

CHAPTER ONE

1. Topographic Surveying and Mapping

1.1 Topographic surveying

Topographic surveying is the process of determining the positions, on the earth's surface, of the natural and artificial features of a given locality, and of determining the configuration of the terrain. The location of the features is known as planimetry and the configuration of the terrain is known as topography. **Topography** refers to the characteristics of the land surface. These characteristics include **relief, natural features, and artificial** (or **man-made**) features. Relief is the configuration of the earth's surface and includes such features as hills, valleys, plains, summits, depressions, and other natural features, such as trees, streams, and lakes. Man-made features are highways, bridges, dams, buildings, and so forth. A graphic representation of the topography of an area is called a **topographic map**. A topographic map is simply a drawing that shows the natural and artificial features of an area. A **topographic survey** is a survey conducted to obtain the data needed for the preparation of a topographic map. This data consists of the horizontal and vertical locations of the features to be shown on the map.

The purpose of the survey is to gather data necessary for the preparation of the topographic map that displays both the planimetric and topographic features which are very essential for the planning and designing of the most engineering projects such as location of highways, railways, design of irrigation and drainage systems, the development of hydroelectric power, layout of city planning and industrial plant.

In this chapter, you will study methods and procedures used to perform topographic surveying and to prepare topographic maps. The fieldwork in a topographic survey consists principally of (1) the establishment of a basic framework of horizontally and vertically located control points (called instrument points or stations) and (2) the determination of the horizontal and vertical locations of details in the vicinity of each instrument point. We will begin our discussions with topographic control.

Topographic control consists of two parts:

- i) Horizontal control, which locates the horizontally fixed position of specified control points, and
- ii) Vertical control, in which the elevations of specified bench marks are established. This control provides the framework from which

topographic details, such as roads, buildings, rivers, and the elevation of ground points, are located.

i) Horizontal Control: Locating primary and secondary horizontal control points or stations may be accomplished by traversing, by triangulation, or by the combined use of both methods. On an important, large-area survey, there may be both primary control, in which a number of widely separated primary control points are located with a high degree of precision; and secondary control, in which stations are located with less precision within the framework of the primary control points.

The routing of a primary traverse should be considered carefully. It should follow routes that will produce conveniently located stations. Such routes might run along roads, ridges, valleys, edges of wooded areas, public land lines, or near the perimeter of tracts of land. This latter route is of particular importance for small areas. When all the details in the area can be conveniently located from stations on the primary traverse, you do not need secondary traverses. However the size or characters of the terrain or both usually make secondary traverses necessary.

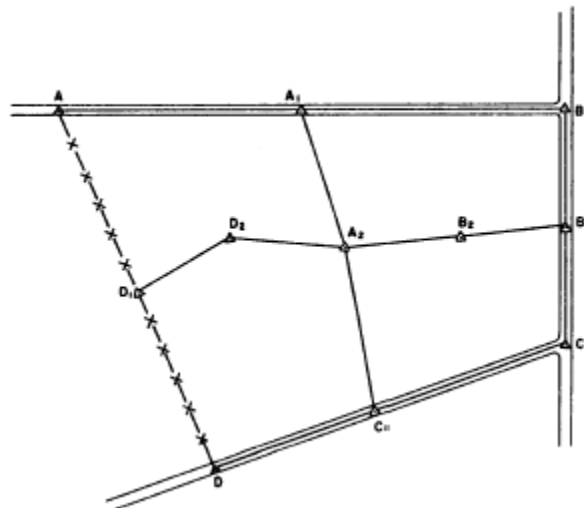


Figure 1-1.-Primary traverse and secondary traverse

iii) Vertical Control

In topographic surveying, bench marks serve as starting and closing points for the leveling operations when you are locating details. Although for some surveys the datum may be assumed, it is preferable that all elevations be tied to bench marks which are referred to the sea-level datum. As a surveyor, you must make

every feasible effort to tie in your surveys to these bench marks to ensure proper location and identification. Often, the established horizontal control marks are used as the bench marks because the level routes generally follow the traverse lines.

Vertical control is usually carried out by direct leveling. Once the topographic control has been established, your next major step in a topographic survey is to locate the details horizontally and vertically in the vicinity of each control point or station. These details consist of (1) all natural or artificial features that will appear on the map and (2) enough ground points and spot elevations to make the drawing of contour lines possible. The methods and the instruments used in topographic surveys depend upon the purpose of the survey, the degree of precision needed, the nature of the terrain to be covered, the map scale, and the contour interval. For a high degree of accuracy, you should locate azimuths with a total station. Measure horizontal distances with the chain or the electronic distance measurement (EDM) device. Determine elevations with a level.

1.2 Topographic Mapping

One of the purposes of a topographic map is to depict relief. In fact, this is the main feature that makes a topographic map different from other types of maps. Before you go any further, refresh your memory on the subject of topographic relief. *Relief* is the term for variance in the vertical configuration of the earth's surface. You may see relief can be shown in a plotted profile or cross section. These, however, are views on a vertical plane, but a topographic map is a view on a horizontal plane. On a map of this type, relief may be indicated by the following methods. A **relief model** is a three-dimensional relief presentation a molded or sculptured model, developed in suitable horizontal and vertical scales, of the hills and valleys in the area. **Shading** is a pictorial method of showing relief by the use of light and dark areas to suggest the shadows that would be created by parallel rays of light shining across the area at a given angle. **Hachures** area pictorial method similar to shading except that the light-and-dark pattern is created by short hachure lines, drawn parallel to the steepest slopes. Relative steepness or flatness is suggested by varying the lengths and weights of the lines. **Contour lines** are lines of equal elevation; that is, each contour line on a map is drawn through a succession of points that are all at the same elevation. A contour is the real-life equivalent; that is, a line of equal elevation on the earth's surface. All of these methods of indicating relief are illustrated in [figure 1.2](#). The contour-line method is the one most commonly used on topographic maps. All engineering construction projects require maps or site plans. All engineers must know how to make maps, to be better able to

interpret them. Maps for ordinary people must be clear and easily understood if they are to give maximum service. Most maps are made for some definite reason. For example to show topography, boundary of properties, precise location of traverse points, routes of highways or railways, soil erosion control areas, forest areas, mineral lands and other features.

