19 Geologic Geometry

SYLLABUS OUTLINE

Areas to be studied (in an applied context):

• Appropriate symbols and notation. • Interpolation and plotting of contours. • Methods of showing slopes and gradients. • Profiles determined from contours. • *Use of skew boreholes in mining problems.* • Determining the true dip of ore strata. • *Determining the apparent dip of ore strata.* • Strike and thickness of strata. • Determination of outcrop. • Cutting and embankment sections for level constructions. • *Cutting and embankment sections for inclined constructions.*

Learning outcomes

Students should be able to:

Higher and Ordinary levels

- Understand concepts such as bearings, grid layout, true north etc.
- Interpolate and plot contours on a map for given data.
- Show profiles determined from contours.
- Determine cuttings and embankments for level roads and surfaces.
- Determine the true dip, strike and thickness of strata.
- Determine the outcrop profile for given strata.

Higher level only

- *Determine cuttings and embankments for inclined roads and surfaces.*
- *Determine the apparent dip of strata.*
- *Solve mining problems through the use of skew boreholes.*

Our studies to date have concerned us with drawings of man-made objects, be they machine parts or houses. This chapter will investigate the natural geological features of the earth, mapping of the earth's surface, mining, and finally the excavatio works necessary for road building. Maps and map data are used throughout the course of the chapter. The accuracy of thes maps and this data is extremely important in this type of work because of the scale of these earthworks projects.

Like all subjects, geologic geometry has its own subject-specific terminology. A good starting point is to define and explain some of these terms with notes and diagrams.

Contours

A contour is a line on a map to locate all points of equal elevation. This elevation/height can be relative to sea level or a chosen datum height. Contours may measure elevations above or below this datum level. On a single contour all point have the same elevation.

Q45. Draw the plan and elevation of a 6-frequency geodesic dome based on a tetrahedron of 120 mm side.

Q46. Draw a 6-frequency, 3/8 icosahedra, geodesic dome based on an icosahedron of 90 mm side.

STRUCTURAL FORMS AND NATURE

Q47. 'Structural engineers should become structural artists by adding an aesthetic component to their work.' Discuss. Support your answer with examples.

Q48. 'An efficient design is not necessarily an aesthetically pleasing one. Numerous structures exist that are efficient but lack aesthetic value. Connecting design to natural forms can avoid this pitfall.' Discuss. Support your answer with examples.

Q49. Make a comparison between Robert Stephenson's 1850 Britannia Bridge in Wales and Brunel's 1859 Royal Albert Bridge in Plymouth under the following headings:

(i) inspirational source,
(ii) form,
(iii) efficiency,
(iv) aesthetic quality.

Q50. Find the link between the designs of the following buildings:

- BMW Pavilion in Frankfurt, Germany.
- Roof of the Gottlieb Daimler Stadium in Stuttgart, Germany.
- Oresund Bridge in Copenhagen, Denmark.

Make simple diagrams of two of these structures to help illustrate your answer.

Q51. Find the link from nature between the designs of the following structures:

- The Garabit Viaduct in Loubaresse, France.
- Montjuic Communications Tower in Barcelona, Spain.
- The Tavanasa Bridge in Tavanasa, Switzerland.

Make a simple diagram of one of these structures to illustrate your answer.

Contour Interval

This is the vertical distance between horizontal planes passing through successive contours. In Fig. 19.1 the contour interval is 10 m. On any given map the contour interval should not change.

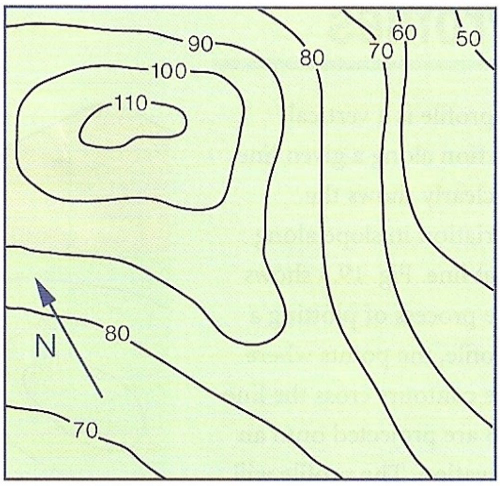


Fig. 19.1

Magnetic North

All maps should have the direction of north marked on them to allow for the correct orientation of the map. Magnetic north is found by using a compass. The direction of other lines or features on the map can be determined by reference to the north direction. On-site compass readings, however, are not to be taken as highly accurate indications of north. There are two reasons for this, (1) local magnetism may affect the position of the compass needle and (2) magnetic north and true north are not exactly the same.

Magnetic north can change due to the shifting of the earth's magnetic field.

True North

For accurate orientation of lines on a map, the angle of a line relative to true north is often needed. Sightings on a star (usually Polaris, the North Star) or the sun can give accurate readings from which true north can be calculated. A map will often indicate by how much magnetic north varies from true north.

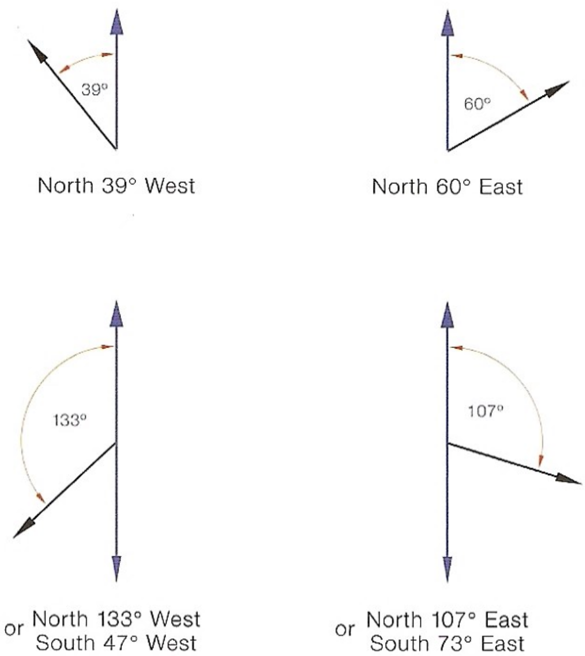


Fig. 19.2

Bearing

The bearing of a line is the angle between the line and magnetic north. The bearing of a line may be established by using a directional compass. The correct method of recording bearings is by reference to the north or the south. Fig. 19.2 shows some examples. If a bearing is N 39° W, it could be also described as S 141° W. Similarly N 133° W could be described as S 47° W.

Profiles

A profile is a vertical section along a given line. It clearly shows the variation in slope along that line. Fig. 19.3 shows the process of plotting a profile, the points where the contours cross the line AB are projected onto an elevation. The profile will not be completely accurate as the profile path between the plotted points is only guessed.

