Survey Manual

Chapter 8

Resources

Colorado Department of Transportation
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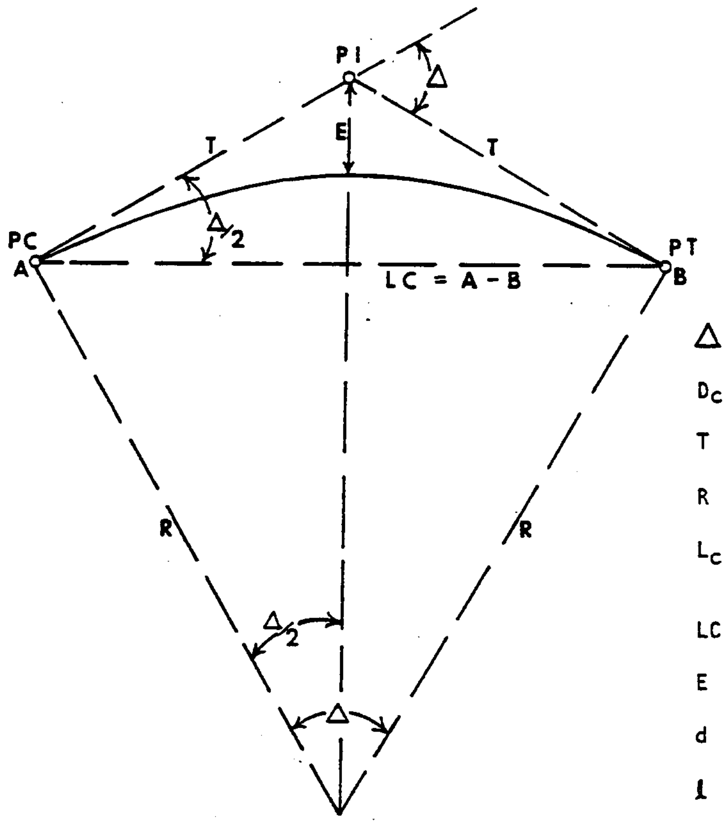
8.1 General

The purpose of this chapter is to provide the surveyor with an easy to use resource of information that will enable the user of this manual to reduce her/his library of reference material needed in the field.

> **This chapter is not intended as a textbook on surveying, rather it provides a reference source for formulas, tables and information. No representation is made or warranty given as to its content. User assumes all risk of use. CDOT assumes no responsibility for any loss or delay resulting from such use.**

8.2 Resources

8.2.1 Simple Curve



Δ = Delta

D_c = Degree of Curve

T = Tangent

R = Radius

L_c = Length of Curve

LC = Long Chord

E = External Distance

d = Deflection

ℓ = Distance from P.C. in Stations

SIMPLE CURVE

Arc Definition (for Highway Curves)

$$\Delta = \frac{L_c D}{100} \qquad L_c = 100\frac{\Delta}{D_c}$$

$$D_c = \frac{5729.58}{R} \qquad LC = 2R \sin\frac{\Delta}{2}$$

$$T = R \tan\frac{\Delta}{2} \qquad E = T \tan\frac{\Delta}{4}$$

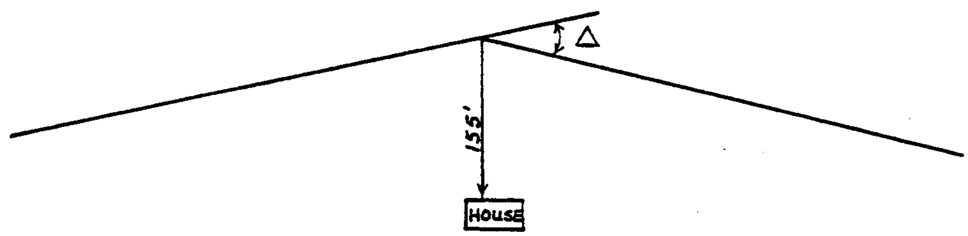
$$R = \frac{5729.58}{D_c} \qquad d = \ell\frac{D_c}{2}$$

Chord Definition (for R.R. curves only)

$$R = \frac{50}{\sin\frac{1}{2} D_c} \qquad L_c = 100\frac{\Delta}{D_c}$$

8.2.2 Simple Curve Computations

SIMPLE CURVE COMPUTATIONS



Given: 2 Lane Crowned Highway
Maximum Design Speed 40 mph
$\Delta = 24°56'$
P.I. Sta. = 568+24.33

Survey Line must be at least 100' from house
Maximum Tangent Length is 480 feet.

To determine maximum degree of curve,
see M Standard M-203-10
D max. = 14°30' e max. = 0.12

The maximum External Distance is
155' - 100' = 55 feet

To find the flattest curve possible, compute Radius, Tangent and External Distance for several different curves.

$$R = \frac{5729.58}{D_c} \qquad T = R \tan\frac{\Delta}{2} \qquad E = T \tan\frac{\Delta}{4}$$

Try 5°00'00" Curve

$$R = \frac{5729.58}{5} \qquad T = 1145.92 \tan\frac{24°56'00''}{2} = 253.34'$$

$$E = 253.34 \tan\frac{24°56'00''}{4} = 27.67'$$

Tangent can be longer. External Distance can be greater.

Try 4°00'00" Curve

8.2.3 Simple Curve Computations

D	R	T	E
4°00'00"	1432.40	316.68	34.59

Tangent can be longer. External can be greater.

D	R	T	E
3°00'00"	1909.86	422.24	46.14

Tangent can be longer. External can be a little longer.

D	R	T	E
2°00'00"	2864.79	633.36	69.18

Tangent is too long. External is too long.

D	R	T	E
2°30'00"	2291.83	506.69	55.34

Tangent is too long. External is OK.

USE 3°00'00" CURVE

From above: Degree of Curve = 3°00'00"
Radius = 1909.86'
Tangent Length = 422.24'
External Distance = 46.14'

$$L_c = \frac{\Delta}{D}100 = \frac{24°56'00''}{3°00'00''}100 = \frac{24.9333}{3.0}100 = 831.11 \text{ ft. } (8.3111 \text{ Sta.})$$

Station Alignment

P.C. Sta. = P.I. Sta. - Tangent (in Sta.) = 568+24.33 - 4+22.24

P.C. Sta. = 564+02.09

P.T. Sta. = P.C. Sta. + L_c = 564+02.09 + 8+31.11

P.T. Sta. = 572+33.20

Computing Curve Deflections

d = deflection $\qquad$ l = distance from P.C. in stations

$$d = l\,\frac{D}{2}$$

For Station 564+50, $d = .4791 \frac{3.0}{2} = 0°43'07''$

P.C. 564+02.09	0°00'00'' *	
+50	0°43'07''	
565+00	1°28'07''	
+50	2°13'07''	
566+00	2°58'07''	
+50	3°43'07''	
567+00	4°28'07''	
+50	5°13'07''	
568+00	5°58'07''	
+50	6°43'07''	
569+00	7°28'07''	
+50	8°13'07''	
570+00	8°58'07''	
+50	9°43'07''	
571+00	10°28 07''	
+50	11°13'07''	
572+00	11°58'07''	
P.T. +33.20	12°28'00''	X 2 = 24°56'00''

To check the total deflection:

$$\frac{\Delta}{2} = \frac{24°56'00''}{2} = 12°28'00''$$

* Deflections may be rounded to the accuracy of the instruments.

COMPUTING CHAINING CORRECTIONS FOR SIMPLE CURVES

By ratio and proportion:

$$\frac{\Delta R}{R} = \frac{Corr}{100}$$

Solving for the correction:

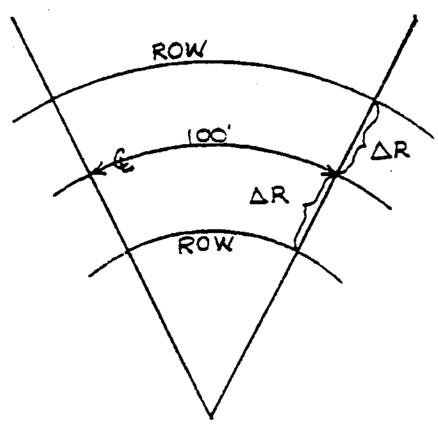
$$Corr = \frac{\Delta R(100)}{R}$$

For a 3 degree curve with 100' ROW, the correction per Station is:

