection of a few districts at random,

Second stage- Sub-division of selected districts into a number of C.D. blocks and sample selection of C.D. blocks randomly,

Third stage- Selection of number of Mouzas from each of the C.D. blocks, selected at the second stage.

The sampling techniques discussed so far are essential for geographical analysis of the great variety of phenomena with which the geographers are deeply involved.

■ 10.1.1.3 ESTIMATES FROM SAMPLE

Samples are used to obtain estimates of numerical characteristics of populations, where it is impractical to measure or count the whole population. Conventionally the term "population parameter" is used to denote a numerical characteristic of a population and "sample statistic" to denote a numerical characteristic of a sample. They are indicated by the following conventional notation:

	Population Parameter	Sample statistic
Number of variates:	N	n
Mean:	μ	$\bar{x}$
Standard deviation:	δ	S

If a large number of samples of equal size n are to be repeatedly drawn from a population and if $\bar{x}_1, \bar{x}_2, \bar{x}_3$............ are their sample means, then the frequency distribution of these sample means is known as **sampling distribution of means**. The standard deviation of the distribution of all possible sample means of a given size is known as **the standard error of the mean**. The standard error of the mean (S.E.)

approximates to the standard deviation of the population (δ) divided by the square root of the number of items in the sample (n).

$$S.E. = \frac{\delta}{\sqrt{n}}$$

One problem is that δ, the standard deviation of the parent population cannot be calculated. However, the reason for sampling is to estimate the characteristics of the parent population. The device of substituting the sample's standard deviation (S) for the parent population's standard deviation (δ) is therefore used. The above formula runs as follows:

$$S.E. = \frac{S}{\sqrt{n}}$$

The value of $\bar{x}$ gives us a rough estimate of μ. This can be illustrated by the following example. A random sample of 100 farms from a region gives the average farm size of 50 acres with a standard deviation of 26 acres. Can the average farm size in the region be taken as 60 acres?

Given $\bar{x} = 50$, $\mu=60$, $n=100$, $S=26$,

The standard error of the mean (S.E.)

$$= \frac{S}{\sqrt{n}} = \frac{26}{\sqrt{100}} = 2.6$$

From the normal curve it is known that 95 times out of every 100, the true mean (μ) will be within two standard error of the sample mean(i.e. 50 ± 5.2 or between 44.8 and 55.2). Hence we cannot take the average farm size in the region as 60 acres, rather it lies between 44.8 and 55.2 acres. The procedure discussed above exemplifies how numerical characteristics of population can be gainfully estimated from the samples.

■ 10.1.1.4 SUMMARIZING GEOGRAPHICAL DATA

In this age of information explosion the geographer has to handle large sets of data. Much of the data is comprised of large numbers of numerical values. We may take, for example, a series of climatic statistics for two places given in terms of temperature and rainfall. The climatic statistics may include the daily maximum and minimum temperatures and the daily rainfall record over a period of 35 years. We are faced with many sheets of figures for each place, giving such a profusion of detailed information that direct comparison is impossible. The information has first to be simplified (or summarized) into a few numbers that represent in some way the various aspects of the large masses of data. In the case of climatic statistics rainfall is generally shown as the mean (or average) annual rainfall over a period of years. Similarly temperatures are conventionally summarized to show the mean monthly maximum and minimum. Thus summarization of data involves the reduction of large sets of data into a few manageable representative figures from which meaningful comparison can be made, if required. Summarization of data may be achieved through the preparation of frequency distribution table, calculation of mean, median and mode, standard deviation, coefficient of variation and measurement of concentration and inequality etc.

● Consolidation

1. Use a topographical sheet of scale 1: 50,000 to estimate the percentage of the map area devoted to different forms of land use/ land cover (cultivated area, current fallow, area under forest, area not available for cultivation etc.) by a random point sampling. This can be done by noting the land use/ land cover at 20 randomly selected grid intersections.

2. Draw a sample of 100 one-digit random numbers from the table of random numbers by taking consecutive digits from as many columns as needed. Classify these numbers into a frequency table.

3. Explain the terms "Population" and "Sample". What do you mean by sample design?

4. Annual rainfall of two places for fifty years is available to you. How would you compare the rainfall of two places on the basis of summarizing the data?

■ 10.1.2 MEASURING INEQUALITY – LORENZ CURVE

Lorenz curve was first expounded in 1905. The curve is named after M.O.Lorenz, the famous statistician. This curve was used by him for the first time to measure the distribution of wealth and income. The Lorenz curve has many applications in geography. It is, for example, a useful technique for comparing the relative concentration or dispersion of population areally. Lorenz curve is actually a percentage cumulative frequency curve. It shows how a particular frequency distribution compares with an even one. If there is a perfect correspondence between two sets of distribution, then when they are plotted in terms of cumulative percentages along the two axes, a straight line running from zero at an angle of 45° across the graph i.e. a diagonal line will result. This diagonal line is called **the line of even distribution or the line of equality**. Any deviation of the curve from the line of equality is a measure of **inequality** of the two distributions and it will be reflected in the degree of concavity of the curve.

The extent of inequality or unevenness of the two sets of distribution is judged by observing how far away from the equality line the Lorenz curve is and it can be measured by an index known as the Gini's co-efficient. The co-efficient is the ratio of area under the curve and the line of equality to the area of the triangle formed by the x-axis, y-axis and the line of equality. In case of uniform distribution it is apparent that the Lorenz curve will fall on the equality line and the area between the curve and the equality line will be zero. For distribution with highest concentration (i.e. when all the values in the distribution are only concentrated at one place), the curve will approach x-axis and y-axis and the ratio will be an unity. Thus the Gini's co-efficient varies between zero and one. It can be numerically worked out by the following formula:

$$\text{Gini's co-efficient (G)} = \frac{1}{100 \times 100}\left(\sum_{i=1}^{n} X_i Y_{i+1} - \sum_{i=1}^{n} Y_i X_{i+1}\right)$$

where i= 1,2,3,..........n, and X_i and Y_i are the cumulative percentage distributions of the two attributes.

● **Exercise:**

Draw a Lorenz curve to show the inequality in the distribution of scheduled caste population in relation to total population of 10 blocks and interpret it.