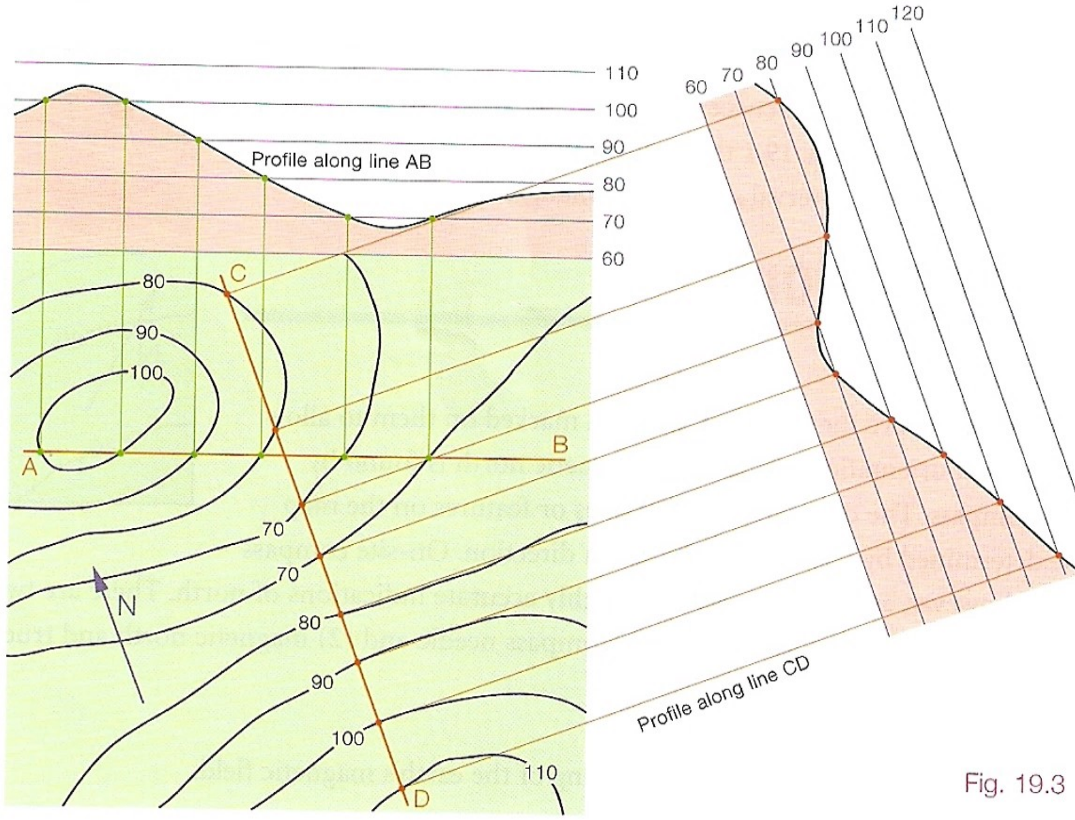


Fig. 19.3

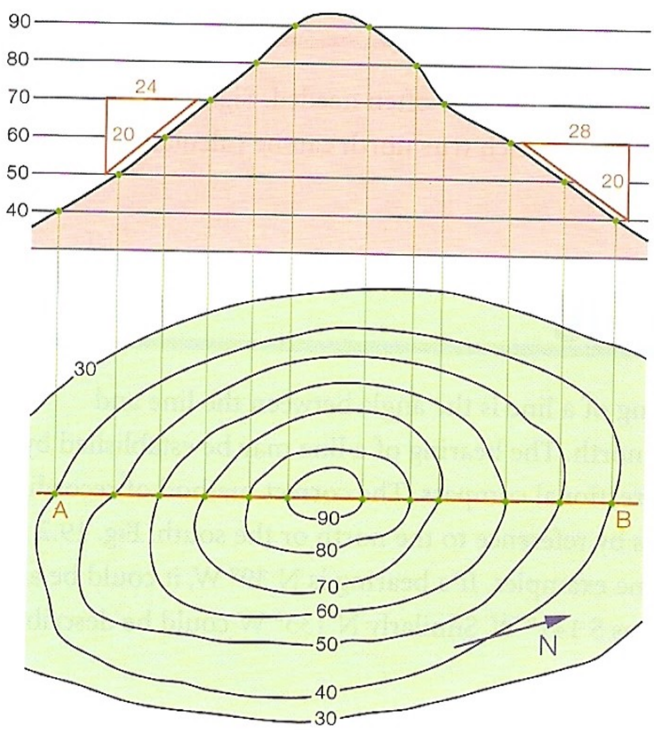


Fig. 19.4

Gradient

The gradient is the slope of the ground at a particular place. examining the contours on a map an approximate gradient c be given. When the contours are close together the gradient i very steep. As the gap between contours widens on the map t slope decreases. Very widely spaced contours indicate land th is almost flat and/or land that is actually flat in places. A mor accurate measurement of gradient is found by drawing a profile. At any point on the profile a slope can be found. Gradient can be given as a ratio or represented by a proportional triangle.

Fig. 19.4 shows how the gradient can be found along line AB. Written as a ratio it compares the vertical gain by the horizon travel. 20:24 = 10:12 = 1:1.2, 1 in 1.2 m. The triangle graphica represents the same ratio.

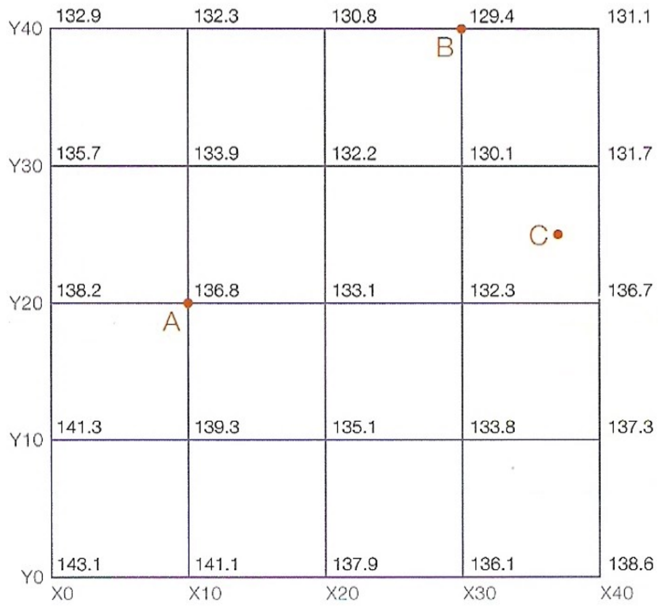


Fig. 19.5

Grid Layout

When surveying a site to determine contours and gradients one of the most practical approaches is to use a grid layout. The size of the grid squares affects the accuracy of the survey. Elevations/levels are taken at the corners of the squares and the ground is assumed to slope uniformly between adjacent level points. It is now possible to find fairly accurate contours by using **interpolation**. Fig. 19.5 shows a portion of a grid layout using 10 m squares. By using xy coordinates each corner can easily be identified. For example, corner A is x10,y20, corner B is x30,y40 and point C, which is not on a corner, may also be specified x37,y25.

Interpolation of Contours

The interpolation of contours is the finding of contours from grid levels. In Fig. 19.6 the position of 2 m contours are needed.

Edge AB of the grid will contain a point on contour 142 m. The difference in levels between A and B is 1.8 m. Divide AB into 18 equal parts and thus locate level 142 m as shown. In a similar way a point on the 142 m contour can be located on edge AC of the grid. The difference in levels here is 2 m. Divide AC into 20 equal parts and locate the 142 m level. Further points can be found using this method. Interpolation can be very slow and tedious. Fig. 19.7 shows the grid levels converted into contours.

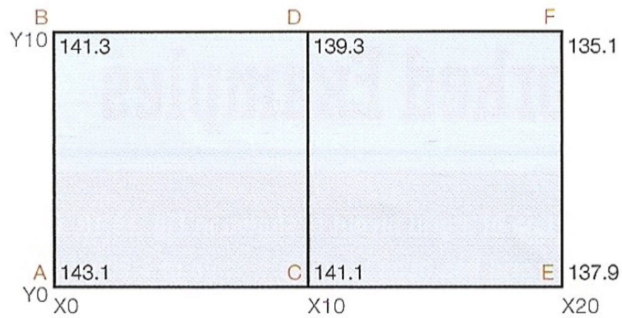


Fig. 19.6

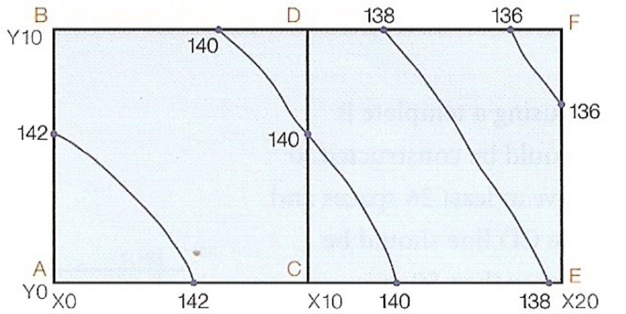


Fig. 19.7

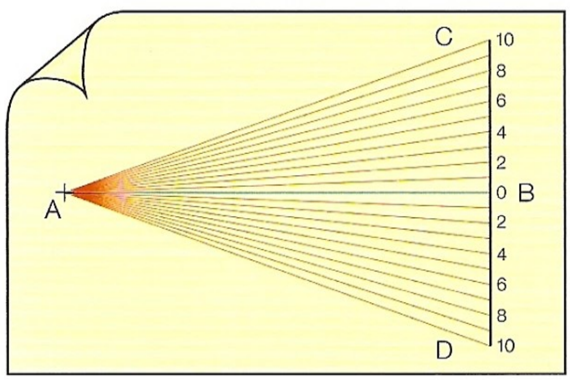


Fig. 19.8

Using a Template to Help

Interpolation is based on the division of the sides of the grid boxes into differing numbers of equal parts. A template to speed up the division process would help a great deal.

(1) On tracing paper draw a line AB of any length and at one end draw a perpendicular CD.

(2) Step a number of equal spaces up and down from B on the line CD.

(3) Join all these points back to A.

Once measurements are taken perpendicular to line AB, it will be seen that the spacing between the lines remain equal all the way from B to A. The line CD should be longer than the sides of the squares of the grid and the number of divisions should be enough to cope with the largest difference in levels between two adjacent corners of the grid.

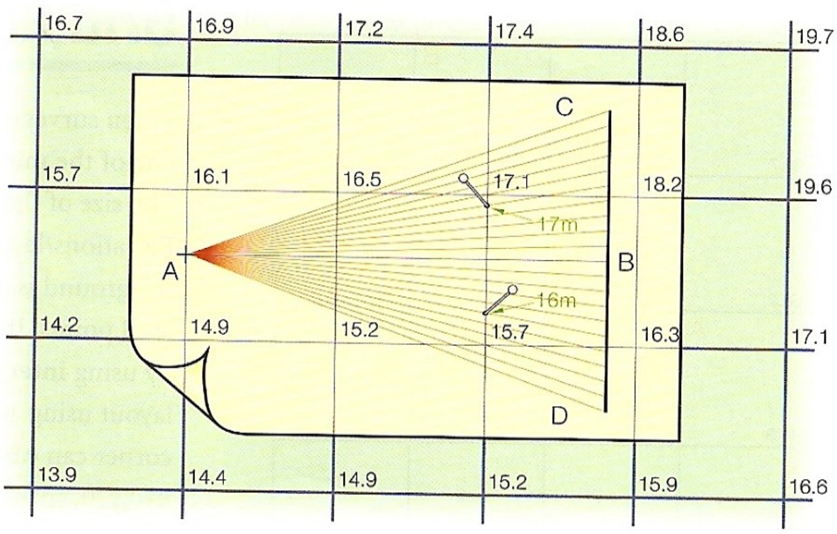


Fig. 19.9

There is a difference of 17.1 – 15.7 = 1.4 m between the two ends of the grid square in Fig. 19.9. Slide the template across the grid until the grid side is divided into 14 divisions. Use a pin to mark the contour positions. The line CD must be kept parallel to the grid sides.

Worked Examples

A portion of a grid layout is shown in Fig. 19.10. A 10 m square grid has been used. To a scale of 1:200 draw out the grid and plot the contour lines at 1 m vertical intervals using interpolation.