1.2.1 Map drafting

There are four stages:

- i. Plotting the traverse
- ii. Plotting details
- iii. Drawing the topography and special data
- iv. Finishing the map

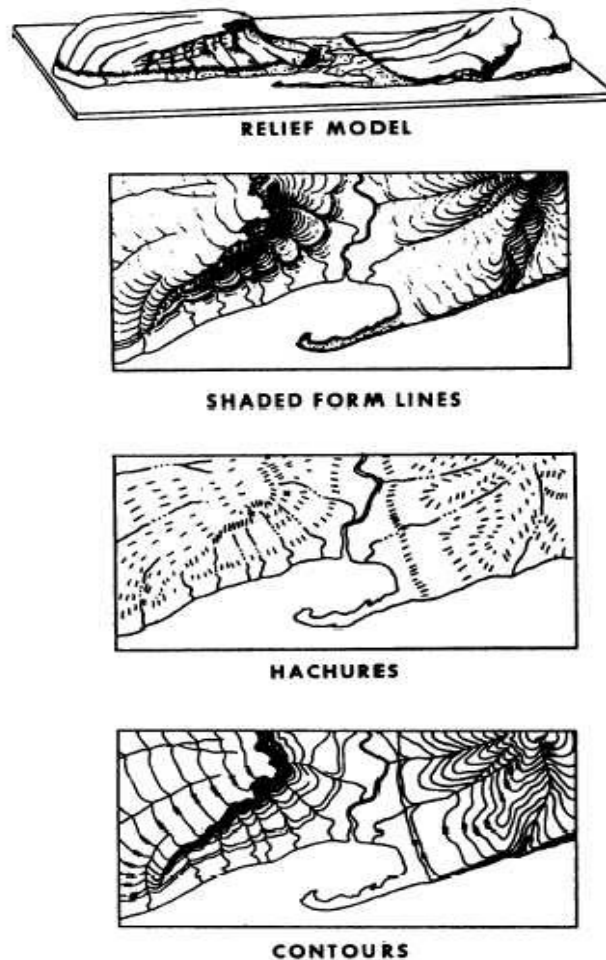


Figure 1.2 Methods of indicating topography

i. Plotting the traverse

Measurement of lengths and angles are used to plot a traverse. Lengths (distances) are plotted from the field data to a selected scale by means of an accurate ruler.

Angles are plotted by **a)** coordinate **b)** tangents **c)** chords

ii. Plotting the details

All contour points are taken as details. Trees, buildings, etc are all details. The positions are plotted using a scale and a protractor.

iii. Drawing the topography and special data

Standard symbols are used to represent special topographic features, thereby making it possible show many details on a single sheet of paper. Before placing symbols on a map, such things as buildings, roads, boundary lines are first plotted. The symbols are then drawn or pasted. A fully detailed map with contouring and shading is a work of art.

iv. Finishing the map

The appearance of a finished map has considerable bearing on its acceptability and value. A map which is poorly arranged, carelessly lettered, and unfinished looking does not inspire confidence in its accuracy. A boarder line somewhat heavier than all other lines improves the appearance of the sheet. The position of the traverse and topography must properly balance the sheet.

Scale of a map

1:100 or less ----- Large scale

1:100 – 1:1000 ----- Medium scales

1:1000 or more ----- small scales

Scale depends on the purpose, size needed and precision required. Area on the map is found using a planimeter.

1.2.2 Contour lines

Contour lines are an imaginary line on the ground surface joining the points of equal elevation is known as contour. Contours begin at sea level, normally the zero contour, and each contour line represents an elevation above (or below) sea level. The distance between adjacent contour lines is as the contour interval. Starting at zero elevation the topographer draws every fifth contour line with a heavier line. These are known as index contours. At some place along each index

contour, the line is broken and its elevation is given. The contour lines falling between index contours are called intermediate contours. They are drawn with a finer line than the index contours and, usually, do not have their elevations given.

1.2.3 Contour Interval and Horizontal Equivalent

The constant vertical distance between two consecutive contours is called the contour interval. On a given map the successive contour lines represent elevation differing by a fixed vertical distance called the **contour interval**. The horizontal distance between two points on the consecutive contour lines for a given slope, is the **horizontal equivalent**. The contour interval is constant between the consecutive contours while the horizontal equivalent is variable and depends upon the slope of the ground.

CONTOUR LINES

These are drawn through points having the same elevation. They show the height of ground above sea level (M.S.L.) in either feet or metres and can be drawn at any desired interval.

