# REPUBLIC OF IRAQ

# THE MINISTRY OF HIGHER EDUCATION & SCIENTIFIC RESEARCH

## *SURVEYING ENGINEERING*

**Lecturer name: *Dr.*Abdulbasit Abdaziz Muhmood**

Mosul Technical Institute/Surveying Department

Coarse weakly outline

**Stage:2nd.Surveying**

**Academic status: P.H.D Civil Engineering**

**Qualification: Lecturer**

# Course Weekly Outline

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|---|---|
| **Course Instructor** | **Dr .Abdulbasit Abdulaziz Muhmood** |
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| **Title** | Engineering Surveying |
| **Course Coordinator** | **Dr .Abdulbasit Abdulaziz Muhmood** |
| **Course Objective** | After studying this course the student should be able to 1-compute the areas of uniform and non-uniform areas and cross section ,2-compute the volumes of earth work and water 3- setting out of all types of road curves ,sewers ,building ...etc ,4- to calculate the unknown measurement 5-divsion and subdivision of lands. |

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| **Course Description** | 2-hr Theoretical , 3-hr Application | | | | |
| **Textbook** | Engineering Surveying, Zeyad AL Bakr, 1989,Baghdad ,Technical Institute. | | | | |
| **References** | Surveying for Construction: 4Th Edition William Ervin, 1998.<br>Surveying for Engineers: 2th Edition Uren ,W,S, 1999<br>Surveying ,Kissam,P,1969<br>Lectures from Internet | | | | |
| **Course Assessments** | Term Tests | Laboratory | Quizzes, continuous evaluation | Project | Final Exam |
| | 40% | ------- | 10% | ----- | 50% |
| **General Notes** | 1-Solving all the questions at the end of each chapter<br>2-prepare projects for each top lesion (areas ,volumes ,curves ,intersection ,resection ) | | | | |

| **Weeks** | **Topics Covered** |
|---|---|
| 1,2.3.4,5.6 | Measurement of areas,<br>Simpson's and trapezoidal method, Offsets at irregular intervals, coordinates method ,DMD method Areas from maps, graphical paper and slices. Planimeter, Cross section of embankment and cut |
| 7 | Volumes :<br>Prismoidal and end area method ;approximate method; Volume from contours; Mass-Haul Diagram M.H.D; curve capacity, |
| 8 | Road curves surveying |
| 9,10 | Vertical curves |
| 11,12 | Horizontal curves, simple ,compound ,and reverse. |

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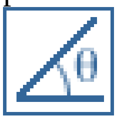
|---|---|
| 13 | Setting out curves; deflection angle method |
| 14 | Setting out curves; from long chord, from tangent, from point of intersection |
| 15 | Small project of roads |
| 16 | Cadastral surveying |
| 17 | Construction Surveying |
| 18 | Omitted measurement ( Intersection) |
| 19,20 | Types of intersections (two sides unknown ,one side and azimuth of another sides are unknown, two direction are unknown). |
| 21 | Techniques used to solve intersection ( triangular method ,analytical method, mechanical method, rotation of coordinates |
| 22 | Solving examples on intersection no.1 and no.2 |
| 23 | Solving examples on intersection no.3 |
| 24 | Resection (the three cases of resections) |
| 25 | Solving Examples on the three types of resection. |
| 26 | Subdivision of land. |
| 27 | Division of land (closed traverse) into two parts by a straight of known direction |
| 28 | Division of land into two equal parts by using a known direction straight. |
| 29 | Small project of known subdivision of land |
| 30 | Continued the project; results, discussion, presentation, and evaluation. |

# The first to the sixth week

## Measurement of areas,

This section of the Plane Surveying site discusses the derivation and use of different formulae for the calculation of areas. To refer to these formulae while you are working in the problem solving areas of this site, please refer to the Areas section of the Formulae page.

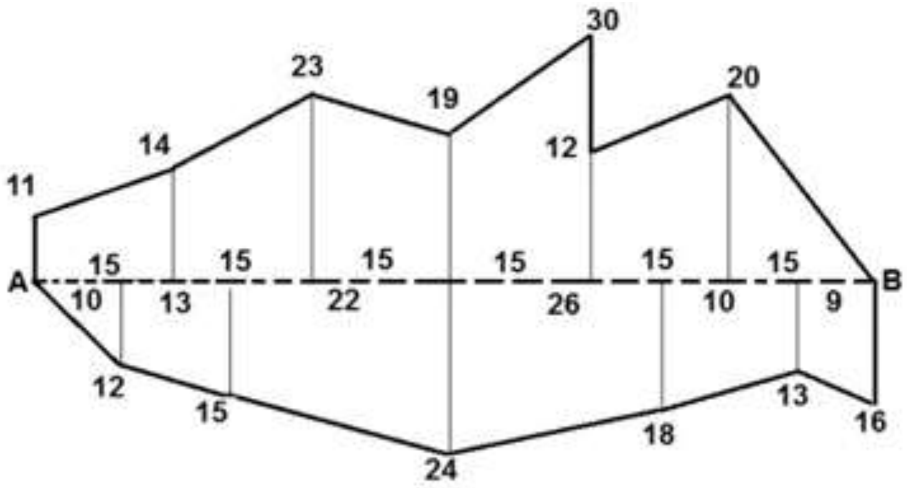


The following notes cover methods for determining the area of land parcels, either using data obtained from field survey measurements or information shown on existing maps and plans.

Uses of Area Calculations

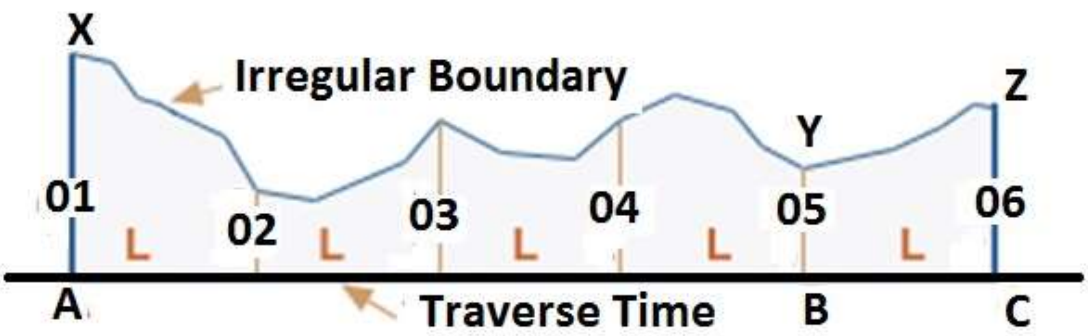
The area of land parcels or regions is often needed as part of a volume calculation, for instance to determine the amount of fertilizer to be applied to a paddock or to determine runoff for stream flow analysis. The legal title description of a land allotment shows the area as well as the dimensions, for example:

Land parcels are not always contained by regular straight line or circular arc boundaries, especially when they front water courses or ridge lines. Methods for surveying these boundaries and computing the enclosed areas are as follows:




Simpson's and trapezoidal method,

1-Trapezoidal Rule




The area **AXYZCBA** is typical of part of a rural allotment bounded on one side by an irregular side (eg. a creek). The regular part of the allotment has been excluded from these calculations by the use of the traverse line **ABC**. The area below this line can be computed by means of triangles as shown in part 1 (and other methods shown later). All that remains is to compute the irregular area **AXYZCBA**. This is done by approximating the area by a series of equally spaced trapezia, measuring these either in the field or off a plan, and then computing the area of each of these.

Using the rules of Euclidean Geometry, the area of the first trapezoid is given by;

$$A1 = \frac{L(O1+O2)}{2} \qquad \text{--------(I)}$$

Where L is the constant distance along the traverse line between offsets O1 and O2. Now the total area of the figure is given by;

$A_T = A_1 + A_2 + A_3 + A_4 + A_5$ --------(2)

so substituting the particular elements, in terms of $O_n$ and L, the total area is given by;

$A_T = L[(O_1 + O_2) + (O_2 + O_3) + (O_3 + O_4) + (O_4 + O_5) + (O_5 + O_6)]/2$ -------(3)

$A_T = L[(O2+On)/2 \quad +O2+O3+O4+O5+\ldots\ldots\ldots+On-1]$ -------(4)

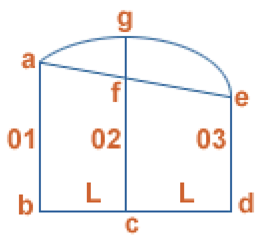
and in more general terms the **Trapezoidal Rule** may be quoted as;

(1st + last + 2 times the sum of the others) -------(5)

where **$O_1$** .. **$O_n$** are offsets; **L** is the uniform distance between offsets and **n** may be odd or even. The resulting area is generally **less** than the true area. The accuracy of the area will depend on the number of offsets (and therefore the distance between them) and the degree of irregularity of the boundary. Of course the more irregular the boundary the more offsets should measured; this will demand a compromise between the time spent gathering the data and the required accuracy.

## 2-Simpson's Rule

The Trapezoidal Rule can be improved by assuming that each two adjacent sub-areas are a single bounded parabola rather than each sub-area being a trapezoid.




For the area contained between 01 and 03;

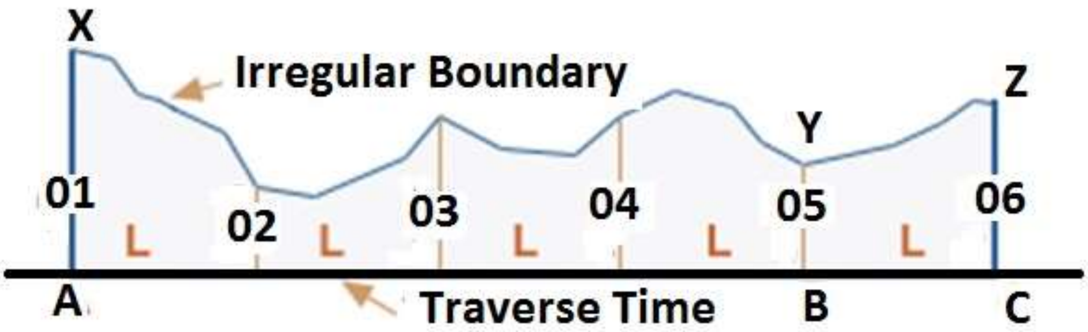
A = Trapezoid (**abdea**) + parabolic area (**agefa**)
A = (01 + 03)L + 2/3(area bounded by parabola)
A = (01 + 03)L + 2/3 x 2L[02 - (01 + 03)/2]
A = L[01 + 402 + 03]/03

**and this may be repeated and summed for a total area of an irregular figure provided that the number of offsets is odd.**

This assumption leads to Simpson's Rule for irregular areas and is quoted as follows;

**$A = [(O_1 + O_n) + 2(O_3 + O_5 + O_{n-2}) + 4(O_2 + O_4 + O_{n-1})]$**

**A = [S(1st + last offset) + 2S(odd offsets) + 4S(even offsets)]**




This formula is more accurate but has the disadvantage that **n** must be odd. In this case it is not possible to directly compute the total area **AXYZCBA**. Instead the area **AXYBA** is computed using Simpson's Rule and the additional area **BYZCB** must be computed separately. This could have been avoided if the irregular area had been originally subdivided into an odd number of sub-area

## Other Methods

It is possible to determine the area of irregular figures shown on maps and plans by using a simple device known as a **planimeter**. This instrument is placed onto the plan and a pointer is traversed around the boundary of the figure whilst a rotary mechanical counter determines the area. There are also recent models that use a microprocessor and digital display of the result, however the final accuracy is determined by the scale of the original plan.

Another method is to plot the figure onto graph paper (or to project a grid over the figure) and to count squares. Although this may seen a very simple technology often the required

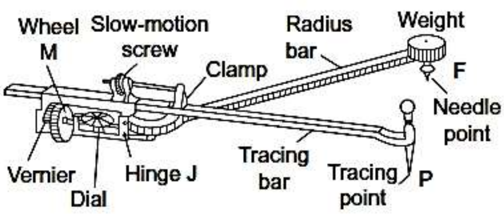



**Fig. 9.3(a)** *Amsler's polar planimeter*

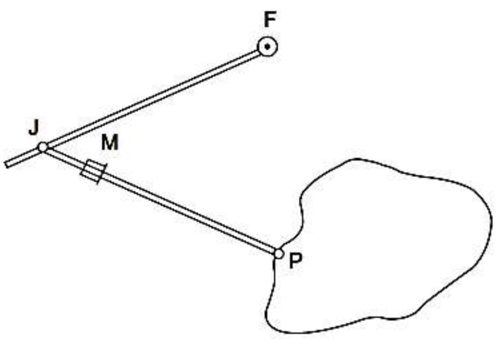
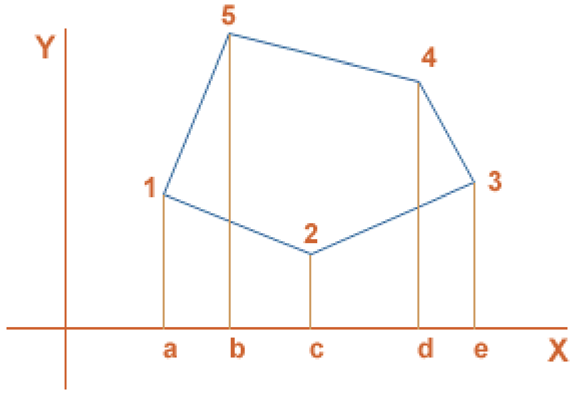



**Fig. 9.3(b)**

precision of the result justifies this simple approach.

## Coordinates Method:

It is required to determine the area of the closed polygon **1,2,3,4,5,1**. For each of the corners the X and Y coordinates are known. A solution may be found by constructing a set of trapezoids bounded by the X axis, the individual sides of the polygon and two sides parallel to the Y axis. These trapezoids can be seen in the figure below and are labeled **12ca1, 23ec2, 34de3, 45bd4** and **51ab5**. The area of the polygon is the sum of the areas of the individual trapezoids.




Working around the polygon in an anti-clockwise direction the sum of the individual areas is;

$$A_T = \frac{[Y_1 + Y_2][X_2 - X_1]}{2} + \frac{[Y_2 + Y_3][X_3 - X_2]}{2} + \frac{[Y_3 + Y_4][X_4 - X_3]}{2} + \frac{[Y_4 + Y_5][X_5 - X_4]}{2} + \frac{[Y_5 + Y_1][X_1 - X_5]}{2}$$

$$2A_T = [Y_1X_2 + \underline{Y_2X_2} - \underline{Y_1X_1} - Y_2X_1 + Y_2X_3 + \underline{Y_3X_3} - \underline{Y_2X_2} - Y_3X_2 + Y_3X_4 + \underline{Y_4X_4} - \underline{Y_3X_3} - Y_4X_3 + Y_4X_5 + \underline{Y_5X_5} - \underline{Y_4X_4} - Y_5X_4 + Y_5X_1 + \underline{Y_1X_1} - \underline{Y_5X_5} - Y_1X_5]$$

Collecting like terms and cancelling out the underlined terms leads to the simplified equation below,

$$2A_T = [Y_1X_2 - Y_2X_1] + [Y_2X_3 - Y_3X_2] + [Y_3X_4 - Y_4X_3] + [Y_4X_5 - Y_5X_4] + [Y_5X_1 - Y_1X_5]$$

If the terms are collected as above the formula may be represented in the general form of,

$$\mathbf{2A = \Sigma[X_{i+1}Y_i - X_iY_{i+1}]}$$

The resultant area will be positive or negative depending on whether a polygon is traversed in a clockwise or anti-clockwise direction. The amount of computations maybe significantly reduced if the coordinates of the first point are reduced to zero; that is $X_1 = Y_1 = 0$.
This may be achieved by the simple transformations,

$x_i = X_i - X_1$ and $y_i = Y_i - Y_1$

For a four sided polygon this will reduce the number of multiplications from eight to four.

## Calculating The Required Precision For Measuring An Irregular Area

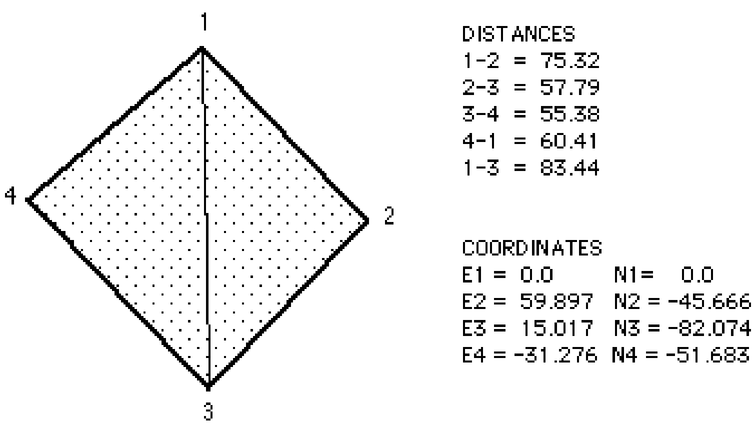
Before taking measurements to calculate the area of an irregular shape, the formula below is useful to check the expected precision of a computed area. It can be shown from propagation of error that the precision of an area can be approximated by the formula :

area precision = 0.5 . $\sqrt{}$ n . average side length . coordinate precision

where: n = the number of sides of the area

# Example

An example of the calculations is shown below. A solution has been provided for **areas by coordinates** and **areas by triangles**. For convenience the coordinates of point one have been reduced to zero.




### By Coordinates

2A = [59.897*(-82.074)] + [15.017*(-51.683)] - [45.666*(15.017)] - [(-82.074)*(-31.276)]

2A =-4915.99 - 776.12 + 685.77 - 2566.95

**|A| = 3786.65** square units

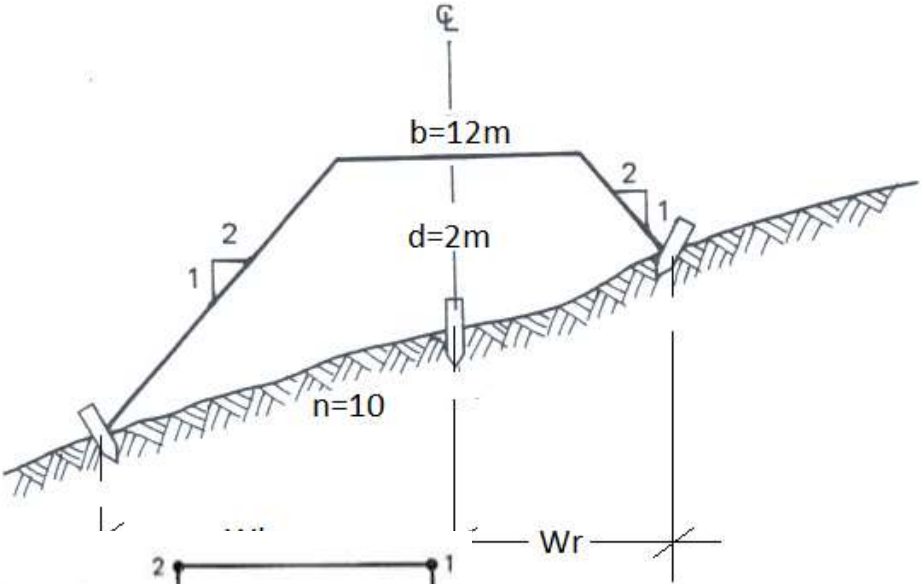
### By Triangles

$S_1$ =108.273

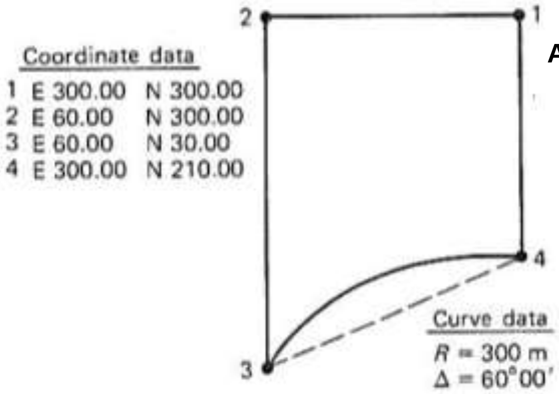
$S_2 = 99.614$

$A = \sqrt{[s(s-a)(s-b)(s-c)]}$

$A_T = \sqrt{4{,}473{,}436.50} + \sqrt{2{,}794{,}346.86}$




**$A_T$ = 3786.68** square units

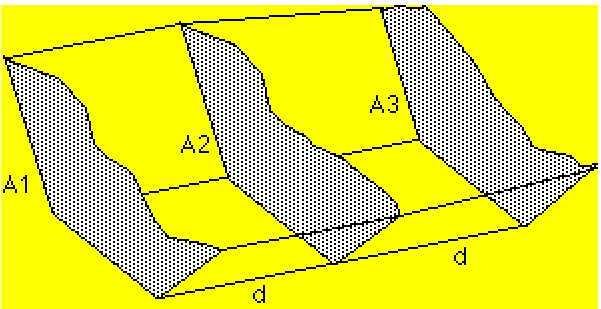


# The seventh week

## Volume Determination:

## The End Area Method

This is the simplest method for determining volumes from cross sections. It closely follows the theory developed for the determination of areas; in this case instead of **offsets** at constant separation (resulting in areas) there are **areas** at constant separations (resulting in volumes).




In the figure it can be assumed that areas $A_1$, $A_2$ and $A_3$ have been determined. Therefore, if $A_1$ is the left end area, $A_2$ the right end area and d the separation between sections, the first volume is,

$$V = d^* A$$

Now consider several successive cross sections situated at equal distances, d, along a fixed direction. Then,

$V = d(A_1 + A_2)/2 + d(A_2 + A_3)/2 + d(A_3 + A_4)/2 + ........ + d(A_{n-1} + A_n)/2$

$V = d[A_1 + 2A_2 + 2A_3 + 2A_4 + ......... + 2A_{n-1} + A_n]/2$

**V = [First area + last area + 2Σ(all remaining areas)]**

This **End Area** formula may be applied to any number of cross sections equally spaced along a straight line.

# Prismoidal Formula

The Prismoidal formula is sometimes called "Simpson's Rule for Volumes", and the derivation is exactly the same as before (see Areas). It is a modification of the End Areas Formula.

An alternative proof can be seen by considering the figure below. Regardless of the combination of rectangular blocks, wedges or prisms, the volume may be expressed in exactly the same form.

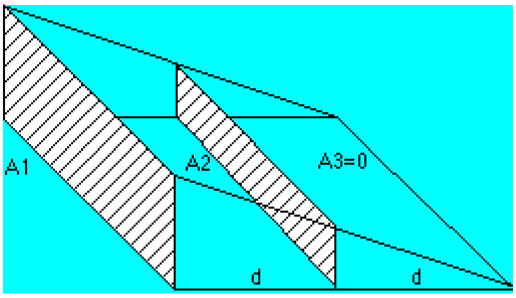
**V = d*A**

Consider firstly a rectangular prism. Clearly $A_1 = A_2 = A_3$. Therefore the volume is,

$V = A_1.2d = 2A_1.d = 6A_1d/3$, but since $A_1 = A_2 = A_3$

$V = d[ A_1 + 4A_2 + A_3]/3$, which is the required generalised form.