$$Corr = \frac{100(100)}{1909.86} = 5.236'$$

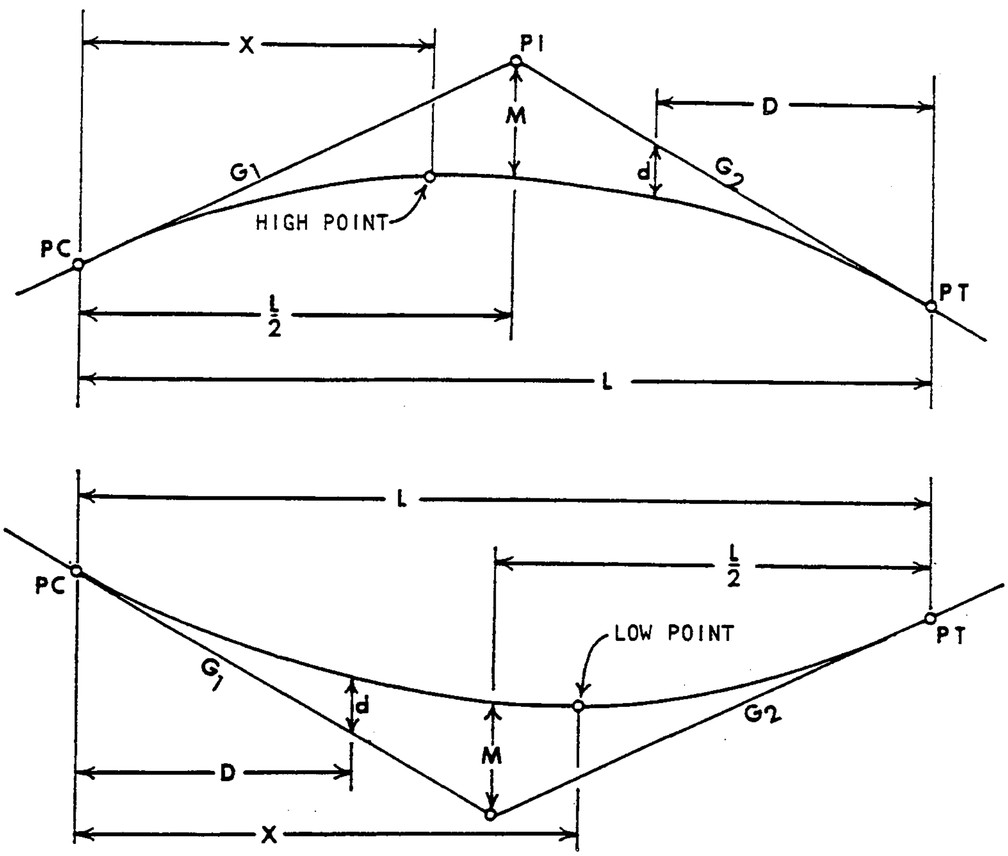
The chaining distance for the outside ROW per station is
100 + 5.236' or 105.236'.

The chaining distance for the inside ROW per station is
100 - 5.236' or 94.794'.



8.2.4 Vertical Curve

VERTICAL CURVE
(Symmetrical)



L = Length of Curve in Stations

D = Distance from P.C. or P.T. in Stations

G_1 & G_2 = Grades in Ft. per 100 Ft.

d = Tangent Offset

$$M = \frac{L(\text{Algebraic Difference in Grades})}{8}$$

$$d = 4M\left(\frac{D}{L}\right)^2 = \frac{(G_1 - G_2)}{2L} D^2$$

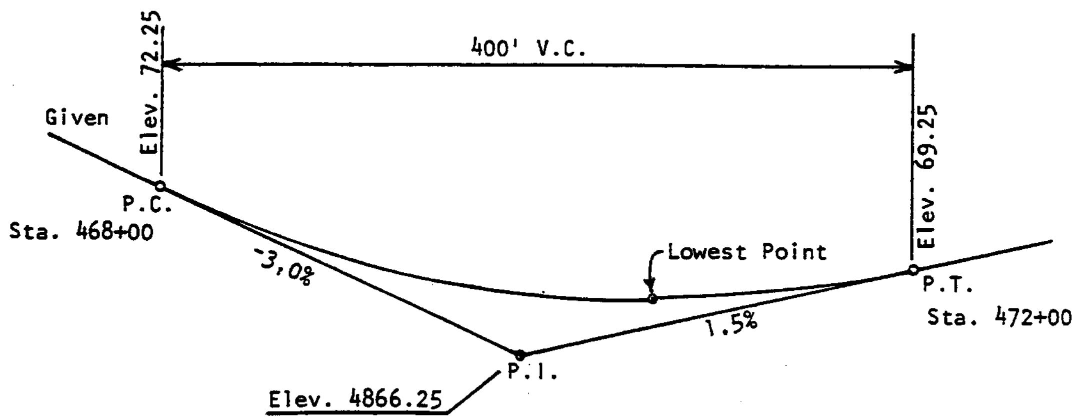
Profile Elevation = Tangent Elev. - Tangent Offset or P.E. = T.E. - d

To determine High Point (or Low Point on Sag Vertical) use the following:

$$x = \frac{G_1 \times L}{\text{Alg. Diff. in Grades}}$$

Where x is the distance from the P.C. of the curve in stations

VERTICAL CURVE EXAMPLE



Compute Profile Elevations for each station and +50s.

$$d = \left(\frac{G_1 - G_2}{2L}\right) D^2 = \left(\frac{(-3.0)-(+1.5)}{2(4.00)}\right) D^2 = -.5625\ D^2$$

for Sta.468+50 $\quad d = -.5625(.5)^2 = -.14 \quad$ P.E. = 70.75 - (-.14) - 70.89

	Sta.	Tangent Elev.	Tangent Offset	Profile Elev.
P.C.	468+00	72.25	0	72.25
	+50	70.75	-.14	70.89
	469+00	69.25	-.56	69.81
	+50	67.75	-1.27	69.02
	470+00	66.25	-2.25	68.50
	+50	67.00	-1.27	68.27
	471+00	67.75	-.56	68.31
	+50	68.50	-.14	68.64
P.T.	472+00	69.25	0	69.25

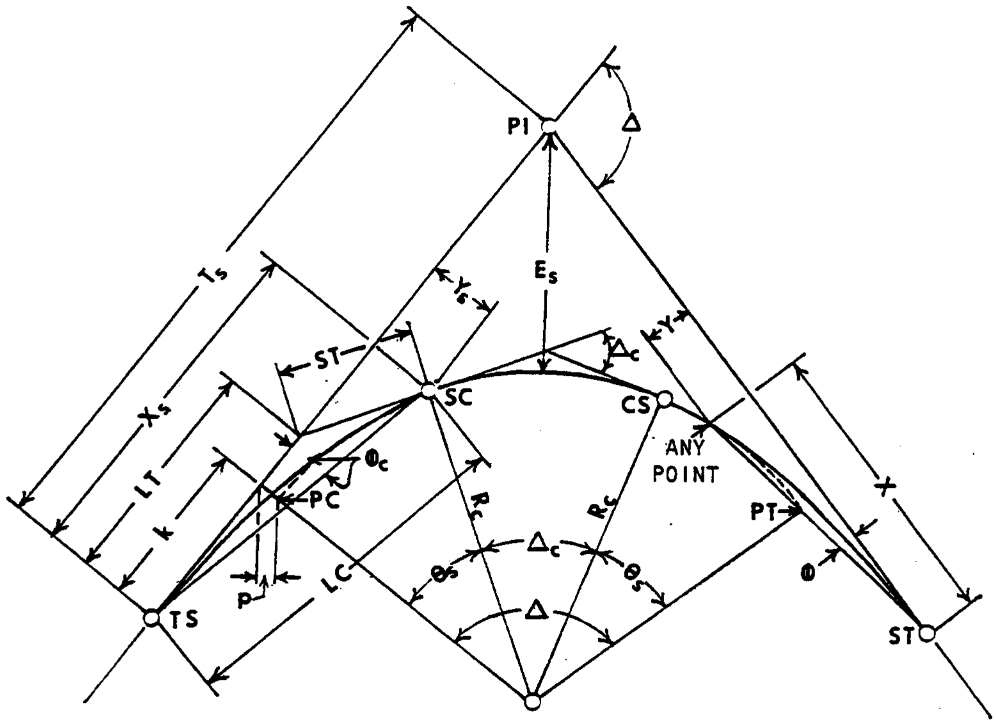
$$\text{Low Point} = \frac{-3.0(4)}{(-3.0) - (+1.5)} = \frac{-12}{-4.5} = 2.667 \text{ Sta.}$$

$$= (468+00) + (2 + 66.67) = 470+66.67$$

$d = -.5625\left[(472 - 470.6667)^2\right] = -1.00 \qquad$ Elev. = 67.25 - (-1.00) = 68.25

8.2.5 Spiral Curve

SPIRAL CURVE



CURVE WITH TRANSITION - BOTH ENDS

$$\theta_s = \frac{D_c L_s}{200} \qquad T_s = \left[(R_c + p)\tan\frac{\Delta}{2}\right] + k \qquad E_s = \frac{R_c + p}{\cos\frac{\Delta}{2}} - R_c$$

$$\Delta_c = \Delta - 2\theta_s \qquad d = \left(\frac{1}{3}\ \frac{\theta_s}{L_s^2}\right) l^2$$

$$p = L_s\left[.00145444104\theta_s - 1.58231456 \times 10^{-8}\ \theta_s^3\right]$$

$$k = L_s\left[.5 - 5.076957 \times 10^{-6}\ \theta_s^2\right]$$

For curves with unequal spirals:

$$T_{s1} = k_1 + (R_c + p_2)\tan\frac{\Delta}{2} - (p_1 - p_2)\frac{1}{\tan\Delta}$$

$$T_{s2} = k_2 + (R_c + p_2)\tan\frac{\Delta}{2} + (p_1 - p_2)\frac{1}{\sin\Delta}$$

For symbol definitions, see page 6-04-1.