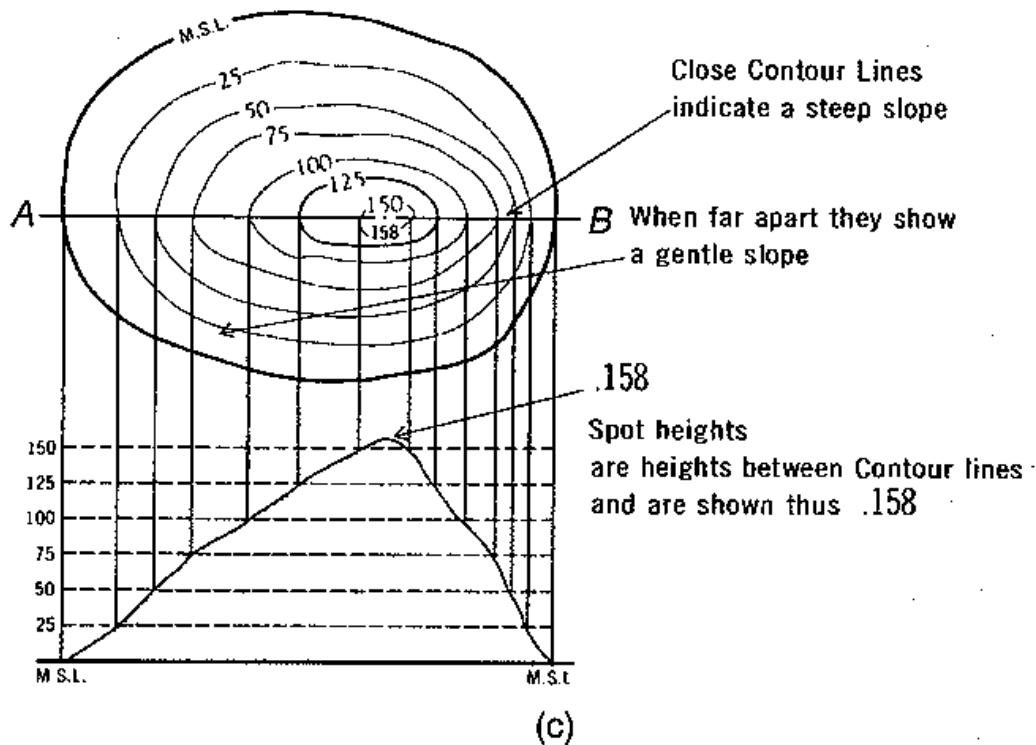


Figure 1.3 Contour plan with derived profile

1.2.3.1 Factors on which Contour Interval depends

The contour interval depends upon the following factors:-

- i) The Nature of the Ground. In flat and uniformly sloping country, the contour interval is small, but in broken and mountainous region the contour interval should be large otherwise the contours will come too close to each other.
- ii) The Purpose and extent of the survey. Contour interval is small if the area to be surveyed is small and the maps are required to be used for detailed design work or for determining the accurate quantities of earth work etc. while wider interval shall have to be kept for large areas and comparatively less important works. . In case of location surveys, for lines of communications and for reservoir and drainage areas, where the extent of survey is large, a large contour interval should be used. If the contour interval is small, greater time and funds will be required in the field survey, in reduction and in plotting the map.
- iii) The Scale of the Map. The contour interval should be in the inverse ratio to the scale of the map i.e. the smaller the scale, the greater is the contour interval.
- iv) Time and Expense of Field and Office work. The smaller the interval, the greater is the amount of field-work and plotting work.

1.2.3.2 Common Values of the Contour Interval

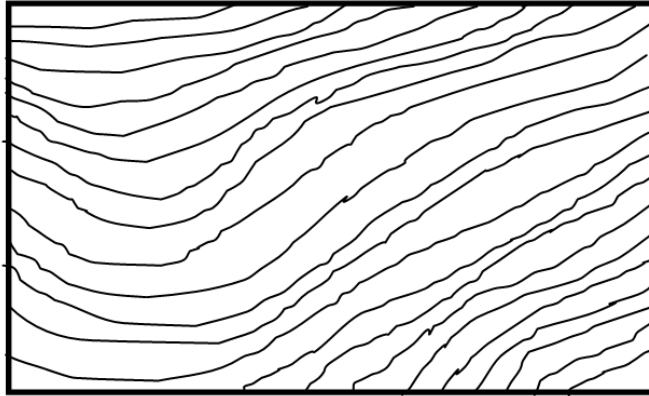
The following are the common values of the contour interval adopted for various purposes:-

- i) For large scale maps of flat country, for building sites, for detailed design work and Calculation of quantities of earth work; 0.2 to 0.5 m.
- ii) For reservoirs and town planning schemes; 0.5 to 2m
- iii) For location surveys; 2 to 3m.
- iv) For small scale maps of broken country and general topographic work; 3m,5m,10m,or 25m.

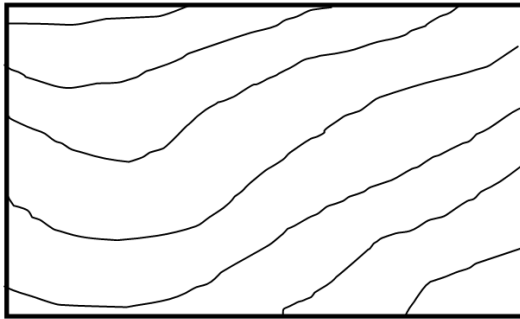
1.2.4 CHARACTERISTICS OF CONTOURS

The following characteristics help in plotting or reading a contour map

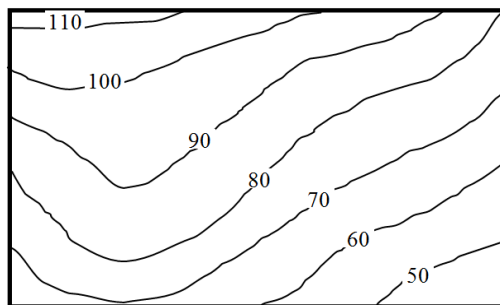
- 1.) Closely spaced contours indicate steep slopes.



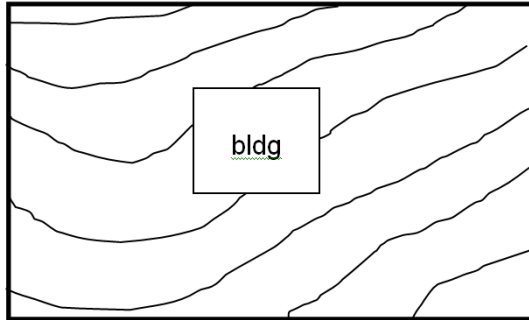
- 2.) Widely spaced contours indicate moderate slopes
(spacing here is a relative relationship).



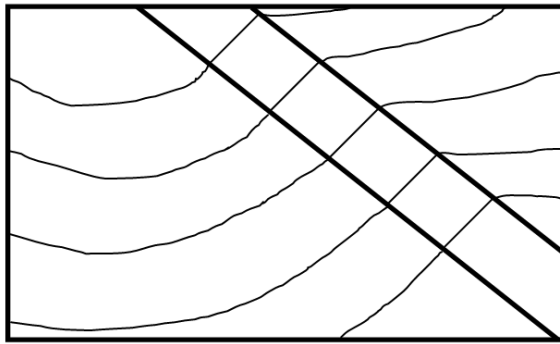
- 3.) Contours must be labeled for elevation value.



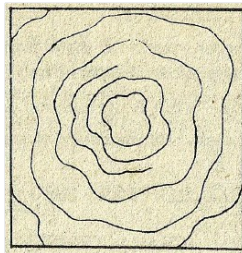
- 4.) Contours are not shown through buildings.



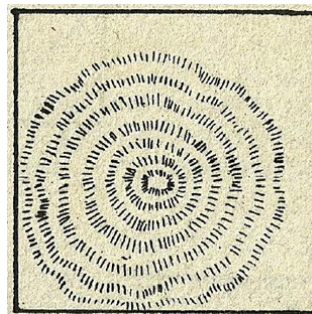
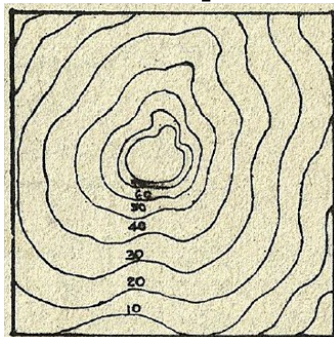
- 5.) Contours crossing a man-made horizontal surface (i.e. roads, railroads) will be straight parallel lines as they cross the facility.