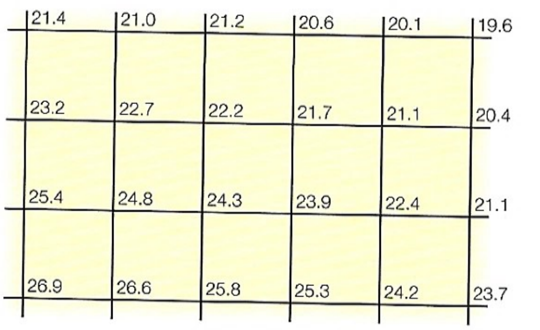


Fig 19.10

(1) If using a template it should be constructed to have at least 26 spaces and the CD line should be longer than 50 mm.

(2) By proportional division of the sides of the grids the contours may also be found. Contour 22 is shown in Fig. 19.11.

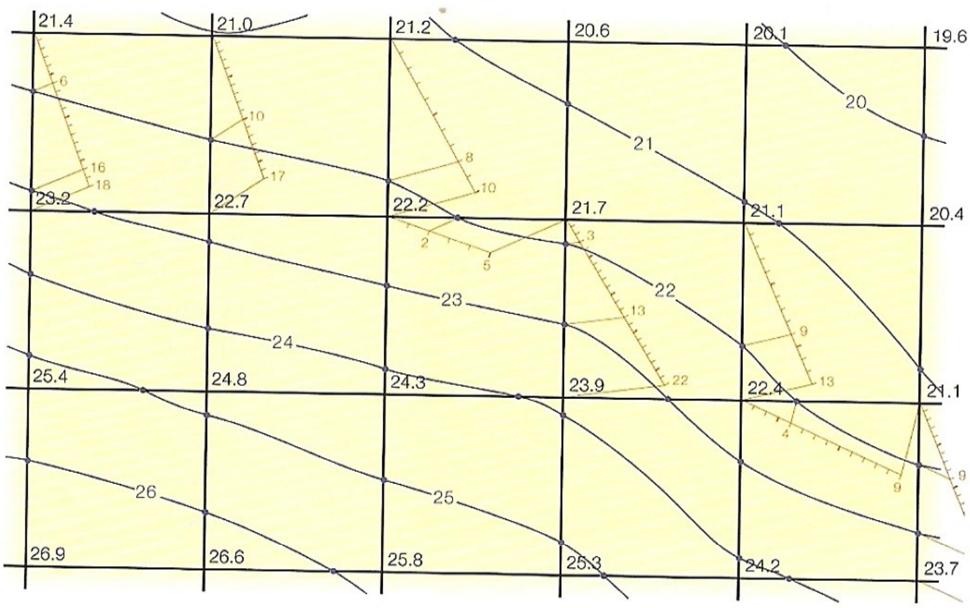
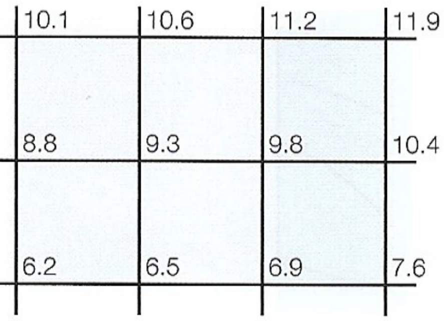


Fig. 19.11



. 19.12

A portion of a 10 m grid with levels is shown in Fig. 19.12. To a scale of 1:200 draw out the grid and plot the contour lines at 1 m intervals using profiles.

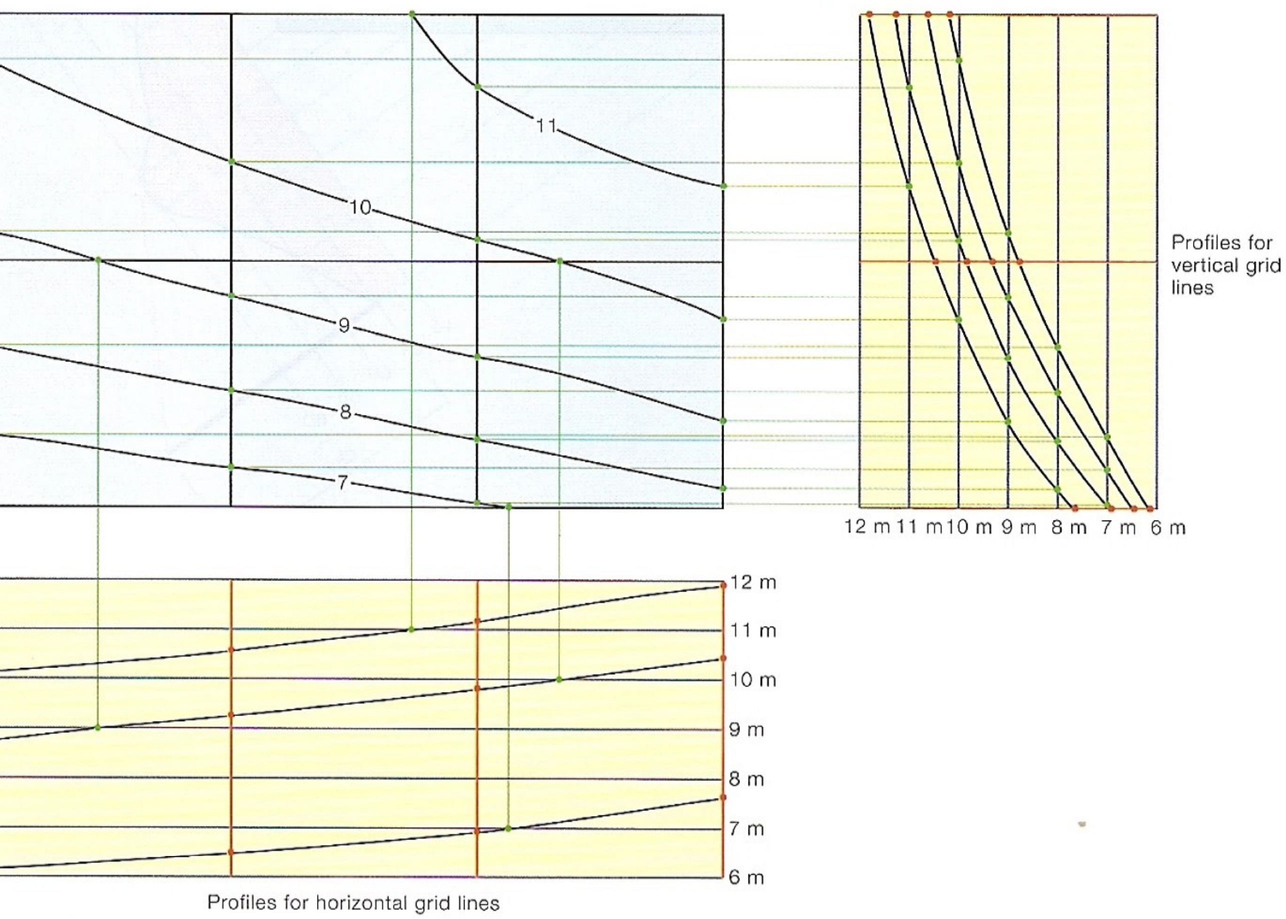
When the grid is small the use of profiles may be a quicker method of finding points on the contour lines.

(1) A profile of each line of the survey is constructed using the levels from the grid.

(2) Horizontal and vertical lines are drawn on the profiles at the levels where the contours are found.

(3) The points at which the profiles cross these lines indicate where the contour lines cross the grid.

(4) In Fig. 19.13 the profiles are superimposed on each other.



. 19.13

The map in Fig. 19.14 shows ground contours at 5 m intervals. An object stands vertically on the ground at A. Determine the minimum height of the object if it is to be visible from the ground at B.

To solve this problem a profile is found along the line AB.

(1) Join A to B.
(2) The lowest point on the profile will be 40 m. Set up the profile lines parallel to line AB.
(3) The spacing between these profile lines will be the scaled equivalent of 5 m.
(4) Project the points where line AB crosses the contours onto the profile. The projection lines are perpendicular to AB.
(5) Draw the profile.
(6) Draw the lowest line of sight from B tangential to the profile (light travels in straight lines).
(7) Draw the vertical object at A to meet the line of sight. If the object is above 38 m tall it will be seen from the ground at point B.