SPIRAL CURVE

$$LT = X_s - Y_s \cot \theta_s$$

$$ST = \frac{Y_s}{\sin \theta_s}$$

$$Y = \frac{1}{100} \left[.5817764173\theta - .1265851665\theta^3 \; (10)^{-4} \right]$$

$$X = \frac{1}{100} \left[100 - .3046174198\theta^2 \; X \; (10)^{-2} + .4295915391\theta^4 \; (10)^{-7} \right]$$

SPIRAL DEFLECTIONS

FROM C.S. OR S.C. TO S.T. OR T.S.

$$d_r = \frac{\left(\frac{D_c}{L_s} \times l\right)\left(3L_s - l\right)}{600}$$

S.C.	682+21.29	0		
	682+00	21.29	(5.5/300x21.29)(3(300)-21.29)/600	= 0°34'18"
	681+50	71.29	(5.5/300x71.29)(3(300)-71.29)/600	= 1°48'19"
	681+00	121.29	(.01833 x 121.29)(900-121.29)/600	= 2°53'09"
	680+50	171.29	(.01833 x 171.29)(900-171.29)/600	= 3°48'50"
	680+00	221.29		= 4°35'21"
	679+50	271.29		= 5°12'42"
T.S.	679+21.29	300.00	(5.5/300 x 300)(3(300)-300)/600	= 5°30'00"

2/3 θ = 5°30'00"

C.S.	689+48.26	0		
	689+50	1.74	(5.5/300 x 1.74)(3(300)-1.74)/600	= 0°02'52"
	690+00	51.74	(.01833 x 51.74)(900 - 51.74)/600	= 1°20'28"
	690+50	101.74		= 2°28'54"
	691+00	151.74		= 3°28'10"
	691+50	201.74		= 4°18'15"
	692+00	251.74		= 4°59'11"
S.T.	692+48.26	300.00		= 5°30'00"

SPIRAL CURVE EXAMPLE

Given $\Delta = 56°29'00''$ P.I. Sta. = 686+32.68
Design Speed = 60 mph
Crowned Highway
e max. = .10

from M Standard M-203-10, the Max $D_c = 5°30'$ for 60 mph

Use 5°30' Curve

Minimum transition length = 270'
Use 300'

Compute $\theta_s = \frac{D_c L_s}{200} = \frac{(5.5)(300)}{200} = 8°15'$

Compute $p = L_s\, [1.45444104\, \theta_s \times 10^{-3} - 1.58231456\, \theta_s^3 \times 10^{-8}]$

$= 300\, [1.45444104\, (8.25)\, 10^{-3} - 1.58231456\, (8.25)^3\, 10^{-8}]$

$= 300\, [.01200 - .00000] = 3.60$ ft.

Compute $k = L_s\, [.5 - 5.076957\, \theta_s^2\, 10^{-6}]$

$= 300\, [.5 - 5.076957\, (8.25)^2\, 10^{-6}] = 149.90$

Compute $R_c = \frac{5729.58}{D_c} = \frac{5729.58}{5.5} = 1041.74$

Compute $T_s = (R_c + p) \tan\frac{\Delta}{2} + k$

$= (1041.74 + 3.60) \tan \frac{56°29'}{2} + k$

$= (1045.34) \tan 28.24167 + 149.90$

$= 711.39$

Compute $E_s = \frac{R_c + p}{\cos\frac{\Delta}{2}} - R_c = \frac{1045.34}{\cos 28.24167} - 1041.74$

$= 851.38$

Compute $\Delta_c = \Delta - 2\theta_s = 56°29' - 2(8°15') = 39°59'$

Compute $L_c = \frac{\Delta_c}{D_c} = \frac{39°59'}{5°30'} \times 100 = 726.97'$

(SPIRAL CURVE EXAMPLE CONTINUED)

Compute Stationing

686+32.68 - T_s = T.S.

T.S. = 686+32.68 - 7+11.39 = 679+21.29

S.C. = 679+21.29 + L_s = 679+21.29 + 3+00 = 682+21.29

C.S. = 682+21.29 + L_c = 682+21.29 + 7+26.97 = 689+48.26

S.T. = 689+48.26 + L_s = 689+48.26 + 3+00 = 692+48.26

Compute Deflections for Spirals

$$d = \left(\frac{\theta_s}{3L^2}\right) l^2 = \left(\frac{8^\circ 15'}{3(300)^2}\right) l^2 = (.00003056) l^2$$

for Sta. 679+50

$d = .00003056\ (679+50 - 679+21.29)^2 = .00003056\ (28.71)^2 = 0^\circ 01' 31''$

for Sta. 680+00

$d = .00003056\ (78.71)^2 = 0^\circ 11' 21''$

for Sta. 692+00

$d = .00003056\ (692+48.26 - 692+00)^2 = .00003056\ (48.26)^2 = 0^\circ 04' 16''$

for Sta. 691+50

$d = .00003056\ (98.26)^2 = 0^\circ 17' 42''$

	Station	Deflection*
T.S.	679+21.29	0°00'00"
	679+50	0°01'31"
	680+00	0°11'21"
	680+50	0°30'22"
	681+00	0°58'33"
	681+50	1°35'54"
	682+00	2°22'25"
S.C.	682+21.29	2°45'00" = 1/3 θ_s = 1/3(8°15') = 2°45'

* Deflections may be rounded to the accuracy of the instruments.

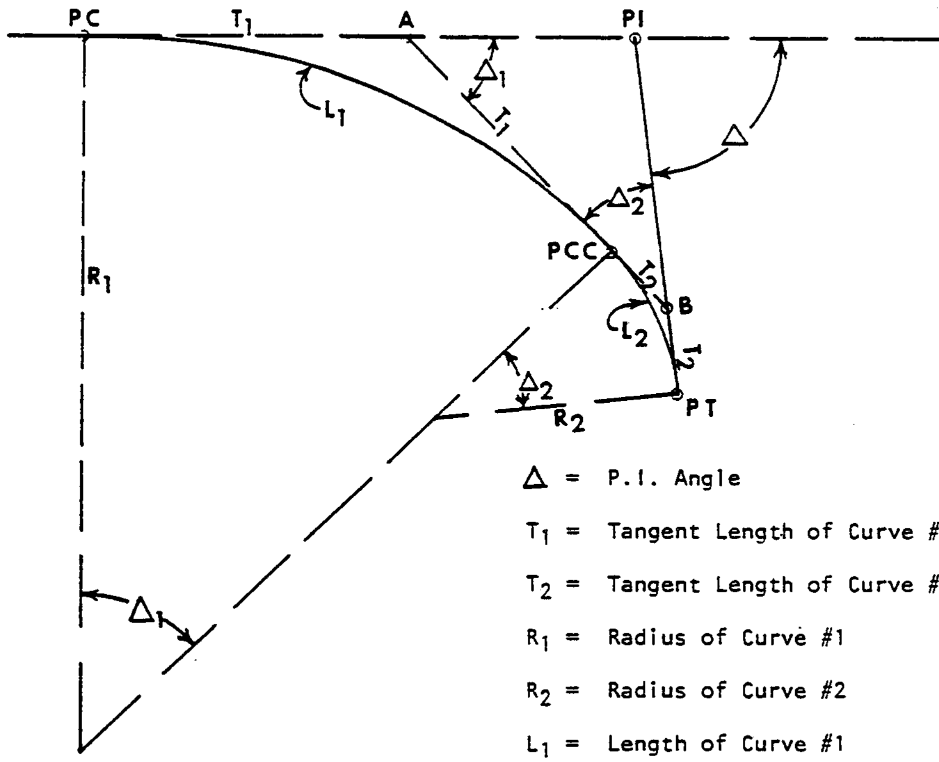
(SPIRAL CURVE EXAMPLE CONTINUED)

Compute Simple Curve Deflection as shown in “Example for Simple Curves”

	Station	Deflection
S.T.	692+48.26	0’00’00”
	692+00	0’04’16”
	691+50	0’17’42”
	691+00	0’40’18”
	690+50	1’12’04”
	690+00	0’53’00”
	689+50	2’43’05”
C.S.	689+48.26	2’45’00”

8.2.6 Compound Curve

COMPOUND CURVES



Δ = P.I. Angle

T_1 = Tangent Length of Curve #1

T_2 = Tangent Length of Curve #2

R_1 = Radius of Curve #1

R_2 = Radius of Curve #2

L_1 = Length of Curve #1

L_2 = Length of Curve #2

D_1 = Degree of Curve of Curve #1

D_2 = Degree of Curve of Curve #2

GIVEN: Δ, R_1, R_2 $\quad \Delta = \Delta_1 + \Delta_2$

$$T_1 = R_1 \tan \frac{\Delta_1}{2} \qquad D_1 = \frac{5729.58}{R_1}$$

$$T_2 = R_2 \tan \frac{\Delta_2}{2} \qquad D_2 = \frac{5729.58}{R_2}$$

Curve is laid out as two adjacent simple curves: one having a radius 'R_1' with its P.I. at 'A'; the other having a radius 'R_2' with its P.I. at 'B'.