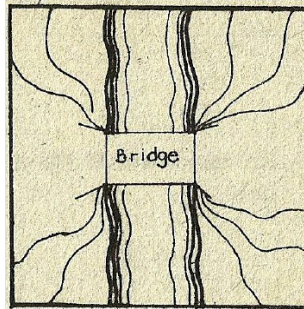
- 6.) Contour lines cannot begin or end on the plan. A contour line must close itself but need not be necessary within the limit of the map.



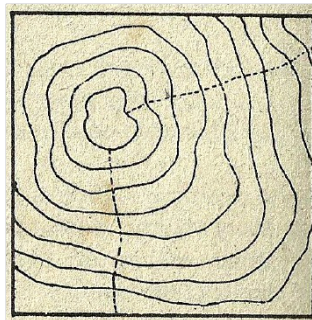
7. A closed contour indicates either a summit or depression. A hachured, closed contour line indicates a depression.



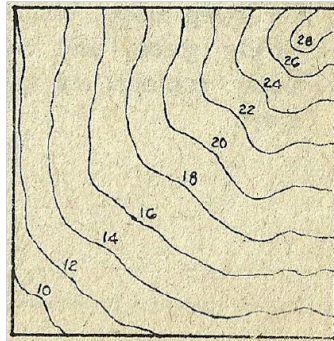
8. As contour lines represent contours of different elevation on the ground, they cannot merge or cross one another on the map, except in cases where there is an overhanging cliff or cave, or bridge abutments.



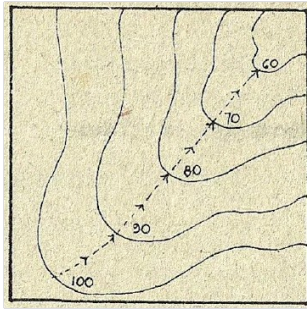
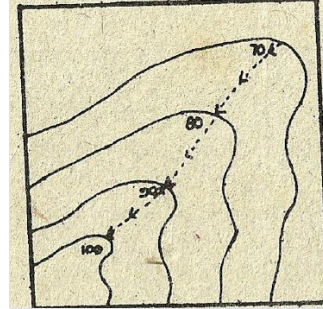
9. As contour lines represents level lines, they are perpendicular to the lines of steepest slope. They are perpendicular to ridge and valley lines where they cross such lines.



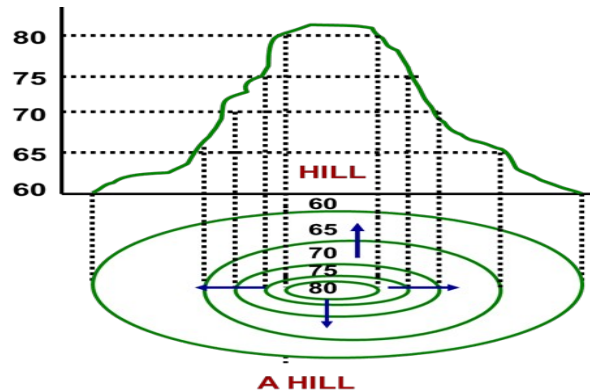
10. On uniform slopes, the contour lines are spaced uniformly.



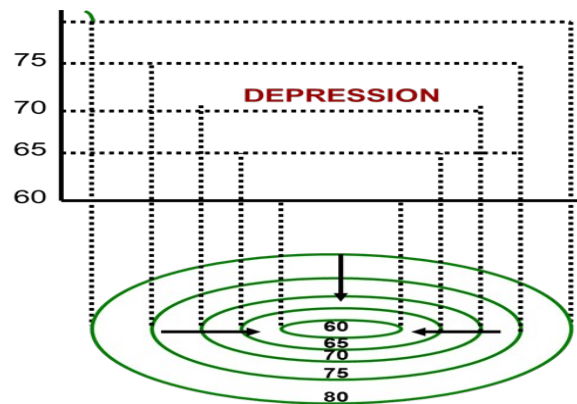
11. Contours deflect uphill at valley lines and downhill at ridge line; line crossing are perpendicular: U-shaped for ridge crossings; V-shaped for valley crossings. The concavity in contours lines is towards higher ground in the case of ridge and towards lower ground in the case of valley.

**Valley****Ridge**

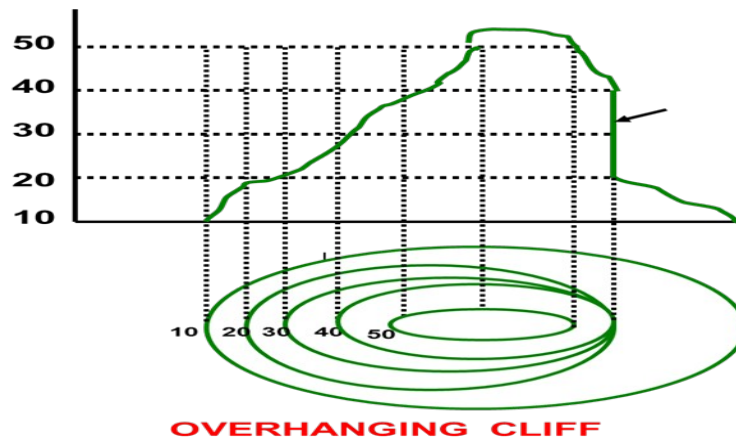
12. A series of closed contour lines on the map represent a hill, if the higher values are inside.



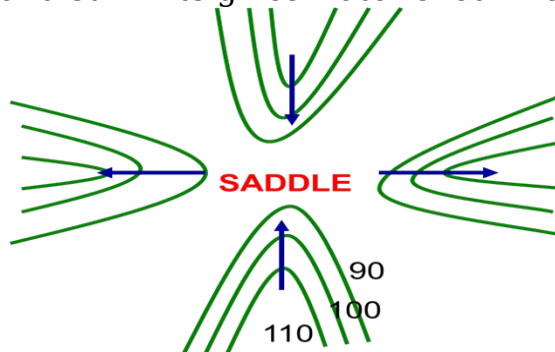
13. A series of closed contour lines on the map indicate a depression if the higher values are outside.