● **Accessories:**

1. A data set of total population and scheduled caste population of 10 blocks
2. Drawing essentials.

● **Procedure:**

1. If it is wished to draw the Lorenz curve for scheduled caste population, compute the proportion of SC population of a block with respect to individual block total.
2. Rank the above values and re-arrange the table according to the descending / ascending rank order.

3. Compute the proportion of population of a block with respect to the population of blocks taken together.
4. Also compute the proportion of scheduled caste population of a block with respect to the SC population of blocks taken together.
5. Calculate the cumulative percentages of step 3 & 4 so that the total of each column is 100.
6. Plot the cumulative percentage of scheduled caste population (Y_i) against the percentage of the corresponding value of population (X_i) for each of the given blocks and join these points with a smooth curve. This is called Lorenz curve (Fig. 3).
7. Join the origin and last point to get the line of even distribution.

Worksheet for Lorenz Curve

Blocks	Population (A_i)	Scheduled Castes (B_i)	Percentage of SC to population (B_i/ A_i)100	Rank based on col.4	Re-arranged table		
					Rank (Descending)	Population (A_i)	SC (B_i)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
A	255,220	31,000	12.15	4	10	132,061	27,992
B	171,066	14,063	8.22	1	9	266,675	48,443
C	132,061	27,992	21.20	10	8	161,828	28,270
D	151,376	24,444	16.15	6	7	237,228	39,846
E	134,360	11,998	8.93	2	5	151,376	24,444
F	266,675	48,443	18.17	9	6	238,686	32,403
G	96,323	9,902	10.28	3	4	255,220	31,000
H	238,686	32,403	13.58	5	3	96,323	9,902
I	237,228	39,846	16.80	7	2	134,360	11,998
J	161,828	28,270	17.47	8	1	171,066	14,063
Total	1844,823 ($\sum A_i$)	268,361 ($\sum B_i$)				1844,823 ($\sum A_i$)	268,361 ($\sum B_i$)

Percentage distribution of Population i.e. ($A_i/\sum A_i$)100	Percentage distribution of SC i.e. ($B_i/\sum B_i$)100	Cumulative percentage of population (X_i)	Cumulative percentage of SC (Y_i)
(9)	(10)	(11)	(12)
7.16	10.43	7.16	10.43
14.46	18.05	21.62	28.48
8.77	10.53	30.39	39.01
12.86	14.85	43.25	53.86
8.21	9.11	51.46	62.97
12.94	12.07	64.40	75.04
13.83	11.55	78.23	86.59
5.22	3.69	83.45	90.28
7.28	4.48	90.73	94.76
9.27	5.24	100.00	100.00
100	100		

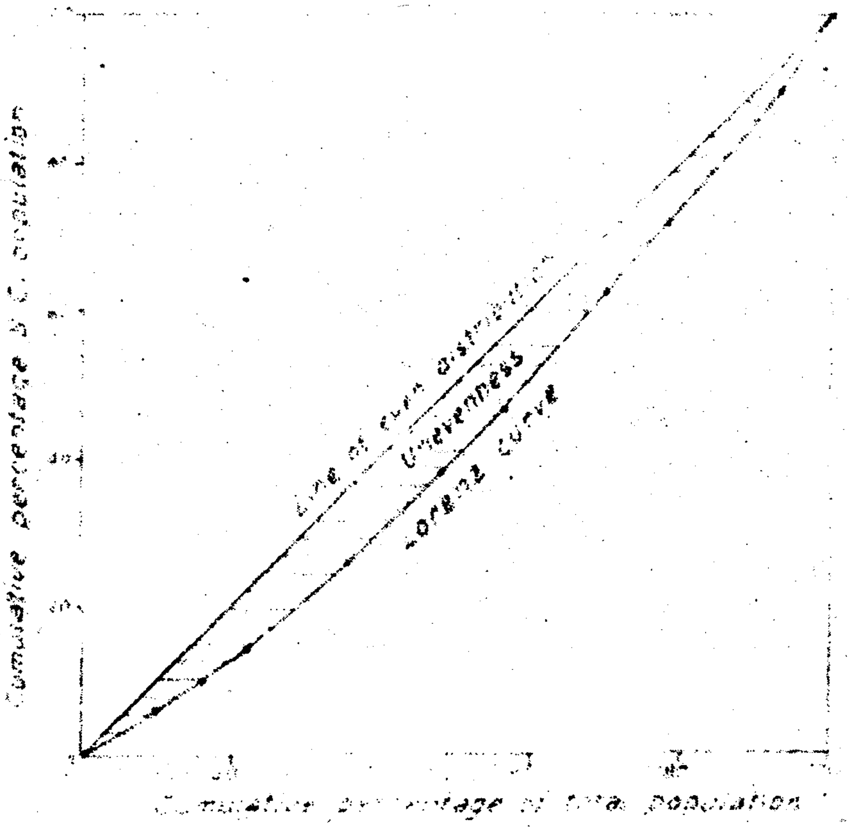

Fig. 3

Calculation of Gini's co-efficient (G)

X_iY_{i+1}	Y_iX_{i+1}	Gini's co-efficient
(13)	(14)	
203.92	225.50	
843.40	865.51	$G = \frac{1}{100 \times 100}\left(\sum_{i=1}^{n} X_iY_{i+1} - \sum_{i=1}^{n} Y_iX_{i+1}\right)$
1636.81	1687.18	
2723.45	2771.64	$= \frac{1}{10000}(38888.85 - 40368.51)$
3861.56	4055.27	
5576.39	5870.38	$= \frac{-1}{10000} \times 1479.66$
7062.60	7225.94	
7907.72	8191.10	$= -0.147966$
9073.00	9476.00	Ignoring the sign, G = 0.148 (approx)
38888.85 ($\sum X_iY_{i+1}$)	40368.51 ($\sum Y_iX_{i+1}$)	

● **Interpretation:**

The departure of the Lorenz curve from the line of even distribution (fig. 3) gives inequality in the distribution of scheduled caste population in relation to total population. The higher the departure the greater is the inequality. Gini's co-efficient as worked out is 0.148. Since this value of 0.148 is close to zero the inequality in the distribution of SC population in the given blocks is not remarkable.