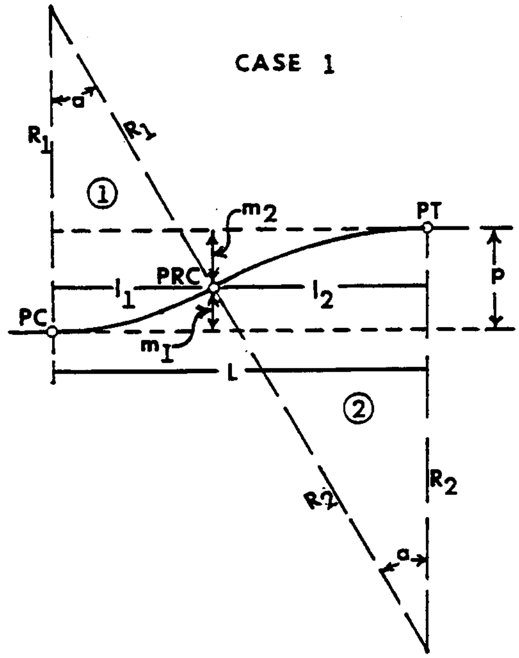
On open highways, the ratio R_1/R_2 should not exceed one and one half(1.5)

On intersection curves, the ratio R_1/R_2 should not exeed two (2).

8.2.7 Reverse Curve

REVERSE CURVES

CASE 1



In Case 1, the two parallel tangents are to be connected by a reversed curve. R_1, and R_2, and p are given.

From triangle 1,
$l_1 = R_1 \sin a$, and $m_1 = R_1 \text{ vers } a$

From triangle 2,
$l_2 = R_2 \sin a$, and $m_2 = R_2 \text{ vers } a$

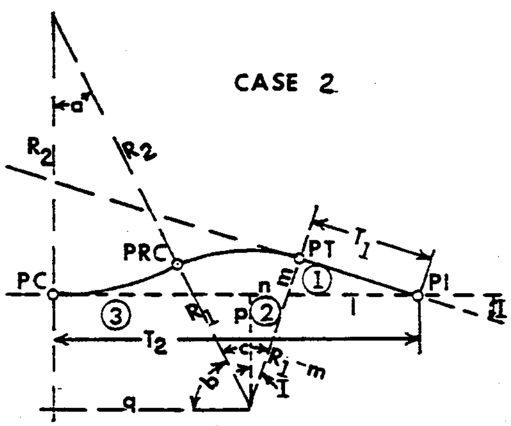
Whence,
$p = m_1 + m_2 = (R_1 + R_2) \text{ vers } a$

$$\text{vers } a = \frac{p}{R_1 + R_2}$$

And $L = l_1 + l_2 = (R_1 + R_2) \sin a$

From these two equations and the ordinary functions of a simple curve, all ordinary cases of reversed curves between parallel tangents can be solved.

CASE 2



In Case 2, the two tangents, intersecting with the angle I, are to be connected by the reversed curve in which T_1, R_1, and R_2 are known, and the tangent distance T_2 and the central angles of the two branches are required.

In triangle 1, the base T_1 and the angles are known, from which the sides l and m can be computed.

In triangle 2, thé hypotenuse is $R_1 - m$, and the angles are known whence the base p and the altitude n are determined.

In triangle 3, the base is $R_2 + p$, and the hypotenuse is $R_1 + R_2$, whence the angles a and b and the distance q can be found.

Then, $c = I + a$

and $T_2 = l + n + q$

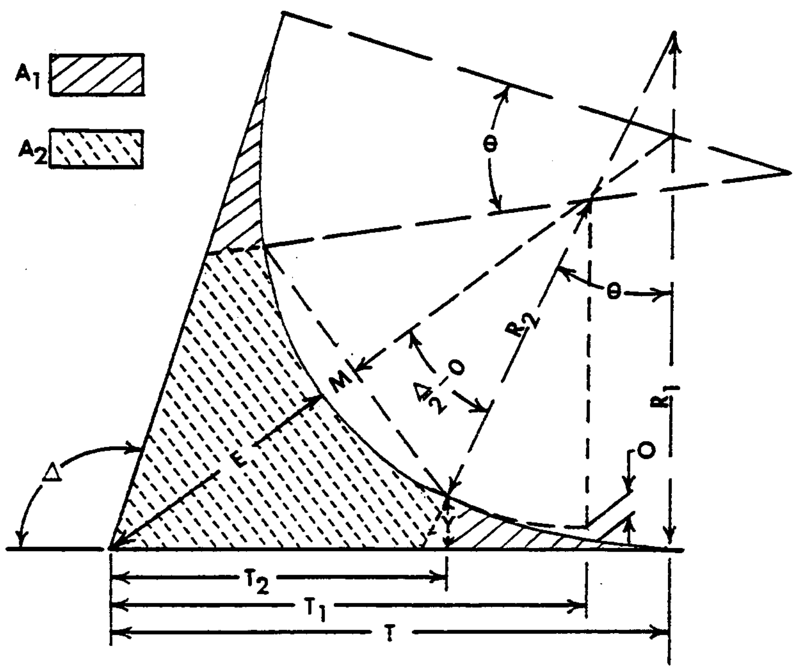
8.2.8 Short Radius Curve

SHORT RADIUS TURNS

FORMULAS FOR THREE-CENTERED CURVES

GIVEN: Δ, 0, R_1 and R_2

TO FIND: T, T_1, T_2, E, M, θ, Y and Area external to compound curve



$$T_1 = (R_2 + 0)\tan\frac{\Delta}{2}$$

$$E = \frac{R_2 + 0}{\cos\frac{\Delta}{2}} - R_2$$

$$T = T_1 + (R_1 - R_2)\sin\theta$$

$$M = R_2 - \left[R_2\cos\left(\frac{\Delta}{2} - \theta\right)\right]$$

$$T_2 = T_1 - R_2\sin\theta$$

$$\theta = \cos^{-1}\left(\frac{R_1 - R_2 - 0}{R_1 - R_2}\right)$$

$$Y = (R_2 + 0) - R_2\cos\theta$$

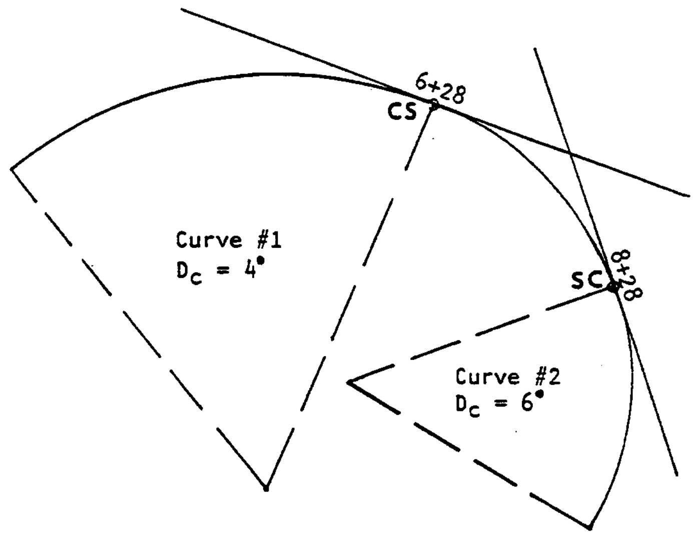
$$\text{Area} = A_1 + A_2$$

$$A = (R_1)^2\tan\theta - \frac{\pi(R_1)^2\theta}{180}$$

$$A_2 = (R_2 + 0)\left[T_1 - (R_2 + 0)\tan\theta\right] - \frac{\pi(R_2)^2(\Delta/2 - \theta)}{180}$$

8.2.9 Deflections for Spiral Transition Between Simple Curves

DEFLECTIONS FOR SPIRAL TRANSITION
BETWEEN SIMPLE CURVES



L_s = Length of Spiral in Stations

ℓ = Distance from C.S. in Stations

D_{c1} = Degree of Curve of Curve #1

D_{c2} = Degree of Curve of Curve #2

d = Deflection of l in degrees

GIVEN: Curve #1 $D_c = 4°$
Curve #2 $D_c = 6°$
C.S. Station = 6+28.00
L_s = 200 feet

$$d = \frac{D_{c2} - D_{c1}}{6L_s}\ell^2 + \frac{D_{c1}}{2}\ell$$

Deflection for Station 6+50.00 ℓ = .22 Sta.