Secondly, the wedge as shown below:




In this case $A_1 = 2A_2$ and $A_3 = 0$. Therefore the total volume is,

$V = 1/2.A_1.2d = A_1.d = d[3A_1]/3$

$V = d[A_1 + 4A_2 + A_3]/3$ which is the required generalized form.

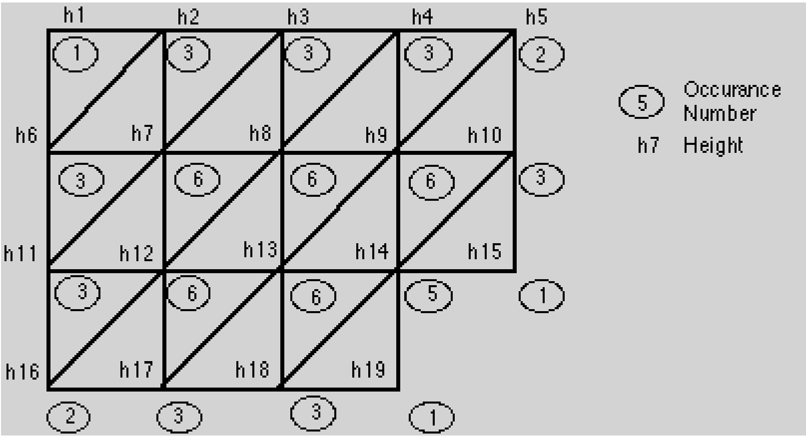
Spaced cross sections is given by,

$$V = \frac{d}{3}[(area_1 + area_n) + 4\Sigma(\text{even areas}) + 2\Sigma(\text{odd areas})]$$

This formula may be applied to an **odd** number (n) of cross sections evenly spaced (d)

# Triangular Base Method (borrow pits)

Triangular elements can better define the surface because any three levels will define a plane where as four levels (in the general case) will only define a warped non planar surface.




In this case the area will become ($s^2/2$). Then the total volume as made up of a series of prisms on triangular bases and be developed by,

$V1 = (h_1 + h_2 + h_6)\ s^2/6$

For the second and third elements the volumes are,

$V2 = (h_2 + h_6 + h_7)\ s^2/6$

$V3 = (h_2 + h_3 + h_7)\ s^2/6$

The total volume of the area covered by the entire grid of levels is,

$V = [V_1 + V_2 + V_3 + \ldots\ldots\ldots\ldots + V_n]$

and therefore the volume in general terms may be expressed as,

$$V = \frac{s^2 \sum_{i=1}^{n} [N_i h_i]}{6}$$

Where $\mathbf{N_i}$ is the occurrence number,

$\mathbf{h_i}$ is the height difference at each point,

$\mathbf{s^2}$ the area of the square grid element,

Of course the occurrence numbers will change from the previous case of the rectangular prisms.

Volumes from spot heights is convenient but is generally restricted to small areas since the setting out and leveling of a large grid can be extremely tedious and time consuming. The use of triangles rather than rectangles will usually increase the accuracy slightly, though it will tend to increase the amount of arithmetic involved.

# Balance of Cut and Fill

As introduced before the above grid leveling formulae will only give the net volume. The datum plane should not ordinarily intersect the terrain. This, in one special case, can be turned into an advantage.

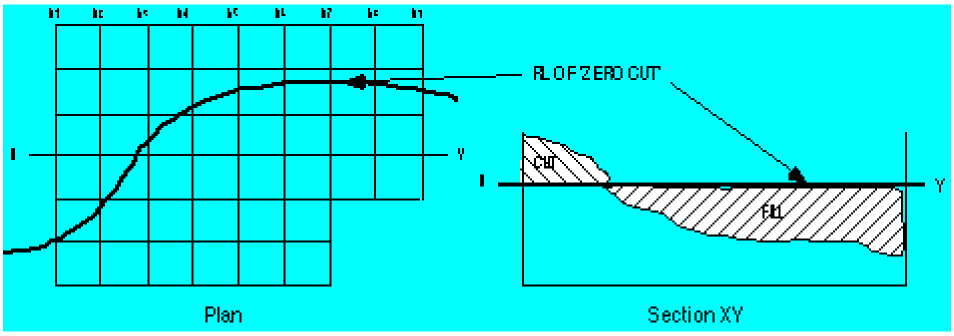
How can an area be **leveled** so that the amount of cut volume is equal to the amount of fill volume?
What is the reduced level of the resulting level plane?

In this case the net volume will be zero; Volume of cut = Volume of fill.
The problem then becomes determining what is the R.L. (Reduced Level) of the line of zero cut/fill. In this particular case the line will be a contour line (i.e. the intersection of a horizontal plane with the terrain) but in general the solution is far more complex.

If the area is grid leveled then let the required Reduced Level be $RL_x$; then for each point

$h_i = RL_i - RL_x$

This amount will be positive in areas of cut and negative in areas of fill and zero on the balance line .




As before the volume of material above $RL_x$ can be given by;

$$V = \frac{s^2 \sum_{i=1}^{n} N_i h_i}{4}$$

For the volume of cut to equal the volume of fill,

$\Sigma N_i h_i . s^2/4 = 0$

that is $\Sigma N_i(RL_i - RL_x) = 0$, but $\Sigma N_i = 4G$ where G is the number of grid elements or sections.

$\Sigma N_i RL_i - \Sigma N_i RL_x = 0$ and $\Sigma N_i RL_i = 4GRL_x$

$\therefore \Sigma N_i RL_i - 4GRL_x = 0$

$$RL_X = \frac{\Sigma N_i RL_i}{4G}$$

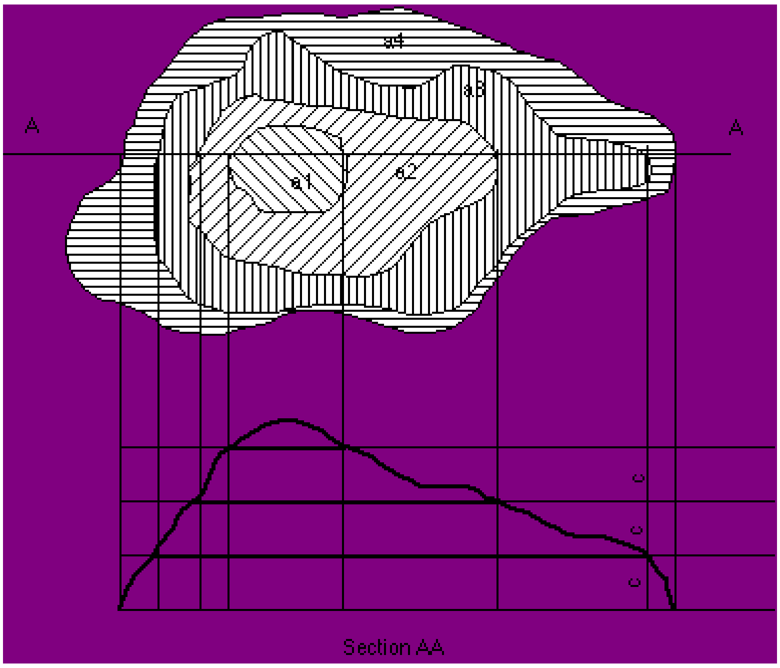
As $\mathbf{N_i}$ and $\mathbf{RL_i}$ are known for every point and **4G** is known for the entire grid area the RL of the cut and fill line may be determined. This solution has been simplified by disregarding two features. Firstly, it is stated that the area is to be leveled; this is a common occurrence for tennis courts and house and building sites but ignores the more complex problem of an inclined intersecting plane or even more complex, the intersection of several planes with the terrain. Secondly, the solution ignores the expansion and contraction of excavated and filled material; material expands after cutting and contracts after filling. A cut/fill ratio, c/f, can be introduced into the derivation to overcome this sometimes invalid assumption. A typical value for c/f is 10/9. If the c/f ratio is included the solution for $RL_X$ becomes an iterative process as the formula will include terms for area of cut and area of fill. Unfortunately these parameters are initially unknown and vary with the c/f ratio and the other unknown $RL_X$. A solution can be found by iteration.

# Volumes from Contours

The method used is simply the end area method or the prismoidal formula, the cross section being replaced by the areas contained within successive contours (see below). The distance between sections, or in this case contours, simply becomes the contour interval. As the contained areas are usually quite irregular they are normally determined by planimeter or by computers and digitizing software. The process is laborious and is becoming less popular with the advent of digital data and digital maps. The volume of the hill shown below is,

$$V = c\,\frac{[a_1 + 2a_2 + 2a_3 + a_4]}{2}$$ where c in the contour interval.

The formula ignores the volume of the apex of the hill top; this could be included by making $a_5 = 0$ or by the additional use of some other suitable method.




# The eighth week

# Horizontal Curves

## Introduction

The establishment of figures on the ground is an important task of the field surveyor, not only in engineering construction but also in cadastral surveying. It is a relatively easy task to peg out the boundary of a rectangular concrete slab, but considerably more difficult to establish the location of points along an elevated curved freeway.

This section will look at the techniques of establishing horizontal circular curves, however more detail will be given in later subject units concerned with road design and construction.

# Basic Properties of Horizontal Circular Curves

## Properties of a Circle

The circle has a few geometric features upon which many of the curve layout formulae are based.

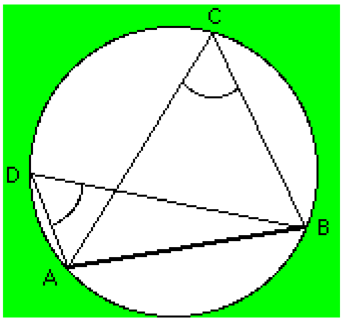
i. Area of circle = $\pi r^2$

ii. Circumference of circle = $2 \pi r$

iii. Area of sector = $\frac{1}{}$ $r^2\theta_{rad}$

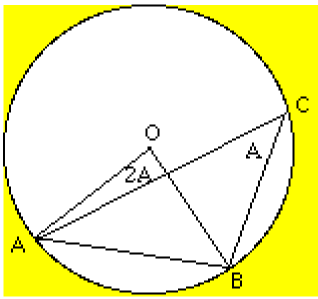
2

iv. Area of a segment = $\frac{1}{2} r^2(\theta_{rad} - \text{Sin}\ \theta)$



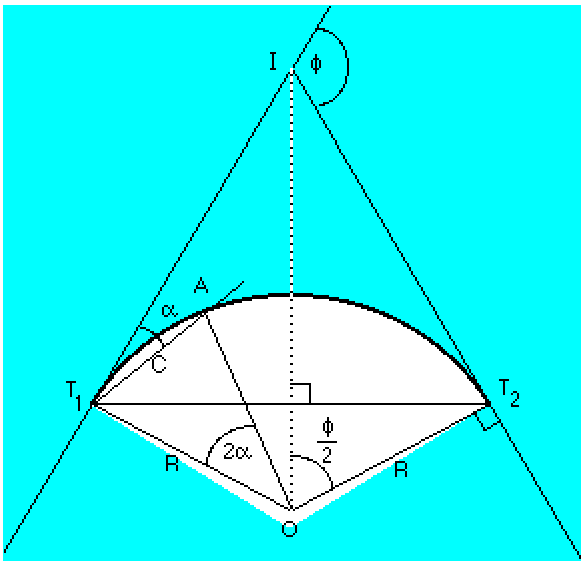

The angles subtended by a chord AB on the circumference are always equal

The angle subtended at the centre by a chord AB is always twice the angle subtended on the circumference.




## Properties of the Horizontal Curve

The road or engineering curve has a particular geometry which is shown below. For the sake of clarity, the diagram uses a much greater intersection angle than usually found in reality.




**The Engineering Curve**

Shown above is the geometry of the horizontal circular curve, used to connect one straight line with another straight line. The two straight line segments (usually roads, rails or pipelines) would have bearings, the intersection angle being determined from the difference between the two.

The intersection point is denoted by **I**, the tangent points (the place where the straight is tangential to the curve and from where the curve starts and finishes) are denoted by $\mathbf{T_1}$ and $\mathbf{T_2}$, the centre of the curve is denoted by **O**, the long chord by **L**, the short chord by **C** and the radius by **R**

Features of the horizontal circular curve are as follows:

a. The tangent length is $T = R \tan \frac{I}{2}$

b. The angle subtended at the centre by the chord is the same as that subtended by the intersecting straights, 'I'.

c. The long chord length is $L = 2 R \sin \frac{\phi}{2}$

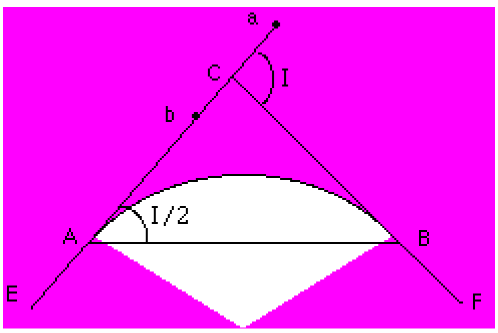
d. The angle subtended by a short chord at the centre is twice the angle subtended between the tangent to the curve and the chord.

e. The arc length (which is the chainage used in computations) is given by $l = R\,\phi$.

f. Points along the curve are located by their **running chainage** from the commencement point of the works. Any marks placed along the curve are also established at regular intervals of centerline chainage.

# Location of the Tangent Points

For a given pair of straights, there is only one point at which a curve of given radius or degree may leave the first straight tangentially in order to sweep tangentially into the second. The points of commencement and termination of the curve must therefore be determined in the field with greater precision than would be possible by merely scaling their positions from the plan.




a. Having located the two tangents and defined them by ranging poles, peg out the first tangent EA up to about the estimated position of A, the theodolite being placed on EA and align two pegs a and b a few feet apart, one being placed on each side of C, the position of which is estimated by from the line of the poles on BF.
b. Transfer the instrument to some convenient point on the second straight, and produce the latter to meet a string stretched between a and b. The point of intersection C of the two tangents thus obtained is marked by a peg.

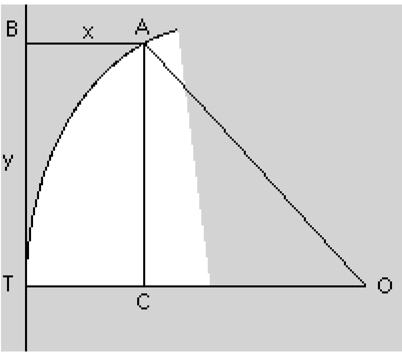
c. Set up the theodolite over C, and measure the angle ECF. By subtracting the result from 180°, the value of intersection angle **I** is obtained. Calculate the tangent lengths.
d. From C, measure back the lengths CA and CB = T, the tangent points A and B being aligned from the instrument at C. Mark A and B in a distinctive manner, either by painted pegs or by three ordinary pegs, the centre one of which defines the point.
e. Transfer the instrument to A, and set it over the tangent point peg. Measure the angle CAB, which should equal $\frac{1}{2}$**I**. This provides a convenient check on the equality of the tangent lengths, which may, however, both be in error by the same amount through a mistake in the measurement of I or in the calculation of T.
f. The chaining of the first straight may now be completed, the chainage of the point A being noted.

# Setting Out

There are several methods available for establishing the location of points along the centre line of the engineering curve. Some of these are rarely used these days, the system is generally dominated by the use of coordinates as the method of computation, so the use of radiations from control points is common. In any case, all pegs and marks placed **must** be checked, and the preferred method for that is to use a different method to check from that used to peg.

# Setting Out - Offsets From The Tangent

When the tangent points have been located, the curve may be set out by means of offsets from the tangents. Consider the circular arc illustrated below with centre O and one of the tangent points, T. It is necessary to calculate the length of the offset BA(c) at distance TB(g) along the tangent. Let radius of arc be R.




Applying Pythagoras Theorem to triangle OAC, we have:

$OA^2 = OC^2 + AC^2 = (TO - TC)^2 + AC^2$

or

$OA^2 = (TO - BA)^2 + TB^2$

Substituting for x, y, and R in this equation:

$$R^2 = (R - x)^2 + y^2$$

or

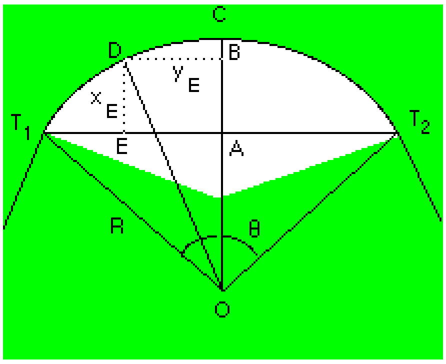
$$(R - x)^2 = (R^2 - y^2)$$

$$\therefore x = \sqrt{(R^2 - y^2)}$$

Hence, values of x may be calculated for regular intervals of y. This method is useful when the angle through which the road deflects is small such that offsets are short. The curve may be adequately defined by setting out offsets from both tangents.

# Setting out - Offsets from the Chord

It is sometimes more convenient to set out the curve from the 'inside'. Many of the points on the tangent may not be accessible whereas points on the chord joining the two tangents points may be easily accessible. In this case it is convenient to establish the mid-point of the long chord and refer the distances along the chord to this point rather than the tangent point.




Let A represent the mid-point of the chord $T_1$ $T_2$ and from the symmetry of the figure OÅ$T_1$will be a right angle. The offset at A to the curve must first be calculated.

Using Pythagoras in $\Delta OAT_1$

$$(OT_1)^2 = (OA)^2 + (AT_1)^2$$

Let the length of the chord $T_1T_2$ be L

$$\therefore AT_1 = \frac{L}{2} = R\sin\frac{\theta}{2} \qquad \text{i.e. } L = 2R\sin\frac{\theta}{2}$$

If the offset at A is taken as $x_0$ and the radius of the curve as R then:

$$R^2 = (R - x_0)^2 + \left(\frac{L}{2}\right)^2$$

$$\therefore x_0 = R - \left\{R^2 - \left(\frac{L}{2}\right)^2\right\}^{\frac{1}{2}}$$

Now consider the offset ($x_E$) from the point E which is a distance $y_E$ from A.

Applying Phythagoras to DOBD, we have

$$(OD)^2 = (OB)^2 + (BD)^2$$
$$= (OA + AB)^2 + (EA)^2 = (OC - CA + DE)^2 + (EA)^2$$

$$R^2 = (R - x_0 + x_E)^2 + (y_E)^2$$

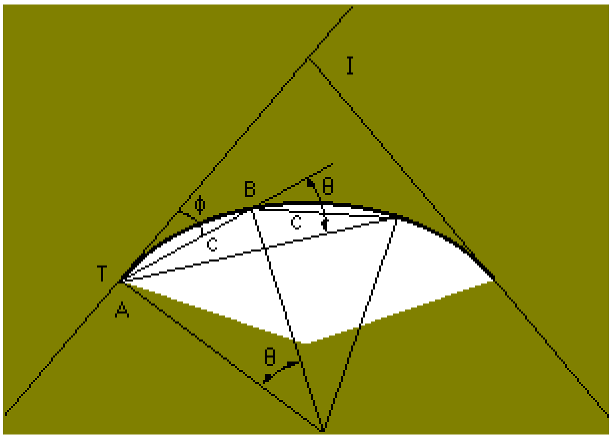
$$\therefore x_E = (R^2 - y_E^2)^{\frac{1}{2}} - (R - x_0)$$

Clearly only offsets for one half of the chord are necessary, the curve is symmetrical.

# Setting out - Deflection Angles

The use of deflection angles (the angle deflected by a chord) is considerable more rigourous than either of the two previous methods. The method also follows the centreline of the curve, unlike the previous two which require access to the chord and centreline.

The method is based on the following geometry:




It will be remembered that the angle subtended at the circumference by a chord is one half of the angle subtended at the centre (in this case $\phi$ and $\theta$). The first angle through which the chord being used for pegging is deflected is therefore half the angle subtended by that chord at the centre. The next angle through which the next chord is deflected is the equal to twice this value that is the same as the angle subtended at the centre. A typical application of the method is as follows:

i. Set the instrument up at the tangent point, sight along the tangent and turn off the first deflection angle $\phi$ ( $=\frac{\theta}{2}$).
ii. fix one end of tape at A, measure off 'c' metres, and swing tape until it aligns with the line of sight. Put in peg B.
iii. Turn theodolite a further $\theta$°. Fix one end of tape at B, measure off 'c' meters, and swing tape until that point on the tape crosses the line of sight. Put in peg C.
iv. Repeat step (iii) until you peg the curve. If the line of sight becomes obstructed, then simply set up on any peg on the curve, sight back along the chord to the previous peg and continue to establish the deflection angles.

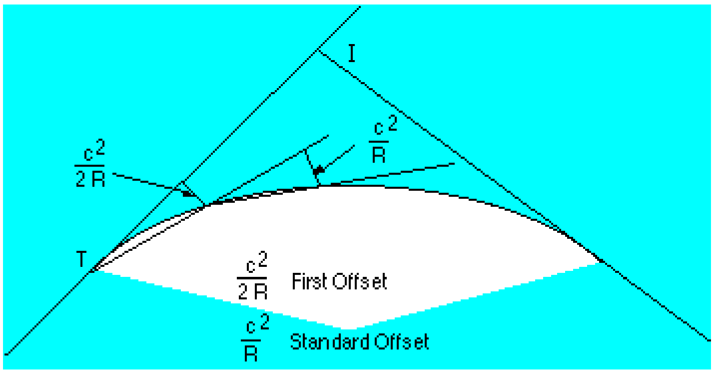
**Precautions to take**

i. Calculate the angle $\theta$ to seconds, or errors will be considerable if many pegs must be placed.

ii. The final reading, to the other tangent point, should equal $\frac{1}{2}$I.

## Setting out - Deflection Distances

The method of establishing a curve using deflection distances is very similar to that of deflection angles.




Deflection distances are the offset from the tangent in the first instance and the produced chord in the subsequent instances. The first offset is calculated from the chord length and radius and is shown above. The second offset, also known as the 'Standard Offset' is twice this, and remains so for the remainder of the curve. These two distances can be cut as notches on a sighting board, which then eliminates the need to measure them in the field. This is a simple method of establishing the curve, and needs a low level of technology to perform.

## Setting out - Quartering

One very simple method of setting out a circular curve quickly is to use the method of quartering. Since the method is based on assumption which can, under certain circumstances, produce significant errors, it should not be used where a high degree of accuracy is required.

Looking at the diagram below, let the length of the long chord be "L" and Radius of curve "R".