● **Consolidation:**

Construct Lorenz curves for (1) female literates and (2) male literates in relation to total population of an administrative unit, say a district. What does each of these Lorenz curves show? What conclusion can be drawn by comparing them?

■ 10.1.3 ANALYSIS OF COMBINATION : WEAVER'S COMBINATION INDEX

In dealing with the problems of analysis of the data relating to different variables some objective method is necessary to identify specific combination of the variables in a particular region. This will help regionalization. In the field of agricultural geography Weaver (1954) was the first to use statistical techniques to establish the crop combination region of the Middle West (USA). Weaver's technique has subsequently been modified by Doi (1957), Thomas (1963), Rafiullah (1965) and others. However Weaver's method of combination analysis is still widely used in geography.

According to him the statistics used for calculation of combination index would be 100 when proportions of distribution are added. Weaver compared the actual percentage area under each crop with a theoretical standard. The theoretical standards as suggested are as follows:

Monoculture = 100 percent of the harvested crop land is one crop

2crop- combination = 50 percent in each of two crops

3crop- combination = 33.33 percent in each of three crops and so on.

Weaver formula for combination index is:

$$\delta = \frac{\sum d^2}{n}$$

where d= difference between the actual percentage area under each crop and the appropriate theoretical standard

n= number of crops in a given combination

The different values of δ corresponding to theoretical standard are needed to be calculated. The smallest value of δ gives the critical crop- combination.

● **Exercise:**

In an area X the percentage distribution of various crops is given below, using Weaver's method identify the critical crop combination of the area.

Percentage distribution of area under different crops

Crops	Rice	Wheat	Barley	Sugarcane	Gram	Others
Percentages	45	22	18	7	5	3

● **Calculation:**

The theoretical standard of Monoculture, 2-crop, 3-crop, 4-crop, 5-crop, 6-crop combinations are taken as 100, 50, 33.33, 25, 20, 16.66 percents respectively as per Weaver's method.

Monoculture

$$= \frac{(100-45)^2}{1} = 3025$$

2-Crop combination

$$= \frac{(50-45)^2+(50-22)^2}{2} = 404.5$$

3-Crop combination

$$= \frac{(33.33-45)^2+(33.33-22)^2+(33.33-18)^2}{3} = 166.5$$

4-Crop combination

$$= \frac{(25-45)^2+(25-22)^2+(25-18)^2+(25-7)^2}{4} = 195.5$$

5-Crop combination

$$= \frac{(20-45)^2+(20-22)^2+(20-18)^2+(20-7)^2+(20-5)^2}{5} = 205.4$$

From the trend of diffe nt values of δ (Weaver combination index) it appears that 166.5 is the lowest among the first decreasing and then increasing trend of values. The calculation of δ for combination higher than 5-crop is immaterial, since the value of δ has already attained a rising trend. Finally it is safer to conclude that the area X belongs to 3-crop combination category.

The importance of this method in the analysis of crop combination is beyond any doubt. However, there is no reason why this method should not be used in any situation that demands classification using a number of variables, provided data are in the form of proportions which add up to 100 percent. A notable use was by D. Smith (1969) who used the techniques to identify 'one – industry' and 'two –industry' towns in Lancashire and Cheshire.

● **Consolidation:**

Using Weaver's method prepare a map showing crop combination regions of West Bengal based on district-wise data in respect of crop acre-age and interpret the map

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PART-I

Paper – V (Practical)

Module - X : Unit – 04

Module Structure

PART-I

Paper -- V(Practical)
Module - X : Unit - 04

QUANTITATIVE METHODS IN GEOGRAPHY

■ 10.4.0 Objectives : In this unit the following matters have been discussed :

- **Nearest Neighbour Analysis**
- **Shortest Path Analysis**
- **Transport Connectivity Indices**

■ 10.4.1 NEAREST NEIGHBOUR ANALYSIS

The dispersion of a point distribution may be measured from a mean centre by standard distance. The dispersion of points (geographic phenomena) in relation to each other can be measured by nearest Neighbour Index (*NNI*). It measures the way in which individuals in a population are distributed over a given area. It relates the observed mean distance ($\overline{d_o}$) to the expected mean distance ($\overline{d_e}$) of the individuals (say settlements) in an area.

$$NNI = \frac{\overline{d_o}}{\overline{d_e}} \quad \text{where, } \overline{d_o} = \frac{\sum NND}{N} \text{ and } \overline{d_e} = \frac{1}{2\sqrt{\frac{N}{A}}}$$

Again, $\sum NND$ = Summation of nearest neighbour distance
A = Area,
N = Number of points.

NNI can be simplified as,

$$NNI = \frac{\overline{d_o}}{\overline{d_e}} = \frac{\frac{\sum NND}{N}}{\frac{1}{2\sqrt{\frac{N}{A}}}} = 2 \times \frac{\sum NND}{N} \times \sqrt{\frac{N}{A}}$$

The NNI generates a scale which measures the degree of departure of an observed spatial distribution from a theoretical random distribution.

The distribution may be considered

Random, when $NNI = 1$
Clustered, when $NNI = 0$
Regular (evenly dispersed), when NNI 2.15

● **Exercise :**

Compute the Nearest Neighbour Index of Settlement Pattern and interpret it.

▲**Accessories:**

1. A map showing the distribution of settlements (Fig. 4.1)
2. Drawing essentials

NEAREST NEIGHBOUR INDEX OF SETTLEMENT PATTERN

TOPOGRAPHICAL MAP No. 73 E/12 (IN PART)

