1.16 Contouring

A map represents 3D Earth surface onto 2D paper. While, the planimetric position of any object/feature is depicted by their latitude and longitude, the third dimension (i.e., elevations) on the maps are represented by the contours. Contour line is an imaginary line on a map, drawn through the points of equal elevation (Figure 1.33). In addition, there might be few BMs present on the maps whose elevations are known. The elevations of various objects/features can be obtained by levelling, and the spot levels of well distributed points to provide a fair representation of minimum and maximum elevations in the area. Their utility in the present form is, however, limited as they don't convey a meaningful information about the variation of topography. The color; hachures, shading, and tinting have also been used to show the relief, but these methods are not quantitative enough, and thus are generally not suitable for surveying and engineering work.

Contour lines, on the other hand, represent much more valuable information about third dimension on the map. They also give a fairly good idea about the topographic slope and the characteristics of terrain present. If a level surface at an elevation is intersected by the ground surface, the outer shape of the ground depicts the contour line at that elevation. The best example of a contour line is the outer line of a lake. Various contour lines at different heights can be drawn on a map by selecting a suitable interval, called *contour interval*.

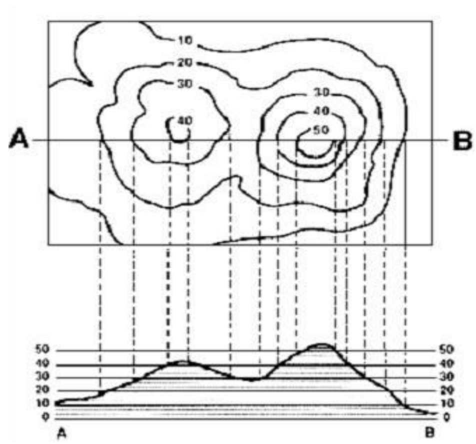


Figure 1.33 Representation of contours

1.16.1 Contour interval

The constant vertical distance between the successive contours is called the contour interval. Smaller the contour interval, greater will be the fieldwork to collect the elevation data. A contour interval sufficient to show features in a hilly region would be insufficient in flat regions. A contour interval for an area/project depends upon several factors, such as the nature of ground, the purpose and extent of survey, the scale of mapping, and the time & funds available.

In a fairly flat area, a large map scale may be appropriate with small contour interval to depict the small ground variation, while in hilly areas, a small scale map with large contour interval will be adequate for representation of details. The contour interval therefore is inversely related to the scale of the map. Small scale maps require large contour interval

otherwise the amount of work will tremendously increase. As an example, the recommended values of the contour intervals are as follows:
For building sites: 0.5 m
For reservoirs, town planning schemes: 1 to 2 m
For location surveys: 2 to 5 m
For topographical surveys: 5 m and above.

1.16.2 Factors deciding the contour interval
Contour interval on a map is decided by the following factors:

(a) Scale of the map: The contour interval is kept inversely proportional to the scale of the map. Smaller the scale of map, larger the contour interval. On the other hand, if the scale of the map is large, the contour interval should be small. If, on a small scale map a small contour interval is taken, the horizontal distance between two consecutive contours, known as *Horizontal equivalent,* would also be small and these contours might unite together. It therefore necessitates selecting the large contour interval on small-scale maps.

(b) Purpose of the map: The contour interval also depends upon the purpose for which the map is to be utilised. If the map is prepared for setting out a highway on hill slopes, a large contour interval might be required. But, if the map is required for the construction of a university campus, a small contour interval is needed for accurate work.

(c) Nature of the ground: The contour interval depends upon the general topography of the terrain. In flat ground, contours at small intervals are surveyed to depict the general slope of the ground, whereas high hills can be depicted with contours at larger contour interval. In other words, the contour interval is inversely proportional to the flatness of the ground i.e., steeper the terrain, larger the contour interval.

(d) Availability of time and funds: If the time available is less, greater contour interval is selected to complete the project in the given time. On the other hand, if sufficient time is available, a smaller contour interval might be taken, keeping in view all the other factors as already described.