14. Contours of different elevations cannot unite (never run into one another) to form one contour, except in the case of a vertical cliff. In this case, several contours coincide and the horizontal equivalent becomes zero.



15. Depressions between summits is called a saddle. It is represented by four sets of contours as shown. It represents a dip in a ridge or the junction of two ridges. And in the case of a mountain range, it takes the form of a pass. Line passing through the saddles and summits gives water shed line.



16. Contours do not have sharp turnings

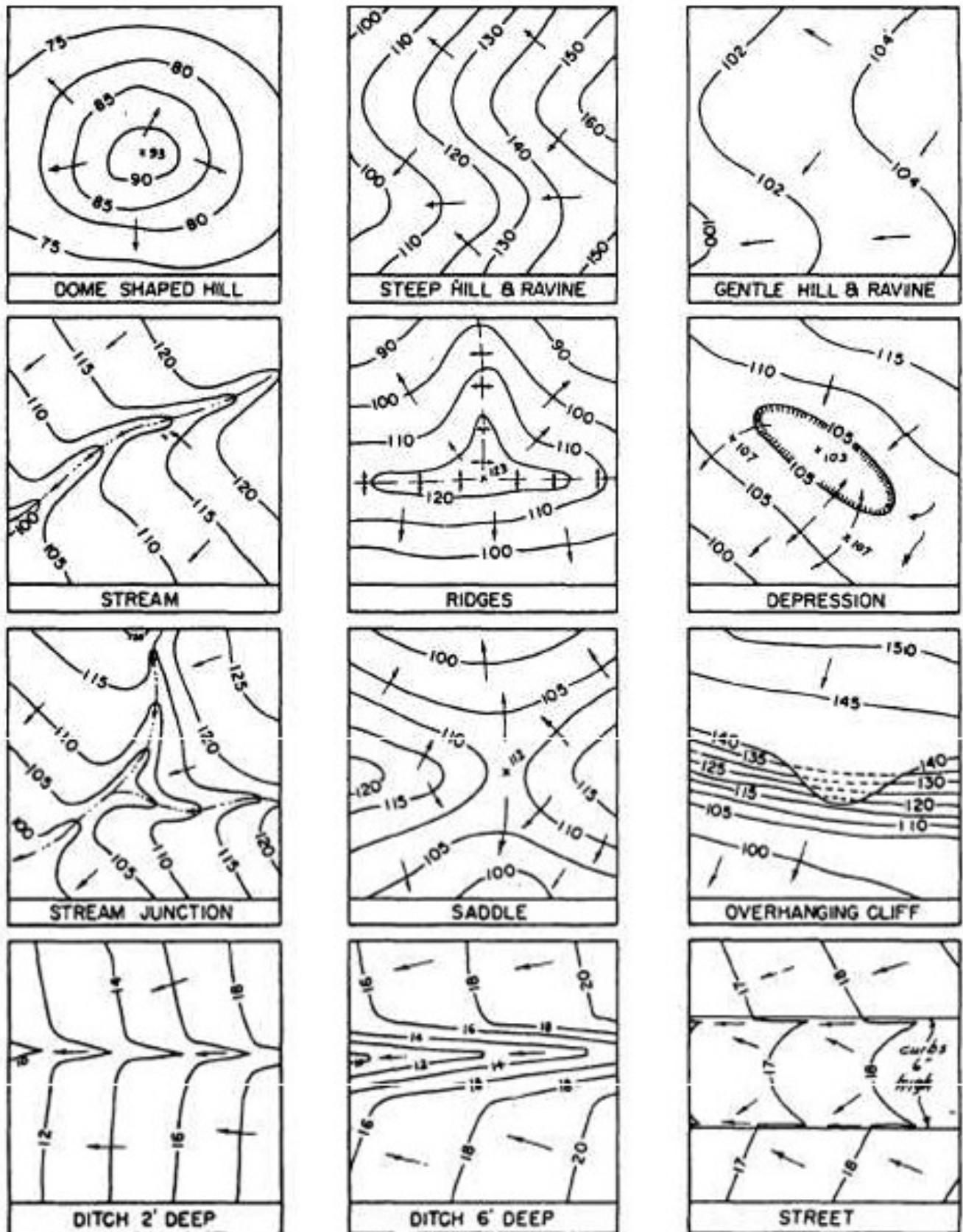


Figure 1.4 Typical contour characteristic

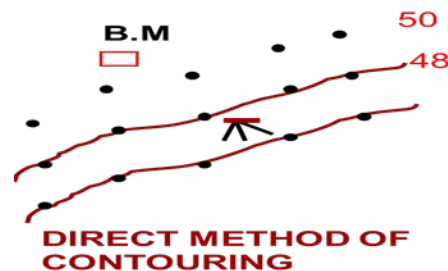
1.2.5 Methods of Contouring

Contouring requires the planimetric position of the points whose elevations have been determined by leveling. The methods of locating contours, therefore, depend up on the instrument used to determine the horizontal as well as vertical position of several points in the area. In general, however the field methods may be divided in to the following two classes:

- Direct Methods
- Indirect Methods

1.2.5.1 Direct Methods

In the direct methods, the contour to be plotted is actually traced on the ground. Only those points are surveyed which happen to fall on a particular contour. After having surveyed such points, they are plotted and joined. The method is slow and tedious. This method is employed only for a small area where superior accuracy is demanded.



1.2.5.2 Indirect Methods

In this method the points located and surveyed are not necessarily on the contour lines but the spot levels are taken along the series of lines laid out over the area. The spot levels of the several representative points representing hills, depressions, ridge and valley lines and the changes in the slope all over the area to be contoured are also observed. Their positions are then plotted on the plan and the contours drawn by interpolation. This method of contouring is also known as contouring by spot levels. In this method, sufficient number of points are located and given spot levels. The contours in between spot levels are **interpolated** and drawn.