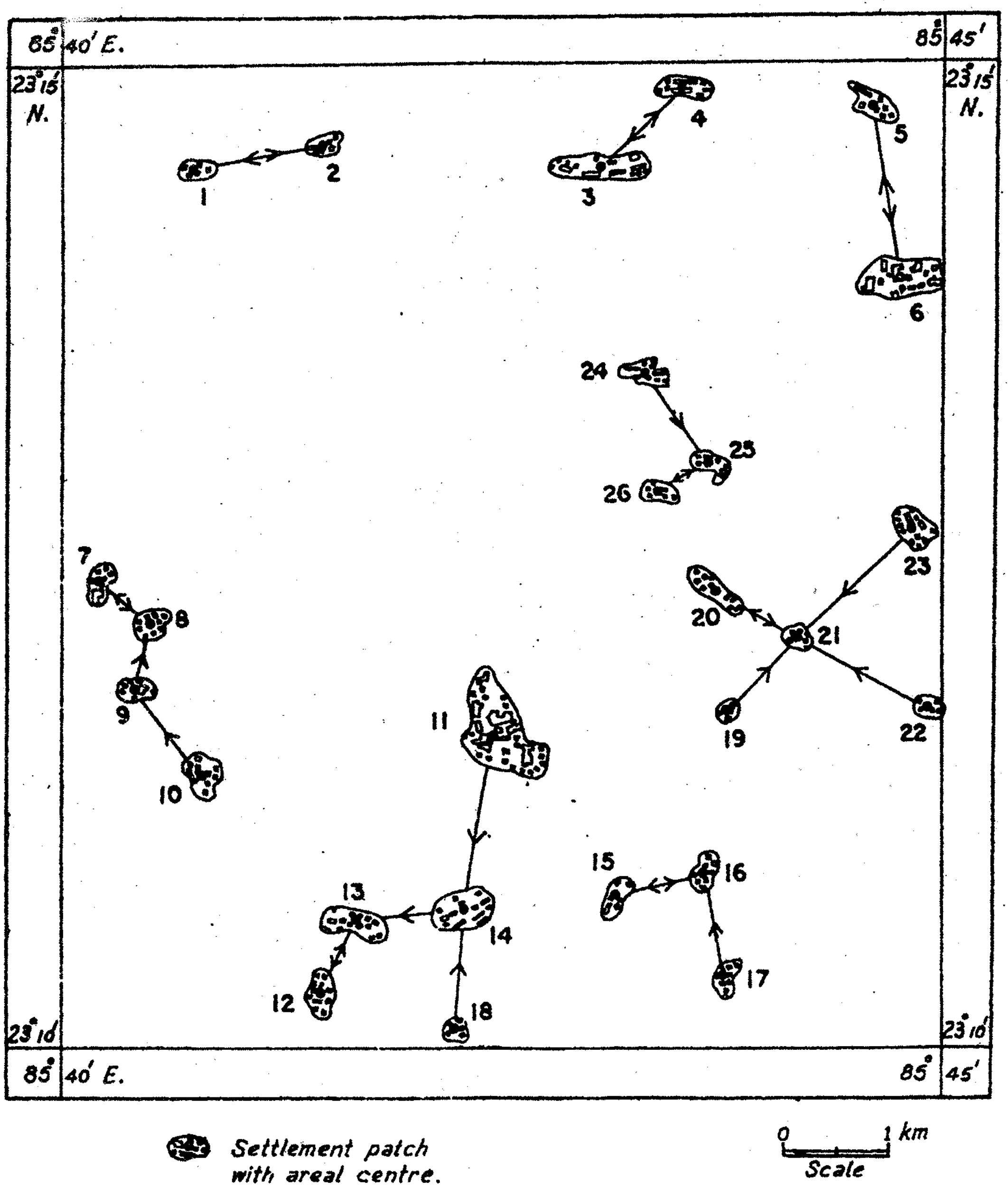

Fig. 4.1

● **Procedure :**

1. Demarcate each settlement by a boundary line and put areal centre on it.
2. Repeat the process for all other settlement sites appearing on the map.
3. Mark the settlement patches (say 1 to 26 as shown on the map)
4. Identify the nearest neighbour of each settlement and measure the distance from areal centre to areal centre of the pair of settlement sites.
5. From the set of nearest neighbour distance, compute the total nearest neighbour distance (*NND*)
6. Note the total number of settlements and the area of the map under consideration
7. Finally calculate the nearest neighbour index (*NNI*).

WORKSHEET FOR NEAREST NEIGHBOUR ANALYSIS

Sl. No. of settlement	Nearest Neighbour	Nearest Neighbour Distance (cm)	Sl. No. of settlement	Nearest Neighbour	Nearest Neighbour Distance (cm)
1	2	2.5	14	13	2.1
2	1	2.5	15	16	1.7
3	4	2.2	16	15	1.7
4	3	2.2	17	16	2.0
5	6	3.3	18	14	2.2
6	5	3.3	19	21	1.9
7	8	1.3	20	21	1.8
8	7	1.3	21	20	1.8
9	8	1.3	22	21	2.9
10	9	2.1	23	21	3.0
11	14	3.4	24	25	2.1
12	13	1.5	25	26	1.1
13	12	1.5	26	25	1.1

Computation:

Total Nearest Neighbour Distance = $\sum NND = 53.8$ cm

No. of settlements = 26

Map area = 17 x 18.6 sq.cm.

$$NNI \text{ (Nearest Neighbour Index)} = 2 \times \frac{\sum NND}{N} \times \sqrt{\frac{N}{A}}$$

$$= 2 \times \frac{53.8}{26} \times \sqrt{\frac{26}{17 \times 18.6}}$$

$$= 1.19$$

Interpretation :

The *NNI* works out to be 1.19. Thus the Nearest Neighbour Analysis applied to the settlement pattern of the given area reveals that the pattern of settlement in neither regular i.e. evenly dispersed nor clustered. It is rather nearer to random.

Consolidation :

Analyse the settlement pattern of another area and calculate Nearest Neighbour Index. This will help in the comparative study of settlement patterns by offering objective and quantitative criteria.

■ 10.4.2 SHORTEST PATH ANALYSIS

Channels of movement occupied by rivers and routeways appear generally as lines on maps. A set of lines (routes) that join or cross each other at junctions form what is called a network. In a network where two or more lines meet, a node is formed and the lines joining nodes are called links or edges. Network analysis particularly in respect of transport geography has become important in recent years. The shortest route between two farthest places in an area ensure lesser cost of construction of the route itself, smaller freight charges and even quicker time of communication. The shortest path analysis is thus an important tool in geographical studies. The measures that are adopted for shortest path analysis include:

1. the measures of accessibility
2. the measures of route sinuosity

■ 10.4.2.1 The measures of accessibility

Accessibility of a node can be expressed in terms of links by which it is connected with the rest of the network. Accessibility measures the intensity of linkage of a node with rest of the network.