It may be noted that contour interval should be such that depending upon the scale of the map, purpose of the map, availability of time and nature of the ground, correct topography of the terrain may be depicted clearly.

1.16.3 Characteristics of contour lines
1. Concentric closed contours with decreasing values towards centre indicate a pond or depression.
2. Concentric closed contours with increasing values towards centre indicate a hill.
3. The same contour would appear on either side of a ridge or a valley.
4. Contour lines with the concavity (inverted V-shape) towards the higher ground indicate a ridge.
5. Contour lines cross with convexity (V-shape) towards the higher ground indicates a valley.

6. Closed contours indicate a steeper slope of the ground.
7. Irregular contours indicate uneven surface.
8. Equally spaced contours indicate uniform slope of the ground.
9. If the contours are straight, parallel and widely spaced, the ground is fairly level with gentle slope.
10. The shortest distance between successive contours indicates the direction of steepest slope, i.e., the steepest slope at a point on a contour is therefore at right angles to the contour.
11. The slope between two adjacent contour lines is assumed to be uniform.
12. A contour cannot branch into two contours at the same elevation.
13. Contours can't have sharp turns.
14. Contour lines of the same elevation can't merge together or intersect, except only in case of a vertical cliff, an overhanging cliff or a cave.
15. A contour must close, not necessarily in the limits of a map.
16. The contour lines don't cross the water surface, (e.g., river, pond).

Contour lines of different terrain shapes are presented in Figure 1.34

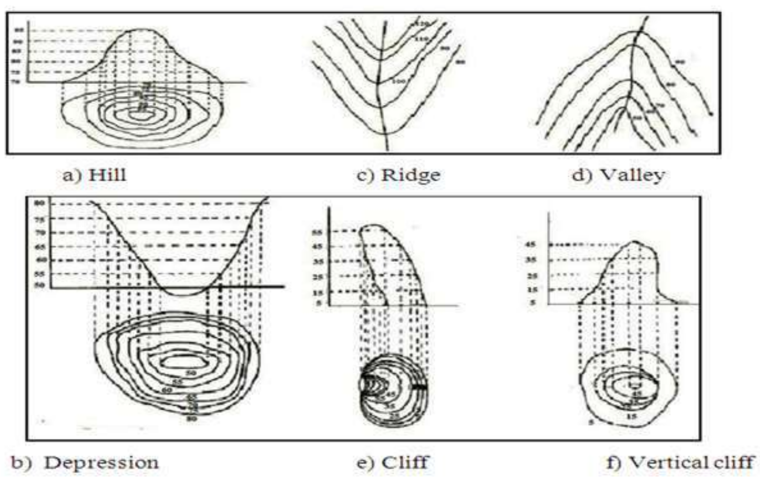


Figure 1.34 Contours depicting various shapes of the ground (e-Krishi Shiksha, 2019)

1.16.4 Uses of a contour map

Maps with contours on them are extremely useful for various engineering projects, as listed below:

1. Contours are most often used to depict the relief. Contours depict the nature and characteristics of the ground, hence useful to identify the suitable site for the project.
2. Profiles of the ground along a line and its cross-section can be drawn using contours. These help in computing the volume of earthwork (i.e., cutting and filling), if the formation level of project is known.
3. The optimum route of the railway, road, canal, pipe line or sewer line can be decided which can minimize the earthwork or balance the earthwork.
4. Intervisibility between any two points can be ascertained from the longitudinal profile of the ground, which is very important in many projects, such as airport planning.

5. Catchment boundary of a river can be drawn and area determined. It helps in determining the quantity of water available at any point along a river. Such study is very important in deciding the location of the bunds, dams, etc.
6. From the contours, the capacity of a reservoir is determined.

1.16.5 Methods of contouring

There are two main methods of surveying:

(a) **Direct method-** This method finds the elevation of points in the area which lie on the selected contour line. The level instrument is set at a commanding position in the area and the elevation of line of collimation of instrument is determined. The required staff reading for a given contour line is then computed. The levelling staff is moved up and down in the area till the required staff reading is observed. The elevation of that point is marked on the plotted map. In this manner, all the points with same staff readings in the area are established, and in the process the instrument is also shifted to another station to cover more area. The same process is repeated for the next value of contour. This method is accurate but slow and tedious, hence suitable for small areas.