$$d = \frac{4-6}{6(2)}(.22)^2 + \frac{4}{2}(.22) = \left(\frac{-2}{12}\right)(.0484) + (2)\ .22$$

$$= 0°25'55''$$

for Station 7+00

$$d = -.16667\ (.72)^2 + 2(.72) = 1°21'13''$$

for Station 7+50

$$d = -.16667(1.22)^2 + 2(1.22) = 2°11'31''$$

for Station 8+00

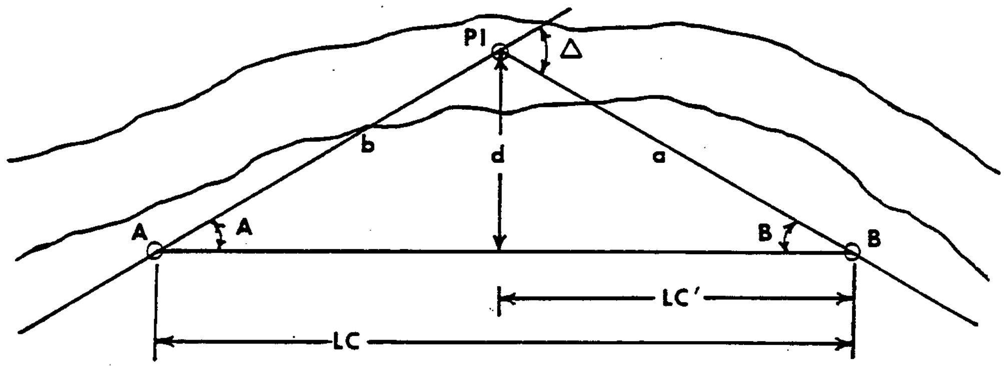
$$d = -.16667(1.72)^2 + 2(1.72) = 2°56'49''$$

for Station 8+28

$$d = -.16667(2.00)^2 + 2(2) = 3°20'00''$$

8.2.10 Inaccessible PI Procedure

INACCESSIBLE P.I. PROCEDURE



1.) Establish Point A at a convenient location on the back tangent.

2.) Establish the ahead tangent and set Point B at a convenient location.

3.) Station Point A.

4.) Measure angles A and B and distance AB.

COMPUTATIONS

$$\angle A + \angle B = \Delta$$

$$b = LC \frac{\sin B}{\sin(180 - \Delta)} \qquad a = LC \frac{\sin A}{\sin(180 - \Delta)}$$

PI Sta. = A Sta. + b/100

To Locate External of Curve

$$d = \frac{a \sin B}{\sin 180 - \left(\frac{180 - \Delta}{2} + B\right)}$$

$$LC' = \frac{a \sin \frac{(180 - \Delta)}{2}}{\sin\left[180 - \frac{(180 - \Delta)}{2} + B\right]}$$

8.2.11 Alignment & Curve Abbreviations & Symbols

ALIGNMENT & CURVE
ABBREVIATIONS & SYMBOLS

C.S.	Point of change from circular curve to spiral.
d	(For Simple and Spiral Curves) Deflection angle. Intersection angle formed by a tangent and a chord. (For Vertical Curves) The tangent offset from the grade line to a point on the curve. (For Inaccessible P.I. Procedure) Distance from the midpoint of the long chord to the P.I.
Dc	Degree of circular curve.
Es	External distance, P.I. to center of circular curve.
K	Distance from T.S. to point tangent opposite the P.C. of the circular curve produced.
I	Length between T.S. and S.T. and any other point on the spiral.
L.C.	Straight line chord distance between T.S. & S.C. (long chord).
Ls	Length of spiral between T.S. & S.C.
L.T.	Long tangent distance of spiral only
P	Offset distance from the tangent of P.C. of circular curve produced.
P.C.	Point of change from tangent to circular curve.
P.C.C.	Point of compound curve.
P.I.	Point of intersection of the main tangents.
P.O.C	Point on a circular curve.
P.O.S.	Point on a spiral curve
P.O.S.T.	Point on a semi-tangent.
P.O.T.	Point on a tangent
P.R.C.	Point on reverse curve.
P.T.	Point of change from circular curve to tangent.
S.C.	Point of change from spiral to circular curve.

ALIGNMENT & CURVE
ABBREVIATIONS & SYMBOLS

S.C.S.	Point of change from on spiral curve to the next spiral cure.
S.T.	Point of change from spiral to tangent.
T_s	Tangent distance from P.I. to T.S. or S.T.
T.S.	Point of change from tangent to spiral.
X_c, Y_c	Coordinate of S.C. from T.S. or C.S. from S.T.
$\measuredangle$	Angle.
$\llcorner$	Right Angle.
Δ	Intersection angle between tangents of entire curve.
Δ_c	Intersection angle between tangents at the S.C. and at the C.S. or the central angle of circular curve portion of the curve.
θ	Intersection angle between tangents of complete curve and tangent at any other point on the spiral.
θ_s	Intersection angle between tangents of complete curve and tangent at the S.C.
ϕ_c	Deflection angle from tangent at T.S. to S.C.

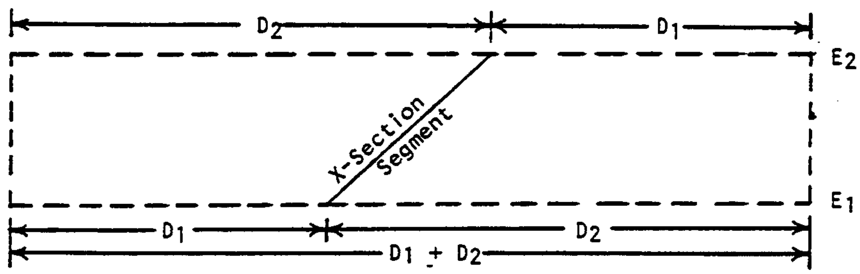
8.2.12 Area Calculations of Earthwork by Double Meridian Distance

AREA CALCULATIONS OF EARTHWORK

BY DOUBLE MERIDIAN DISTANCE

METHOD #1

The D.M.D. method is based on the accumulated area of many trapezoids.



$$A\ \text{Segment} = \tfrac{1}{2}(b_1 + b_2)h$$

where $H = E_2 - E_1$, $b_1 = D_1$, $b_2 = D_2$

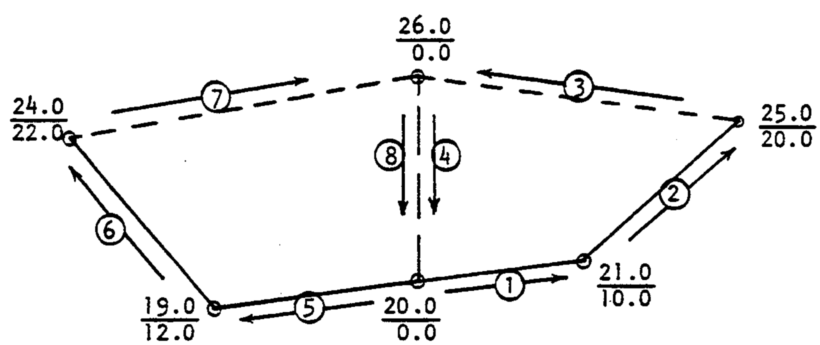
$$A = \frac{(D_1 + D_2)(E_2 - E_1)}{2}$$

$$\text{Total Area} = \frac{\sum \left[(D_1 + D_2)(E_2 - E_1)\right]}{2}$$

$$2A = \sum \left[(D_1 + D_2)(E_2 - E_1)\right]$$

D.M.D. Example

METHOD #1



$$2A = (E_2 - E_1)(D_2 + D_1) = \overset{(1)}{(21 - 20)(10 + 0)} + \overset{(2)}{(25 - 21)(20 + 10)}$$

$$+ \overset{(3)}{(26 - 25)(0 + 20)} + \overset{(4)}{(20 - 26)(0 + \ )} + \overset{(5)}{(19 - 20)(12 + 0)} +$$

$$\overset{(6)}{(24 - 19)(22 + 12)} + \overset{(7)}{(26 - 24)(0 + 22)} + \overset{(8)}{(20 - 26)(0 + 0)}$$

$$2A = 10 + 120 + 20 + 0 + (-12) + 170 + 44 + 0$$

$$2A = 352$$

$$A = 352/2 = 176 \text{ Sq.Ft.}$$

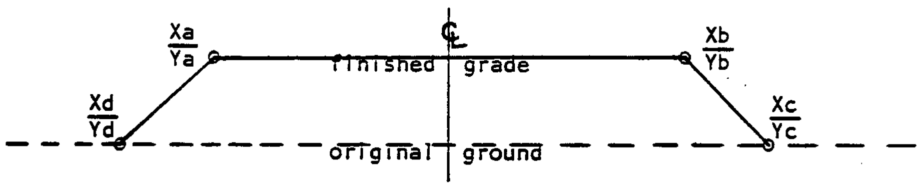
AREA CALCULATIONS OF EARTHWORK

BY DOUBLE MERIDIAN DISTANCE

METHOD #2

Cross multiplication is another method of calculating areas of earthwork by Double Meridian Distance. The following formula is for the basic section shown below.

$$\tfrac{1}{2}\Big[(X_a)(Y_b) + (X_b)(Y_c) + (X_c)(-Y_d) + (X_d)(-Y_a) - (X_a)(-Y_d) - (X_d)(Y_c) - (X_c)(Y_b) - (X_b)(-Y_a)\Big]$$



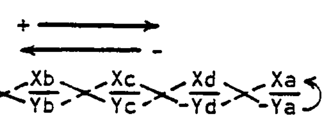
where x = ground elevation
y = distance right or left of centerline

Distances left of centerline are shown as negative and distances right of centerline are shown as positive.