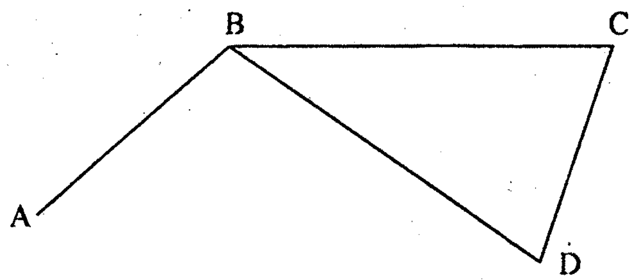

Fig. 4.2

ABCD be the route network (Fig. 4.2). The accessibility can be expressed by **Shimbel** index. For this accessibility matrix is prepared by noting the numbers of edges required to connect any node with all others by the shortest route.

	A	B	C	D	Row total = Shimbel index
A	0	1	2	2	5
B	1	0	1	1	3
C	2	1	0	1	4
D	2	1	1	0	4

Total = 16

The Shimbel index for the node B is 3, which is the least value indicating highest accessibility. The total accessibility can be measured by adding all the **shimbel** indices together. Here the total accessibility comes out to be 16.

The road distances between the nodes may also be put in matrix form to get distance matrix. The distance matrix will be least for node B. Therefore accessibility would be the highest.

Linear Programming can also be used for the measurement of accessibility.

■ 10.4.2.2 The measures of route sinuosity

Many routes followed by roads, railways or even by airliners are not the most direct, rather they are sinuous. The deflection of routes by physical and other barriers or by inclusion of other places on the way are studied for accessibility of networks. The accessibility is measured by detour index (D.I.). The route sinuosity can be expressed by detour index.

The D.I. is the amount of detour of the shortest route connecting two nodes.

$$\text{D.I.} = \frac{\text{Shortest route distance between A and B}}{\text{Shortest distance between A and B}} \times 100$$

Multiplication by 100 is done in order to get the value in percentage. The closer the detour index gets to 100%, the more is the efficiency of network. On the other hand detour index of more than 100 indicates the greater sinuosity of the route i.e. the lesser efficiency of network.

The detour indexes for all nodes in a network can be set out in a matrix, and both nodal means and a mean detour index for the whole network can be calculated.

Besides, detour index of the nodes of a network can be calculated from a base point.

● **Exercise :**

Draw a detour index map for the road transport network to show accessibility and interpret it.

● **Accessories :**

1. A map showing the State Highway network of Bankura district (Fig. 4.3)
2. Drawing essentials and map measurer (rotameter)

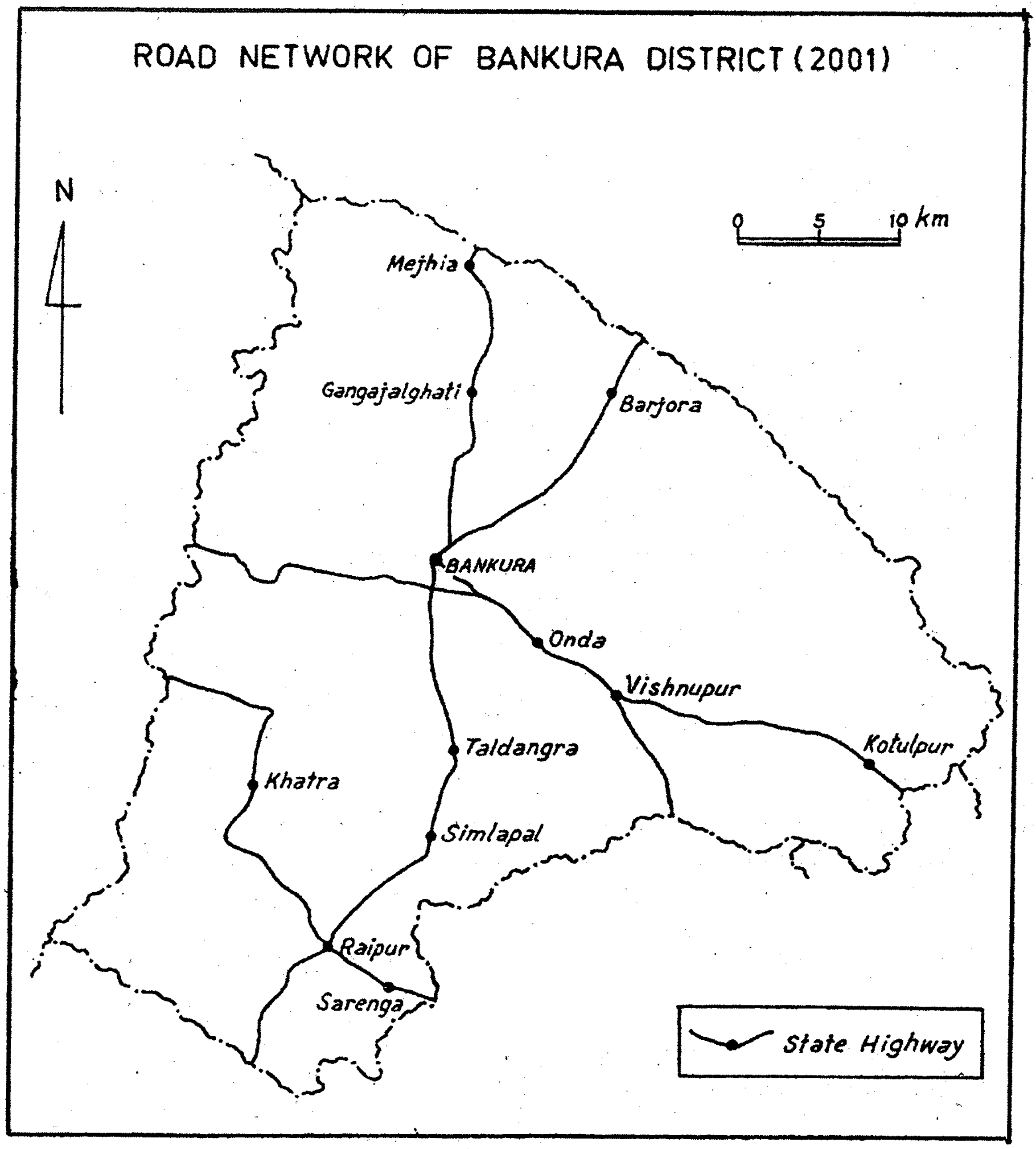

Fig. 4.3

- **Procedure :**
  1. Taking location of Bankura as base point i.e. central point, measure short distances (direct map distances) between Bankura and every other point by a ruler.
  2. Using rotameter measure also the shortest route distances (actual map distances) between Bankura and every other point.
  3. Compute the detour index for the different points (nodes) except Bankura.
  4. Plot the detour indexes at the respective points.