There are three different ways of employing the indirect method of contouring

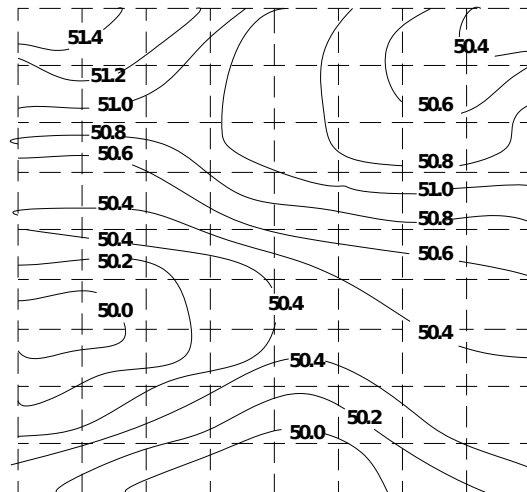
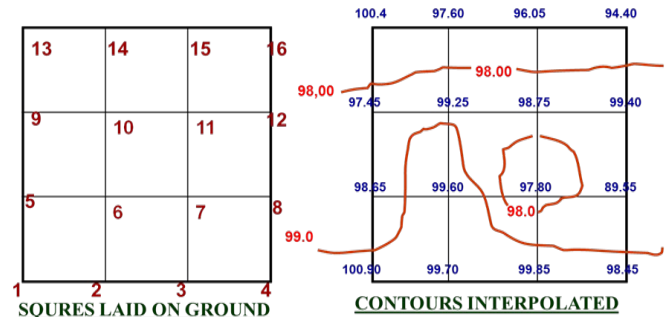
- **Grid Method(Square method)**
- **Cross-section Method**

- **Radial Line Method**

➤ **Grid Method**

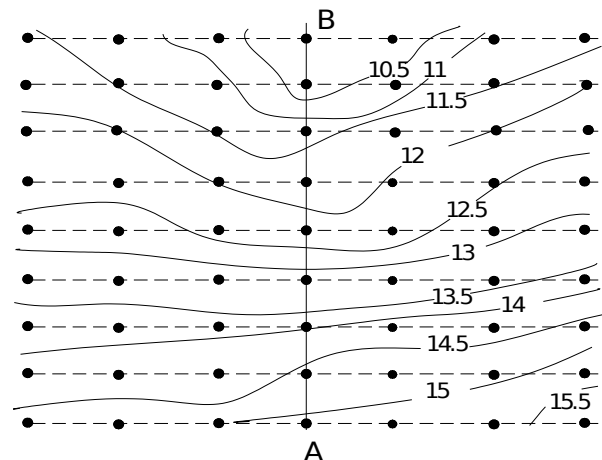
If the area is not large, it is divided into a grid or series of squares. The grid size may vary from 5 m X 5 m to 25 m X 25 m depending upon the nature of the ground, the contour interval, and the scale of the map. Also, the grids may not be of the same size throughout but may vary depending upon the requirement and field conditions. The grid corners are marked on the ground and spot levels of these corners are given by normal method of leveling using a level. The contours of desired values are then located by interpolation. This method is commonly employed in all kinds of surveys as this is cheaper, quicker and less tedious as compared to direct method. The corners of the squares are pegged out and the reduced levels of these points are determined with a level. The squares are plotted and the

reduced levels of the corners are written on the plan.



Contouring by Grid Method

contours are interpolated assuming uniform slope between adjacent points and joined by a smooth curve.



Contouring by Cross-Section Method

➤ Radial Lines Method (Tachometric method):

In this method, a number of radial lines are set out at known angular interval at each station and points are fixed at convenient constant distance apart on the rays that are set by compass or, for greater accuracy, by theodolite. This method is convenient in hilly terrain with level stations chosen at high points so as to command a large area from each. Horizontal distance may be obtained by taping. If we are using theodolite it may also be used for providing horizontal and vertical controls. A number of radial lines are laid out at a known angular interval and representative points are marked by pegs along these radial lines. Their elevations and distances are then calculated and plotted on the plan and the contour lines are then interpolated. A **tachometer** is a transit theodolite having a diaphragm fitted with two stadia wires, one above and other below the central wire. The horizontal distance between the instrument and staff station may be determined by

multiplying the difference of the staff readings of the upper and lower stadia wires with the stadia constant of the instrument, which is usually 100. Thus the tachometer is used for both the vertical as well as horizontal measurements.

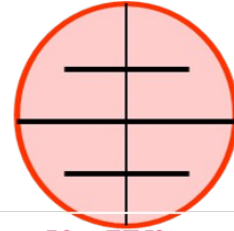
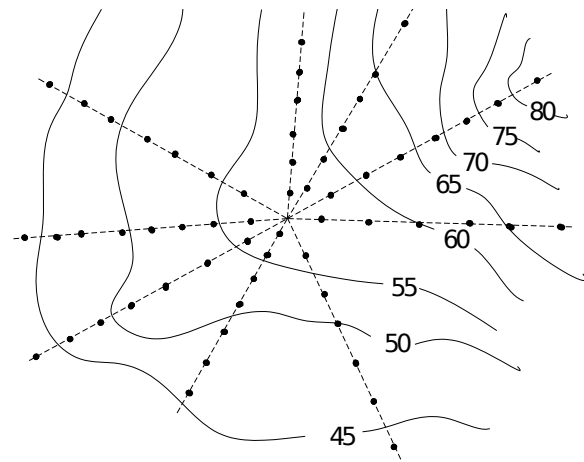


Fig. Stadia Wires at Diaphragm



Contour by Radial Line Method

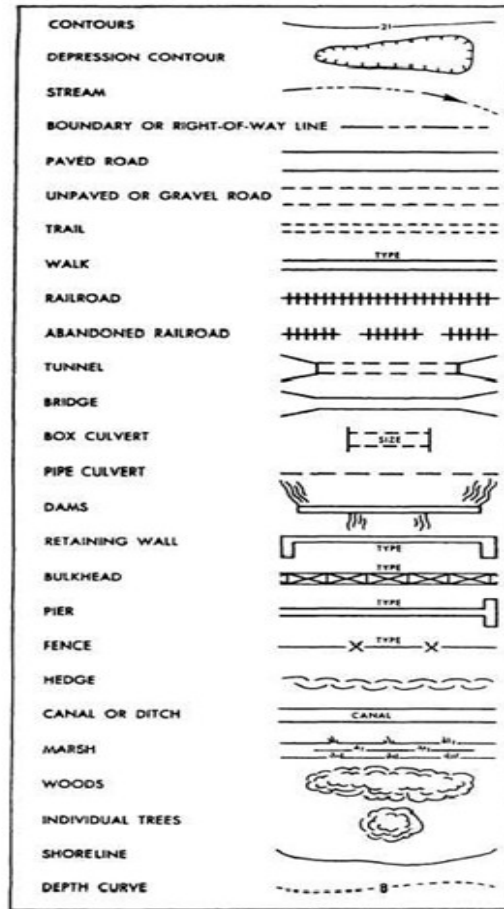


Figure 1.5 Commonly used map symbol

1.2.6 Interpolation of Contours

The process of spacing the contours proportionally between the plotted ground points is termed as interpolation of contours. It is also defined as the process of determining intermediate values between two points. This becomes necessary in the case of indirect contouring as only the spot levels are taken in this method.