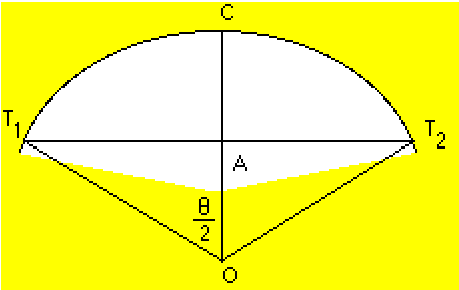
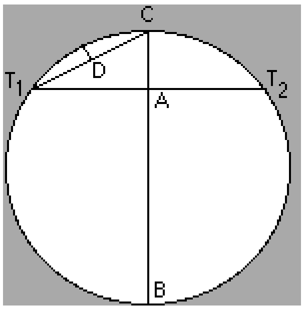



Diagram (1)

⇨ $AT = C/2 = \frac{L}{2} = R\sin\frac{\theta}{2}$ or $C = 2R\sin\frac{\theta}{2}$

Now look at the diagram below.




$T_1A^2 = AC \times BA$

Now if we let the offset at A be $x_0$

then $(\frac{L}{2})^2 = x_0\,(2R - x_0)$

$= 2Rx_0 - x_0^2$

Now since $x_0$ is very small compared with R, the term involving $x_0^2$ may be neglected yielding:

$$x_0 = (\frac{L}{2})2 \times \frac{1}{2R} \text{ which simplifies down to } x_0 = \frac{L^2}{8R}$$

Now having established this point 'C' we may consider the chord $CT_1$ and treat it in exactly the same way as the long chord. Here another assumption is made which is that

$$CT_1 \sim \frac{T_1T_2}{2} = \frac{L}{2}$$

This will be nearly true for small deflection angles but will introduce significant errors where larger deflection angles are involved.

We now can calculate the offset at the mid point of the chord (D) following the same procedure as before.

As we have assumed $CT_1 = \frac{L}{2}$

⇨ $CD = \frac{L}{4}$

hence $2Rx_0 = \frac{L^2}{4}$

$$\Rightarrow \quad x_0 = \frac{L^2}{32R}$$

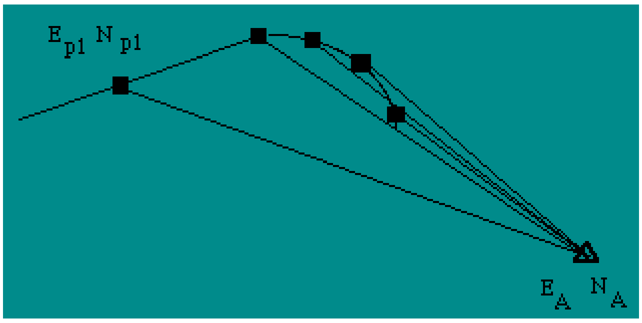
It will be noticed that this offset is **one quarter** of that to be set out from C.

This procedure may be repeated as often as is necessary in order to define the curve adequately. For each successive chord, the central offset will be a quarter of that from the previous chord.

Since the assumption on which the method is based is that the length of chord and arc are approximately equal the technique can only be applied where very small deflection angles between the tangents are concerned. Alternatively it offers a convenient method of setting out circular arcs quickly where precision is not so important, for example the curb line on a residential estate.

# Setting Out by Coordinates:

A very common method for establishing the centreline of curves on the ground is to compute the coordinates of the peg positions (using any of the available methods covered previously), and to radiate to these coordinates from survey control stations. This has many advantages, especially when electronic tacheometers are used. The layout is quick, the instrument can be located away from the main works area, and precomputed coordinates can be stored in the memory of many modern instruments and data recorders eliminating the need for on site calculations. Most major engineering constructions are now fully coordinated and all site layout is performed using this method.




An appropriate method is used to calculate the position of the pegs, for example using the deflection angle method to determine bearings to each peg from the tangent point and using the chord distances to calculate change in coordinates. Once the coordinates for each peg have been calculated, the bearing and distance from the control points to the pegs are then calculated and used to establish the location of the pegs on the ground. Once again, another method would need to be used to check the location of each peg.

- Reverse curve: A reverse curve consists of two simple curves jointed together, but curving in opposited directions. For safety reason this curve is seldom used in highway construction as it would tend to send an outomobile off the road.
- Spiral curve: The spiral is a curve which has a varing radios. It is used on railroads and some modern highway. Its purpose is to provide a transition from the tangent to asimple curve or between simple curves in a compound curve:

**Element of a simple curve**

$P.I \rightarrow Point\ of\ intersection$

$I\ or\ \Delta \rightarrow The\ intersecting\ angle.\ and\ or\ central\ angle$

$R \rightarrow radins$

$P.C \rightarrow Point\ of\ curvature$

$P.T \rightarrow Point\ of\ targency$

$L \rightarrow length\ of\ the\ curve$

$T \rightarrow Tangent\ distance$

$C \rightarrow The\ long\ covd$

$E \rightarrow External\ distance\ \ (from\ P.I\ to\ the\ midpoint\ of\ the\ curve$

**Exercises**

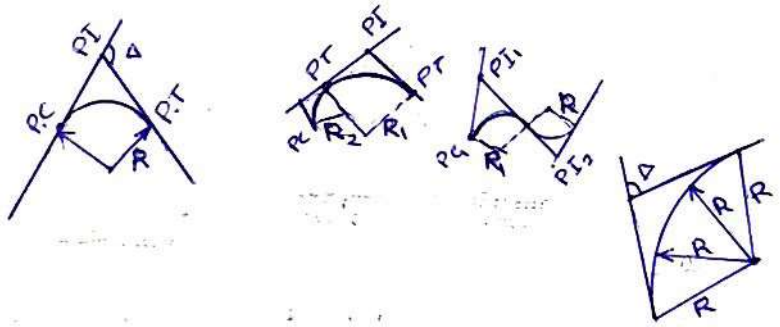
# Horizontal curves

**Types of Horizontal curves:**

Curves may be simple compound, reverse, or spiral. Compound and reveres curves are treated a combination of two or more simple curves, where are the spiral curve is based avarying radius.

Curves of short radius (usually less than one tape length) can be established by holding one end of the tape at the ceutre of the circle and swinging the tape in an are, marking as many points as many be desired. As the radius and length of curve increases, the tape becomes impractical and the surveyer must use other methods. The common method is to measure angles and strigh-line sight distance by which selected points, know as stations, may be located on the circumference of the are.

The four types of curves are described briefly as




- Simple curve: is an acre of a circle – most often used.
- Compound curve: Frequently the terrain will mecessitate the used of compound curve.
- Reverse curve: A reverse curve consists

- Reverse curve: A reverse curve consists of two simple curves jointed together, but curving in opposited directions. For safety reason this curve is seldom used in highway construction as it would tend to send an outomobile off the road.
- Spiral curve: The spiral is a curve which has a varing radios. It is used on railroads and some modern highway. Its purpose is to provide a transition from the tangent to asimple curve or between simple curves in a compound curve:

**Element of a simple curve**

*P.I → Point of intersection*

*I or Δ → The intersecting angle. and or central angle*

*R → radins*

*P.C → Point of curvature*

*P.T → Point of targency*

*L → length of the curve*

*T → Tangent distance*

*C → The long covd*

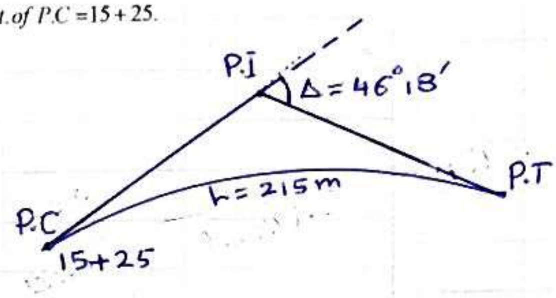
*E → External distance (from P.I to the midpoint of the curve*

**Exercises**

QP 5.1 Compute the elements and stations for the following simple horizontal curve;

(A) $L = 215m$ $\Delta = 46°18'$ at. of P.C = 15 + 25.

solution:




1- Draw sketch

2- Compute station of P.T

$st.\ P.T = st.\ PC + L = 1525 + 215 = 1740m$

$= 17 + 40$

3- $T = R\tan\frac{\Delta}{2}$ ; *Two unknow T & R*

$L = \frac{\pi R \Delta}{180}$ ; $215 = \frac{\pi R 46°18'}{180}$

$R = 266.06m$

$T = 266.06 * \tan\frac{4618}{2} = 113.759m$

4-

$St.\ of\ P.I = St.\ of\ P.C + T$

$= 1525 + 113.759 = 1632.759\ m$

$= 16 + 38.759$

5-

$C = 2R\sin\frac{\Delta}{2} = 2 * 266.06 * \sin 23°.15'$

$= 209.195m \cong 209.2m$

6-

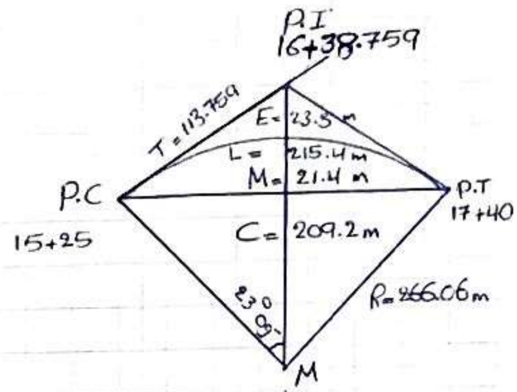
$E = R(\frac{1}{\cos\frac{\Delta}{2}} - 1) = 266.06(\frac{1}{\cos 23°15°} - 1)$

$= 23.3m$

7-

$$M = R(1-\cos\tfrac{\Delta}{2}) = \ 266.06(1-\cos 23.15'')$$
$$= 21.424m$$

8- Draw The sketch with the computed data



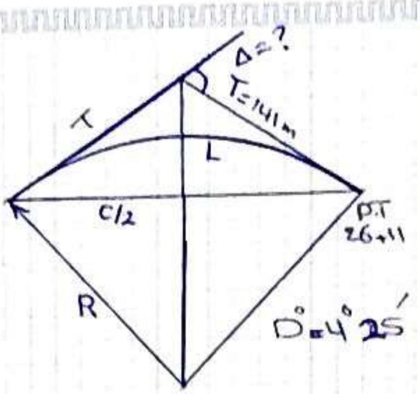

9- Great a table

table of elements

| | Stations or element | Value in (m) or st |
|---|---|---|
| 1- | P.C | 15+25 |
| 2- | P.I | 16+38.759 |
| 3- | P.T | 17+40 |
| 4- | T | 113.759 |
| 5- | C | 209.200 |
| 6- | L | 215 |
| 7- | R | 266.06 |
| 8- | E | 23.30 |
| 9- | M | 21.40 |

$B-\quad T = 141\,m \quad D = 4°25' \quad st.of\ P.T = 26+11$

solution: 1- Draw sketch




2- Compute the element

$$R=\frac{573}{D}=\frac{573}{4^\circ 25'}=129.736m$$

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3-

$T=R\tan\frac{\Delta}{2}$ ; $\tan\frac{\Delta}{2}=\frac{T}{R}$ ; $\tan\frac{\Delta}{2}=\frac{141}{129.736}=1.08682$

$\Delta=2\tan^{-1}1.08682=94^\circ\ 45'\ 54'' \leftarrow l'$

عادة تقرب الى ثلاث مراتب بعد الفارزة

4- $C=2R\sin\frac{\Delta}{2}=2*129.736\ \sin\frac{94\ 45\ 54}{2}=190.943m$

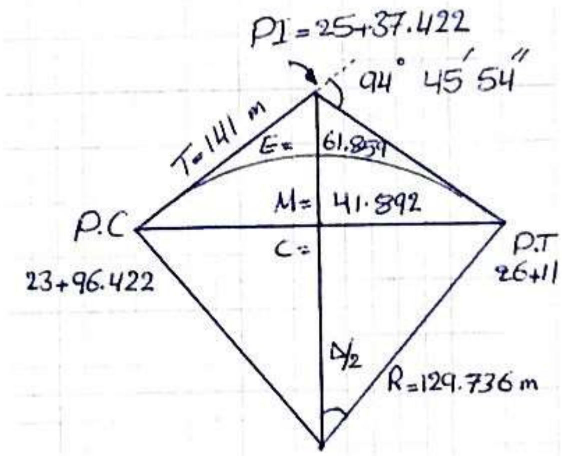
5- $L=\frac{\Pi R\Delta}{180}=\frac{\Pi*129.736*94^\circ\ 45'\ 54''}{180}=214.678m$

6- $E=R(\frac{1}{\cos\frac{\Delta}{2}}-1)=129.739\ (\frac{1}{\cos\frac{94\ 45\ 54}{2}}-1)=61.869m$

7- $M=R(1-\cos\frac{\Delta}{2})=129.736\ (1-\cos\frac{94\ 45\ 54}{2})=41.892m$

8- $St.of\ P.C-St.of\ P.T-L=2611-214.578=2396.422$

9- $St.\ of\ P.I=St.of\ P.C+T=2396.422+141=2537.422$

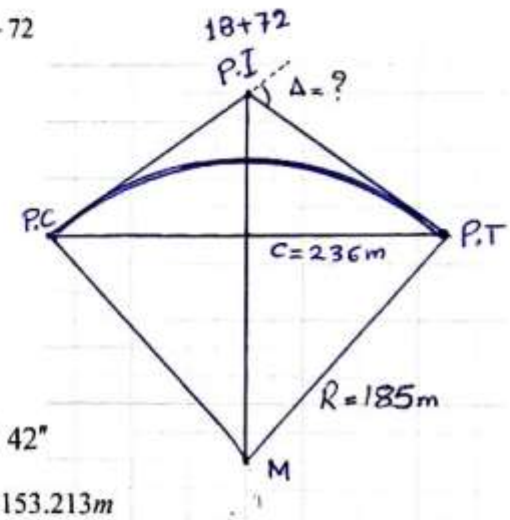


| Stations or element | Value in (m) or st |
|---|---|
| P.C | 23 + 96.422 |
| P.I | 25 + 37.422 |
| P.T | 25 + 11.0 |
| R | 129.736 |
| T | 141 |
| C | 190.943 |

C-

$C = 236m \quad R = 185m \quad St.of\ P.I = 18 + 72$

Solution: Draw sketch




1-

$D^{\circ} = \frac{573}{185} = 3^{\circ}\ 5'\ 50''$

2- Compute elements

$C = 2R\sin\frac{\Delta}{2}$

$\sin\frac{\Delta}{2} = \frac{C}{2R} = \frac{236}{2*185}$

3- $\Delta = 2\sin^{-1} 0.6378 = 79^{\circ}\ 15'\ 42''$

4- $T = R\tan\frac{\Delta}{2} = 185\tan\frac{79\ 15\ 42}{2} = 153.213m$

5- $L = \frac{\Pi * R\Delta}{180} = \frac{\Pi * 185 * 79^{\circ}\ 15'\ 42''}{180} = 255.924m$

6- $E = R(\frac{1}{\cos\frac{\Delta}{2}} - 1) = 185(\frac{1}{\cos\frac{79\ 15\ 42}{2}} - 1) = 55.206m$

7- $M = R(1 - \cos\frac{\Delta}{2}) = (1 - \cos\frac{79\ 15\ 42}{2}) = 42.518m$

8- $St.of\ P.C = 1872 - 153.213 = 1718.787$ m

9- $St.of\ P.T = 1718.787 + 255.924 = 1974.711$ m

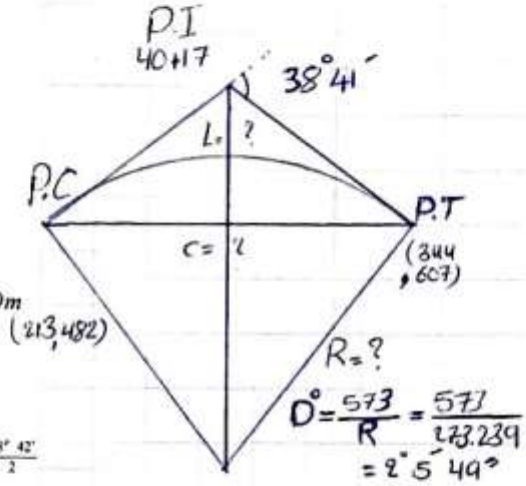
*(213 , 482) , (344 , 607) respectively*

$\Delta = 38^\circ\ 42'$ $\quad$ *St.of* $P.I = 40 + 17$

**Solution:-**

Draw the sketch

Find the elements and stations




1-

$$C = \sqrt{(213-344)^2 + (482-607)^2}$$
$$= \sqrt{(-131)^2 + (-125)^2} = 181.069m$$

2-

$$C = 2R\sin\tfrac{\Delta}{2}\ ;\ 181.069 = 2R\sin\tfrac{38^\circ\ 42'}{2}$$
$$R = 273.239m$$

3- $T = R\tan\frac{\Delta}{2} = 273.239\tan\frac{38^\circ\ 42'}{2} = 95.955m$

4- $L = \frac{\Pi R\Delta}{180} = \frac{\Pi * 273.239 * 3842}{180} = 184.557m$

5- $E = R(\frac{1}{\cos\frac{\Delta}{2}} - 1) = 273.239(\frac{1}{\cos\frac{3842}{2}} - 1) = 16.329m$

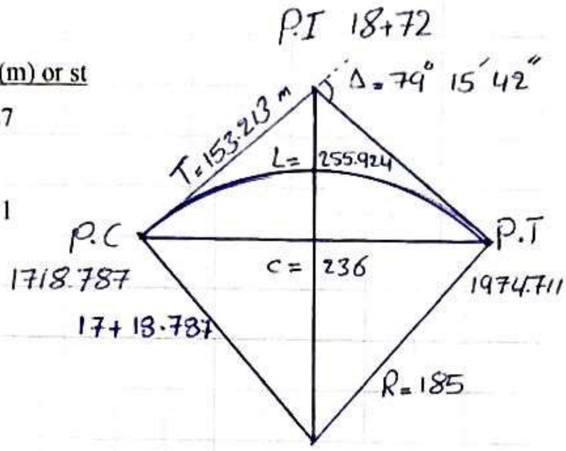
6- $M = R(1 - \cos\frac{\Delta}{2}) = 273.239(1 - \cos\frac{3841}{2}) = 15.435m$

7- *St.of P.C* $= 4017 - 95.955 = 3921.045 = 39 + 21.045$

8- *St. of P.T* $= 3921.045 + 184.557 = 4105.602 = 41 + 05.602$

**Draw sketch and table**

| Stations or element | Value in (m) or st |
|---|---|
| P.C | 17 + 18.787 |
| P.I | 18+72 |
| P.T | 19 + 74.711 |
| C | 236 |
| I | 153.213 |
| L | 255.924 |
| M | 42.518 |
| E | 52.206 |
| R | 185 |
| Δ | 79° 15' 42'' |
| D | |




I- *St. of P.C is at point with coordinates*

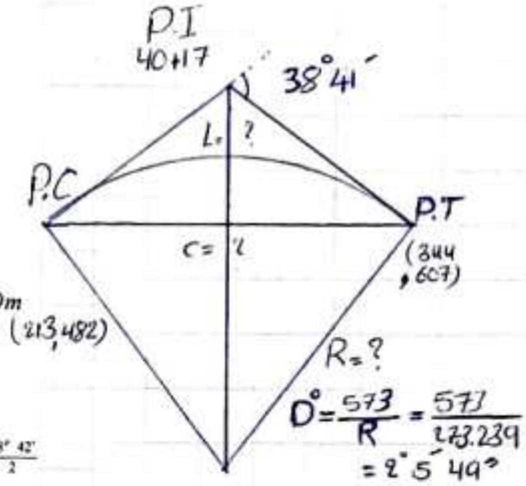
*(213 , 482) , (344 , 607) respectively*

$\Delta = 38^\circ\ 42'$ *St.of P.I* $= 40 + 17$

**Solution:-**

Draw the sketch

Find the elements and stations




1-

$$C = \sqrt{(213-344)^2 + (482-607)^2}$$
$$= \sqrt{(-131)^2 + (-125)^2} = 181.069m$$

2-

$$C = 2R\sin\tfrac{\Delta}{2}\ ;\ 181.069 = 2R\sin\tfrac{38^\circ\ 42'}{2}$$
$$R = 273.239m$$

3- $T = R\tan\frac{\Delta}{2} = 273.239\tan\frac{38^\circ\ 42'}{2} = 95.955m$

4- $L = \frac{\Pi R\Delta}{180} = \frac{\Pi * 273.239 * 3842}{180} = 184.557m$

5- $E = R(\frac{1}{\cos\frac{\Delta}{2}} - 1) = 273.239(\frac{1}{\cos\frac{3842}{2}} - 1) = 16.329m$

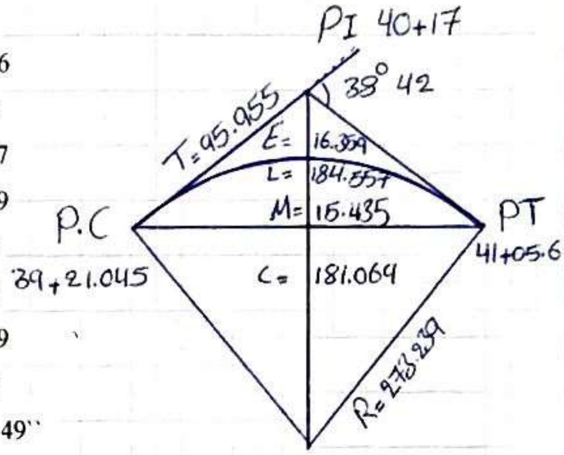
6- $M = R(1 - \cos\frac{\Delta}{2}) = 273.239(1 - \cos\frac{3841}{2}) = 15.435m$

7- *St.of P.C* $= 4017 - 95.955 = 3921.045 = 39 + 21.045$

8- *St. of P.T* $= 3921.045 + 184.557 = 4105.602 = 41 + 05.602$

**Draw sketch and Tap up**

| <u>Stations or element</u> | <u>Value in (m) or st</u> |
|---|---|
| P.C | 39+21.045 |
| P.I | 30+17 |
| P.T | 41+05.6 |
| T | 95-955 |
| L | 184.337 |
| C | 181.069 |
| M | 15.435 |
| E | 16.359 |
| R | 273.239 |
| Δ | 38 42 |
| D | 2° 5` 49`` |