(b) **Indirect methods**- Here, RLs of some selected points (also known as *spot levels*) are taken. The contour lines are interpolated using the RLs of these selected points. For selecting the points, several approaches may be used: (*i*) Method of squares, (*ii*) Method of cross-section, and (*iii*) Radial line method. Out of the three approaches, first approach is most commonly used. In the method of square, the area is divided into a number of squares and all grid points are marked on the ground at regular interval. The grid interval is to be decided by the surveyor, depending on the terrain and scale of mapping. The RLs of all grid points are determined by levelling. The square grid is plotted on the drawing sheet, and RLs of grid points marked. Points of specific elevation value are drawn by linear interpolation method. These points are joined together with smooth contour line and its elevation value is written along the contour line. French curves may be used for drawing the smooth lines. To provide, more readability to contour values, every fifth contour line is made slightly thicker.

Contours are drawn on maps by interpolating between points whose positions and elevations have been measured and plotted. Although, computerized mapping and contouring systems are replacing the manual plotting methods, but the principles of interpolating contours are still basically the same.

1.16.6 Digital elevation models (DEMs)

Elevation data form one of the important sources of ancillary data, which is most widely used in Earth-related investigations. The most common form for representation of elevation data in digital format is the grid type or raster format. The elevation matrix consists of a well- known regular grid of elevations representing real topography. Several names are in current use, including Digital Terrain Model (DTM), Digital Elevation Model (DEM), Digital Elevation Data (DED) and Digital Ground Model (DGM).

A DEM is an ordered array of numbers that represents the spatial distribution of elevations above some arbitrary datum in the landscape. It is a numerical representation of the spatial variation in land-surface elevation, which represents the land-surface as a matrix of elevation values (Z) implicitly located by their geographic coordinates (X, Y). Any point in a DEM can be related to its neighboring cells if the data storage is regular. While DEM consists of an array of values that represent topographic elevations measured at equal intervals on the Earth surface, the Digital Terrain Model (DTM) comprises of any terrain data. A DTM is a topographic map in digital format, consisting not only of a DEM, but also the types of land use, settlements, types of roads and drainage lines and so on.

Applications of DEM

Contours from topographic maps, stereo-air photos or stereo-satellite images can be used to generate DEM. The requirements of elevation and positional accuracy at different scales are given in Table 1.5. Once the DEM is in digital form, large number of other products may be derived from it useful for road planning and layout purposes.

Table 1.5 Requirements of contour interval for standard maps (Garg, 2021)

Map scale	*Positional accuracy (m)*	*Elevation accuracy (m)*	*Typical C.I. (m)*
1:1,000,000	300	30	100
1:5,00,000	150	15	50
1:250,000	75	8	25
1:1,00,000	30	6	20
1:50,000	15	3	10
1:25,000	8	2	5

DEMs have several applications, which include–

(i) Site selection for engineering projects
(ii) Analysing and comparing different types of terrain
(iii) Selecting the alignment of roads, railways, canals, pipelines, etc.
(iv) Cut-and-fill analysis in road design and other engineering projects.
(v) Computing terrain parameters (e.g., slope, aspect, profiles, catchment area, etc.) to assist runoff and erosion studies.
(vi) Displaying landforms in three dimensions, for design and planning of landscape
(vii) Generating drainage network for hydrological studies.
(viii) Ascertaining the intervisibility between two points
(ix) Improving classifications when combined with satellite data.
(x) Storing elevation data for digital topographic maps in national databases.