Cut sections are done in the same manner as fill sections. Where cuts and fills appear in the same section, they must be calculated separately.

For cross multiplication, the elevations and distances should be arranged in the form of fractions, beginning with any corner, proceeding clockwise around the entire area and repeating the initial fraction to give a closed boundary.

Thus we have



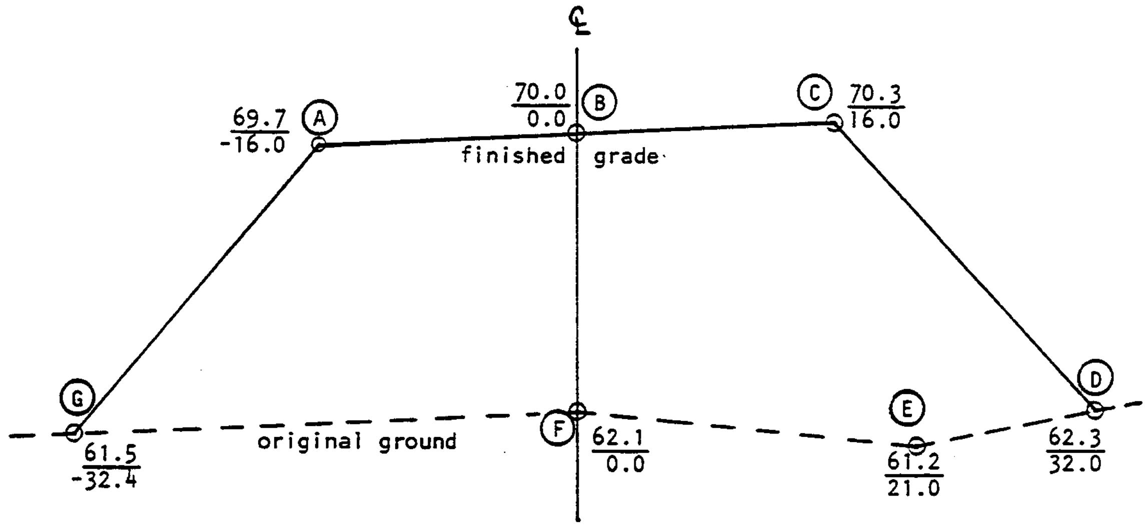
Multiply along the solid diagonals, adding the products; multiply along the dashed diagonals, subtracting the products. The end result is a double area and must be divided by 2 to get the desired area of section (sq.ft.).

Careful attention must be paid to algebraic signs, since both sets of products contain positive and negative quantities.

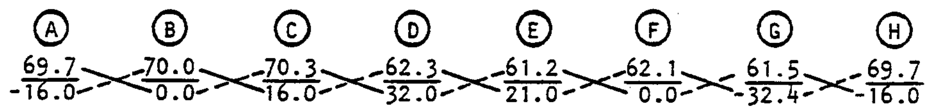
Once the method is fully understood, the areas can be quickly computed from the fraction tabulation. This method is easily adaptable to machine computation. Fractions can be taken from plotted sections or directly off the Terrain Data Sheet (DOH Form 653).

D.M.D. Example

METHOD #2



For shot A: X = 69.7' (ground elevation)
Y = -16.0' (distance left from centerline)



½ [(69.7)(0.0) + (70.0)(16.0) + (70.3)(32.0) + (62.3)(21.0) + (61.2)(0.0)
+ (62.1)(-32.4) + (61.5)((-16.0) - (69.7)(-32.4) - (61.5)(0.0) - (62.1)(21.0)
- (61.2)(32.0) - (62.3)(16.0) - (70.3)(0.0) - (70.0)(-16.0)]

= ½ [0 + 1120.0 + 2249.6 + 1308.3 + 0 + (-2012.0) + (-984.0) - (-2258.3) -
0 - 1304.1 - 1958.4 - 996.8 - 0 - (-1120.0)]

= 400.4 Sq./Ft. or 400 Sq. Ft.

8.2.13 Earthwork Volume Calculations by Average End Area

EARTHWORK VOLUME CALCULATIONS

BY THE AVERAGE END AREA METHOD

$$V = \frac{A_1 + A_2}{2}(L)$$

$$V \text{ in Cu.Ft.} = \frac{(A_1 + A_2)}{2}(S_2 - S_1)100$$

$$V \text{ in Cu.Yd.} = \frac{(A_1 + A_2)}{2}(S_2 - S_1)\frac{100}{27}$$

$$= (A_1 + A_2)(S_2 - S_1)1.852$$

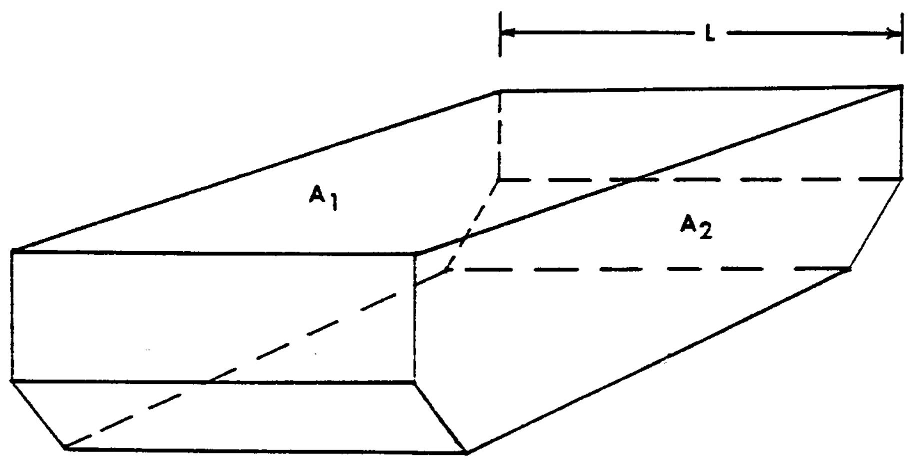
A_1 = Area of Section #1

A_2 = Area of Section #2

L = Distance from Section #1 in stations

S_1 = Station No. of Section #1 in stations

S_2 = Station No. of Section #2 in stations



EXAMPLE OF EARTHWORK CALCULATIONS

STATION	AREA Exc.	AREA Emb.	VOLUME Exc.	VOLUME Emb.
465+00	153	24		
			769	133
466+00	262	48		
			670	267
467+00	100	96		
			133	103
467+48	50	20		
			193	19
468+00	150	0		
			89	0
468+32	0	0		
		Totals	1854 Cu.Yds.	522 Cu.Yds.

$V = (A_1 + A_2)(S_2 - S_1)1.852$

Excavation computations:

(153 + 262)(466 - 465)1.852 = 769 Cu. Yds.

(262 + 100)(467 - 466)1.852 = 670 Cu. Yds.

(100 + 50)(467.48 - 467.00)1.852 = 133 Cu. Yds.

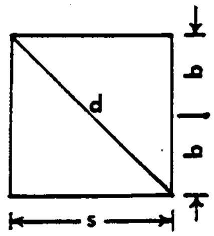
(50+150)(468.00 - 467.48)1.852 = 193 Cu. Yds.

(0 + 150)(468.32 - 468.00)1.852 = 89 Cu. Yds.

Work embankment in the same manner.

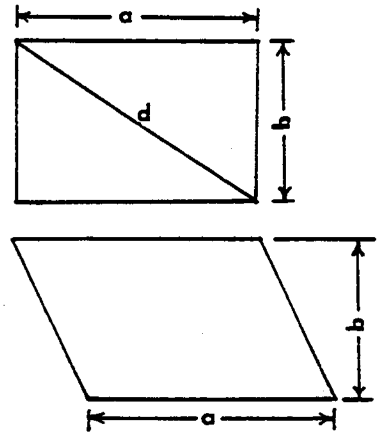
8.2.14 Area of Plane Figures

AREAS OF PLANE FIGURES



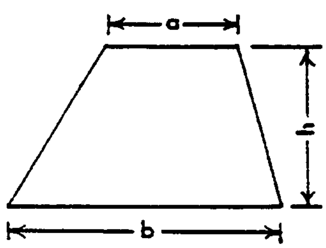
SQUARE

Diagonal = $d = s\sqrt{2}$
Area = $S^2 = 4b^2 = 0.5d^2$.
Example. $s = 6$; $b = 3$. Area = $(6)^2$
= 36 Ans.
$d = 6 \times 1.414 = 8.484$ Ans.



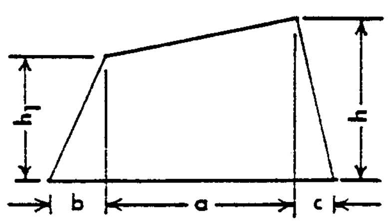
RECTANGLE AND PARALLELOGRAM

Area = ab or $b\sqrt{d^2 - b^2}$
Example. $a = 6$; $b = 3$.
Area = $3 \times 6 = 18$ Ans.