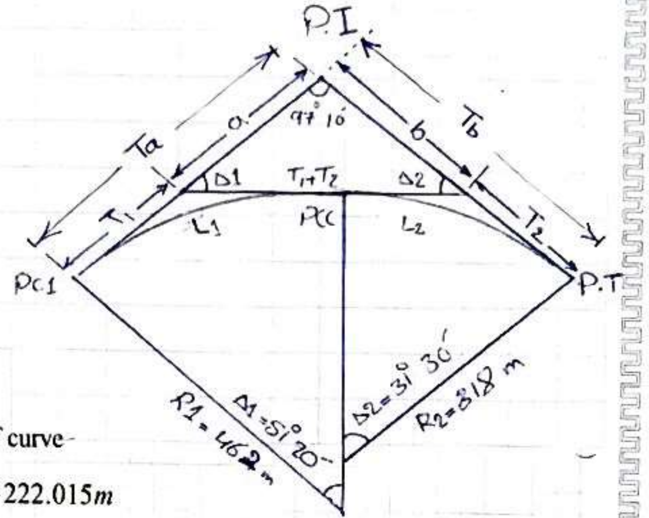



حسب مواصفات AASHTO فان الفرق بين القوسين لا يتجاوز 1.5

Q 5-2 Compute the stations of the sompound curves

A) $P.I = 56 + 21$ $R_1 = 462m$ $R_2 = 318m$

Sketch the curve $\Delta_1 = 51°\ 20'$ $\Delta_2 = 31°\ 30'$




Compute the elements stat of curve

- $T_1 = R_1 \tan\frac{\Delta_1}{2} = 452\ \tan\frac{5120}{2}\ 222.015m$
- $L_1 = \frac{\Pi R_1 \Delta_1}{180} = \frac{\Pi * 462 * 51°\ 20'}{180} = 413.922m$
- $T_2 = R_2 \tan\frac{\Delta_2}{2} = 318 \tan\frac{31\ 30}{2} = 89.685m$
- $L_2 = \frac{\Pi R_2 \Delta_2}{180} = \frac{\Pi * 318 * 31°\ 30'}{180} = 174.830m$

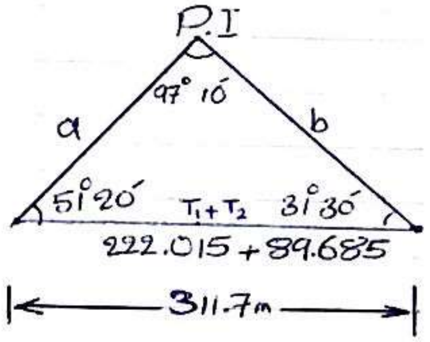
(مفتاح الحل في المنحنيات المركبة هو المثلث) (قانون الجيوب)

In Triangle shown (show the triangle using sine law)

$$\frac{a}{\sin 31\ 30} = \frac{b}{\sin 51\ 20} = \frac{222.015 + 89.685}{\sin 97°\ 10'}$$

a = 164.15m

b = 245.29m




$a = 164.15m$

$b = 245.29m$

$T_a = T_1 + a = 222.015 + 164.150 = 386.165m$

St. of P.C = 5621-386.165=5234.835 → 52+34.835

St. of P.C.C = PC+$L_1$

= 5234.835+413.922

= 5658.757 = 56+58.757

St. of P.T = P.C.C +$L_2$

= 5658.757 +174.830

= 5833.587

= 58 + 33.587

**Example on Reverse Curve**

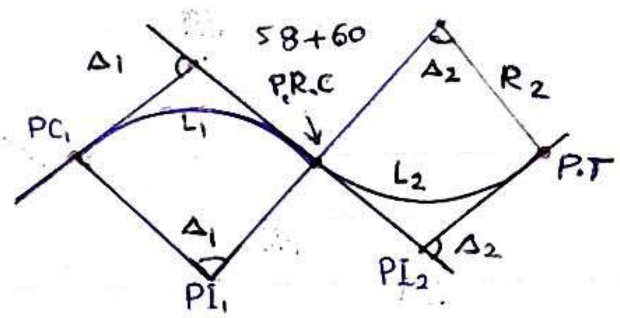
Ex. 5.8 P. 205:

Compute the stations of the following reverse curve

$St.\ of\ PRC = 58+60$

$R_1 = 200m$ $\Delta_1 = 25^\circ\ 32'$

$R_2 = 350m$ $\Delta_2 = 35^\circ\ 40'$




Solution

$$T_1 = 200 \tan 12^\circ\ 46' = 45.32$$

$$L_1 = \frac{\Pi * 200 * 25.5333}{180} = 89.12$$

$$T_2 = 350 \tan 17^\circ\ 50' = 112.6m$$

$$L_2 = \frac{\Pi * 350 * 35.667}{180} = 217.9m$$

$St.\ of\ P.C = PRC - L_1 = 5860 - 89.12 = 5770.88 = 57+70.88$

$St.\ of\ P.I_1 = PC + T_1 = 5770.88 + 45.32 = 2816.2 = 58+16.2$

$St.\ of\ PI_2 = PRC + T_2 = 5860 + 112.6 = 59+72.60$

$St.\ of\ PT = PRC + L_2 = 5860 + 217.9 = 60+77.9$

الحالات التي ينشأ فيها المنحني المعكوس

١- وجود عائق مثل بناية على نفس الاتجاه.

٢- التقاطع مع نهر او سكة حديد .

## Methods of setting out the horizontal curve

1- method using offsets from the long chord .

2- method using offset on the tangent .

3- method using of deflection angle.

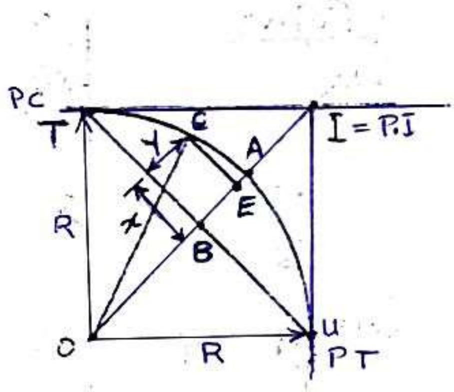
4- Setting out from point of intersection.

### 1- Using offset from long chord :

Derive the formula

$$y = \sqrt{R^2 - X^2} - \sqrt{R^2 - (\frac{C}{2})^2}$$

AB = AO = OB




= AO - $\sqrt{OU^2 - UB^2}$

= R2 - $\sqrt{R^2 - (\frac{C}{2})^2}$

Draw CE parallel to TU

Y= EB = EB = EO – BO

$EO^2 = CO^2 - CE^2$ $\quad EO = \sqrt{R^2 - X^2}$

$$y = \sqrt{R^2 - X^2} - \sqrt{R^2 - (\frac{C}{2})^2}$$

Derive Data for setting out the curb line shown the former shape , if the radius be 12 m and $T\hat{O}U = 90^{\circ}$ offset , are required at 2m intervals .

$TU^2 = TO^2 + OU^2 = 12^2 + 12^2 = 288$

Therefore TU = C = 16.97 m

$$\sqrt{R^2 - (\frac{C}{2})^2} = 8.49\ m$$

| Point | x | $X^2$ | $R^2 - x^2$ | $\sqrt{R^2 - X^2}$ | Y (m) offset |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 144 | 12 | 3.51 |
| 2 | 2 | 4 | 140 | 11.83 | 3.34 |
| 3 | 4 | 16 | 128 | 11.31 | 2.82 |
| 4 | 6 | 36 | 108 | 10.93 | 1.9 |
| 5 | 8 | 64 | 80 | 9.94 | 0.45 |

Point T & U would be located be measuring IT( = IU) from the intersection point (P.V.I)

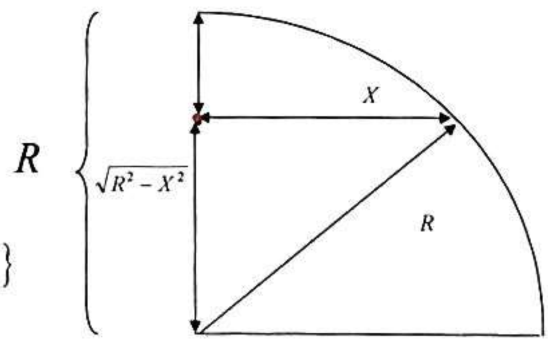
## 2- **Tangent – offsets method:**

Depends one the formula $Y = R\left[1 - \sqrt{1 - (\frac{x}{R})^2}\right]$

$$R = y - \sqrt{R^2 - X^2}$$

$$y = R - \sqrt{R^2 - X^2}$$

$$y = R\left\{1 - \sqrt{1 - (\frac{x}{R})^2}\right\}$$



| Point | X | $y = R\left\{1 - \sqrt{1-(\frac{x}{R})^2}\right\}$ |
|---|---|---|
| 1 | $x_1$ | $Y_1$ |
| 2 | $x_2$ | $Y_2$ |
| 3 | $x_3$ | $Y_3$ |
| 4 | $x_4$ | $Y_4$ |
| . | . | . |
| . | . | . |

**Q5-3 page 183**

setting out a horizontal circular curve with $\Delta = 43^\circ - 24$; $D = 4^\circ 30$ st. of P. I =38 + 20ssss; using 4 different method

(1) Tangential angle method (2) offset on tangent (3) off-set on long chord (4) off-set from point of intersection .

**solution :** compute the curve elements

$$R = \frac{573}{\Delta} = \frac{573}{4.5} = 127.33\ m$$

$$T = R.\ \tan\frac{\Delta}{2} = 127.33\ \tan\frac{4324}{2} = 50.67\ m$$

$$L = \frac{TR\Delta}{180} = \frac{T * 127.33 * 43.4}{180} = 96.45\ m$$

$C = 2\,R \sin\frac{\Delta}{2} = 2*127.33*\sin 21\ 42 = 9.416m$

$C/2 = \frac{94.16}{2} = 47.08\ m$

$E = R\,(\frac{1}{\cos\frac{\Delta}{2}} - 1) = 127.33\ (\frac{1}{\cos 21\ 42} - 1) = 9.71\ m$

$M = R\,(1 - \cos\frac{\Delta}{2}) = 127.33\ (1 - \cos 21\ 42) = 9.02\ m$

St.of P.c = st.of P.I –T = 3820 -50.67 = 3769.33 m

37+ 69.33 m

st. of P.I = st. of. P.C + L = (37 +69.33) + (96.54) = 38 +65.78

setting out:

**<u>1) using deflection angle method:</u>**

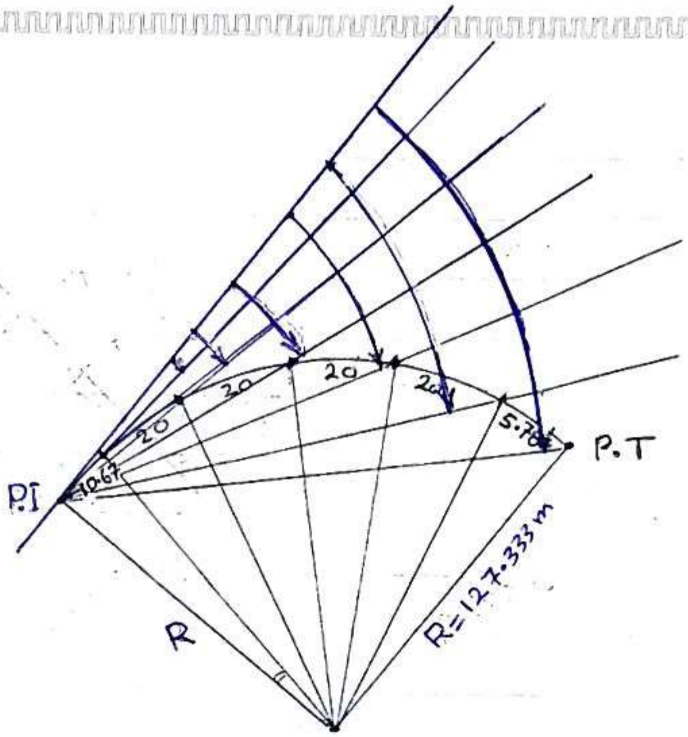
- depending on the L = 96.46 m and the interval =20 m, st. of P.c = 37 +69 .33 the staking out will be:

| | | |
|---|---|---|
| 37 + 69.33 | ⟶ | The st. of P.C |
| 37 + 80 | ⟶ | 1 st |
| 38 +00 | ⟶ | 2 nd |
| 38 + 20 | ⟶ | 3 rd |
| 38 + 40 | ⟶ | 4 th |
| 38 + 60 | ⟶ | 5 th |
| 38 + 65.57 | ⟶ | 6 th st .of P.T |

$$L = \frac{\pi \ R \ \Delta}{180}$$

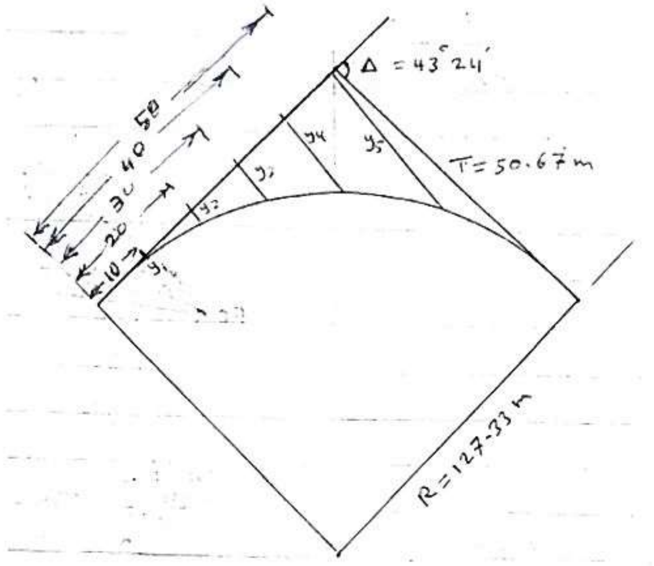
$$\ell = \frac{\pi \ R \ \alpha}{90}$$

$$\alpha = \frac{90 \ \ell}{\pi \ R}$$




| Stations | $\ell \ (m)$ | $\alpha = \frac{90 \ \ell}{\pi \ R}$ | Total $\alpha$ | C= 2 R sin |
|---|---|---|---|---|
| P. C 37 + 69.33 | 0.0 | 0 00 | 0.00 | 0.00 |
| 37 + 80 | 10.67 | 2 24 | 2 24 | 10.66 |
| 38 +00 | 20 | 4 30 | 6 54 | 29.00 |
| 38 + 20 | 20 | 4 30 | 11 24 | 50.34 |
| 38 + 40 | 20 | 4 30 | 15 54 | 68.23 |
| 38 + 60 | 20 | 4 30 | 20 24 | 88.77 |
| P. T 38 + 65.57 | 5.78 | 1 18 | 21 42 | 94.16= C |

## 2) Tangent off- set Method:

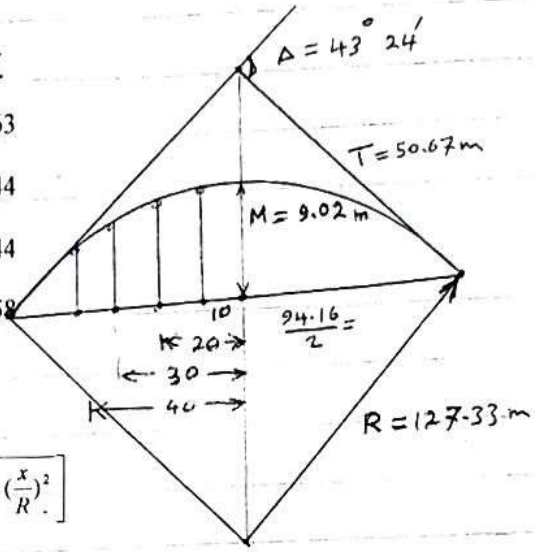



| Point | xm | Y |
|---|---|---|
| 1 | 10 | 0.39 |
| 2 | 20 | 1.58 |
| 3 | 30 | 3.58 |
| 4 | 40 | 6.45 |
| 5 | 50 | 10.23 |

$$Y = R\left[1-\sqrt{1-(\frac{x}{R})^2}\right]$$

### 3) off–set on long chord:

| Point | xm | Y |
|---|---|---|
| 1 | 10 | 8.63 |
| 2 | 20 | 7.44 |
| 3 | 30 | 5.44 |
| 4 | 40 | 2.58 |




$$y = R\left[\sqrt{1-(\frac{x}{R})^2} - \sqrt{1-(\frac{x}{R.})^2}\right]$$

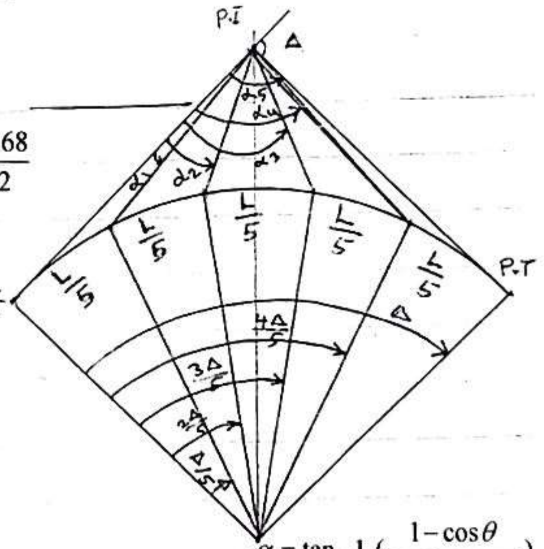
### 4) from point of intersection

$$\frac{L}{5} = \frac{96.45}{5} = 19.29\ m$$

$$C = 2R\sin\alpha = 2*127\sin\frac{0.68}{2}$$

C= 19.27

| Point | $\theta$ | $\alpha$ |
|---|---|---|
| 1 | 8.68 | 2 39 |
| 2 | 17.36 | 24 35 |
| 3 | 26.04 | 112 01 |
| 4 | 34.72 | 133 57 |
| 5 | 43.40 | 136 36 |



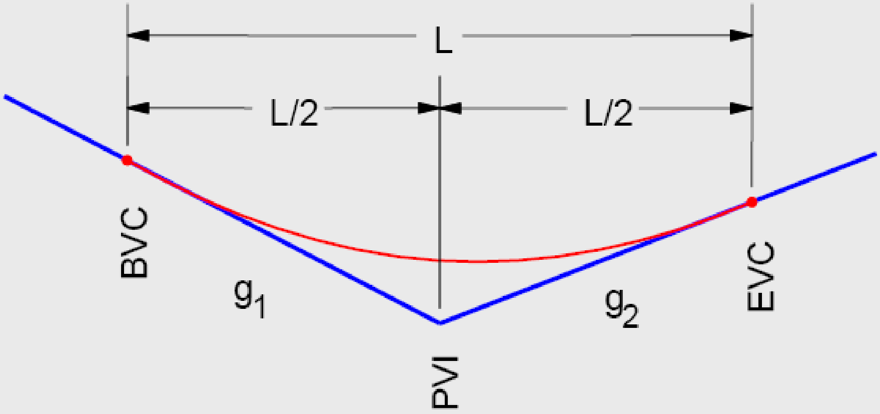

$$\alpha = \tan^{-1}\left(\frac{1-\cos\theta}{\tan\frac{\Delta}{2} - \sin\theta}\right)$$

$\theta$ هي القيمة المتغيرة لـــ $\Delta$ ، حيث ان $\theta_1 = \frac{\Delta}{5}$

# Vertical Curves:

1. Nomenclature

*Equal Tangent* Curve




| | |
|---|---|
| BVC | Beginning of vertical curve; aka PVC |
| PVI | Point of vertical intersection; aka VPI |
| EVC | End of vertical curve; aka PVT |
| $g_1$ | incoming grade |
| $g_2$ | outgoing grade |
| L | curve length |

2. Equations

$$Sta_{BVC} = Sta_{PVI} - L/2$$

$$Sta_{EVC} = Sta_{PVI} + L/2$$

$$Elev_{BVC} = Elev_{PVI} - \frac{g_1 L}{2}$$

$$Elev_{EVC} = Elev_{PVI} + \frac{g_2 L}{2}$$

$$k = \frac{g_2 - g_1}{L}$$

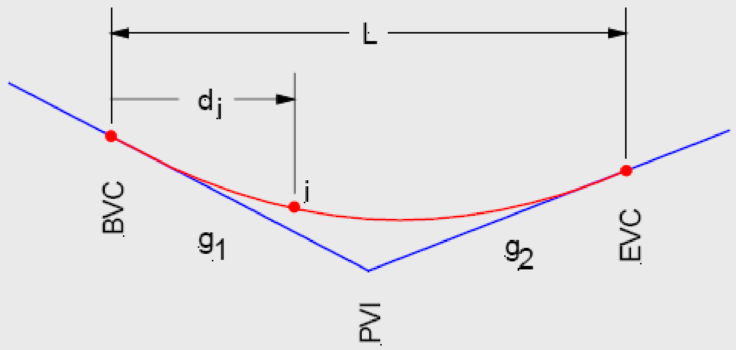
k is the grade change rate; % per station

When computing:

if g in percent, use L and distances in stations:
g=3%, L=10.00 sta

if g in ratio, use L and distances in feet
g=0.03, L=1000.00 ft

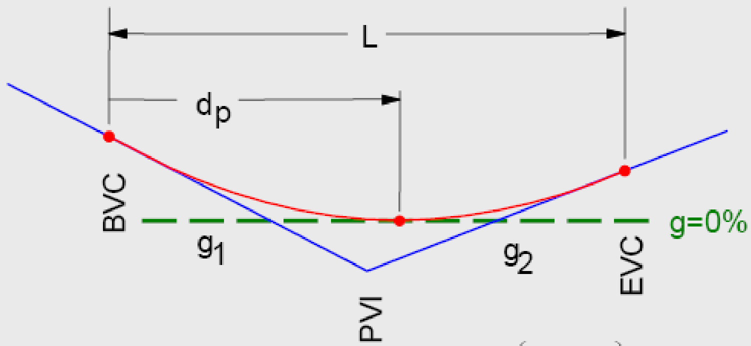
3. Elevation & Grade at any point on the curve



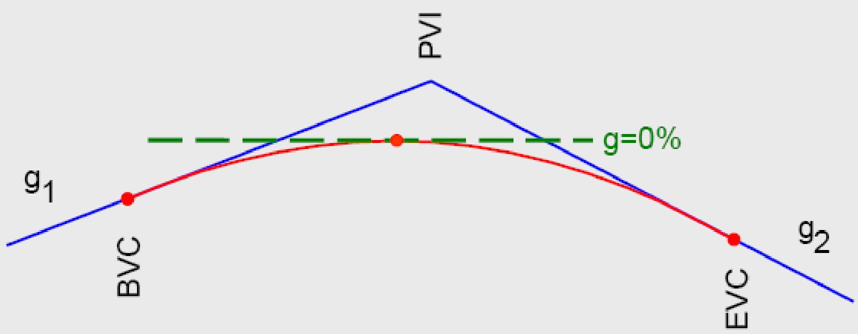

Elevation at station *i* $$Elev_i = Elev_{BVC} + g_1 d_i + \left(\frac{g_2 - g_1}{2L}\right) d_i^2$$