5. Draw the isopleths and finally choropleth to show the spatial variation of the detour indexes from the base point (Fig. 4.4).

WORK-SHEET FOR DETOUR INDEX OF STATE HIGHWAY OF BANKURA DISTRICT FROM BASE POINT, BANKURA.

Base point: Bankura

Place	Actual map distance (cm):AD	Direct map distance (cm): DD	Detour index (AD / DD) X 100%
Gangajalghati	3.00	2.95	102
Mejhia	5.50	5.05	109
Barjora	4.50	3.25	138
Onda	2.50	2.30	109
Vishnupur	4.00	3.90	103
Kotulpur	9.00	8.45	107
End point of Vishnupur	6.50	6.05	107
Taldangra	3.50	3.40	103
Simlapal	5.00	4.85	103
Raipur	8.00	7.05	113
Sarenga	9.00	7.60	118
End point of Raipur	10.00	9.40	106
Khatra	12.00	5.10	235
End point of Khatra	15.00	5.20	288
End point of Bankura	5.00	4.20	119

▲ **Interpretation :**

The values of detour index as measured from Bankura town in respect of state highway vary from 102 to 288 percent in the district of Bankura. The region around Bankura town with the extension as far as Gangajalghati in the north, Onda in the east and Taldangra in the south has detour index of 100 percent. This region has the highest accessibility in respect of routeways. On the contrary the south-western part of the district has got the highest detour index and as such the accessibility is least. There is a small area in the mid-north where the detour index is also high. Rest of the area of the district enjoys the detour indices ranging from 100 to 115 percent. Consequently this part of the district is bestowed on high accessibility.

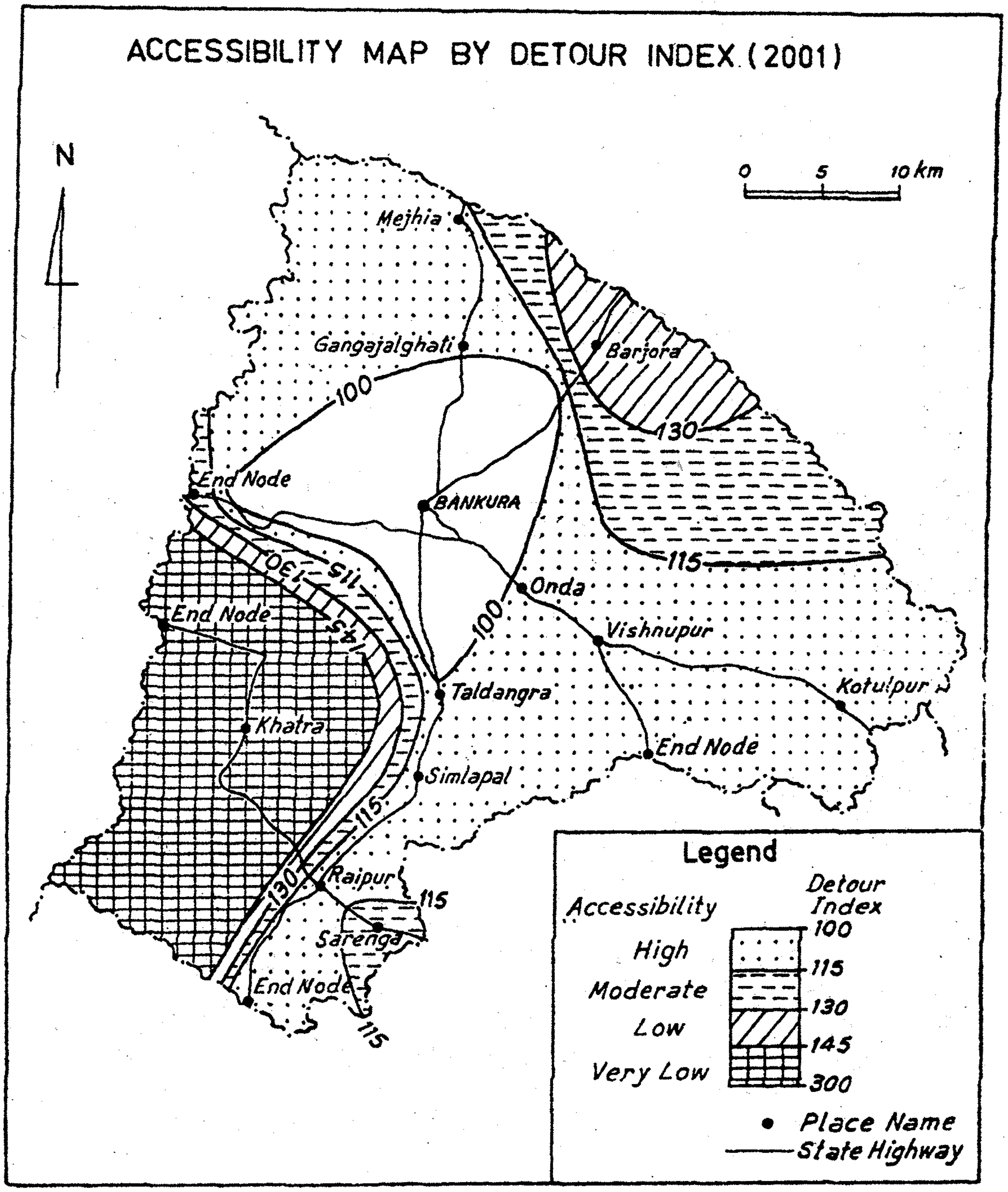

Fig. 4.4

- **Consolidation :**

A. Taking Vishnupur as base point prepare another map of detour index regarding state highway of Bankura district. How does this map differ from the map prepared by taking Bankura as base point in respect of accessibility from a centre?