TRAPEZOID

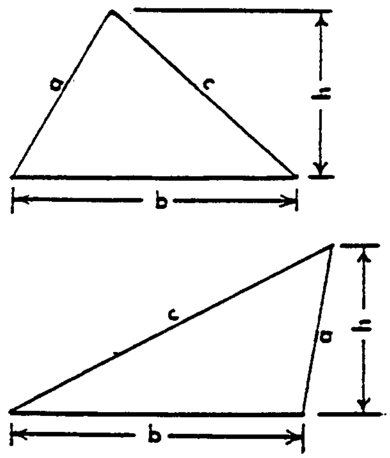
Area = $\frac{1}{2}h(a + b)$
Example, $a = 2$; $b = 4$; $h = 3$.
Area = $\frac{1}{2} \times 3(2 + 4) = 9$ Ans.



TRAPEZIUM

Area = $\frac{1}{2}[a(h + h_1) + bh_1 + ch]$.
Example. $a = 4$; $b = 2$; $c = 2$; $h = 3$;
$h_1 = 2$.
Area = $\frac{1}{2}[4(3 + 2) + (2 \times 2) + (2 \times 3)] =$
15 Ans.

AREAS OF PLANE FIGURES



TRIANGLES

Both formulas apply to both figures.

Area = $\frac{1}{2}bh$.

Example. $h = 3$; $b = 5$.

Area = $\frac{1}{2}(3 \times 5) = 7\frac{1}{2}$ Ans.

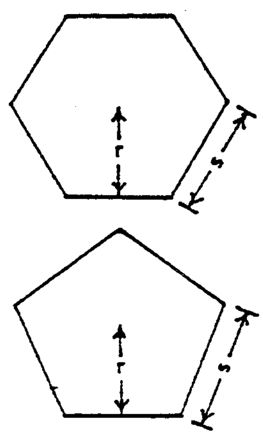
Area = $\sqrt{S(S - a)(S - b)(S - c)}$

when $S = \frac{a + b + c}{2}$

Example. $a = 2$; $b = 3$; $c = 4$.

$S = \frac{2 + 3 + 4}{2} = 4.5$

Area = $\sqrt{4.5(4.5 - 2)(4.5 - 3)(4.5 - 4)} =$ 2.9 Ans.



REGULAR POLYGONS

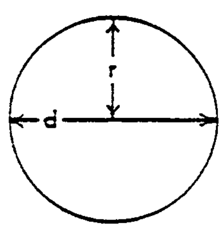
Area =

5 sides	$= 1.720477\ S^2 = 3.63271\ r^2$
6 sides	$= 2.598150\ S^2 = 3.46410\ r^2$
7 sides	$= 3.633875\ S^2 = 3.37101\ r^2$
8 sides	$= 4.828427\ S^2 = 3.31368\ r^2$
9 sides	$= 6.181875\ S^2 = 3.27573\ r^2$
10 sides	$= 7.694250\ S^2 = 3.24920\ r^2$
11 sides	$= 9.365675\ S^2 = 3.22993\ r^2$
12 sides	$= 11.196300\ S^2 = 3.21539\ r^2$

n = number of sides; r = short radius;
S = length of side; R = long radius.

$$\text{Area} = \frac{n}{4} S^2 \cot\frac{180^\circ}{n} = \frac{n}{2} R^2 \sin\frac{360^\circ}{n}$$

$$= nr^2 \tan\frac{180^\circ}{n}$$



CIRCLES

$\pi = 3.1416$; A = area; d = diameter;
p = circumference or periphery; r = radius.

$p = \pi d = 3.1416d$. $p = 2\sqrt{\pi A} = 3.54\sqrt{A}$

$p = 2\pi r = 6.2832r$.

$d = \frac{p}{\pi} = \frac{p}{3.1416}$

$r = \frac{p}{2\pi} = \frac{p}{6.2832}$

$A = \frac{\pi d^2}{4} = 0.7854d^2$

$A = \pi r^2 = 3.1416r^2$

$p = \frac{2A}{r} = \frac{4A}{d}$

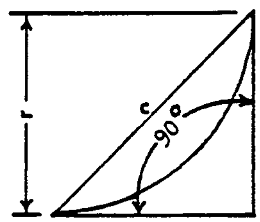
$d = 2\sqrt{\frac{A}{\pi}} = 1.128\sqrt{A}$

$r = \sqrt{\frac{A}{\pi}} = 0.564\sqrt{A}$

$A = \frac{p^2}{4\pi} = \frac{p^2}{12.57}$

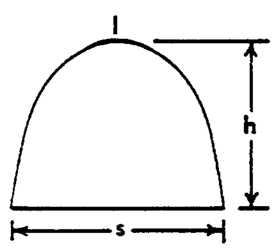
$A = \frac{pr}{2} = \frac{pd}{4}$

AREAS OF PLANE FIGURES



SPANDREL

Area = $0.2146r^2 = 0.1073c^2$
Example. $r = 3.$
Area = $0.2146 \times 3^2 = 1.9314$ Ans.



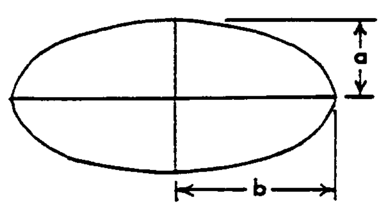
PARABOLA

l = length of curved line = periphery - s

$$l = \frac{s^2}{8h}\left[\sqrt{c(1+c)} + 2.0326 \times \log\left(\sqrt{c} + \sqrt{1+c}\right)\right]$$

in which $c = \left(\frac{4h}{s}\right)^2$

Area = $\frac{2}{3}sh$
Example. $s = 3;\ h = 4.$
Area = $\frac{2}{3} \times 3 \times 4 = 8$ Ans.



ELLIPSE

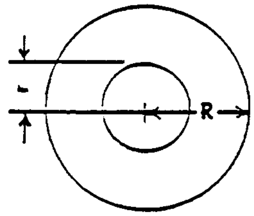
Area = $\pi ab = 3.1416ab.$

Circum. = $2\pi\sqrt{\frac{a^2 + b^2}{2}}$ (close approximation)

Example. $a = 3;\ b = 4.$
Area = $3.1416 \times 3 \times 4 = 37.6992$ Ans.

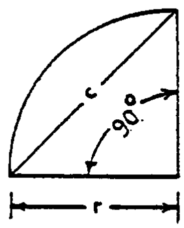
Circum. = $2 \times 3.1416\sqrt{\frac{(3)^2 + (4)^2}{2}}$
$= 6.2832 \times 3.5355 = 22.21$ Ans.

AREAS OF PLANE FIGURES



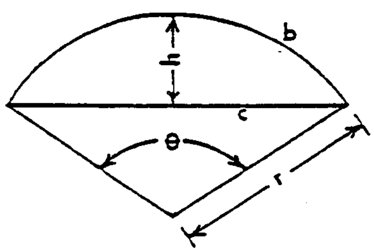
CIRCULAR RING

Area = $\pi(R^2 - r^2) = 3.1416(R^2 - r^2)$
Area = $0.7854(D^2 - d^2) = 0.7854(D - d)(D + d)$
Area = difference in areas between the inner and outer circles.
Example. $R = 4$; $r = 2$.
Area = $3.1416(4^2 - 2^2) = 37.6992$ Ans.



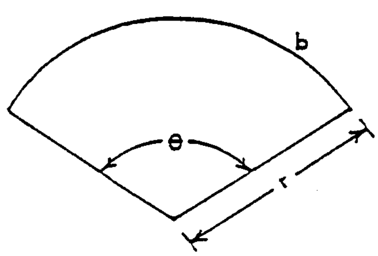
QUADRANT

Area = $\frac{\pi r^2}{4} = 0.7854r^2 = 0.3927c^2$
Example. $r = 3$; c = chord.
Area = $.7854 \times 3^2 = 7.0686$ Ans.



SEGMENT

b = length of arc. θ = angle in degrees
c = chord = $\sqrt{4(2hr - h^2)}$
Area = $\frac{1}{2}[br - c(r - h)]$
$= \pi r^2 \frac{\theta}{360} - \frac{c(r - h)}{2}$
When θ is greater than 180° then $\frac{c}{2} \times$ difference between r and h is added to the fraction $\frac{\pi r^2 \theta}{360}$
Example. $r = 3$; $\theta = 120°$; $h = 1.5$
Area = $3.1416 \times 3^2 \times \frac{120}{360} - \frac{5.196(3 - 1.5)}{2}$
$= 5.5278$ Ans.



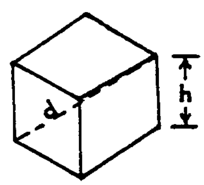
SECTOR

Area = $\frac{br}{2} = \pi r^2 \frac{\theta}{360°}$
θ = angle in degrees; b = length of arc.
Example. $r = 3$; $\theta = 120°$
Area = $3.1416 \times 3^2 \times \frac{120}{360} = 9.4248$ Ans.