Grade at station *i* $$g_i = g_1 + d_i\left(\frac{g_2 - g_1}{L}\right)$$

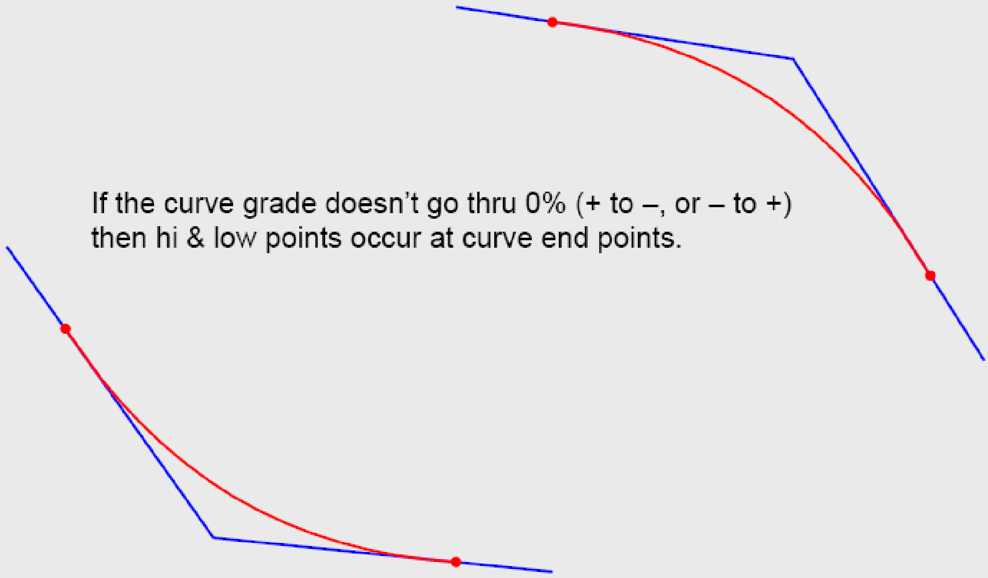
5. Location of high or low point



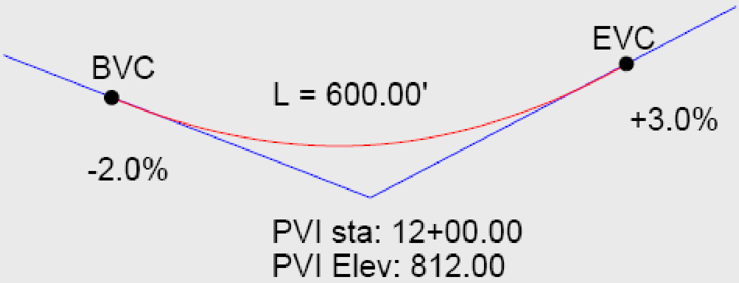

Low (or high) point occurs where the curve grade is 0% $$d_p = L\left(\frac{g_1}{g_1 - g_2}\right)$$



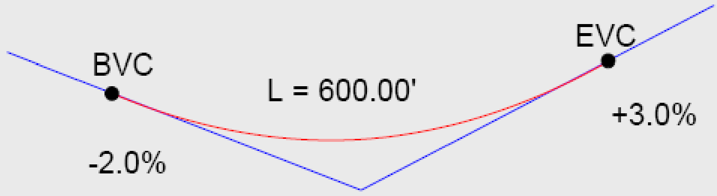
5. Location of high or low point




*Example:*



*Example:*




PVI sta: 12+00.00
PVI Elev: 812.00

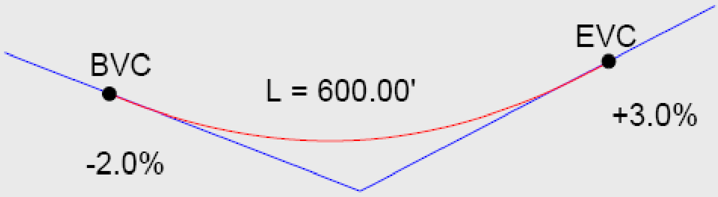
$Sta_{BVC}$ = (1200.00-600.00/2) = 9+00.00
$Sta_{EVC}$ = (1200.00+600.00/2) = 15+00.00

$Elev_{BVC}$ = 812.00-(-2.0)(6/2) = 818.00
$Elev_{EVC}$ = 812.00+(+3.0)(6/2)= 821.00

$$Elev_i = 818.00 + (-2.0)(d_i) + \left[\frac{3.0-(-2.0)}{2(6)}\right] d_i^2$$

$d_i = Sta_i - Sta_{BVC}$

*Example:*

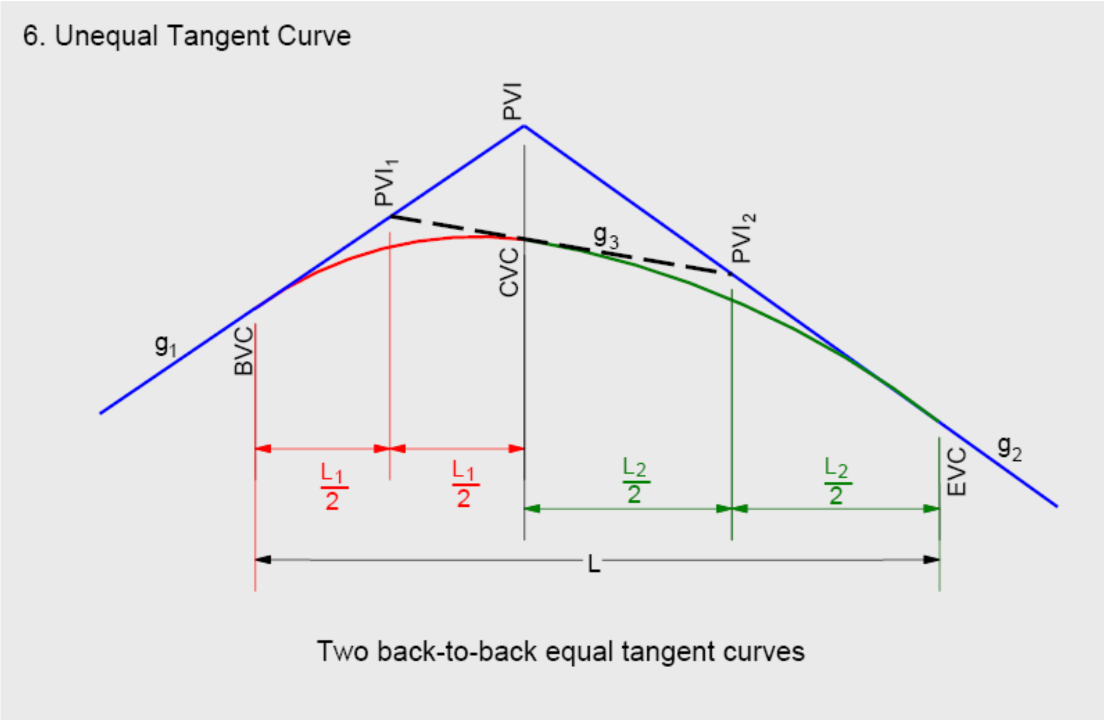



PVI sta: 12+00.00
PVI Elev: 812.00

$$Elev_i = 818.00 + (-2.0)(d_i) + \left[\frac{3.0-(-2.0)}{2(6)}\right] d_i^2$$

| | Sta | $d_i$ (sta) | Elev (ft) |
|---|---|---|---|
| EVC | 15+00.00 | 6.00 | 821.00 |
| | 14+00.00 | 5.00 | 818.42 |
| | 13+00.00 | 4.00 | 816.67 |
| | 12+00.00 | 3.00 | 815.75 |
| | 11+00.00 | 2.00 | 815.67 |
| | 10+00.00 | 1.00 | 816.42 |
| BVC | 9+00.00 | 0.00 | 818.00 |

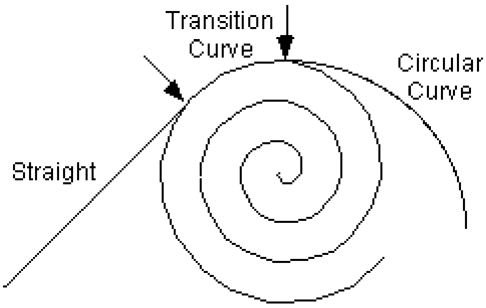
Low point: sta 11+40.00; elev: 815.60'



Two back-to-back equal tangent curves

# Transition Curves

If one considers the dynamics of a vehicle of some kind travelling in a straight line and then turning into a circular curve, the vehicle changes from a state of zero acceleration into a state of full circular acceleration instantaneously. If this happened in reality the vehicle, especially a rail vehicle, would fall off the tracks (and if a road vehicle, the occupants would be thrown around and the car would wander across the road). This is obviously not acceptable. Instead a curve that starts at radius infinity (a straight line) and gradually changes to the radius of the curve is inserted at the start and end of the curve. This is known as a **transition curve** and is generally (mathematically) part of a cubic spiral.




Most high speed country roads and all railway lines, conveyor systems and Sydney's monorail use transition curves as part of the curve design. The computation and layout of transition curves will be left for following chapters and later years of study.

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# The seventeeth week

# *Construction Surveys*

## INTRODUCTION

Construction is one of the largest industries in the United States, and thus surveying, as the basis for it, is extremely important. It is estimated that 60 *% of all* hours spent in surveying are on location-type work, giving line and grade. Nevertheless, insufficient attention is frequently given to this type of survey.

An accurate topographic survey and site map are the first requirement! signing streets, sewer and water lines, and structures. Surveyors then lay o position these facilities according to the design plan. A final "as-built" map incorporating any modifications made to the design plans, is prepared during after construction, and filed. Such maps are extremely important, especially underground utilities are involved, to assure that they can be located qui trouble develops, and that they will not be disturbed by later improvemen[1]

Construction surveying involves establishing both *line* and *grade* by of stakes and reference lines which are placed on the construction site. These the contractor so that proposed facilities are constructed according to a placement of the stakes is most often done by making the fundamental measuring of horizontal distances, horizontal and vertical angles, and differences in ele using the basic equipment and methods described in earlier chapters of the However, the global positioning system (GPS) is also being used with in a frequency for construction surveys (see Section 23-10). Other specialized equipment, including laser alignment devices and reflectorless electronic distant surveying equipment, (see Section 23-2) have also been developed which greatly facilitates construction surveying.

All surveyors, engineers, and architects who may be involved with pb designing and building constructed facilities should be familiar with the mental procedures involved in construction surveying. This chapter describes procedures *i* applicable for some of the more common types of construction projects. ters 24.25, and 26 cover the subjects of horizontal curves, vertical curves, and computations, respectively. These topics are all pertinent to construction **eys.** particularly those for transportation routes.Construction surveying is perhaps best learned on the job, and consists in ting fundamental principles to the undertaking at hand. Since each project F involve unique conditions, and present individual problems, coverage in this t is limited to a discussion of the fundamentals.

## |23-2 SPECIALIZED EQUIPMENT FOR CONSTRUCTION SURVEYS

looted above, the placement of stakes for line and grade to guide construction ns accomplished using the surveyor's standard equipment— . tapes, total station instruments and GPS receivers. Recent advances in mod-: technology, however, have produced some additional new instruments that : improved, simplified, and greatly increased the speed with which certain types ^construction surveying can be accomplished. *Visible laser-beam* alignment in-aents and *pulsed laser EDM* instruments (total stations equipped with re-torless electronic distance measuring devices) are among the new innovations. ; are described briefly in the subsections that follow.

**-2.1 Visible Laser Beam Instruments**:

Fundamental purpose of laser instruments is to create a visible line of known enation or a plane of known elevation, from which measurements for line and ie can be made. Two general types of lasers are described here: *Single-beam lasers,* as shown in Figures 23-1 and 23-2, project visible refer-; lines ("string lines" or "plumb lines") that are utilized in linear and vertical alignment applications such as tunneling, sewer pipe placement, and 1 struction.The instrument shown in Figure 23-1 is a single-beam type 1 been combined with a total station instrument. This combination pr bilities that are convenient for a variety of construction layout applic laser beam is projected collinear with the instrument's line of sight, a fe facilitates aligning it in prescribed horizontal alignments and/or along ] grade lines. The instrument can be used to project string lines for dist about 1000 m. With the zenith angle set to either 90° or 270°, if the total < strument is rotated about its vertical axis, the laser will generate a horizonui| Also if it is turned about its horizontal axis, the laser will define a vertical The instrument shown in Figure 23-2 projects a visible laser beam a < of 5 m below and 100 m above the instrument along the plumb line. These i ments are useful for alignment of objects in vertical structures. A similar tyj single-beam laser projects a visible laser-beam at a selected grade—a device I is especially useful in aligning pipelines.*Rotating-beam lasers* are merely single-beam lasers with spinning optics 1 rotate the beam in azimuth, thereby creating planes of reference. They expedite 1 placement of grade stakes over large areas such as airports, parking lots, and« divisions, and are also useful for topographic apping.Figure 23-3 shows a rotating-beam type laser. It projects a beam up to **350i** while rotating at 600 rpm. The laser signal can be picked up by one or more i ceivers attached to grade rods or staffs. The instrument is self-leveling and quicfchrl set up. If somehow bumped out of level, the laser beam shuts off and does not come back on until it is releveled. It can be operated with the laser plane oriented horizontally for setting footings, floors, etc., or the beam can be turned 90° and used vertically for plumbing walls or columns. Because laser beams are not readily visible to the naked eye in bright sunlit, special detectors attached to a hand-held rod are often used. To lay out hor-ital planes with either of these devices, the height of the instrument above i, *HI,* must be established. Then the height on a graduated rod that a refer-: mark or detector must be set is the difference between the *HI* and the plane's auired elevation.

**STAKING OUT A PIPELINE** ics are used to carry water for human consumption, storm water, sewage, oil, I gas, and other fluids. Pipes which carry storm runoff are called *storm sew*-: those which transport sewage, *sanitary sewers.* Flow in these two types of sew-> is usually by gravity, and therefore their alignments and grades must be care**-ly** set. Flow in pipes carrying city water, oil, and natural gas is generally under sure, so usually they need not be aligned to as high an order of accuracy. In pipeline construction, trenches are usually opened along the required lent to the prescribed depth (slightly below if pipe bedding is required), the : is installed according to plan, and the trench backfilled. Pipeline grades are I by a variety of existing conditions, topography being a critical one. A profile : that of Figure 5-12 is usually used to analyze the topography and assist in de-ig the grade line for each pipe segment. To minimize construction difficulties : costs, excavation depths are minimized, but at the same time a certain mini-hum cover over the pipeline must be maintained to protect it from damage by heavy loading from above and to prevent freezing in cold climates. Minimum f shades also become an important design factor for pipes under gravity flow. Ac-i accordingly, a grade of at least 0.5 percent is recommended for storm sewers, but slightly higher grades are needed for sanitary sewers. In designing pipe grade lines, other existing underground elements often must be avoided, and due regard must also be given to the grades of connecting lines and the vertical clearances needed to construct manholes, catch basins, and outfalls.

Prior to staking a pipeline, the surveyor and contra tails of he project. An understanding must be reached trench width, where the installation equipment will be pla the excavated material will be stockpiled. Then a reference < appropriately established that will (1) meet the contractor's i destruction, and (3) not interfere with operations.

The alignment and grade for the pipeline are taken ; set reference line parallel to the required centerline is estab or 50-ft stations when the ground is reasonably uniform.. together on horizontal and vertical curves than on straight: large diameter, stakes may be placed for each pipe length—**say.1** surfaces where stakes cannot be driven, points are marked **by)** scratch marks.

Precise alignment and grade for pipe placement are guided! *boards* or laser beams. Figure 23-5 shows one arrangement of a I sewer line. It is constructed using 1 X 4 in., 1 X 6 in., or 2 X 4 in.! 2 x 4 in. posts which have been pointed and driven into the grc of the trench. Depending upon conditions, these may be placed at.' other convenient distance along the sewer line. The top of the 1 erally placed a full number of feet above the *invert* (flow line or I face) of the pipe. Nails are driven into the board tops so a string« between them will define the pipe centerline. A graduated pole -often called a *story pole,* is used to measure the required distance: to the pipe invert. Thus, the string gives both line and grade. It can **bel** hanging a weight on each end after wrapping it around the nails.

**STAKING PIPELINE GRADES**I

pipeline grades is essentially the reverse of running profiles, although in ations the centerline must first be marked and stationed in horizontal lo-tlhe actual profiling and staking are on an offset line, formation conveyed to the contractor on stakes for laying pipelines usu-sts of two parts: (1) giving the depth of cut (or fill), normally only to the 10.1 ft, to enable a rough trench to be excavated; and (2) providing precise : information, generally "to the nearest 0.01 ft, to guide in the actual place-**lof** the pipe invert at its planned elevation. Cut (or fill) values for the first : vertical distances from ground elevation at the offset stakes to the pipe inter the pipe's grade line has been computed and the Set up the level and get an *HI* by reading a plus sight on a BS *HI* = 2.11 + 100.65 = 102.76 (see Plate B-6 and Figure 25-^ Obtain the elevation at each station from a rod reading at every stake (column 4) — for example, 4.07 at station I - i B-6 and Figure 23-6) — and subtract it from the ///(column 5l 102.76 - 4.07 = 98.69 at station 1 + 00.

5. Subtract the pipe elevation from the ground elevation to get < (-) (column 7); for example. 98.69 - 95.34 = C 3.35 (see Piaiel ure 23-6).
6. Mark the cut or fill (using a permanent marking felt pen or 1 set stake facing the centerline; the station number is written < side.In another variation, which produces the same results, *grade i* between *HI* and pipe invert) is computed, and *ground rod* (reading i at stake) is subtracted from it to get cut or fill. For station 1 + 00.! 102.76 - 95.34 = 7.42, and 7.42 - 4.07 = C 3.35.After the trench has been excavated based on cuts and fills i stakes, batter boards are set. Marks needed to place them can be made i cil or felt pen on the offset stakes during the same leveling operation i tain cut and fill information. Figure 23-6 also illustrates the process.'. at station 1 + 00, the batter board will be set so its top is exactly 5.00 ft i pipe invert. The rod reading necessary to set the batter board is obt trading the pipe invert elevation plus 5.00 ft from the *HI;* thus 102.76 — < 5.00) = 2.42 ft (see Figure 23-6). The rod is held at the stake and adjt tical position by commands from the level operator until a rod reading! is obtained; then a mark is made at the rod's base on the stake. (To fa process, a rod target or a colored rubber band can be placed on the rod *i* quired reading.) The board is then fastened to the stake with its top at 1 using nails or C clamps, and a carpenter's level is used to align it horizont the trench. A nail marking the pipe centerline is set by measuring the • set distance along the board.If a laser is to be employed, this same leveling procedure can be usedl tablish the elevation of the laser beam at some desired vertical offset dist the pipe's in vert. The procedure is used to establish the height of the laser i ment, and also to set another identical offset elevation at a station forward* Then the laser beam is aimed at that target to establish the required grade 1

## • 23-6 STAKING OUT A BUILDING

The first task in staking out a building is to locate it properly on the correct 1 making measurements from the property lines. Most cities have an ordina tablishing setback lines from the street and between houses to improve app and provide fire protection.Stakes may be set initially at the exact building corners as a visual check* the positioning of the structure, but obviously such points are lost immed when excavation is begun on the footings. A set of batter boards and refer

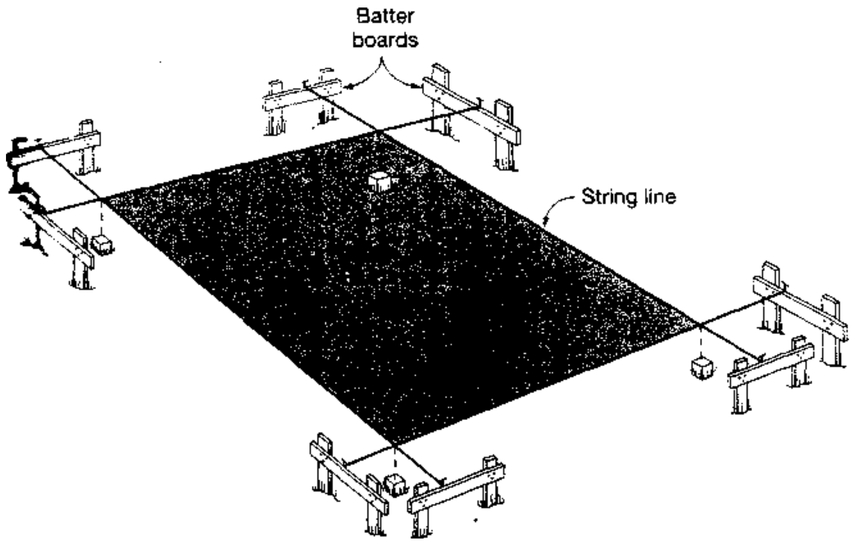



**Figure 23-7**
Batter boards for building layout., placed as shown in Figure 23-7, is therefore erected near each corner, but I of the way of construction. The boards are nailed a full number of feet above t footing base, or at first-floor elevation. (The procedure of setting boards at a ed elevation was described in the preceding section.) Nails are driven into shatter board tops so that strings stretched tightly between them define the out-: wall or form line of the building. The layout is checked by measuring diago- »and comparing them with each other (for symmetric layouts) or to their com-l values. Figure 23-8 illustrates the placement on a lot and staking of a slightly : complicated building. The following are recommended steps in the procedure:

1. Set hubs *A* and *B* 5.00 ft inside the east lot line, with hub *A* 20.00 ft from the south lot line and hub *B* 70.00 ft from *A*. Mark the points precisely with nails.
2. Set a total station instrument over hub *A*, backsight on hub *B*, and turn a clockwise angle of 270° to set batter board nails 1 and 2 and stakes *C* and *D*.
3. Set the instrument over hub *B*, backsight on hub *A*, and turn a 90° angle. Set batter board nails 3 and 4 and stakes *E* and *F*.
4. Measure diagonals *CF* and *DE* and adjust if the error is small or restake if large.
5. Set the instrument over *C* backsight on *E*, and set batter-board nail 5. Plunge the instrument and set nail 6.
6. Set the instrument over D, backsight on *F*, and set nail 7. Plunge and set nail 8.
7. Set batter board nails 9,10,11,12,13, and 14 by measurements from established points.
8. Stretch the string lines to create the building's outline, and check all diagonals.

As an alternative to this building stakeout procedure, radial i scribed in Section 9-9) can be used. This can substantially reduce the i strument setups and stakeout time required. In the radial method. ( all building corners are computed in the same coordinate system as the 1 Then the total station instrument is set on any convenient control ] ented in azimuth by sighting another intervisible control point. Angles *t* tances, computed from coordinates, are then laid off to mark each bu The layout is checked by measuring the distances between adjacent j also the diagonals. (An example illustrating radial stakeout of a circular i given in Section 24-11.) After constructing the batter boards and setting i pieces at the desired elevations, the alignment nails on the batter boards ( by pulling taut string lines across established corners. In Figure 23-8, for < with corners *D* and *F* marked, a line stretched across these two points i placing nails 7 and 8 on the boards. With the strings in place after setting I board nails, diagonals between corners should again be checked.