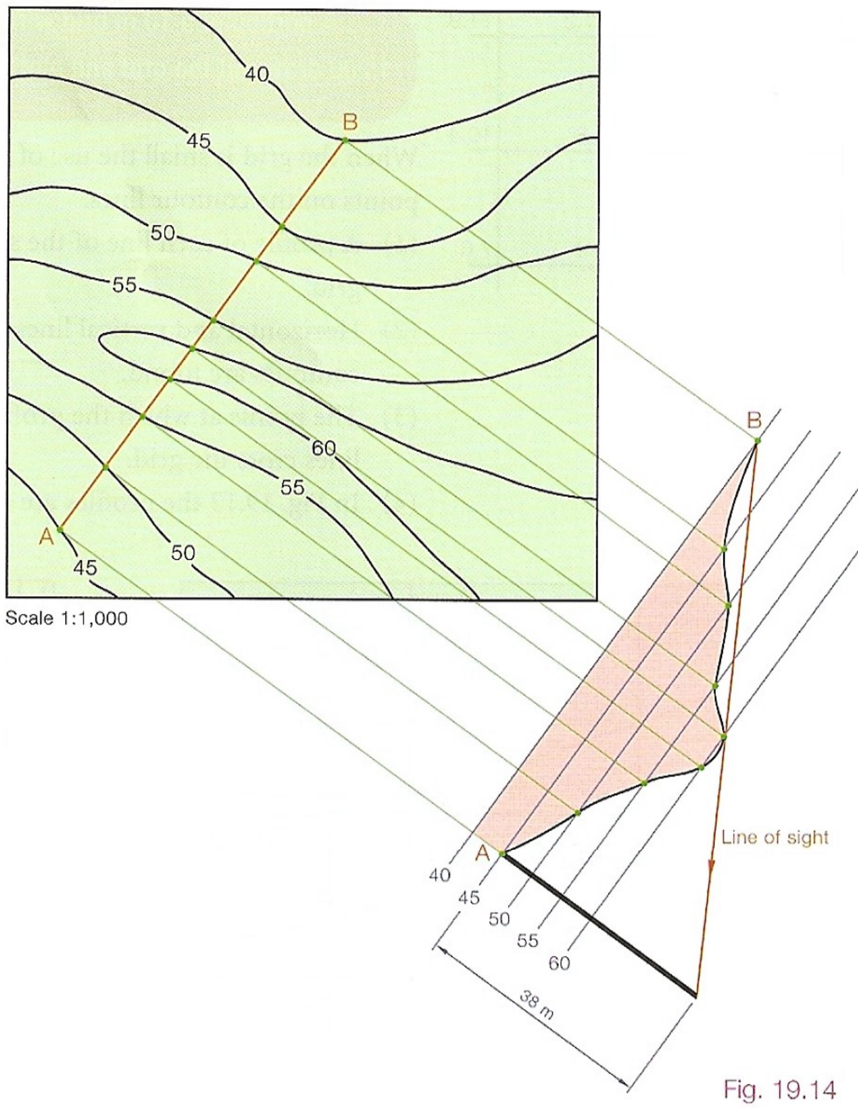


Fig. 19.14

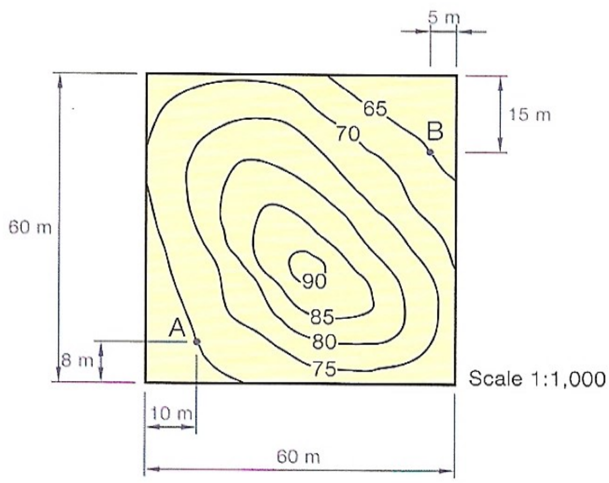


Fig. 19.15

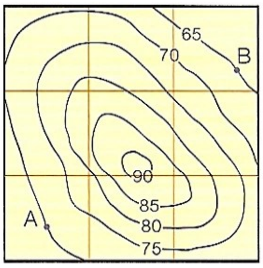
The map in Fig. 19.15 shows ground contours at 5 m vertical intervals. An object 40 m tall stands vertically at A. Reproduce this map to a scale of 1:500 and determine if the object at A is visible from the ground at B.

The given map is to a scale of 1:1,000. The new map is to be reproduced to a scale of 1:500, i.e. doubled in size.

(1) Divide the original map into smaller boxes.
(2) Draw the new grid layout to the larger scale. The contours are now drawn carefully in the bigger grid. If care is taken a reasonably accurate enlargement can be produced.
(3) Locate points A and B and join.
(4) Draw a profile along the line AB.

(5) Draw the object at A to a height of 40 m. Also draw the line of sight from B tangential to the profile line.

(6) It can be seen that the object at A is not visible from B



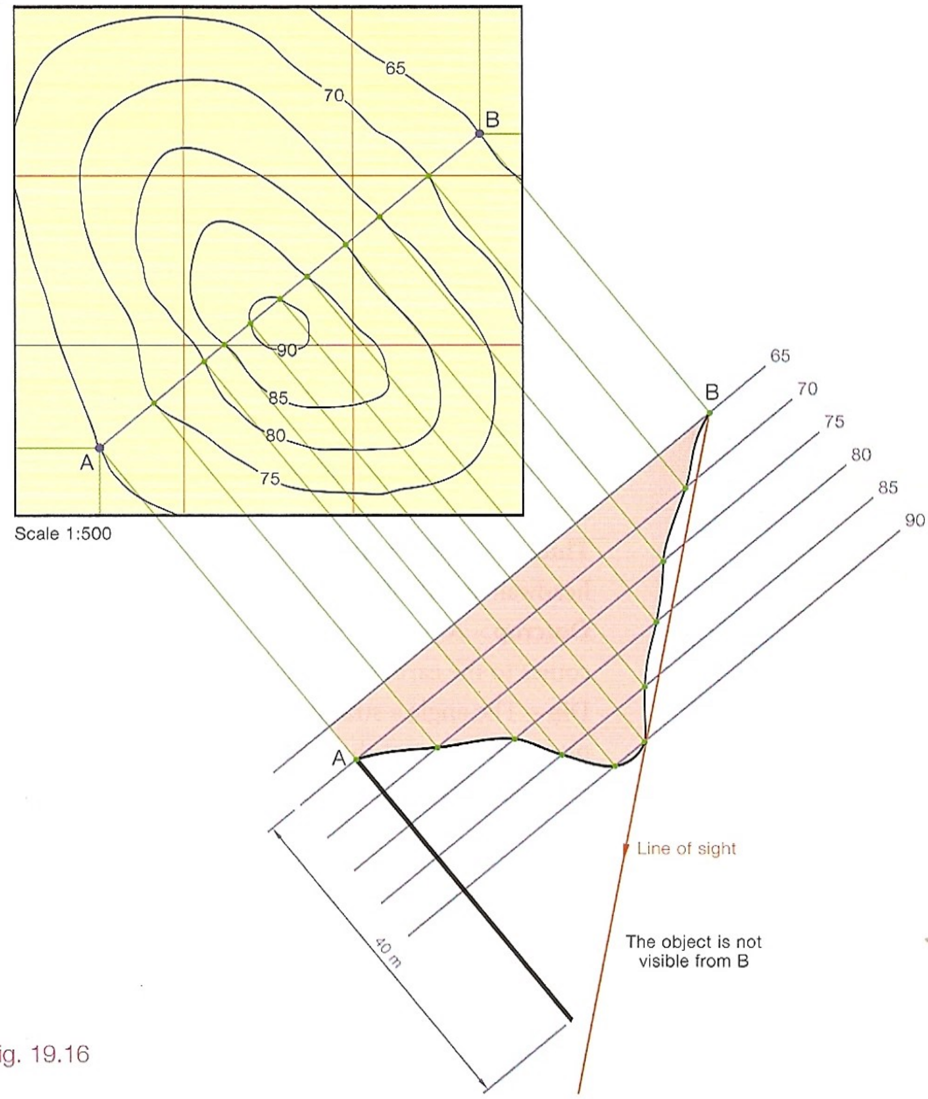


Fig. 19.16

The Geometry of Mining

Mining concerns the removal of useless material and useful material both on the surface (opencast mining) and beneath the surface. Mining companies like to minimise the mining of useless material and maximise the mining of useful material. To this end, surveying, testing and planning is involved.

For the duration of this chapter we deal with mineral deposits with definite limits and boundaries. These are known as **veins** or **strata**. The strata is made up of rock or **ore** and is assumed to be of uniform thickness and be planar on top and bottom surfaces. Obviously in real geographic situations the stratum may undulate and vary in thickness.

The stratum of ore may come to the surface as in Fig. 19.17. This is an outcrop point. Outcrop points may facilitate open mining and thus minimise expense. The vein, however, may not intersect the surface of the earth. In cases like this the vein's theoretical outcrop point may serve as a starting point for mining.

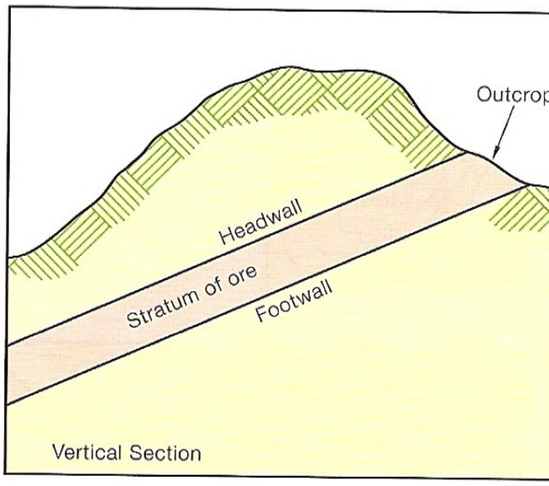


Fig. 19.17

Terminology

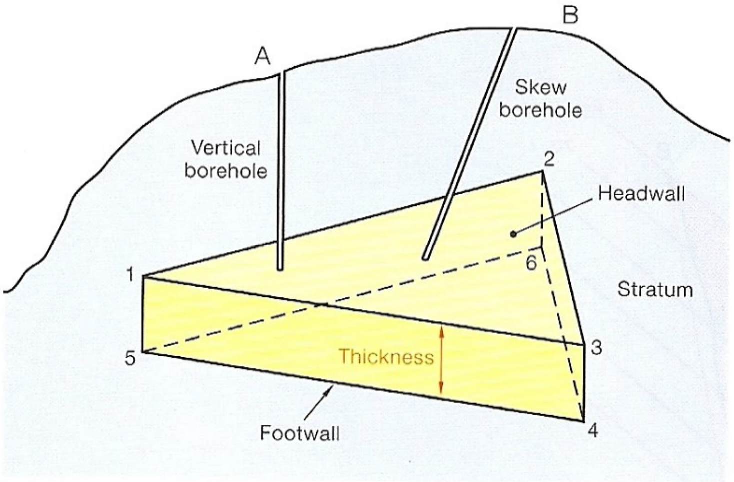


Fig. 19.18

Stratum – A layer, seam or vein of ore, generally assumed to be an inclined plane of uniform thickness.