DEM can be considered analogous to digital remote sensing images, except that each pixel represents an elevation measurement, rather than a brightness value. Various derived products can be obtained from DEM such as -

1. Block diagrams, profiles and horizons
2. Volume estimation by numerical integration
3. Contour maps
4. Line of sight maps
5. Maps of slope convexity, concavity, and aspect

6. Shaded relief maps
7. Drainage network and drainage basin delineation

1.16.7 Area and volumes

The land is always dealt with area. For any engineering project, land is acquired first on the basis of area requirement. In some projects, land may be required along a corridor of defined width (e.g., rail, road, pipeline etc.), while in other projects a large catchment area may be involved, such as flood protection devices, reservoir, etc.). Thus, determining the requirement of area in a project is an essential part of surveying. Similarly, the volume of earthwork involved in projects, like road, rail, canal etc., or capacity of a reservoir, are to be determined by surveying methods.

(a) Computation of areas

It is very easy to determine the area of a regular figure (plot of land), such as a triangle, a square, a rectangle, etc. However, most of the time, the project land is irregular in shape with no defined shape, so computation of area is not straight forward in such cases. For this purpose, from a survey line offsets are taken at regular intervals, and area is calculated from any of the following methods:

(*i*) Trapezoidal rule
(*ii*) Simpson's rule
(iii) Using planimeter
(iv) From coordinates

(i) Trapezoidal rule

In trapezoidal rule, the area is divided into a number of trapezoids, (as shown in Figure 1.35) and boundaries are assumed to be straight between pairs of offsets. The area of each trapezoid is determined and added together to compute the entire area. If there are 'n' offsets at equal interval of 'd' then the total area is computed as-

$$A = d\left(\frac{O_1 + O_n}{2} + O_2 + O_3 + \dots\dots\dots + O_{n-1}\right) \qquad (1.10)$$

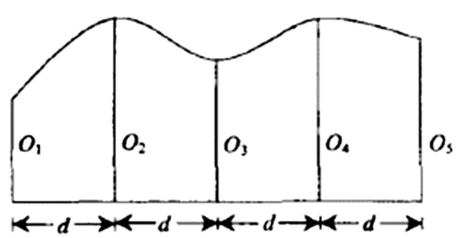


Figure 1.35 Area of trapezoids

(ii) Simpson rule

In Simpson's rule, it is assumed that the irregular boundary is made up of parabolic arcs. The areas of the successive pairs of intercepts are added together to get the total area, as below:

$$A = \frac{d}{3}\left[(O_1 + O_n) + 4(O_2 + O_4 + \dots\dots + O_{n-2}) + 2(O_3 + O_5 + \dots\dots + O_{n-1})\right]$$

(1.11)

(iii) Using Planimeter

Planimeter is a mechanical instrument used for measuring the area of a plan. It consists of a hard steel roller and a disc. The axis of roller coincides with the axis of tracer arm, hence it rolls only at right angles to the tracer arm. The roller carries a concentric drum which has 100 divisions, and is provided with a vernier to read tenth of roller division. A suitable gear system moves a pointer on disc by one division for every one revolution of the roller. Since the disc is provided with 10 such equal divisions, the reading on the integrating unit has four digits: (*i*) Unit read on the disc, (*ii*) Tenth and hundredth of a unit read on the roller, (*iii*) Thousandth read on the vernier. If the reading on disc is 2, reading on roller is 42 and vernier reads 6, then the total reading F = 2.426.

To find the area from a map, anchor pin of the planimeter may be placed either outside the map if the area on the map is small or inside the map if the area on the map is large. It is placed outside the plan. On the boundary of the area, a point is marked and tracer arm is set on it. The planimeter reading is taken. Tracer arm is carefully moved over the outline of the area in clockwise direction till the starting point is reached. The reading of planimeter is noted. Now the area of the plan may be determined as-

$$\text{Area} = M\,(F - I + 10\,N + C) \qquad (1.12)$$

where M is the multiplying constant is equal to the area of the plan (map) per revolution of the roller i.e., area corresponding to one division of disc
F is the final reading
I is the initial reading
N is the number of completed revolutions of disc. Plus sign to be used if the zero mark of the dial passes index mark in clockwise direction and minus sign if it passes in anticlockwise direction.
C is the constant of the instrument, which when multiplied with M, gives the area of zero circle. It is added only when the anchor point is inside the area.
Multiplying constants, M and C, are normally written on the planimeter. The user can verify these values by (*i*) Measuring a known area (like that of a rectangle) keeping anchor point outside the area, and (*ii*) Again measuring a known area by keeping anchor point inside a known area.