Another method of laying out buildings, is to stake two points on the \ ing, occupy one of them with the total station instrument, take a backsight < other, and stake all (or many) of the remaining points from that setup using ] calculated angles and distances. In some cases, advantage can be taken of i metrical layouts to save considerable time. Figure 23-9 shows an unusual metrical building shape which was laid out rapidly using only two setups (at j A and O). With this choice of stations, half the corners could be set from •. setup, and the same calculated angles and distances could be used (see the :

| | | | |
|---|---|---|---|
| 220.00 ft | Rt | 0°00' | *0* |
| 98.00 ft | Rt | 90°00' | F |
| 135.00ft | Rt | 90°00' | G |
| 169.74ft | Rt | 120°00' | E |
| 196.00ft | Rt | 150°00' | D |
| 169.74ft | Rt | 180°00' | C |
| 98.00 ft | Rt | 210°00' | B |
| 7K @ Point O | | | |
| 220.00 ft | Lt | 0°00' | *A* |
| 98.00 ft | Lt | 90°00' | J |
| 135.00ft | Lt | 90°00' | H |
| 169.74ft | Lt | 120°00' | K |
| 196.00ft | Lt | 150°00' | L |
| 169.74ft | Lt | 180°00' | M |
| 98.00 ft | Lt | 210°00' | N |

structures, such as retaining walls, offset lines are necessary[1] because 1 face is obstructed. Positions of such things as interior footings.; columns, and special piping or equipment can first be marked by 23 with tacks. Survey disks, scratches on bolts or concrete surfaces. 3 also be used. Batter boards set inside the building dimensions for < have to be removed as later construction develops.

On multistory buildings, care is required to ensure vertical; construction of walls, columns, elevator shafts, structural steel, **etc.!** checking plumbness of constructed members is to carefully aim a • of sight on a reference mark at the base of the member. The line • raised to its top. For an instrument that has been carefully leveled! proper adjustment, the line of sight will define a vertical plane as i should not be assumed that the instrument is in good adjustment. 1 line should be raised in both the direct and reversed positions. It a check plumbness in two perpendicular directions when using this | guide, construction of vertical members in real-time, two instr up with their lines of sight oriented perpendicular to each other.; monitored as construction progresses. Alternatively, lasers can be : and monitor vertical construction.

If the surveyor does not give sufficient forethought to the bask *t* required, the best method to establish them, and the most efficient; staking out a building, the job can be a time-consuming and difficuji ] number of instrument setups should be minimized to conserve time.j tions made in the office if possible, rather than in the field while a : waits.

## • 23-7 STAKING OUT HIGHWAYS

Alignments for highways, railroads, and other transportation routes **arei** after careful study of existing maps, ah- photos, and preliminary survey < area. From alternative routes, the one that best meets the overall obje minimizing costs and environmental impacts is selected. Before const begin, the surveyor must transfer that alignment (either the centerline < set reference line) to the ground.
Normally staking will commence at the initial point where the firs *t* segment *(tangent)* is run, placing stakes *at full stations* (100 ft intervals) if I lish system of units is used, or at perhaps 30 or 40 m spacing if the metric i is employed. Stationing (this subject is described in Section 5-9.1) contini the planned alignment changes direction at the *first point of intersection* »1 deflection angle is measured there and the second tangent stationed forward! next PI, where the deflection angle there is measured. The process com the terminal point. Staking continuously from the initial point to the ter result in large amounts of accumulated error on long projects. Therefore i should be checked by making frequent ties to intermediate horizontal. points, and adjustments should be made as necessary. Alternatively, on projects the alignments can be run from both ends to a point near the mick

ter tangents are established, horizontal curves (usually circular arcs) are I at all Pis according to plan. The subject of horizontal alignments, includ-ds for computing and laying out horizontal curves, is discussed in detail Her 24. Vertical alignments are described in Chapter 25. ^ After the centerline or reference line (including curves), has been estab-Ltbe Pis, intermediate *points on tangent* (POTs) on long tangents, and points : horizontal curves begin (PCs), and end (PTs), are referenced using proce-idescribed in Section 9-5. Points used in referencing must be located safely the construction limits. Referencing is important because the centerline [ be destroyed during various phases of construction and will need to be I several times. Bench marks are also established at regular spacing (usu-t more than about 1000 ft apart) along the route. These are placed on the I of way, far enough from the centerline to be safe from destruction, but con-**it** for access.After the centerline or reference line has been established, stakes marking ay should be set. This is normally done by carefully measuring per-Jar offsets from the established reference line. The right-of-way is staked ery change in its width, at all changes in alignment, including each PC and 1 at sufficient other intermediate points along the tangents so that it is clearly ated.When the reference line and right-of-way have been staked, the limits of ac-I construction are marked so that the contractor can clear to them. Following . some contractors want points set on the right-of-way with subgrade eleva-* showing cut or fill to a given elevation, for use in performing rough grading 1 preliminary excavation of excess material.To guide a contractor in making final excavations and embankments, *slope* : are driven at the *slope intercepts* (intersections of the original ground and i side slope), or offset a short distance, perhaps 4 ft (see Figure 23-11).The cut r fill at each location is marked on the slope stake. Note that there is no cut or fill t a slope stake—the value given is the vertical distance from the ground elevation I the slope stake to grade.*Grade stakes* are set at points that have the same ground and grade elevation. {This happens when a grade line changes from cut to fill, or vice-versa. As shown s in Figure 23-12, three *transition sections* normally occur in passing from cut to fill (or vice versa), and a grade stake is set at each one. A line connecting grade stakes.

perhaps scratched out on the ground, defines the change from < *ABC* in Figure 26-1.

Slope stakes can be set at slope intercept locations pre office from cross-sectional data. (Methods for determining from cross-sections are described in Chapter 26.) If ] cepts are used, the ground elevation at each stake must still be che to verify its agreement with the cross section. If a significant dis vation exists, the stake's position must be adjusted by a trial-and-i be described. The amount of cut or fill marked on the stake is comp actual difference in elevation between the ground at the slope stake; evation.

If slope intercepts have not been precalculated from cross-section < stakes are located by a trial-and-error method based on mental < volving the *HI*, grade rod, ground rod, half roadway width, and side sic two trials are generally sufficient to fix the stake position within an allo* of 0.3 to 0.5 ft for rough grading. The infinite number of ground variations | use of a standard formula in slope staking. An experienced surveyor er mental arithmetic, without scratch paper or hand calculator. Whether method to be described or any other, systematic procedures must be foil avoid confusion and mistakes.

Example 23-1 lists the sequential steps to be taken in slope staking, *t ing for simplicity, academic conditions of a level roadway.* In practice, travel!aiders of modern highways have lateral slopes for drainage, then a steeper t to a ditch in cut, and another slope up the hillside to the slope intercept. ion sections may have half-roadway widths in cuts different from those in **kto** accommodate ditches, and flatter side slopes for fills that tend to be less : than cuts. But the same basic steps still apply, and can be extended by stu-> after learning the fundamental approach.t the field procedures, including calculations, necessary to set slope stakes for I ft wide level roadbed with side slopes of 1:1 in cut and 1-1/2:1 in fill (see Fig-s 23-11 and 23-12).

1. Compute the cut at the centerline stake from profile and grade elevations (603.0 - 600.0 = C 3.0 in Figure 23-11). Check in field by grade rod minus ground rod = 7.8 - 4.8 = C 3.0 ft. Mark the stake C 3.0/0.0. (On some jobs the center stake is omitted and stakes are set only at the slope intercepts.)

2. Estimate the difference in elevation between the left-side slope-stake point (20+ ft out) and the center stake. Apply the difference—say, +0.5 ft—to the center cut and get an estimated cut of 3.5 ft.3. Mentally calculate the distance out to the slope stake, 20 + 1(3.5) = 23.5 ft, where 1 is the side slope.

4. Hold the zero end of a cloth tape at the center stake while the rodperson goes out at right angles with the other end and holds the rod at 23.5 ft. [The right angle can be established by prism (see Figure 16-10) or by using a total station instrument or (theodolite).]

5. *Forget all previous calculations to avoid confusion of too many numbers and remember only the grade-rod value.*6. Read the rod with the level and get the cut from grade rod minus ground rod, perhaps 7.8 - 4.0 = C 3.8 ft.

7. Compute the required distance out for this cut, 20 + 1(3.8) = 23.8 ft.

8. Check the tape to see what is actually being held and find it is 23.5 ft.

9. The distance is within a few tenths of a foot and close enough. Move out to 23.8 ft if the ground is level and drive the stake. Move farther out if the ground slopes up, since a greater cut would result, and thus the slope stake must be beyond the computed distance, or not so far if the ground has begun to slope down, which gives a smaller cut.

10. If the distance has been missed badly, make a better estimate of the cut, compute a new distance out, and take a reading to repeat the procedure.

11. In going out on the other side, the rodperson lines up the center and left-hand slope stake to get the right-angle direction.

12. To locate grade stakes at the road edge, one person carries the zero end of the tape along the centerline while the rodperson walks parallel, holding the 20-fmark until the required ground-rod reading is found by grade rod changes during the movement but can be computed! tervals. The notekeeper should have the grade rod listed in i quick reference at full stations and other points where slope < 13. Grade points on the centerline are located using a starting < mined by comparing cut and fill at back and forward staticPractice varies for different organizations, but often the 4 ft beyond the slope intercept. It is marked with the required cut < out from the centerline to the slope-stake point, side-slope ratio. < width noted on the side facing the centerline. Stationing is given *an* 1 A reference stake having the same information on it may also be ] more farther out of the way of clearing and grading. On transition; stake points are marked. –

Total station instruments, with their ability to automatically i slope distances to horizontal and vertical components, speed slope < icantly, especially in rugged terrain where slope intercept elevations ( from centerline grade. Some data collectors allow the user tc Input: template" (see Section 26-3) from which the data collector rapidly < positions of the slope stakes using field observed data. GPS receivers < the real-time kinematic mode (see Section 14-2.5) can also be advantage in these types of terrain if satellite visibility exists.

Slope staking should be done with utmost care, for once cut; bankments are started, it is difficult and expensive to reshape them if a i discovered.

After rough grading has shaped cuts and embankments to near i tion, finished grade is constructed more accurately from *blue tops* (st tops are driven to grade elevation and then marked with a blue keel or < These are not normally offset, but rather driven directly on centerline or j points. The procedure for setting blue tops at required grade elevation is < in Section 25-7.

Highway and railroad grades can often be rounded off to multiples« or 0.10 percent without appreciably increasing earthwork costs or sacrific drainage. Streets need a minimum 0.50 % grade for drainage from inter intersection, or from midblock both ways to the corners. They are also cro« provide for lateral flow to gutters. Drainage profiles, prepared to verify ori struct drainage cross sections, can be used to locate drainage structures and i ments accurately. An experienced engineer when asked a question regarding I three most important items in highway work, thoughtfully replied "dra drainage, and drainage." This requirement must be satisfied by good surveying a design.

To ensure unobstructed drainage after construction, culverts must be pL in most fill sections so that water can continue to flow in its normal pattern : one side of the embankment to the other. In staking culverts, their locations, **skeorl** angles if any, lengths, and invert elevations are taken from the plans. Requirtdl Jnents and grades are marked using stakes, offset from each end of the nded centerline.The invert elevation (or an even number of feet above f a) is noted on the stake.This field procedure, like setting slope stakes, re-ting a point on the stake where a rod reading equals the difference be-: required grade and the current *HI* of a leveling instrument. • the subgrade has been completed, if the highway is being surfaced with rete pavement, paving pins will be necessary to guide this operation. : usually about 1/2 in. diameter steel rods, driven to mark an offset line I to one edge of the required pavement. This line is usually staked at 50 ft nts. but closer spacing may be used on sharp curves. The finished grade eparallel to it but offset vertically above) is marked on the pins using tape, *ts.* a special stringline holding device. Again in this operation, elevations by marking the stake where a rod reading equals the difference between ed grade (or a vertically offset one) and a current *HI.* (The need for fre-iject bench marks at convenient locations is obvious.) Sty relocation surveys may be necessary in connection with highway con-:for example, manhole or valve-box covers have to be set at correct grade tearthwork begins so they will conform to finished grade. Here differential i resulting from the transverse surface slope must be considered. Utilities I by centerline station and offset distance.plication staking for railroads, rapid-transit systems, and canals follows the eral methods outlined above for highways.

## OTHER CONSTRUCTION SURVEYS

ig and constructing causeways, bridges, and offshore oil platforms, it is essary to perform hydrographic surveys (see Section 16-12).These types require special procedures to solve the problem of establishing hori-I positions and depths where it is impossible to hold a rod or reflector. Mod-eying equipment and procedures, and sonar mapping devices, are used to ig cross sections for underwater trenching and pipe laying. Today more are crossing wider rivers, lakes and bays than ever before. Mammoth projects now in progress to transport crude oil, natural gas, and water e introduced numerous new problems and solutions. Permafrost, extremely sratures, and the need to provide animal crossings are examples of spe-blems associated with Alaska pipeline construction. Large earthwork projects such as dams and levees require widespread per-t control for quick setups and frequent replacement of slope slakes, all of i may disappear under fill in one day. Fixed signals for elevation and align-l painted or mounted on canyon walls or hillsides can mark important refer-: fines. Failures of some large structures, such as at the Teton Dam, demon-: the need for monitoring them periodically so that any necessary remedial *i* can be done.

Underground surveys in tunnels and mines necessitate transferring lines and dons from the ground above, often down shafts. Directions of lines in mine



tunnels can be most conveniently established using north-seeking gyros| tion 18-1). In another, and still practiced method, two heavy plumb bobs! wires (and damped in oil or water) from opposite sides of the surface i be aligned by total station there and in the tunnel. (A vertical collimatori provide two points on line below ground.) A total station or laser is "? (see Section 8-16) on the short line defined by the two plumb-bob wires.a mark set in the tunnel ceiling above the instrument, and the line exter setups are made beneath spads (surveying nails with hooks) anchored in 1 ing. Elevations are brought down by taping or other means. Bench marks i strument stations are set on the ceiling, out of the way of equipment.Surveys are run at intervals on all large jobs to check progress for ] payments to the contractor. And finally, an *as-built* survey is made to > compliance with plans, note changes, make terminal contract payment. anM ment the project for future reference.

Airplane and ship construction requires special equipment and met part of a unique branch of surveying called *optical tooling.* The precise k erection of offshore oil drilling platforms many miles from a coast utilizes* surveying technology, principally the global positioning system.

## • 23-9 CONSTRUCTION SURVEYS USING TOTAL STATION INSTRUMENTS

The procedures described here apply to most total station instruments, alt] some may require interfaced data collectors to perform the operations desBefore using a total station for stakeout, it is necessary to orient the ir ment. Depending on the type of project, *horizontal* or both *horizontal and* i *cal* orientation may be needed. For example, if just the lot corners of a sub sion are being staked, then only horizontal orientation (establishing instrument's position and direction of pointing) is needed. If grade stakes are I be set, then the instrument must also be oriented vertically (its *HI* determinedl.With total station instruments, three methods are commonly used for i zontal orientation: (1) *azimuth,* (2) *coordinates,* and (3) *resection.* The first i apply where an existing control point is occupied, and the latter is used when the! instrument is set up at a non-control point. In azimuth orientation, the coordinates 1 of the occupied control station and the known azimuth to a backsight station are entered into the instrument. If the occupied station's coordinates have been downloaded into the instrument prior to going into the field, it is only necessary to input its point number. The backsight station is then sighted, and when completed, the azimuth of the line is transferred to the total station by a keyboard stroke, whereupon it appears in the display.

The coordinate method of orientation uses the same approach, except that the coordinates of both the occupied and the backsight station are entered. Again these data could have been downloaded previously so that it would only be necessary to key in the numbers identifying the two stations. The instrument computes the backsight line's azimuth from the coordinates, displays it, and prompts the operator to sight the backsight station. Upon completion of the backsighrimuth is transferred to the instrument with a keystroke, and it appears on the •y.In the resection procedure, a station whose position is unknown is occupied |tbe instrument's position determined by sighting two or more control stations t Sections 11-7 and 11-10). This is very convenient on projects where a certain t of high elevation in an open area gives good visibility to all (or most) points : staked. As noted, two or more control points must be sighted. Measurements ;les, or of angles and distances, are made to the control stations. The micro-sor then computes the instrument's position by the methods discussed in ions 11-7 and 11-10.Project conditions will normally dictate which orientation procedure to use. rdless of the procedure selected, after orientation is completed, a check should unade by sighting another control point and comparing the observed azimuth I distance against their known values. If there is a discrepancy, the orientation edure should be repeated. It is also a good idea to recheck orientation at reg-• intervals after stakeout has commenced, especially on large projects. In fact, sible a reflector should be left on a control point just for that purpose. Vertical orientation of a total station (i.e., determining its *HI)* can be achieved ag one of two procedures. The simplest case occurs if the elevation of the oc-!>ied station is known, as then it is only necessary to *carefully* measure and add : *hi* (height of instrument above the point) to the elevation of the point. If the npied station's elevation is unknown, then another station of known elevation st be sighted.The situation is illustrated in Figure 23-13, where the instrument i located at station *A* of unknown elevation, and station *B* whose elevation is awn is sighted. From slope distance S and zenith angle *z* the instrument computes K Then its *HI is*

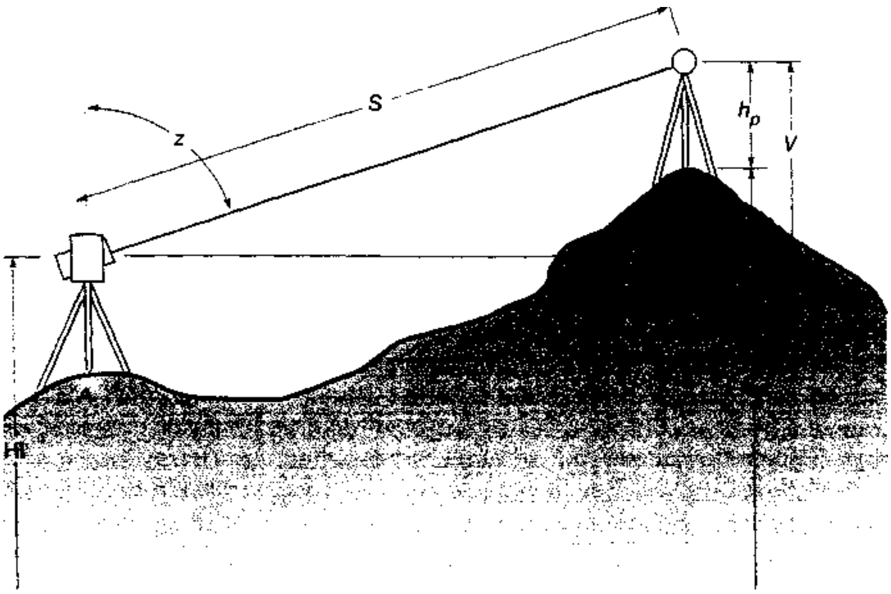



**Figure 23-13**
Vertical orientation of total station.
Datum



$$HI = elev_B + h_r - V$$

where $h_r$ is the reflector height above station *B*. As with he is good practice to check instrument's vertical orientation I vertical control point.

Once orientation is completed, project stakeout can 1 ing is either a two- or three-dimensional problem. Staking lots< layout of horizontal construction alignments is generally staking, blue-top setting, pipeline layout, and batter board pla horizontal position and elevation and are therefore three For two dimensional stakeout, after the file of coordinates 1 tions and points to be staked is downloaded and the instrumeati zontally, the identifying number of a point to be staked is ente ment through the keyboard. The microprocessor immediat horizontal distance and azimuth required to stake the point.The* the instrument's current direction of pointing and that required is < erator turns the telescope until the difference becomes zero to ; direction. With total stations having robotic capabilities, the i in direction to the proper azimuth without any further operator n

Following azimuth alignment, the distance to the point mart I do this, the reflector is directedonto the azimuth alignment and **al** tance reading taken, whereupon the difference between it and thati played. The reflector is then directed inward or outward, as nc distance difference is zero and the stake placed there. A two-way i able for communicating with the reflector person in this operatioaJ a small tape measure can often be used to speed the process of Ic its correct position. This procedure for stakeout is discussed 24-13, and an example problem presented.Special tracking systems have been developed to aid the ref getting on line. For example, some total stations utilize "constraint" i lights to indicate whether the reflector is left or right of the line of; ers use lights of different colors. The prism person, upon seeing thael mediately knows what direction to move to get on line.

For three-dimensional staking, the total station must be orientail as well as horizon tally. The initial part of three-dimensional stakeout s« that described for the two-dimensional procedure; that is, the hor of the stake is set first. Then simultaneously with the measurement of 1 horizontal position, its vertical component, and thus its elevation is det difference AZ between the required elevation and the stake's ele* played with a plus or minus sign, the former indicating fill, the latter < formation is communicated to the reflector person for marking the ; crementally driving it further down until the required grade, or if de even number of feet above or below grade is reached.

With the high order of accuracy possible using total station stakes quite distant from the instrument can be laid out, and thus many j from a single setup. Often, in fact, an entire project can be staked from< tion. This is made possible in many cases because of the flexibility that: orientation provides in instrument placement. It should be remembered 1

: involved in three-dimensional staking, earth curvature and re-**Ibe** considered (see Section 4-4). Also with total stations, each point r of the others, and thus no inherent checks are available. Checks : be made by either repeanng the measurements, checking place-:nt control stations, or measuring between staked stations to as-ative accuracies.