Headwall – The top surface of the stratum, 1, 2, 3, Fig. 19.18.

Footwall – The lower surface of the stratum, 4, 5, 6, Fig. 19.18.

Thickness – The perpendicular distance between the headwall and the footwall.

Outcrop – A point at which a section of the stratum comes to the earth's surface.

Dip – The angle a stratum makes with the horizontal plane (the slope of the stratum).

Strike – The bearing of a level line on the surface of the stratum. It is usually related to the compass north. It is shown in plan.

Borehole – Hole drilled from the surface of the earth through a stratum of ore in order to determine its position and thickness.

The map shown in Fig. 19.19 shows ground contours at 10 m vertical intervals. Also shown are points A, B and C which are outcrop points on a stratum of ore. Determine the strike of the stratum.

(1) Since A, B and C are outcrop points they are all on the stratum. Join the points giving a triangular plane of ore.

(2) Project an elevation of this plane using the heights of the contours.

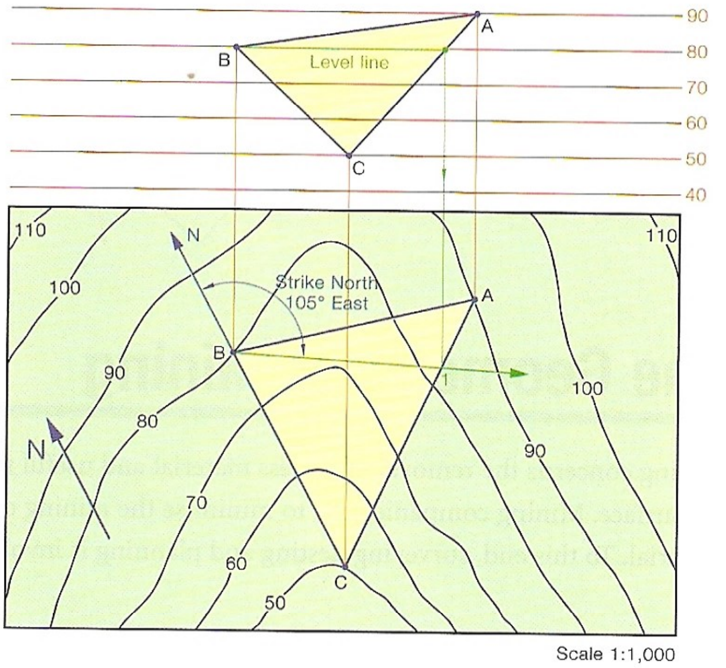


Fig. 19.19

(3) In elevation draw a level line across the plane ABC. Usually the starting point for this level line is the mid-height vertex. In this example the line is drawn from B to intersect edge AC at point 1.

(4) Find line B1 in plan by projecting point 1 down to edge AC in plan. Joint point 1 to vertex B.

(5) The angle the line B1 makes with the given north is the strike. It is written as North 122° East.

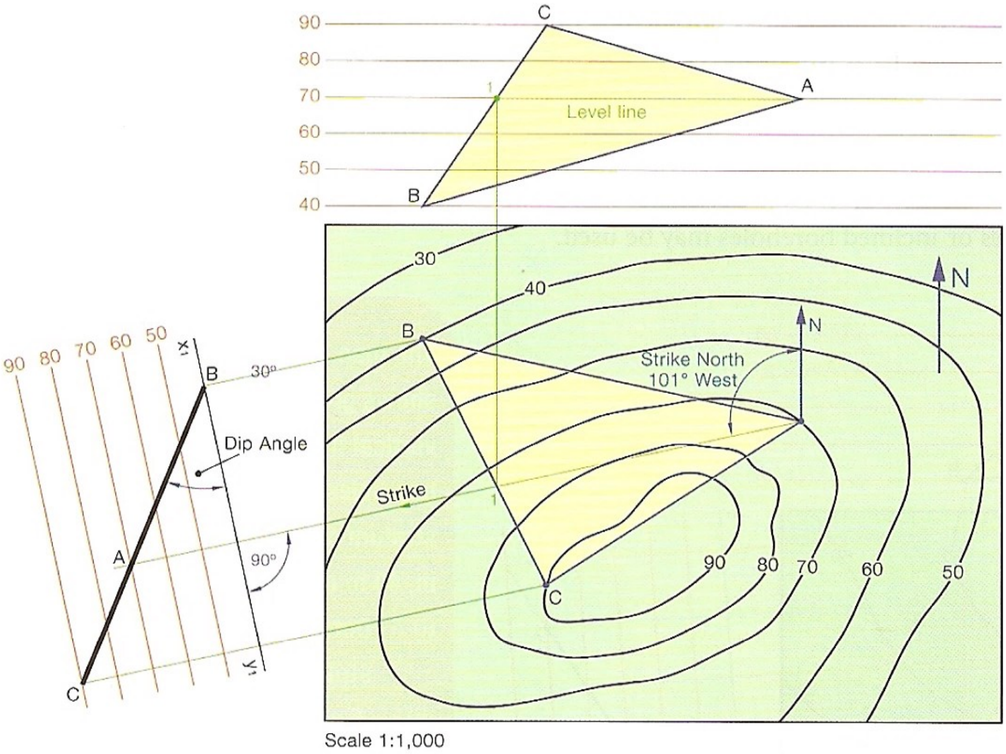


Fig. 19.20

The map shown in Fig. 19.20 shows ground contours at 10 m intervals. Also shown are points A, B and C which are outcrop points on a stratum of ore. Determine the dip and strike of the stratum.

(1) Construct the plan and elevation of the stratum as explained in the previous example.

(2) A level line is drawn in elevation and is projected to plan. The angle line A1 makes with the given north is the strike.

(3) By projecting an auxiliary view of the stratum viewing in the direction of the strike an edge view of the stratum is found. Points A, B and C line up.

(4) The angle the edge view of the stratum makes with the horizontal is the dip.

Fig. 19.21 shows ground contours at 10 m vertical intervals on a map. A, B and C are outcrop points on a stratum of ore.

(i) Determine the dip and strike of the stratum.

(ii) Find the outline of the outcrop between points A and C, and between points C and B.

(1) Find the dip and strike as outlined previously.

(2) The outcrop line is where the stratum comes to the surface. In the auxiliary the stratum is seen as an edge view.

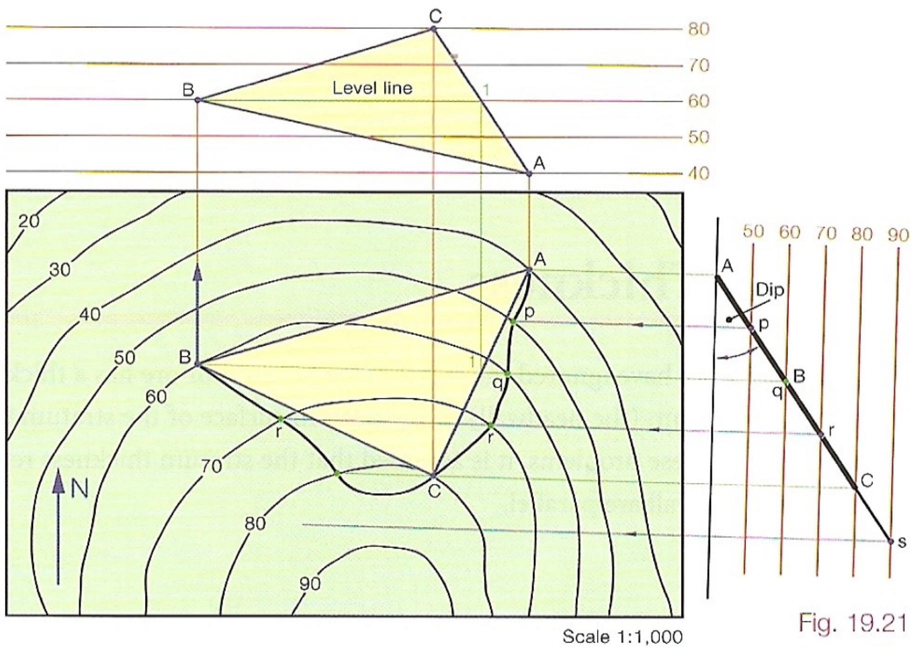


Fig. 19.21

Where this edge view crosses the levels lines they are projected back to give points on the contours in plan. For example, the edge view crosses the 50 m level at point p. Point p is projected back to the map and is found on th 50 m contour line. Similarly for point q. Point r when projected back crosses the 70 m contour twice and thus gi two points on the outcrop.

(3) Join the points with a line remembering to include points A, B and C.

(4) It should be noted that the 90 m contour definitely does not include outcrop points. This is proved by extending the edge view in the auxiliary to the 90 m level at point s. This point projected back does not intersect the 90 m contour in plan.

Up to now the examples given have all used outcrop points to locate the stratum. Boreholes may also be used to locate points on the stratum. Vertical boreholes or inclined boreholes may be used.