There are three main methods of interpolation:

i) By Estimation: The position of the contour points between ground points are estimated roughly and the contours are then drawn through these points. This is a rough method and is suitable for small scale maps.

ii) By arithmetical calculation: This is very tedious but accurate method and is used for small areas where accurate results are necessary. The contours are interpolated by arithmetical calculation: Suppose A and B are two points at a distance of 30 m and the reduced level of A and B are 25.45m and 27.54m

respectively. Taking the contour interval as 1m, 26 and 27 m contours may be interpolated in between A and B. The difference of level between A and B is 2.09m. the difference of level between A and 26m, and A and 27m is 0.55m and 1.55 m respectively.

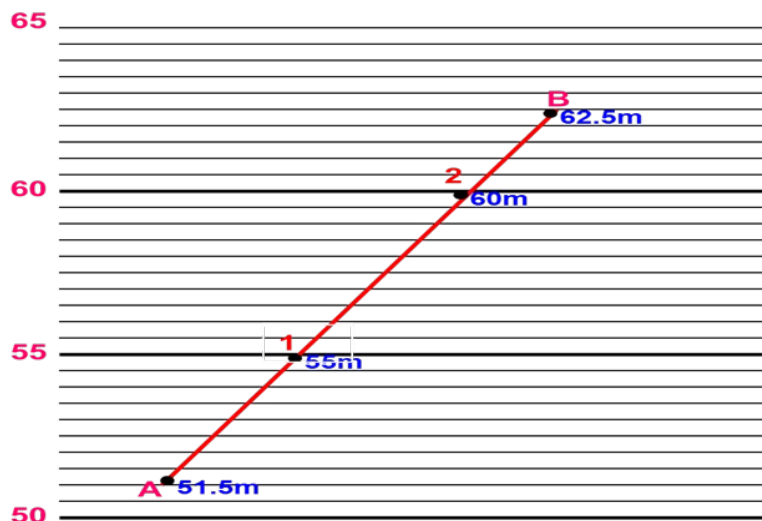
Therefore the horizontal distance between A and 26 m contour $= 0.55/2.09 \times 30\text{m}$ and

Between A and 27 m contour $= 1.55/2.09 \times 30\text{m}$.

These distances are then plotted to scale on the map.

(iii) By Graphical method

Graphical method of interpolation is simpler as compared to arithmetical method and also the results obtained are accurate. Out of several graphical methods, the most common is as given below:



Graphical method

As shown in the fig. suppose the contour interval is 5m, then on a piece of tracing cloth, a number of parallel lines spaced at 0.5 m (usually 1/10th of the contour interval) are drawn. Every tenth line being made thick. Suppose it is required to interpolate contours between two points A and B of elevation 51.5m and 62.5m respectively. If the bottom line represents an elevation of 50, then the successive thick lines will represent 55m, 60m and 65m, etc. Place the tracing cloth so that the point A is on the third line from the bottom, now move the tracing cloth until B is on the fifth line above the 60m thick line. The intersection of the thick lines 1 and 2 representing elevations of 55m and 60 m and the line

AB give the position of the points on the 55m and 60m contours respectively and are pricked through on the plan with a pin.

1.2.7 Drawing the Contour lines

Contour lines are drawn as fine and smooth free hand curved lines. Sometimes they are represented by broken lines. They are inked in either in black or brown color. A drawing pen gives a better line than a writing pen and French curves should be used as much as possible. Every fifth contour is made thicker than the rest.

The elevation of contours must be written in a uniform manner, either on the higher side or in a gap left in the line. When the contour lines are very long, their elevations are written at two or three places along the contour. In the case of small scale maps, it is sufficient to figure every fifth contour.

1.2.8 USES OF CONTOUR MAP

- (i) Determination of the characteristics of the terrain or features of the ground, whether it is flat, undulating or mountainous.
- (ii) Selection of suitable site
- (iii) Determination cross-section. From a contour map, sections may be easily drawn in any direction.
- (iv) Inter-visibility between two points. Inter-visibility between two ground points plotted on map can be ascertained.
- (v) It enables an engineer to approximately select the most economical or suitable site for an engineering project such as a road, a railway, a canal or a pipe line etc.
- (vi) Location of route. A route of a given grade can be traced on the map.
- (vii) Determination of the catchments area. Catchment area and capacity of a reservoir may be determined from the contour map.
- (viii) Contour map may be used to determine the quantities of earth work. eg. Estimation of reservoir capacity.

1.3 Source of error in topographic survey

1. Control not established, checked and adjusted before topography is taken
2. Control point too far apart
3. Control points poorly selected for proper coverage of area

Handout 1, Topographic Surveying and Mapping

4. Poor selection of points for contour delineation

1.4 Mistakes in topographic survey

1. Improper selection of contour interval
2. Unsatisfactory equipment or field method for particular survey and the terrain conditions.
3. Insufficient horizontal and vertical control of suitable precision.
4. Too few contour points chosen
5. Omission of topographic details

1.5 Digital Elevation Model

A Digital Elevation Model (DEM) is a digital file providing a highly detailed representation of the topographical (i.e. relief) variations in the Earth's surface. Combined with other digital data, such as maps or orthophotographs, it can provide a 3D image of the land surface. Consisting of terrain elevations for ground positions at regularly spaced horizontal intervals, the added dimension and visualization offered by a DEM can help in many decision-making processes.

Applications

- Planning
- Engineering
- Visualization
- Height Analysis
- Environmental Impact Analysis
- Wind flow and pollution dispersion
- Soil erosion modeling
- Flow direction and accumulation
- Watershed delineation

Data for use in automated contouring system is collected in arrays of points whose horizontal positions are given by their X and Y coordinates and whose elevation are given as Z coordinates. Such three-dimensional arrays provide a digital elevations model (DEMs). Alternatively, the term digital terrain model (DTM) is sometimes used.