B. Prepare an accessibility matrix for the different nodes of Bankura district. Note the node-wise variations of the values of Shimbel index. Use these values for the cartographic representation of accessibility by isopleths and interpret the overall pattern of accessibility.

■ 10.4.3 TRANSPORT CONNECTIVITY INDICES

Transportation lines that join or cross each other are taken as examples of Networks. For analytical study networks may be reduced to topological graphs which are arrays of points connected or not connected to one another by lines (Fig. 4.5).

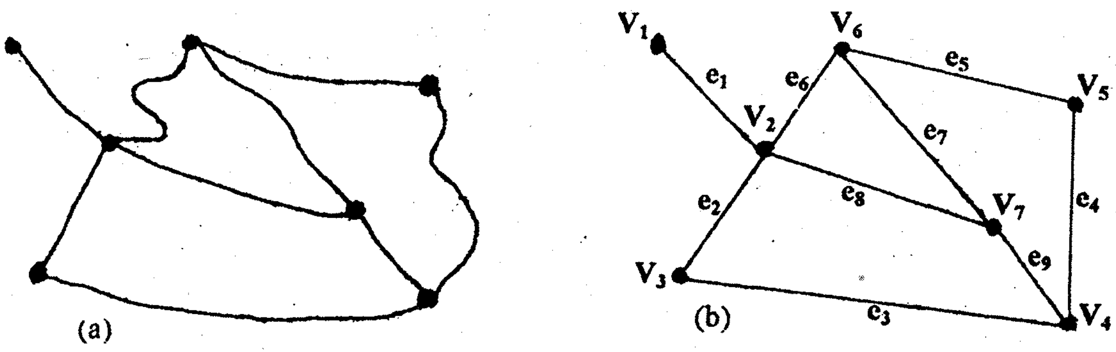

Fig. 4.5: (a) Real Network, (b) Topological Graph

Topological Graph (Map)

This graph (map) consists of a set of vertex (nodes) v connected by edges (links) e. A node is a terminal point or an intersection point of a graph. It is the abstraction of a location such as town, a road intersection or a transport terminal. An edge is a link between two nodes. Graphs may be planar (two-dimensional) or non-planar (three-dimensional).

Connectivity

It may be defined as the degree to which the nodes of a network are directly connected to each other. K.J. Kansky (1963) developed a number of descriptive indices measuring the connectivity of networks.

(i) The beta (β) index,

where $\beta = \dfrac{\text{arcs}}{\text{nodes}} = \dfrac{e}{v} = \dfrac{6}{4} = 1.5$ (Fig. 4.6).

or, $\beta = \dfrac{e}{v} = \dfrac{3}{4} = .75$ (Fig. 4.7).

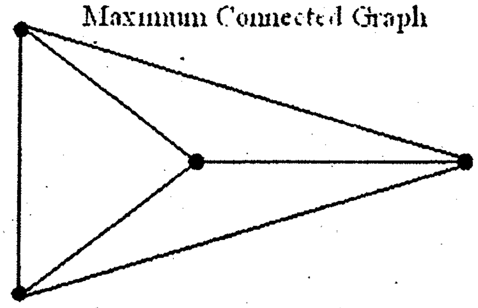

Fig. 4.6

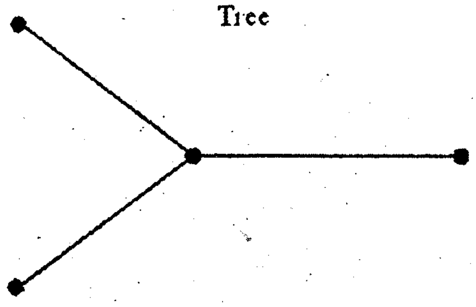

Fig. 4.7

The β index ranges from 0 for networks consisting of only nodes and no arcs, through 1 and higher for networks that are well connected.

(ii) The gamma (γ) index,

$$\text{where } \gamma = \frac{\text{arcs}}{3\,(\text{nodes} - 2)} = \frac{e}{3(v-2)} = \frac{6}{3(4-2)} = 1 \text{ (Fig. 4.6)}$$

$$\text{or, } \gamma = \frac{e}{3(v-2)} = \frac{3}{3(4-2)} = .5 \text{ (Fig. 4.7)}$$

The gamma (γ) index will always lie between 0 (for no arcs) and 1 (for a completely connected network)

(iii) The alpha (α) index,

$$\text{where } \alpha = \frac{e-v+g}{2v-5} = \frac{6-4+1}{8-5} = 1 \text{ (Fig. 4.6).}$$

$$\text{or, } \alpha = \frac{e-v+g}{2v-5} = \frac{3-4+1}{8-5} = 0 \text{ (Fig. 4.7).}$$

Note that for one graph g=1, for two graphs g=2

The alpha (α) index is expressed as a ratio between the observed number of circuits (cyclomatic number) and the maximum number of circuits (cyclomatic number) possible. The index varies from zero to one. By multiplying the alpha index by 100, the index value will vary from 0 to 100. It also measures the percentage of a maximum connectivity.

● **Exercise :**

Compute the attributes of connectivity of State Highway Network of Bankura district and interpret it.

▲ **Accessories :**

1. A map showing the route (State Highway) network of Bankura district (Fig. 4.3).
2. Drawing essentials and calculator.

● **Procedure :**

1. Identify the nodes and prepare a topological map (Fig. 4.8) based on the route network of Bankura district.
2. Count the number of vertices, edges, subgraphs from the topological map.
3. Compute the alpha, beta and gamma indices and interpret the values.