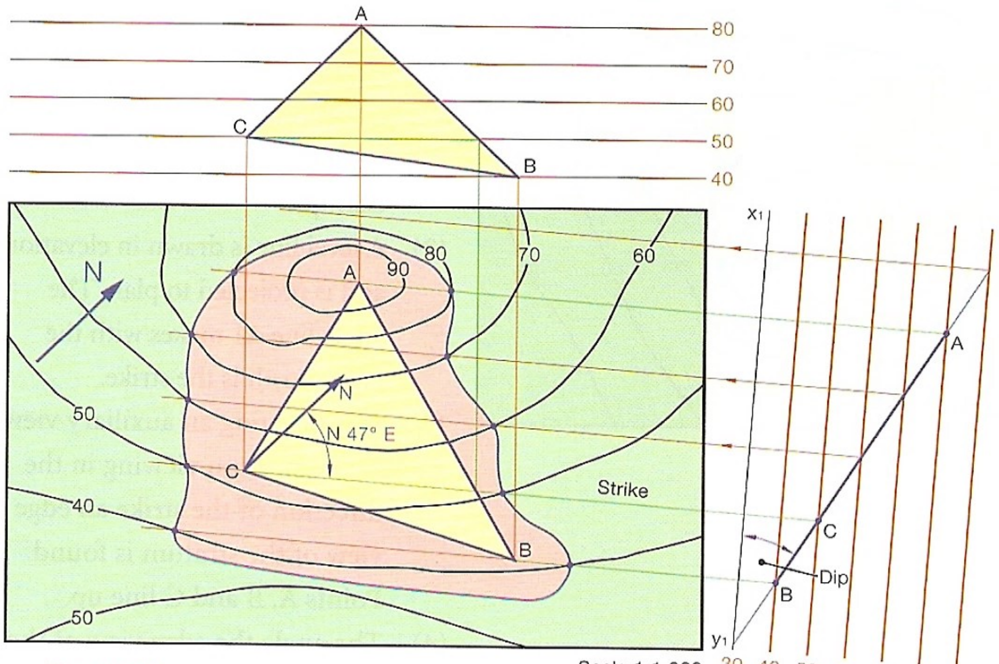


Fig. 19.22

The map shown in Fig. 19.22 shows ground contours at 10 m vertical intervals. Vertical boreholes at A, B and C strike a stratum of ore at altitudes of 80 m, 40 m and 50 m respectively.

(i) Determine the dip and strike of the stratum.

(ii) Find the complete outline of the outcrop.

(1) Points A, B and C are found using the altitudes from the question.

(2) Find the strike and dip of th stratum in the usual way.

(3) The outcrop is found as explained in the previous example. It should be noted that A, B and C are not part of the outcrop.

(4) There are two outcrop points on the 80 m contour and none on the 90 m contour. When drawing the outcrop lin care must be taken to join the two points without crossing a contour line. In a similar way there are two outcrop points on the 40 m contour. These points must be joined without crossing the 50 m contour line.

Stratum Thickness

Up to this point we have ignored the fact that the stratum of ore has a thickness. The problems have dealt with the top surface of the stratum (the headwall) or the bottom surface of the stratum (the footwall). As has been mentioned earli in the solving of these problems, it is assumed that the stratum thickness remains constant throughout, i.e. that the headwall and footwall are parallel.

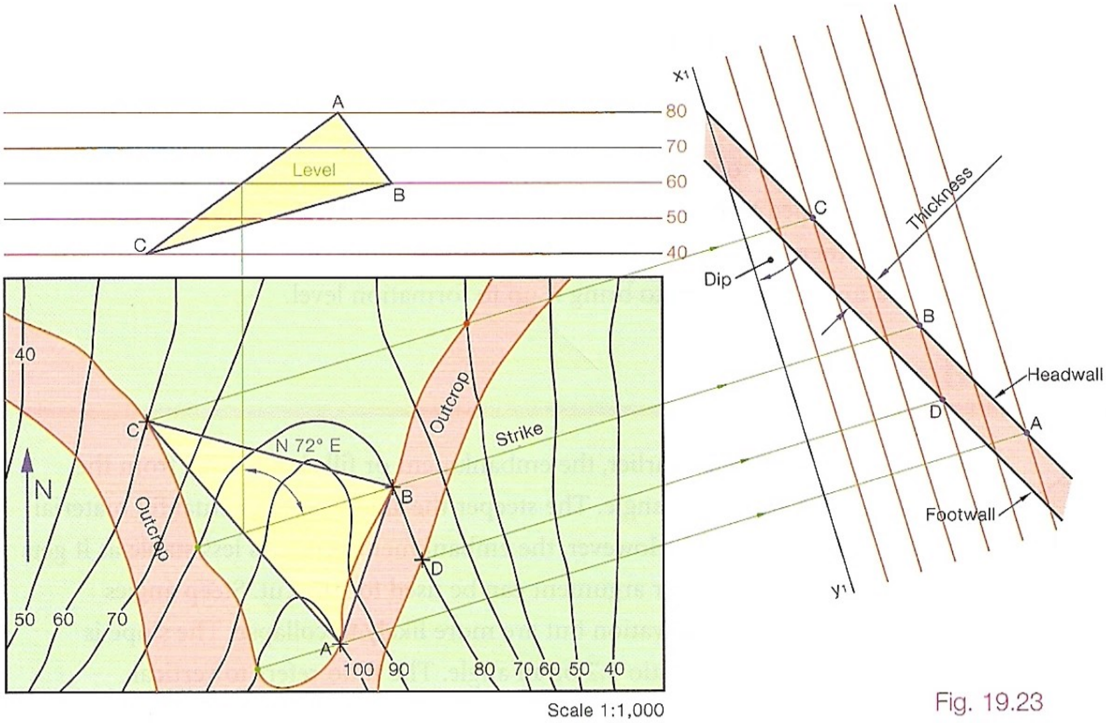


Fig. 19.23

The diagram Fig. 19.23 shows ground contours at 10 m vertical intervals. A, B and C are outcrop points on the headwall of a stratum of ore and D is an outcrop point on the footwall.

(i) Determine the strike, dip and thickness of the stratum.

(ii) Determine the outline of the outcrop.

(1) Join the outcrop points on the headwall to make a triangle. Use this triangle to find the strike and dip of the stratum in the usual way.

(2) Project D which is on the footwall onto the auxiliary view.

(3) Draw the footwall in the auxiliary parallel to the headwall.

(4) Mark in the thickness of the stratum as the **perpendicular** distance between the two lines.

(5) Find the outcrop as before using the headwall and the footwall.

Earthworks

When constructing roads, car parks, railroads etc., extensive use is made of contour maps to determine how much filling is needed in the hollows and how much cutting away of soil is needed in the high areas. Particularly if a road or railway is to be built on irregular terrain, then for the comfort of the drivers, the land must be levelled or at least reduced to an acceptable gradient. A profile along the proposed road will show what the road looks like and what the topography of the land is along the length of the road.

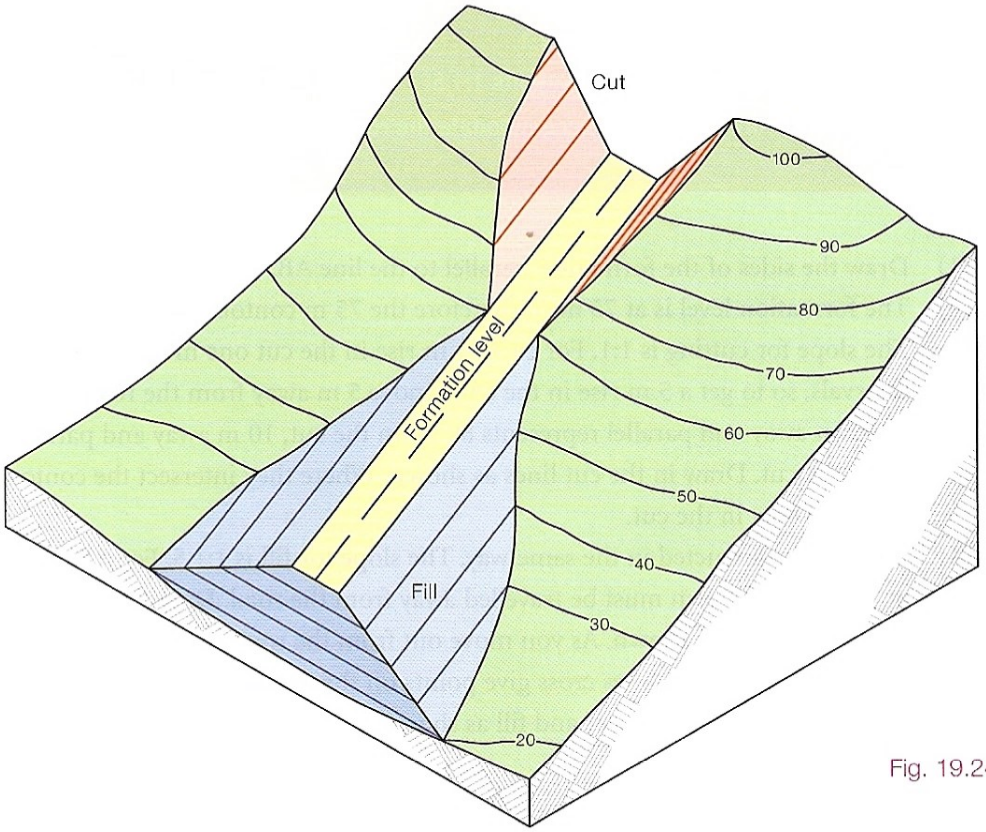


Fig. 19.24

The **formation** level refers to the level of the proposed road or car park. The **cut** is the amount of land that has to be cut away to bring the level of land down to the formation level. The **fill** is the amount of fill of material that needs to be put in a hollow to bring the level up to the formation level. In the construction of most roads there will be both cut and fill.

The side slopes for the fill are kept the same for the whole road and similarly for the slope of the cutting. Fig. 19.24 shows a pictorial of a level road passing through a sloped terrain. The road is level and has a height of 60 m. It can be seen that when the road crosses the 60 m contour there is no cut or fill needed. As the ground rises above 60 m it must be cut away and as it drops below 60 m the area needs to be filled to bring it up to formation level.