Two geometric configurations are normally used in the field for collecting DEM data: **the grid method**, and **the irregular method**, although often a

combination of the two methods is employed. In the grid method, elevations are determined on points that conform to a regular square or rectangle grid. From the array of grid data, the computer interpolates between points along the grid lines to locate contour points and then draws the contour lines. The major disadvantage of this method is that critical high and low points and changes in slope do not generally occur at the grid intersections, and thus they are missed in the data collection process, which result inaccurate relief portrayal.

The irregular method is simply involves determining the elevations of all high and low points and points where slopes change (called breaks in grade change). Of course, this produces a DEM with an irregularly spaced configuration of surveyed points.

The first step taken by computerized contouring systems that utilize irregular spaced spot elevations is to create a so-called triangulated irregular network (TIN) model of the terrain from the spot elevations. It is very important to understand the TIN model concept to ensure that an appropriate array of controlling points is selected and surveyed in the field if an automated contouring system is to be used. A TIN model is constructed by connecting points in the array to create a network of adjoining triangles. Various criteria can be used in the development of TIN models from any array of surveyed points, but one commonly used standard creates the “most equilateral network” of triangles.

Automated contouring systems generally make two assumptions concerning TIN models: (1) all triangle sides have a constant slope, and (2) the surface area of any triangle is a plane. Based on these assumptions, elevation of contour crossings are interpolated along the triangle edges and contours are constructed such that they change direction only at triangle boundaries.

It is important to note that additional information must be provided for computer-driven system to depict contours accurately. That important added information is the identification of contouring features, also more often called breaklines, or fault lines in modern computer mapping terminology. Breaklines are linear topographic features that delineate the intersection of two surfaces that have uniform slopes, and thus define changes in grade. Automated mapping

algorithms use these lines to define sides of the triangle that form the TIN model, and thus elevations are interpolated along them. Streams, lake shores, roads, railroads, ditches, ridgelines, etc. are example of controlling features or break lines. Curved breaklines such as streams must have enough data points so that when adjacent one are connected with straight lines, they adequately define the feature's alignment.

The important lesson of the foregoing is that an automated contouring system is used, field points must be selected carefully, breaklines identified, and the data properly input to meet the system's assumptions.

In order to avoid missing significant data during topographic surveys, it is usually best to collect features in groups. This is, data should be gathered first for (1) Planimetric features, followed by (2) breaklines, (3) significant controlling points of elevation, and finally (4) sufficient grade points (those remaining points surveyed only to enable accurate depictions to be made of slopes and grades between the other types of points). Grade points are often most efficiently collected in a grid pattern throughout the entire area to be mapped. This grid should be sufficiently dense to avoid triangles in the TIN that are geometrically weak; i.e., long and slender figures with one small angle. Varying grid size can be used, with larger spacing applied in areas of gradual slopes, and more dense patterns employed as the terrain becomes more undulating.

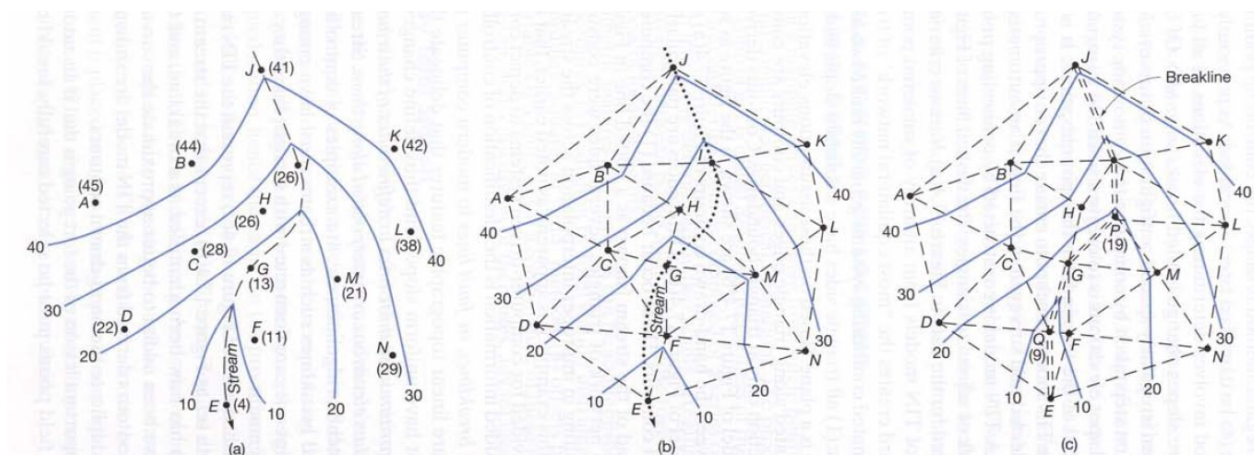
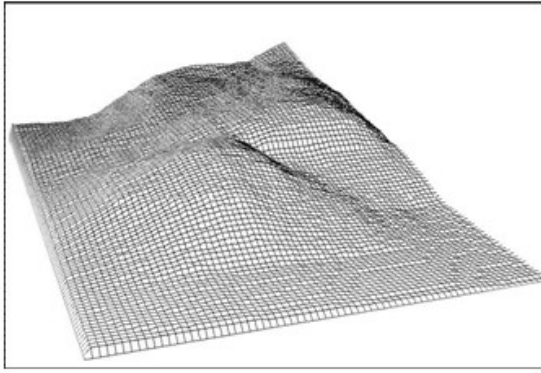
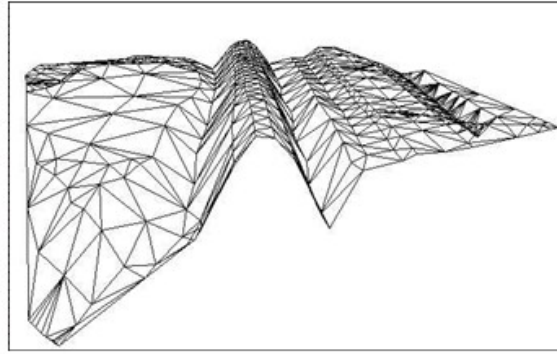


Figure 1.6 a) Contours compiled by hand from controlling points A to N b) TIN Model (dashed lines) constructed from data of a), and c) TIN Model (dashed lines) constructed from data of a) but with additional break lines.



a)



b)

Figure 1.7 a) Digital Elevation Model in grid method b) Digital Elevation Model in irregular method