(iv) From coordinates

The area of an irregular closed polygon is usually computed by the coordinate method. In this procedure, coordinates of each turning point in the figure must be known. They are normally obtained by traversing, but any other method (e.g., GPS or LiDAR) that provides the coordinates can also be used. The coordinate method is easily visualized; it reduces to one simple equation that applies to all geometric configurations of closed polygons, and can be easily programmed for obtaining solution through computer-based system. The procedure for computing areas by coordinates can be developed with reference to Figure 1.36 as shown below.

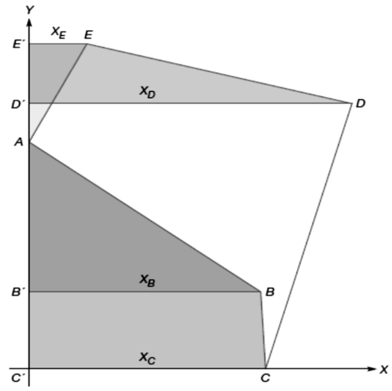
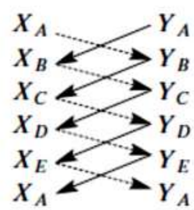


Figure 1.36 Computation of area of closed irregular polygon

$$2(\text{area}) = +X_AY_B + X_BY_C + X_CY_D + X_DY_E + X_EY_A - X_BY_A - X_CY_B - X_DY_C - X_EY_D - X_AY_E \tag{1.13}$$

The above equation can easily be remembered by listing the x and y coordinates of each point in in two columns, as shown below, with coordinates of the starting point repeated at the end. The products noted by diagonal arrows are ascertained with dashed arrows considered plus and solid ones with minus. The algebraic summation of all products is computed, and its absolute value is divided by 2 to get the area.



(b) Computation of volumes

The computation of volumes from the measurements taken in the field is required in design and planning of several engineering works. For example, volume of earthwork is required for feasible alignment of road, canal and sewer lines, etc. The computation of volume of various materials, such as coal, sand, gravel is required to check the stockpiles. For estimation of volume of earthwork, normally the cross sections are taken at right angles to a fixed alignment, which runs continuously through the earthwork. The spacing of the cross sections will depend upon the accuracy required. The volume of earthwork is computed from these cross-sections, using either the Trapezoidal rule or Prismoidal rule, as given below.

(i) Trapezoidal Rule

It is also known as average or mean sectional area formula. This method is based on the assumption that the mid-area of a pyramid is half the average area of the ends, and the end sections are in parallel planes.

If A_1 and A_2 are areas of the ends and d is the length between two sections, the volume of the prismoid is given by-

$$V = d/2\,[\,A_1 + A_n + 2\,(A_2 + A_3 + A_4 + A_5 + \ldots\ldots\ldots + A_{n-1}) \qquad (1.14)$$

where '*n*' are number of segments at interval of '*d*', Area at L = *nd*, being A*n*.

(ii) Prismoidal Rule

The prismoidal formula can be used to compute volume of all geometric solids that are considered as prismoids. A prismoid, as shown in Figure 1.37, is a solid having ends that are parallel but not similar and trapezoidal sides that are also not congruent. Most earthwork solids obtained from cross-section data fit into this classification.

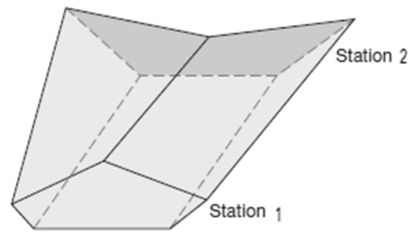


Figure 1.37 Prismoidal section

$$V = d/3\,[(A_1 + A_n) + 4\,(A_3 + A_5 + \ldots + A_{n-1}) + 2\,(A_2 + A_4 + \ldots + A_{n-2})] \qquad (1.15)$$

where *n* is number of even segments.