Slopes of Cut and Fill

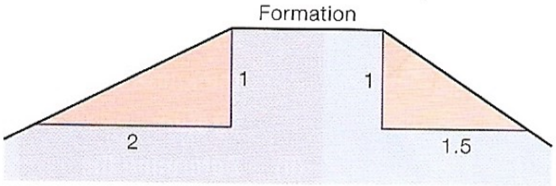


Fig. 19.25

As mentioned earlier, the embankment or fill slopes away from the road at an even angle. The steeper the angle the less actual fill material will be needed. However, the embankment becomes less stable as it gets steeper. A similar argument can be used for the cut. Steep angles involve less excavation but are more likely to collapse. The slope is expressed as a ratio 1:2 or an angle. The ratio refers to vertical height:width. The left side of Fig. 19.25 has a slope of 1:2 and the right side of 1:1.5.

Fig. 19.26 shows ground contours at 5 m vertical intervals. AB is the line of a proposed roadway. The road is to have the following specifications:

(i) Formation width 16 m.
(ii) Formation level 75 m.
(iii) Side slopes for cuttings 1:1.
(iv) Side slopes for embankments 1:1.5.

Show the earthworks needed to accommodate the roadway.

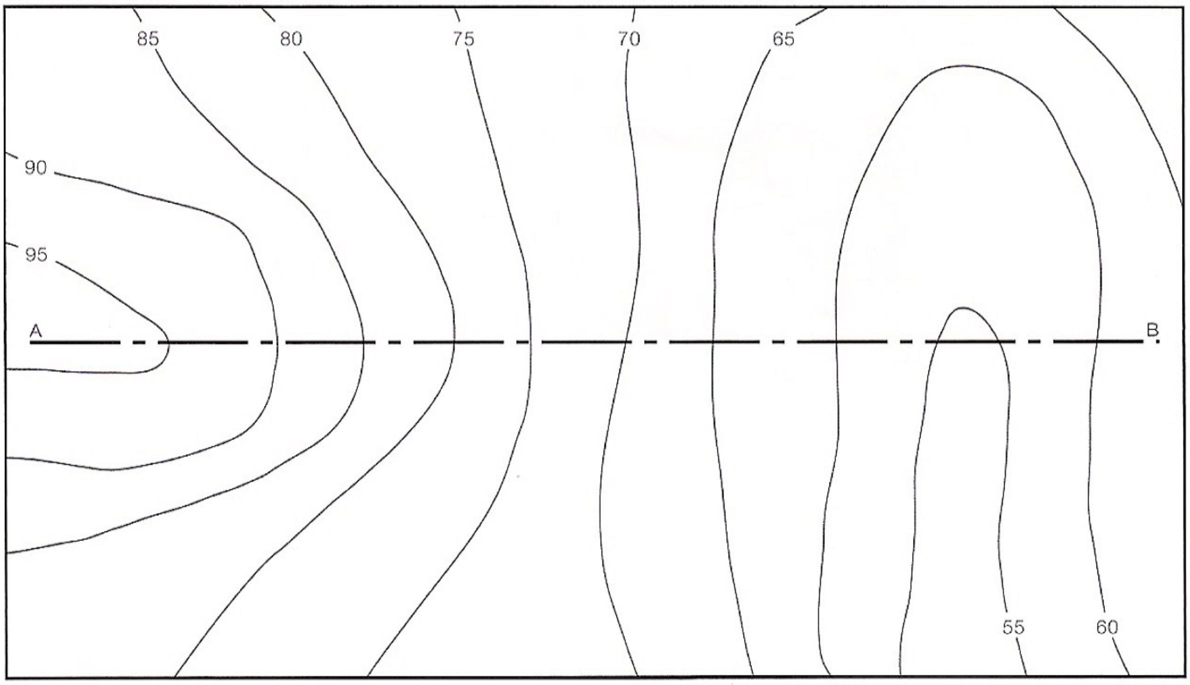
(1) Draw the sides of the formation parallel to the line AB.

(2) The formation level is at 75 m so therefore the 75 m contour will have neither cut nor fill.

(3) The slope for cutting is 1:1. For every 1 m rise in the cut one moves 1 m from the road. The contours are at 5 m intervals, so to get a 5 m rise in the cut a move 5 m away from the road is needed. The road side is at 75 m level. A line 5 m away and parallel represents 80 m on the cut, 10 m away and parallel to the side of the road represents 85 m on the cut. Draw in the cut lines as shown. Where they intersect the contour lines, locate points on the cut outline. Draw in the cut.

(4) The fill is constructed in the same way. The slope for fill is 1:1.5. For a 5 m fall in the embankment level, a distance of 1.5×5 m = 7.5 m must be travelled away from the road. Draw in the embankment lines parallel to the roadside and 7.5 m apart as shown. As you move out from the road you move down the bank, the level drops. Where the fill lines and the contour lines cross give points on the embankment line.

(5) Draw in the symbols for cut and fill as shown.



Scale 1:1,000

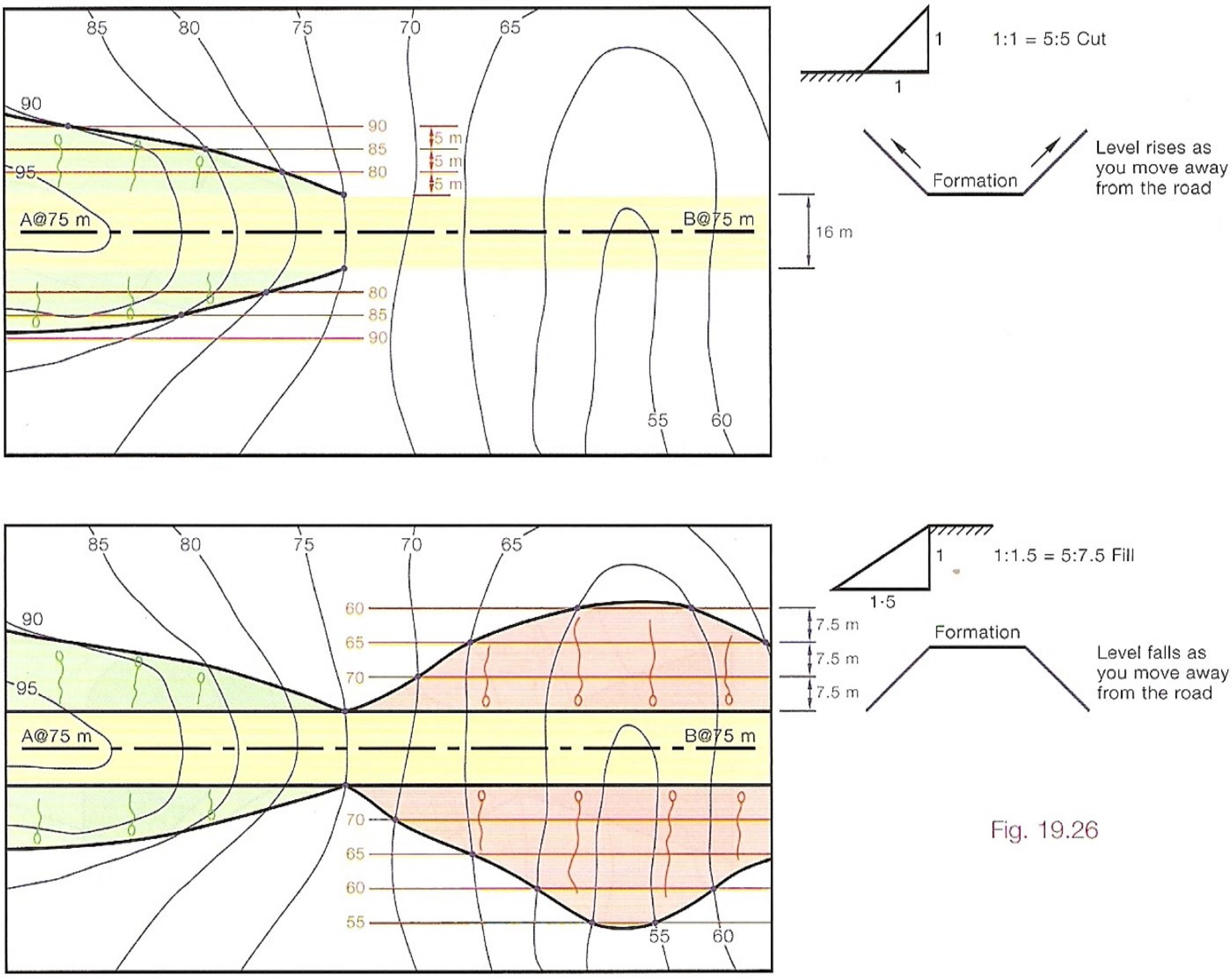


Fig. 19.26

Figures 19.27a and 19.27b show ground contours at 4 m vertical intervals. ABCD is the centre line of a proposed roadway with the centre for the curve at O. The road is to have the following specification.

(i) Formation width 14 m.
(ii) Formation level 52 m.
(iii) Side slopes for cutting 1:1.5.
(iv) Side slopes for embankment 1:2.

Show the earthworks needed to accommodate the roadway.

(1) Draw in the formation.
(2) Mark the 52 m contour as it crosses the side of the formation.
(3) Cutting slope 1:1.5. With the difference between contours at 4 m this will mean a spacing between the cutting contours of 6 m (4 × 1.5). Draw in the cuttings.
(4) Embankment slope of 1:2. With the contours at 4 m intervals this will mean a spacing between the fill contours of 8 m (4 × 2). These cutting contours remain parallel to the formation even around the curve.
(5) Complete the outline of the earthworks as shown in Fig. 19.27b.