## ^CONSTRUCTION SURVEYS USING GPS EQUIPMENT

surveying methods discussed in Section 14-2 could be used on [projects. Specifically, static surveys can be used to establish project I kinematic surveys can be used to produce maps for planning and de-in Section 16-9.5. Finally, real-time kinematic (RTK) surveys (see 5) can be used to locate construction stakes.uction staking using RTK surveying, a minimum of two receivers are i is equipped with a radio modem. One receiver occupies a nearby con-.and the other called the "rover" is moved from one point to be set to : points being set must have their required coordinates known before . The receiver at the control station broadcasts its raw GPS signals r. At the rover, an on-board computer processes the signals from both i real-time using relative positioning techniques. This immediately yields ; determination of the rover's location. If its measured coordi-taot agree with the required values for the point being staked, the GPS unit : the direction and distance that it must be moved, the rover's position 1 until agreement is reached, and the stake is set.agh excellent horizontal accuracy can be achieved using GPS, elevations trcliable. GPS receivers determine ellipsoid heights to subcentimeter ac-to get an orthometric height (elevation related to datum) the geoidal i must be applied, as discussed in Section 19-5. Unfortunately geoidal un-i are not precisely known, but models are available which give values that ly accurate to within a few centimeters in flat areas, but can be off by 1 decimeters in mountainous regions. For this reason, if very precise eleva-: required in construction staking, GPS is unsatisfactory. However for much **iv** work, such as slope staking, it can provide suitable accuracy, assuming3ns are made for geoidal undulations. GPS is particularly useful in staking widely spaced points, especially in areas : terrain or vegetation makes it difficult to conduct traditional ground surveys. ; subdivisions containing large parcels in rugged terrain, and setting slope , in rugged areas where deep cuts and fills, exist, are examples of situations ; GPS can be very convenient for construction surveying. GPS of course re-; overhead clearance so that the satellites will be visible. In recent years, research has led to *stakeless* construction where GPS units ! lasers are used to guide earth-moving equipment in real-time. Data necessary r this operation include a digital elevation model (DEM) (see Section 16-8) of : construction area, and construction plans with their alignments, grades, and ign templates developed in the same three-dimensional coordinate system as : DEM. With GPS and lasers to guide the equipment operators, and an on-board

computer which continually updates cut and fill in for accomplished without the need for construction stakes, and i of grade foremen. While this form of construction staking ticipated that with time it will gain greater acceptance in r try due to its potential in cost savings. As this happens, the • struction surveying will shift to such tasks as establishing coordinate systems, and developing the necessary data for

## • 23-1 1 SOURCES OF ERROR IN CONSTRUCTION

Important sources of error in construction surveys are:

1. Inadequate number and/or location of control points on i
2. Errors in establishing control.
3. Measurement errors in layout.

4. Failure to double-center in laying out angles or extending 1 to check vertical members by plunging the instrument.
5. Careless referencing of key points.
6. Movement of stakes and marks.
*1.* Failure to use tacks for proper line where justified.

## • 23-12 MISTAKES

Typical mistakes often made in construction surveys are:

1. Lack of foresight as to where construction will destroy points.
2. Notation for cut (or fill) and stationing on stake not checked.
3. Wrong datum for cuts, whether cut is to finished grade or su
4. Arithmetic mistakes, generally due to lack of checking.
5. Use of incorrect elevations, grades, and stations.
6. Failure to check the diagonals of a building.
7. Carrying out computed values to too many decimal places (one j dredth is better than all the bad thousandths).
8. Reading the rod on top of stakes instead of on the ground beside I filing and in slope staking.

## PROBLEMS

**23-1** Describe the types of construction projects where visible laser-beam in itare useful for stakeout.
23-2 Discuss how line and grade can be set with a total station instrument.
23-3 Describe how a plumbing level can be used to ensure verticality in the conof a tall building.
23-4 In what types of construction is a rotating beam laser level most advantage
23-5 For what types of construction projects, or conditions, are reflectorless pulsed 1 EDM instruments most advantageous?

Should stakes for pipelines on a curve be closer together or farther apart than for a straight section? Explain. Describe how real-time kinematic GPS surveys can be used in sewer line layout. State two conflicting requirements that enter the decision on how far offset stakes should be set beyond the construction line.A se\\er pipe is to be laid from station 10 + 00 to station 13 + 20 on a -0.75 % grade, starting with invert elevation 852.30 ft at 10 + 00. Calculate invert elevations at each 50-ft station along the line.
A sewer pipe must be laid from a starting invert elevation of 1250.75 ft at station 9 -t- 50 to an ending invert elevation 1244.10 ft at station 13 + 75. Determine the uniform grade needed, and calculate invert elevations at each 50-ft station. Grade stakes for a pipeline running between stations 0 + 00 and 5 + 64 are to be set at each full station. Elevations of the pipe invert must be 1168.25 ft at station 0 + 00 and 1162.05 ft at 5 + 64, with a uniform grade between. After staking an offset centerline. an instrument is set up nearby, and a backsight of 4.06 taken on BM *A* (elevation 1173.25 ft). The following foresights are taken with the rod held on ground at each stake: (0 + 00, 5.51); (1 + 00, 5.67); (2 + 00,5.03); (3 + 00, 7.16); (4 + 00.7.92): (5 + 00.8.80): (6 + 00,9.10); and (6 + 46,9.25). Prepare a set of suitable field notes for this project (see Plate B-6) and compute the cut required at each stake. Close the level circuit back to the bench mark.
If batter boards are to be set exactly 8.00 ft above the pipe invert at each station on the project of Problem 23-11, calculate the necessary rod readings for placing the batter boards. Assume the instrument has the same HI as in Problem 23-11. How are streets and street grades arranged for drainage in a city with flat terrain? **H4** By means of a sketch, show how and where batter boards should be located: (a) for an I-shaped building (b) For an L-shaped structure.
A building in the shape of an L must be staked. Corners *ABCDEF* all have right angles. Proceeding clockwise around the building, the required outside dimensions are *AB* = 80.00 ft. *BC* = 30.00 ft, CD = 40.00 ft, *DE* = 40.00 ft, *EF* = 40.00 ft, and *FA* = 70.00 ft. After staking the batter boards for this building and stretching string lines taut, check measurements of the diagonals should be made. What should be the values of *AC, AD, AE, FB, FC, FD,* and *BD?* **H6** Compute the floor area of the building in Problem 23-15.
H7 The design floor elevation for a building to be constructed is 1068.48. An instrument is set up nearby, leveled, and a backsight of 6.26 taken on BM *A* whose elevation is 1070.22 ft. If batter boards are placed

exactly 1.00 ft above floor elevation, what rod readings are necessary on the batter board tops to set them properly? H8 Compute the diagonals necessary to check the stakeout of the building in Figure 23-8. **«-19** Can the corners of a building be plumbed using a total station instrument? Explain. **k20** Should a street, or highway, be designed with a grade of 0.00%? Explain.

Discuss the importance of tying in and referencing critical centerline points on highway construction surveys. |

23-22 Explain why slope stakes are placed at an offset distance from slope intercepts. What offset distance is recommended? J

23-23 What information is normally lettered on slope stakes? ; 25-24 Describe a field procedure for setting slope stakes.

23-25 Discuss the procedure and advantages of using total station instruments with data collectors for slope staking.

23-26 Describe how control can be brought quickly into a deep open-pit mine.

23-7 highway centerline subgrade elevation is 985.20 ft at station 12 + 00 and 993.70 ft at 17 + 00 with a smooth grade in between. To set blue tops for this portion of the

| | |
|---|---|
| 21 | Techniques used to solve intersection ( triangular method ,analytical method, mechanical method, rotation of coordinates |

# Example: 9.12

| points | sides | length | AZ | Em | Nm |
|---|---|---|---|---|---|
| A | | | | 1000 | 100 |
| | AB | 500 | 20 30' | | |
| B | | | | 1175.104 | 568.336 |
| | BC | 600 | 275 10' | | |
| C | | | | 1772.666 | 514.304 |
| | CD | 290.564 | 185 10' | | |
| D | | | | 1746.499 | 224.921 |
| | DA | 756.880 | 80 30' | | |
| A | | | | 1000 | 100 |

<C2=90-<C1=56 37' 59"

نستخدم قانون Sin نجد الضلع AD,CD

$$\frac{AC}{Sin < D} = \frac{AD}{Sin < C2} = \frac{CD}{SinA2}$$

$$\frac{876.733}{Sin104\ 40'} = \frac{AD}{Sin56\ 37'59"} \gg AD = 756.880m$$

$$\frac{876.733}{Sin104\ 40'} = \frac{CD}{Sin18\ 42'01"} \gg CD = 290.564m$$

نجد احداثيات كل النقاط واحداثيات نقطة A معلومة (1000,100)

XB=1000+500*Sin20 30'≫XB=1175.104m

YB=100+500*Cos20 30'≫ $YB = 568.336m$

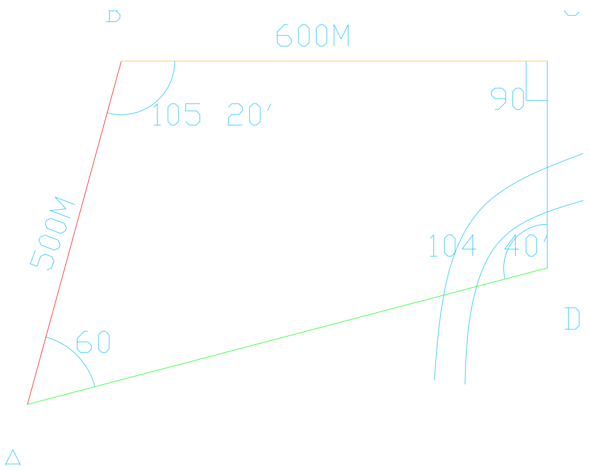
XD=1000+756.880*Sin80 30'= $1746.499m$

YD=100+756.880*Cos80 30'=224.921m

$AZ_{AC}=AZ_{AB}+<A1=20\ 30'+41\ 17'59"=61\ 47'\ 59"$

XC=1000+876.733*Sin61 47'59"=1772.666m

YC=100+876.733*Cos61 47'59"=514.304m




نجد قيمة الزوايا الداخلية للشكل الرباعي

Internal angle=n-2*180

intrnal angle=4-2*180=360

$<A=AZ_{AD}-\mathbf{AZ_{AB}=80\ 30'-20\ 30'=60}$

$<B=AZ_{AB}-AZ_{CB}=360-275\ 10'+20\ 30'=105\ 20'$

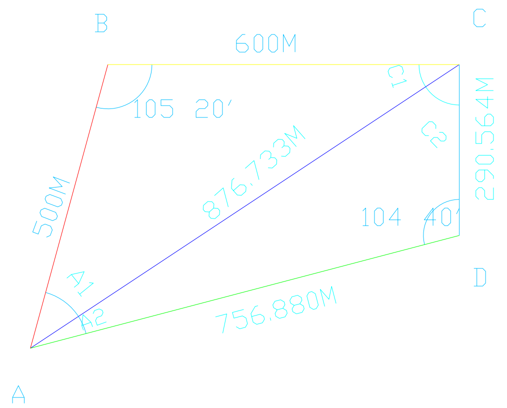
$<C=AZ_{CB}-AZ_{CD}=275\ 10'-185\ 10'=90$

$<D=AZ_{CD}-AZ_{AD}=185\ 10'-80\ 30'=104\ 40'$

Internal angle=$<A+<B+<C+<D=360$

Internal angle=60+105 20'+90+104 40'=360

نقوم بتقسيم الشكل الرباعي الى مثلثين ونجد طول الضلع




$b^2=a^2+c^2-2ac\ Cos<B$

$b^2=600^2+500^2-2_*600_*500Cos105\ 20'=876.733$

$$\frac{b}{Sin<B}=\frac{a}{Sin<A1}=\frac{c}{Sin<C1}$$

$$\frac{876.733}{Sin105\ 20'}=\frac{600}{Sin<A1}$$

$<A1=\frac{600*Sin105\ 20'}{876.733}$

<A1=41 17'59"

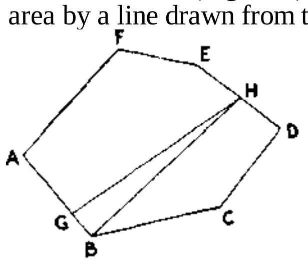
<A2=60-41 17' 59"=18 42' 01"

$$\frac{876.733}{Sin105\ 20'}=\frac{500}{SinC1} \gg C1=\frac{500*Sin105\ 20'}{876.733}$$

C2=33 22'

**. Subdivision of an Area into Given Parts from a Point on Boundary.**

Let ABCDEFA (Fig. 202) be a plot of land, and let be required to cut off a definite area by a line drawn from the H on the boundary.




Calculate the area of the figure ABCDEFA from the coordinates and also plot the figure on a fairly large scale. By inspectic or by trial and error on the plotted plan, find the station B so th the area bounded on one side by the line HB is nearer in value u» the given area than that bounded by a line from H to any other I

The length and bearing of the line BH have been computed from the coordinates of H and B and, since the bearing of BG is known, **the** angle HBG is known. Consequently, BG can be computed and the coordinates of G found.

**406. Subdivision of an Area into Given Parts by a Line of Given Bearing.** Let it be required to divide the area ABCDEFGA (Fig. 203) into two parts by a line whose bearing is given.

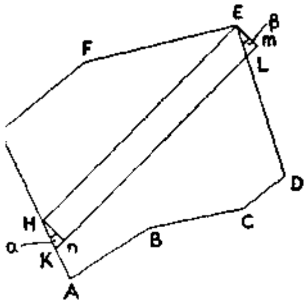



FIG. 203.

Calculate the area of the figure from the coordinates and plot it on a fairly large scale. Draw the line EH from one station E, and in the given direction, so that it cuts off an area HEFGH approximately equal to *A*, the area required. Calculate the bearing and distance of GE. Then, since the bearings of the lines GE, EH, and HG are known, the three angles of the triangle GEH are known and, from these and the computed distance GE, the lengths HE and GH can be calculated. Hence, the coordinates of H can be found. Using these coordinates, and those of the points E, F, and G, calculate the area of the figure HEFGH. Let *A'* be this area. Then, if LK is the line needed to cut off the area *A*, we must have:

$$A - A' = \text{Area of figure HKLEH.}$$

From E draw Em perpendicular to EH to meet KL in m, and from H draw Hn perpendicular to KL. Let Em = Hn = *x* and angle



KHn = a, and *ELm* = /?, these angles being known bearings of the different lines are known. Then, lengtfc HE — *x* . tan /? + *x* . tan *a*. Hence,

Area of figure HKLEH = ^(HE + KL)

= |(2HE + x(tan *a* - tan 01 j

2

= x . HE + y{tana-tan/?).

Hence,.
*A*-*A'*=

y(tana-tan£).

This is a quadratic equation which can be solved for x. having found *x*, we have:

EL = x . sec /?; HK = x . sec a. Hence, the coordinates of K and L

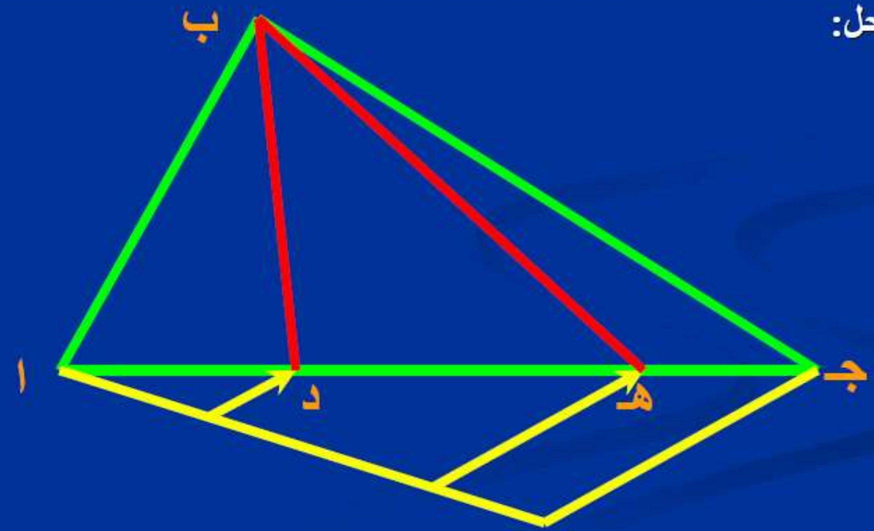
can be found.

## الحالة الأولى

شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى ٣ أقسام بنسبة س:ص:ع

الشرط : الاشتراك فى نقطة ب (منفعة عامة مثل مصدر مياه)

الحل:

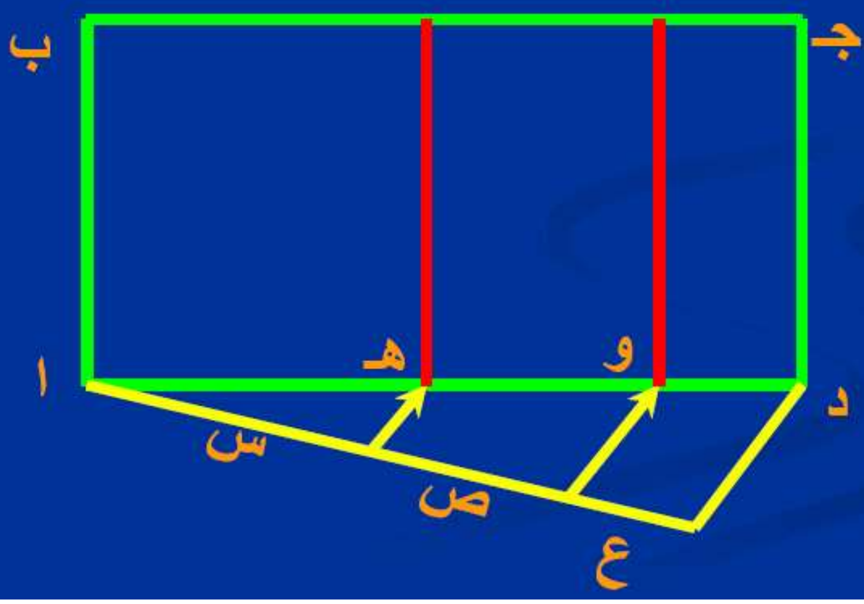



## الحالة الثانية

شكل قطعة الأرض : مستطيل ا ب جـ د يراد تقسيمه بنسب س:ص:ع

الشرط : الاستفادة من طريقين ب جـ ، ا د

الحل:

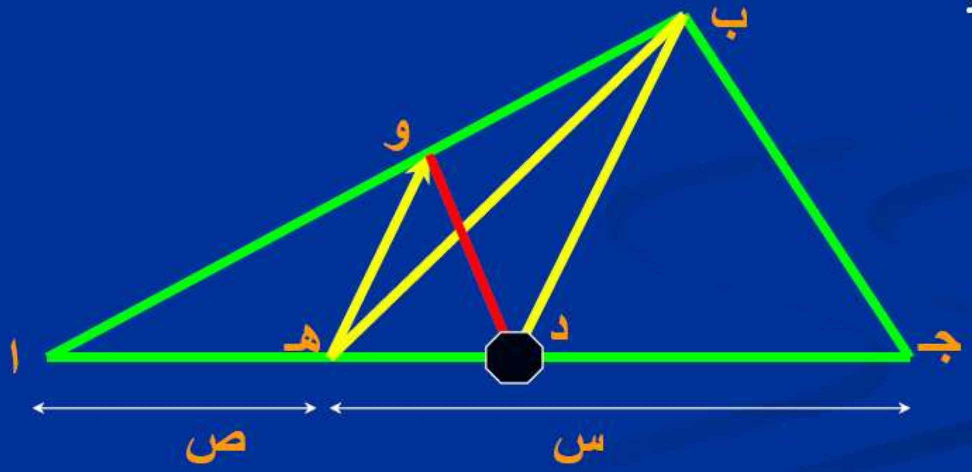


## الحالة الثالثة

شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى قسمين بنسبة س:ص

الشرط : أن يمر خط التقسيم بنقطة د على الضلع ا جـ

الحل:

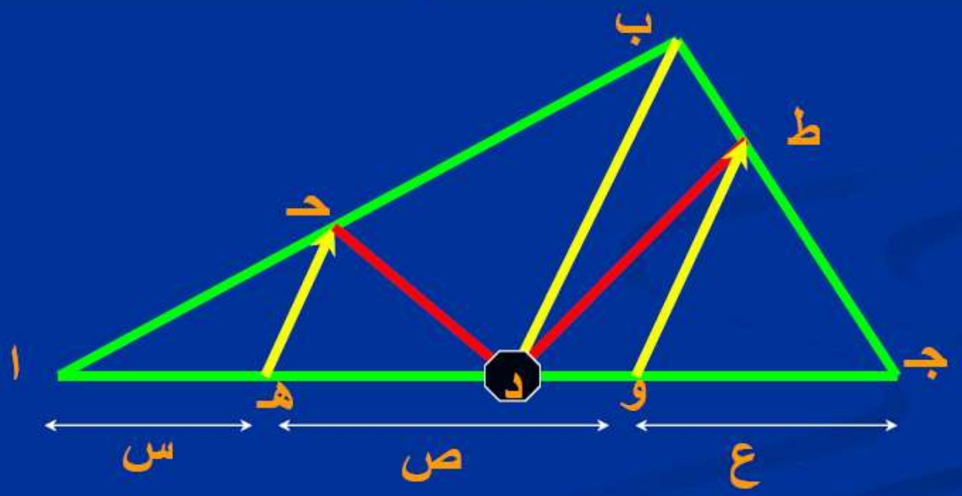



## الحالة الرابعة

شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى ٣ أقسام بنسبة س:ص:ع

الشرط : أن يمر خط التقسيم بنقطة د على الضلع ا جـ

الحل:

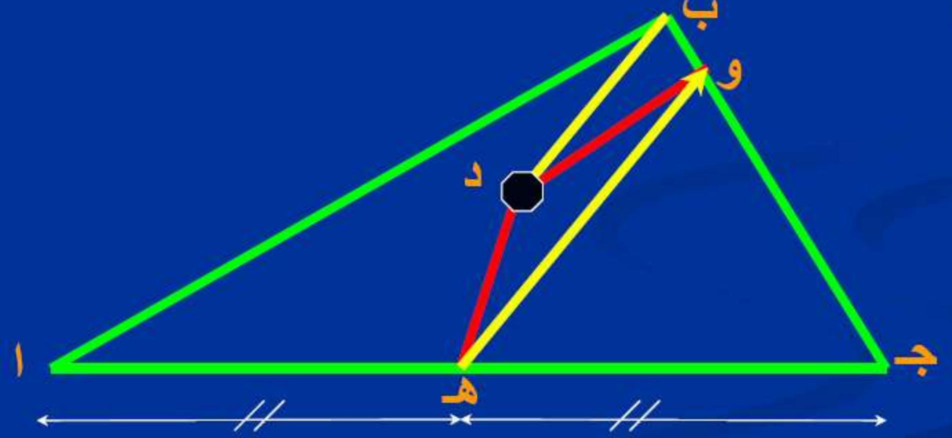


## الحالة الخامسة

شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى  قسمين متساويين

الشرط : أن يمر خط التقسيم بنقطة  د  داخل المثلث

الحل:

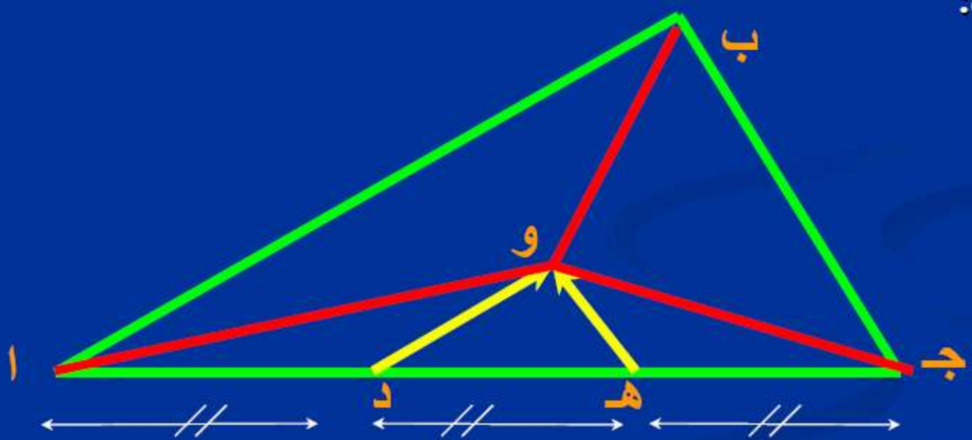


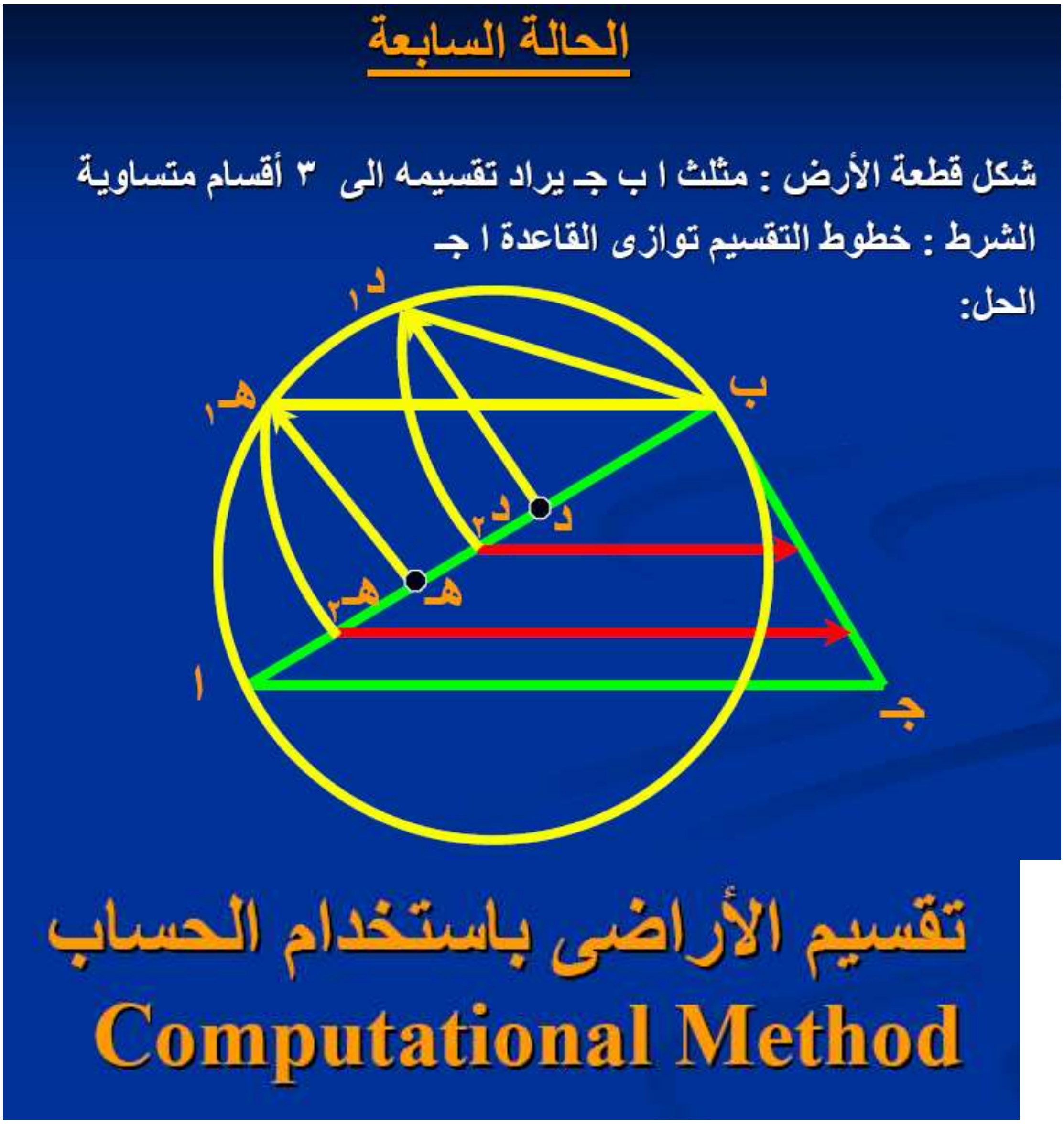

## الحالة السادسة

شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى  ٣ أقسام متساوية

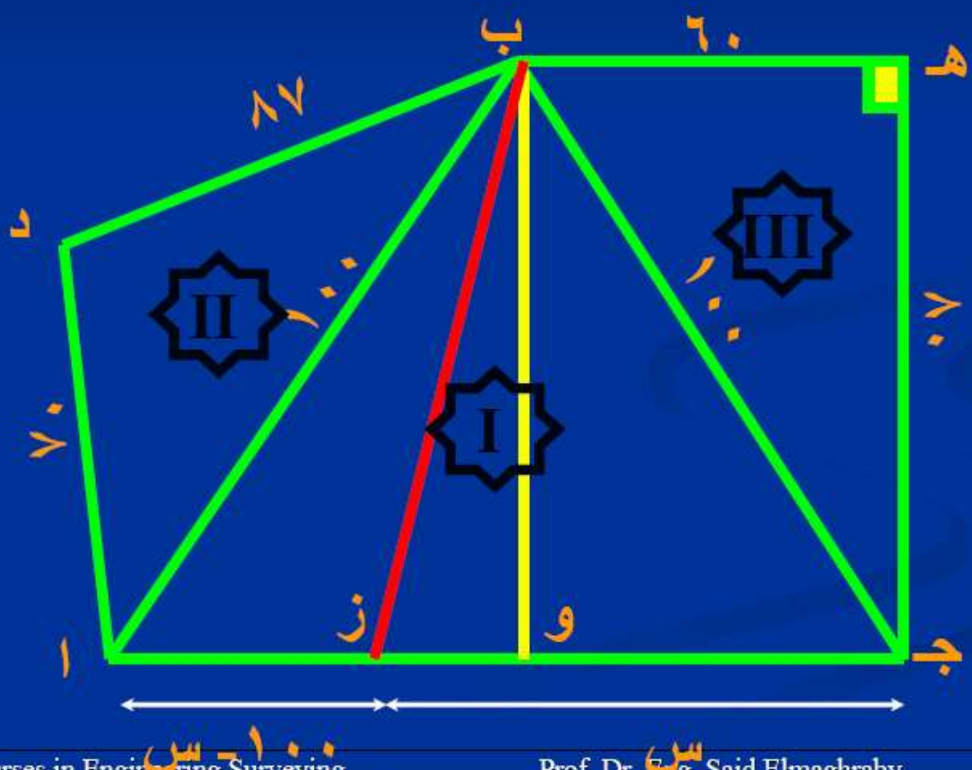
الشرط : كل ضلع يمثل حد لكل قسم

الحل:




الحالة السابعة
شكل قطعة الأرض : مثلث ا ب جـ يراد تقسيمه الى ٣ أقسام متساوية
الشرط : خطوط التقسيم توازى القاعدة ا جـ
الحل:
د١
ب
هـ١
د٢
د
هـ٢
هـ
ا
جـ
تقسيم الأراضى باستخدام الحساب
Computational Method

# مثال عددى لتقسيم الأراضى بالطريقة الحسابية




شكل الأرض: الأرض محددة بخطوط مستقيمة أطوالها:

ا ب = ب جـ = جـ ا = ١٠٠م ، ب هـ = ٦٠م ، هـ جـ = ٨٠م، ا د = ٧٠م ، ب د = ٨٧م .

الشرط : تقسيمها الى قسمين متساويين وخط التقسيم يمر بالنقطة ب

الحل :

المثلث I : المساحة = ½ x ١٠٠ x ١٠٠ جا ٦٠ = ٤٣٣٠ م٢

المثلث II : ح = ½ x(١٠٠ + ٨٧ + ٧٠) = ١٢٨

المساحة = [(١٢٨ x (١٢٨ – ١٠٠) x (١٢٨- ٧٠) x (١٢٨-٨٧)] ½

= ٢٩٥٦,٨ م٢

المثلث III : المساحة = ½ x ٦٠ x ٨٠ = ٢٤٠٠ م٢

المساحة الكلية = ٤٣٣٠ + ٢٩٥٦,٨ + ٢٤٠٠ = ٩٦٨٦,٨ م٢

حصة كل قسم = ٩٦٨٦,٨ \ ٢ = ٤٨٤٣,٤ م٢

٤٨٤٣,٤ = مساحة I + المثلث ا ب ز = مساحة II + المثلث ب جـ ز

= ٤٣٣٠ + ½ x س x ١٠٠ جا٦٠

س= ٥٦,٤٣ م

سؤال:11.10/قطعة ارض على شكل مضلع مغلق JKLMفي الشكل ادناه ، تمر خلالها قناة الرأي عرضها 6م باتجاه : N 70° W وابتداءاً من نقطة K . اريد تقسيم الجزء الواقع الى جنوب تلك القناة . الى مساحتين متساويتين من نقطة P الذي تقع في منتصف KH والمطلوب حساب : أ) مساحات اجزاء JGF وGKHF و KLMH .

ب) طول واتجاه الخط PR وموقع نقطة R .

الحل:-

**J(100,100)**

**Ek=100+40*Sin 180°=100 m**

**Nk=100+40*Cos 180º=60 m**

**EL=100+50*Sin 126º 45'=140.063 m**

**NL=60+50*Cos 126º 45'=30.083 m**

**EM=140.063+100*Sin 270º=40.063 m**

**NM=30.083+100*Cos 270º=30.083 m**

**EJ=40.063+92*Sin 40º 35'=99.914 m**

**NJ=30.083+92*Cos 40º 35'=99.953 m**

| Point | Sild | Length | AZ. | Dep. | Lat | X | Y |
|---|---|---|---|---|---|---|---|
| J | | | | | | 100 | 100 |
| | JK | 40 | 180º | 0 | -40 | | |
| K | | | | | | 100 | 60 |
| | KL | 50 | 126º 45' | 40.063 | -29.916 | | |
| L | | | | | | 140.063 | 30.084 |
| | LM | 100 | 270º | -100 | 0 | | |
| M | | | | | | 40.063 | 30.084 |
| | MJ | 92 | 40º 35' | 59.851 | 69.870 | | |
| J | | | | | | 99.914 | 99.954 |
| | | 282 | | -0.086 | -0.046 | | |

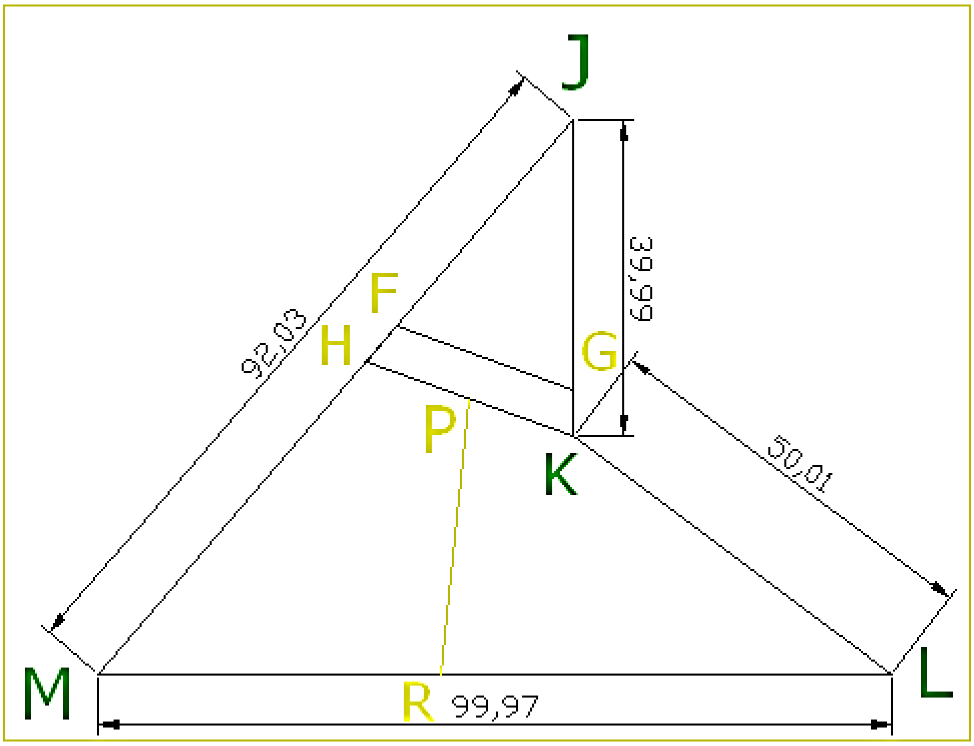
| Corr. Dep. | Corr. Lat. | Corrected Dep. | Corrected Lat. | X | Y |
|---|---|---|---|---|---|
| | | | | 100 | 100 |
| 0.012 | 0.006 | 0.013 | -39.994 | | |
| | | | | 100.013 | 60.006 |
| 0.015 | 0.008 | 40.078 | -29.908 | | |
| | | | | 140.091 | 30.098 |

| | | | | | |
|---|---|---|---|---|---|
| **0.030**<br><br>**0.028** | **0.016**<br><br>**0.015** | **-99.970**<br><br>**59.879** | **0.016**<br><br>**69.886** | **40.121**<br><br>**100** | **30.114**<br><br>**100** |

**T.C for Deps=0 – Σ dep=0.086**
**T.C for Lats=0 – Σ Lats=0.046**

$$\textbf{Corrected for Dep of Side} = \frac{\textbf{T.C}}{\Sigma\ \textbf{Length}} * \textbf{Length of the side}$$

$$\textbf{Corrected for Lat of Side} = \frac{\textbf{T.C}}{\Sigma\ \textbf{Length}} * \textbf{Length of the side}$$




**J(100,100)**
**K(100.013,60.006)**
**L(140.091,30.098)**
**M(40.121,30.114)**
**J(100,100)**

**JK =39.994 m**
**KL =50.007 m**
**LM =99.970 m**
**MJ =92.030 m**
**AZ. JK =179º58'53"**
**AZ. kL=126º43'55"**
**AZ.LM=270º00'33"**
**AZ. MJ=40º35'25"**
**JG =1/2 JK**
**JG =33.994 m**
**<J =40º36'32"**
**<JGF =69º58'53"**
**<JFG = <JHK =69º24'35"**

$$\frac{JG}{\sin \angle F} = \frac{FG}{\sin \angle J}$$

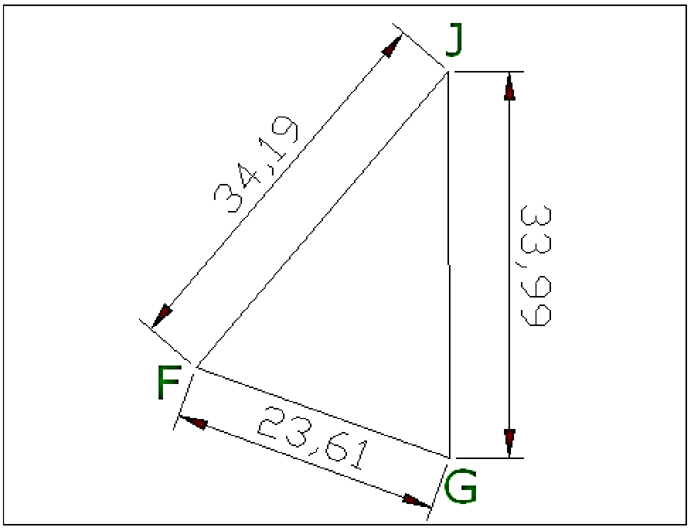
$$FG = \frac{33.994 \cdot \sin 40^\circ 36' 32''}{\sin 69^\circ 24' 35''} = 23.636\ m$$

$$\frac{HK}{\sin \angle J} = \frac{JK}{\sin \angle H}$$

$$HK = \frac{39.994 \cdot \sin \angle 40^\circ 36' 32''}{\sin 69^\circ 24' 35''} = 27.808\ m$$

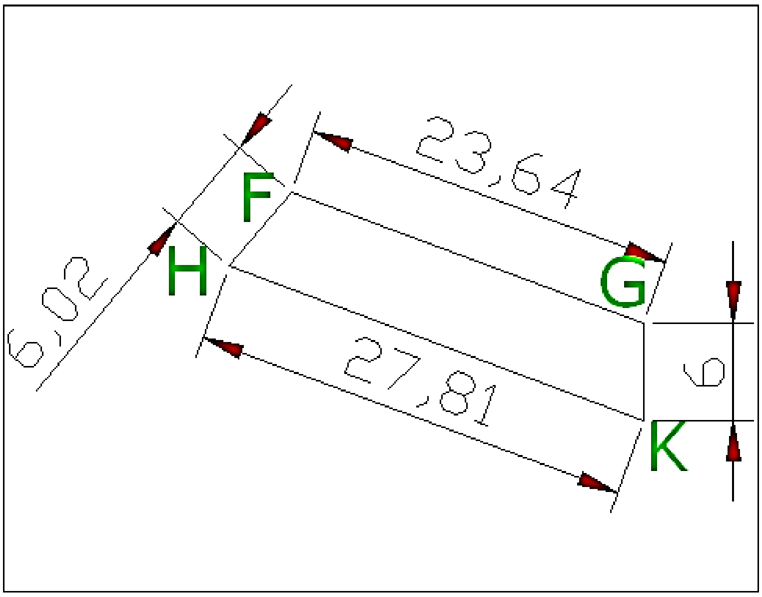
**EG =100.013+6*sin 00º01'07" = 100.015 m**
**NG =60.006+6*cos 00º01'07" = 66.006 m**
**Area of Δ JGF = 1/2 FG*JG sin 69º58'53"**
**Area of Δ JGF = 1/2 *23.636*33.994 sin 69º58'53"=377.468 m²**

**نجد مساحة مثلث JKG**



EH =100.013+27.808*sin 290º =73.882 m
NH =60.006+27.808*cos 290º = 69.517 m
PK = 1/2 HK =1/2 *27.808 =13.904 m
EF =100.015+23.636*sin 290º =77.804 m
NF =66.006+23.636*cos 290º = 74.090 m
EP =100.013+13.904*sin 290º =86.947 m
NP =60.006+ 13.904*cos 290º =64.761 m

الان نجد مساحة مضلع FGKH




| point | E | N |
|---|---|---|
| F | 77.804 | 74.090 |
| G | 100.015 | 66.006 |
| K | 100.013 | 60.006 |
| H | 73.882 | 69.517 |
| F | 77.804 | 74.090 |

**23563.552-23853.633=290.081**
**Ar=290.081/2=145.041 m²**

**L(140.091,30.098)**
**P(86.947,64.761)**
**PL =63.449 m**
**AZ.LP = 303º 06'51"**

| point | E | N |
|---|---|---|
| H | 73.882 | 69.517 |
| K | 100.013 | 60.006 |
| L | 140.091 | 30.098 |
| M | 40.121 | 30.114 |
| H | 73.882 | 69.517 |

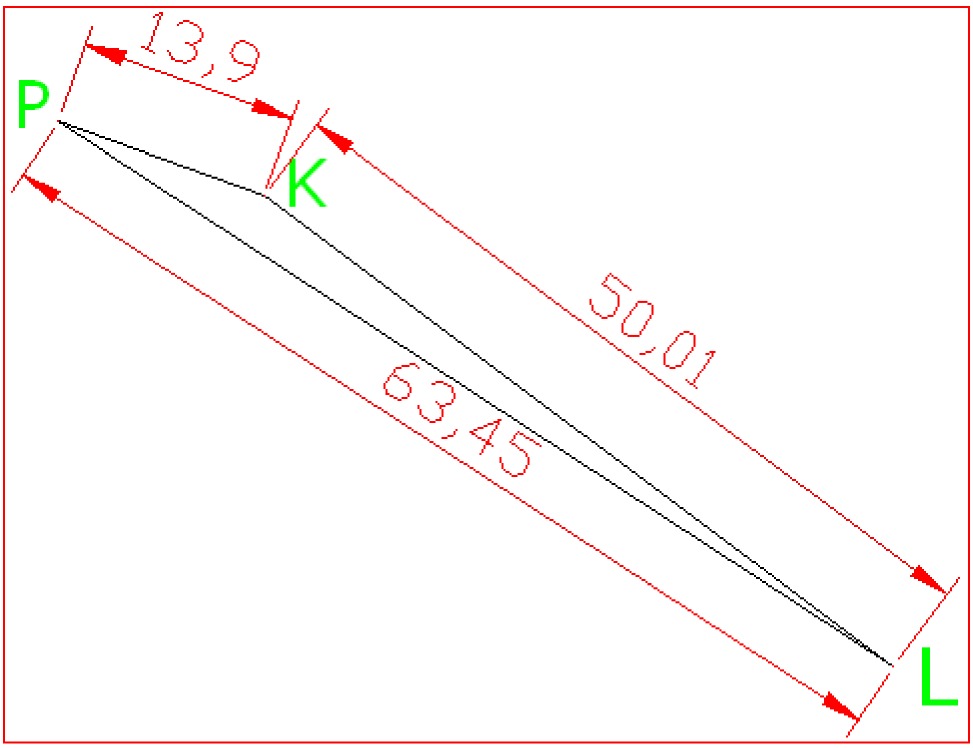
**2 Ar= 14451.346-18791.349=4340.002**
**Ar=2170.001 m²**

**نقسم مضلع HKLM الى قسمين ليكون المضلع PKLR مساحتها 1085** متر مربع

**نوصل خط من P الى L نجد منها الطول والاتجاه**

**LP=63.449 m**
**AZ.LP=303º 06'51"**

**نجد مساحة المثلث PKL**



**Area of Δ PKL=1/2*KL*LP*sin3º37'40"**
**Area of Δ PKL=1/2*50.007*63.449*sin3º37'40"**
**Area of Δ PKL=100.105 m²**

**نجد مساحة المثلث PLR**

**Area of Δ PLR=1085-100.105=984.895 m²**

**نعوضها بالقانون**

**Area of Δ PLR=1/2* LP*LR*sin33º06'18"**

$$LR=\frac{984.895}{17.327} = 56.842 \text{ m}$$

$$E_R=140.091+56.842*\sin 270^{o}\ 00'33''=83.249 \text{ m}$$
$$N_R=30.098+56.842*\cos 270^{o}\ 00'33''=30.017 \text{ m}$$

**R(83.249 , 30.107)**