WORKSHEET FOR CONNECTIVITY INDICES (STATE HIGHWAY NETWORK OF BANKURA DISTRICT - 2001)

1. Total no. of arcs (edges) = 15
2. Total no. of nodes = 16

A. alpha index $= \dfrac{\text{arcs} - \text{nodes} + 1}{2 \times \text{nodes} - 5} = \dfrac{15 - 16 + 1}{2 \times 16 - 5} = \dfrac{0}{27} = 0$

B. beta index $= \dfrac{\text{arcs}}{\text{nodes}} = \dfrac{15}{16} = .94$

C. gamma index $= \dfrac{\text{arcs}}{3\,(\text{nodes} - 2)} = \dfrac{15}{3(16-2)} = \dfrac{15}{42} = .36$

▲ **Interpretation :**

Analysis of indices like α, β & γ reveals the connectivity of transport network with respect to state highway of Bankura district. The value of α index is 0, indicating the fact that not a single circuit i.e. road for round movement has not developed. It is a manifestation of poor development of state highway.

Again β index is low and its value is .94. It reveals also poor connectivity.

The value of γ index is .36. In other words 36% of connectivity has been achieved. The values of α, β & γ in general indicate the low level of connectivity of transport network with regard to the state highway in the district of Bankura.

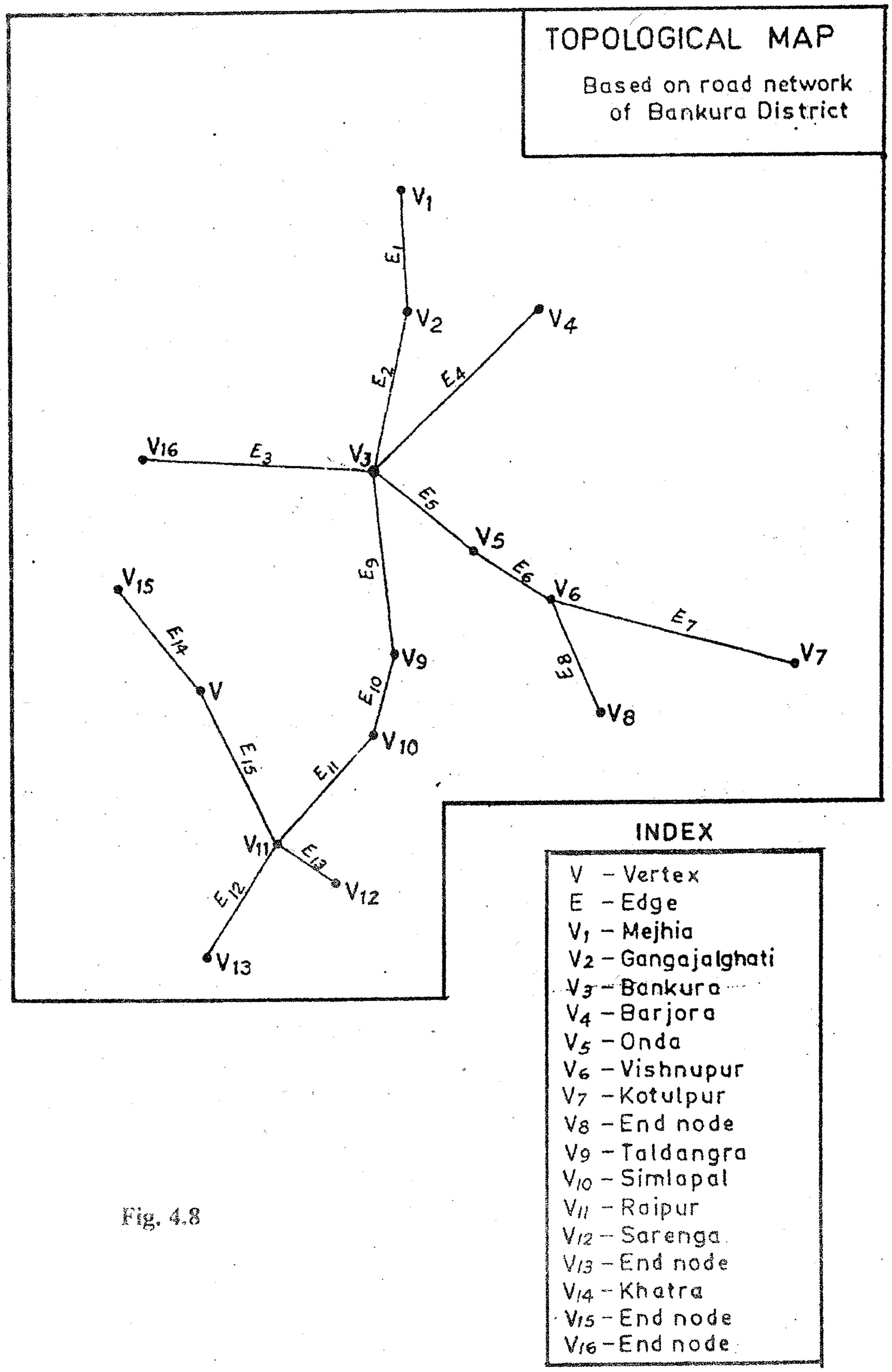
TOPOLOGICAL MAP
Based on road network
of Bankura District
V1
E1
V2
V4
E2
E4
V16
E3
V3
E5
V5
E9
E6
V6
V15
E7
V7
E14
V9
E8
V
E10
V8
V10
E15
E11
V11
E13
V12
E12
V13
INDEX
V – Vertex
E – Edge
V1 – Mejhia
V2 – Gangajalghati
V3 – Bankura
V4 – Barjora
V5 – Onda
V6 – Vishnupur
V7 – Kotulpur
V8 – End node
V9 – Taldangra
V10 – Simlapal
V11 – Raipur
V12 – Sarenga
V13 – End node
V14 – Khatra
V15 – End node
V16 – End node

Fig. 4.8

■ 10.4.4 Bibliography

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"Learner's Feed-back"

After going through the Modules/ Units please answer the following questionnaire.
Cut the portion and send the same to the Directorate.

To
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Vidyasagar University,
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1. The modules are : (give ✓ in appropriate box)

   ☐ Easily understandable; ☐ very hard; ☐ partially understandable.

2. Write the number of the Modules/Units which are very difficult to understand :

   ....

   ....

   ....

3. Write the number of Modules/ Units which according to you should be re-written :

   ....

   ....

   ....

4. Which portion/page is not understandable to you? (Mention the page no. And Portion)

   ....

   ....

   ....

   ....

5. Write a short comment about the study material as a learner.

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(Full Signature of the Learner)

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