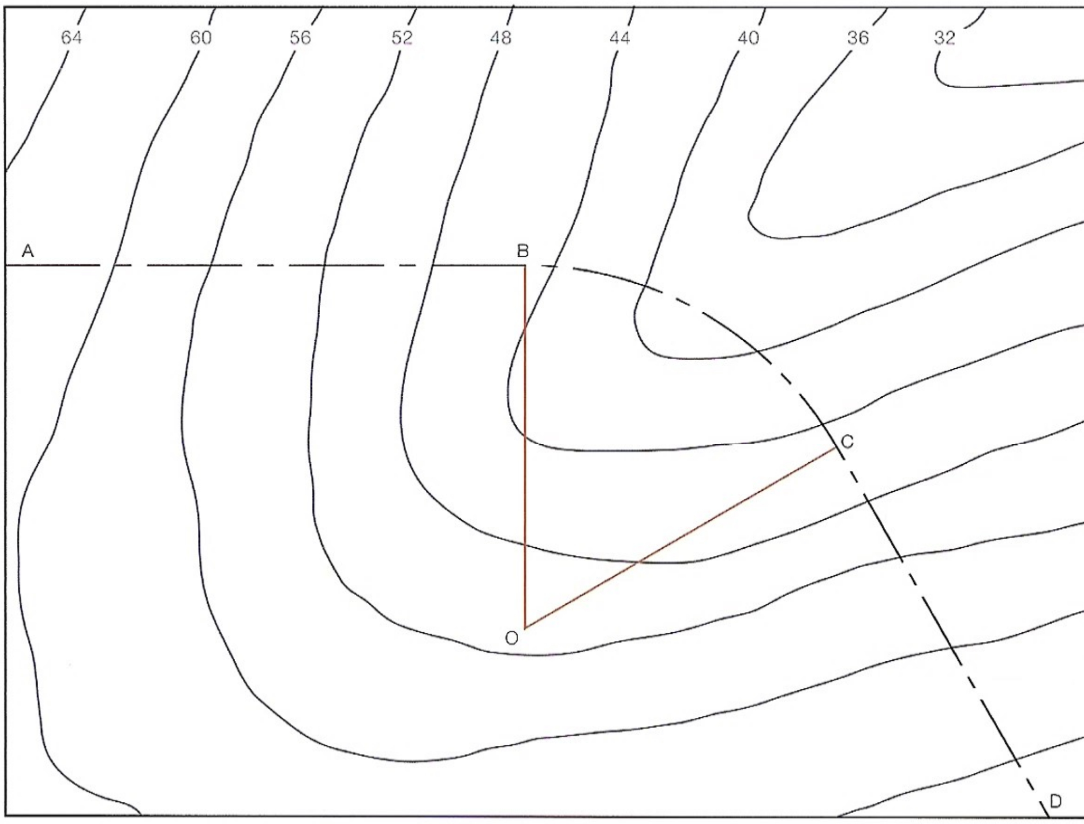
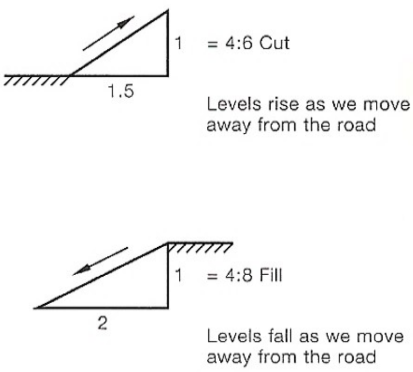


Fig. 19.27a



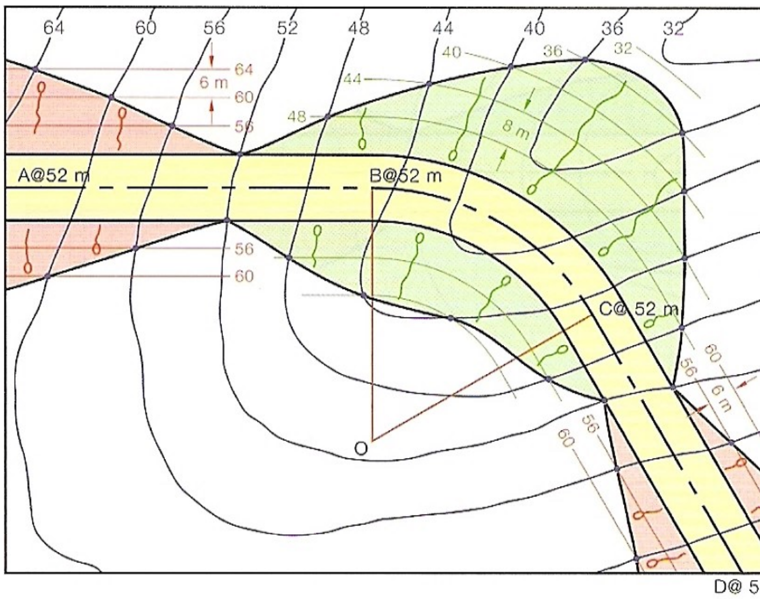


Fig. 19.27b

Figures 19.28a and 19.28b show ground contours at 2 m vertical intervals. AB shows a proposed roadway with CDEF being a car park. The car park is level and at the same level as the road. The road and car park are to have the following specifications:

(i) Formation width 12 m.

(ii) Formation level 110 m.

(iii) Side slopes for cutting 1:2.

(iv) Side slopes for embankment 1:2.5.

Show the earthworks necessary to accommodate the road and car park.

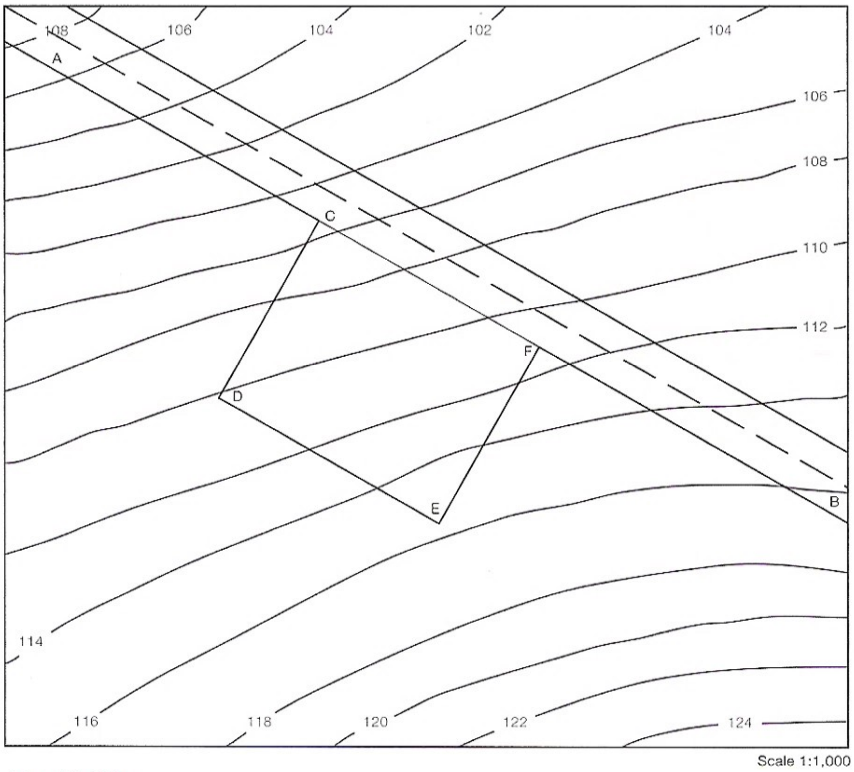


Fig. 19.28a

(1) Ignore the car park initially and find the cut and fill for the road. The slopes for cutting are 1:2 and the contours are at 2 m vertical intervals. The cutting contours are at (2 × 2 m) 4 m spacings from the side of the road. Draw the cut outline.

(2) The slopes for embankment are 1:2.5 and the contours are at 2 m vertical intervals. The fill lines are at (2 × 2.5 m) 5 m spacing from the side of the road. Draw the cut outline.

(3) Each side of the car park is treated like the side of a road. The cut and fill are plotted slightly beyond the sides.

(4) The earthworks for each side intersect each other.

(5) It should be noted that at corner, C, E and F where embankments intersect, and cuts intersect, a valley or ridge will be formed. These are indicated in Fig. 19.28b.

(6) Draw in the symbols.

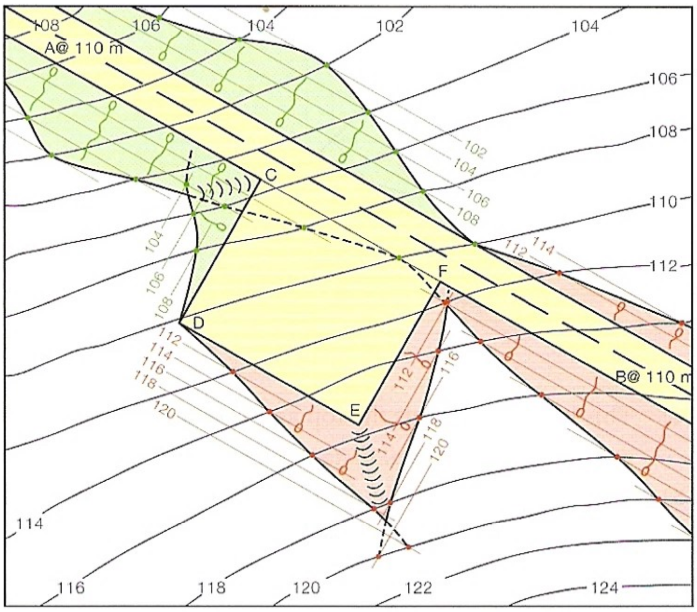


Fig. 19.28b