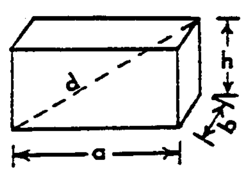
8.2.15 Volume and Surface Areas of Solids

VOLUME AND SURFACE AREAS OF SOLIDS

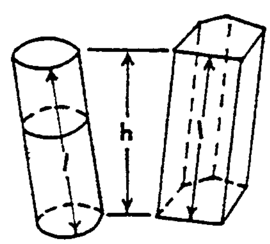
V = Volume
S = Lateral Surface Area
T = Total Surface Area
B = Area of Base
P = Perimeter Perpendicular to Sides
P_b = Perimeter of Base
A = Area of Section Perpendicular to Sides
l = Lateral Length
h = Perpendicular Height
d = Diagonal Length



$V = h^3$
$T = 6h^2$
$S = 4h^2$
$d = h\sqrt{3}$



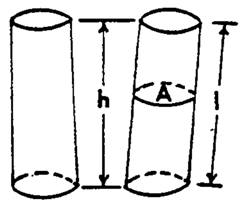
$V = abh$
$T = 2(ab + ah + bh)$
$S = 2(ah + bh)$
$d = \sqrt{a^2 + b^2 + h^2}$



$V = Al$
$S = Pl$
$T = Pl + 2B$
(Note $A = B$, $P = P_b$ and $l = h$ for right cylinders and prisms)

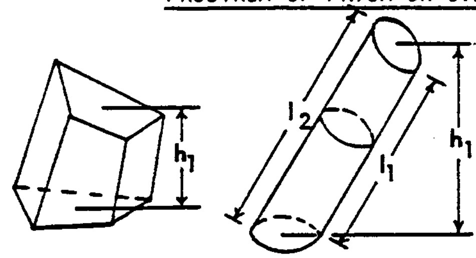
VOLUME AND SURFACE AREAS OF SOLIDS

CYLINDER, RIGHT OR OBLIQUE, CIRCULAR OR OTHERWISE, PARALLEL ENDS



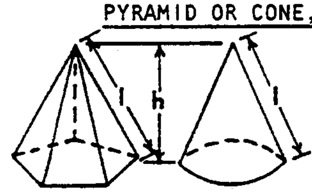
$V = Bh$ (Right Cylinder)
$V = Al$ (Oblique Cylinder)
$S = P_b h$ (Right Cylinder)
$S = Pl$ (Oblique Cylinder)
$T = P_b h + 2B$ (Right Cylinder)
$T = Pl + 2B$ (Oblique Cylinder)

FRUSTRUM OF PRISM OR CYLINDER



$V = Bh_1$ (where h_1 is perpendicular height from base to c.g. of top)
or, for cylinder
$V = \frac{A}{2}(l_1 + l_2)$

PYRAMID OR CONE, RIGHT AND REGULAR

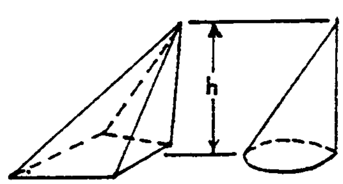


$V = \frac{Bh}{3}$

$S = \frac{P_b l}{2}$

$T = \frac{P_b l}{2} + B$

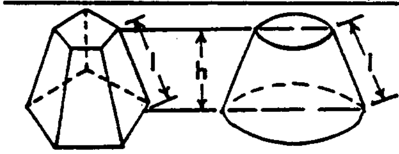
PYRAMID OR CONE, RIGHT OR OBLIQUE, REGULAR OR IRREGULAR



$V = \frac{Bh}{3}$

VOLUME AND SURFACE AREAS OF SOLIDS

FRUSTRUM OF PYRAMID OR CONE, RIGHT AND REGULAR, PARALLEL ENDS



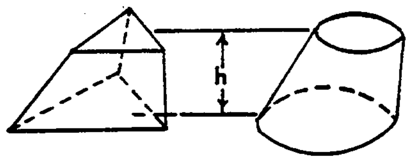
$$V = \frac{h}{3}\left(B + B_1 + \sqrt{BB_1}\right)$$

$$S = \frac{1}{2}\left(P_b + P_T\right)$$

$$T = \frac{1}{2}\left(P_b + P_T\right) + B + B_1$$

where : B_1 = Area of Top
P_T = Perimeter of Top

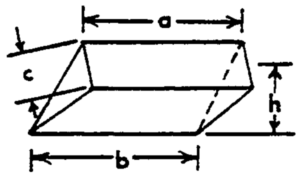
FRUSTRUM OF ANY PYRAMID OR CONE, PARALLEL ENDS



$$V = \frac{h}{3}\left(B + B_1 + \sqrt{BB_1}\right)$$

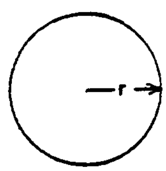
where: B_1 = Area of Top

WEDGE, REGULAR



$$V = \frac{ch}{6}\left(2a + b\right)$$

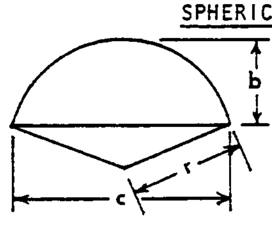
SPHERE



$$V = \frac{4\pi r^3}{3}$$

$$S = 4\pi r^2$$

SPHERICAL SECTOR

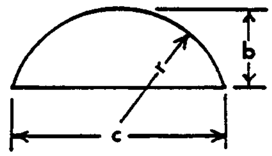


$$S = \tfrac{1}{2}\pi r(4b + c)$$

$$V = \frac{2}{3}\pi r^2 b$$

VOLUME AND SURFACE AREAS OF SOLIDS

SPHERICAL SEGMENT

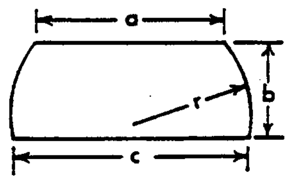


$$S = 2\pi rb = \tfrac{1}{4}\ (4b^2 + c)$$

$$V = \frac{1}{3}\pi b^2(3r - b)$$

$$= \frac{1}{24}\pi b(3c^2 + 4b^2)$$

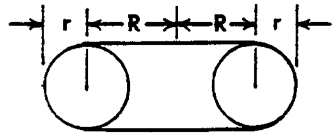
SPHERICAL ZONE



$$S = 2\pi rb$$

$$V = \frac{1}{24}\pi b(3a^2 + 3c^2 + 4b^2)$$

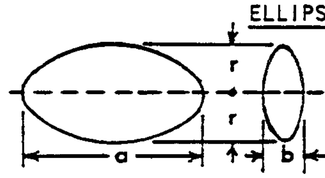
CIRCULAR RING



$$S = 4\pi^2 Rr$$

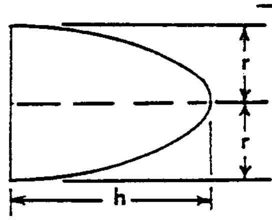
$$V = 2\pi^2 Rr^2$$

ELLIPSOID



$$V = \frac{1}{3}\pi\ rab$$

PARABOLOID



$$V = \tfrac{1}{2}\pi r^2 h$$

8.2.16 Abbreviations

A	A
ABC	aggregate base course
Abn	abandon
Abut	abutment
Adj	adjusted
AC	asphalt cement
Ah	ahead
AHW	allowable headwater
Alt	alternate
Approx	approximate
Asph	asphalt
Assy	assembly
Att	attenuator
Ave	avenue
Avg	average
@	at
B	B
BCR	begin curb return
Beg	begin
Bit Ctd	bituminous coated
Bit SL	bituminous seal
Bit Surf	bituminous surfacing
Bk	back
Bkf	backfill
BL	base line
Bldg	building
Blvd	boulevard
BM	bench mark
Bot	bottom
Br	bridge
BS	backsight
BT	beginning of transition
BW	barbed wire
C	C
C	cut
CAA	cable anchor assembly
Calc	calculated
CAP	corrugated aluminum pipe
CBC	concrete box culvert
CCS	Colorado Coordinate System
CDOH	Colorado Department of Highways
CF or Cu.Ft	cubic feet (foot)
C & G	curb and gutter
Chnl	channel

Cl	class
CL	chain link
∞	Chainman
C_L	centerline or control line
Clr	clear, clearance
Co	county
Conc	concrete
Cond	conduit
Conn	connector
Const	construction
Cont	continued
Coord	coordinate
CPS	concrete pipe sewer
Cr	creek
CSP	corrugated steel pipe
CSPA	corrugated steel pipe arch
CSPS	corrugated steel pipe sewer
CTB	cement treated base
Culv	culvert
CY or Cu.Yd.	cubic yard(s)

<u>D</u>	<u>D</u>
Dbl	double
Def	deflection
Deg	degree
Del	delineator
Det	detour
DHW	design headwater
Dl	drop inlet
Dia or θ	diameter
Dim	dimension
Dist	distance or district
Dr	drive
Dwy	driveway

<u>E</u>	<u>E</u>
E	east
Ea	each
Easmt	easement
ECR	end curb return
EDM	electronic distance meter
Elev	elevation
Emb	embankment
EO	edge of oil
EP	edge of pavement
Eq	equation
ES	edge of shoulder
ET	end of transition
ETW	edge of traveled way

Exc	excavation
Exist	existing
F	F
F	fill
Fdn	foundation
Fe	fence
FH	fire hydrant
Flr	flare
FL or F_L	low line
FP	fence post
FR	frontage road
FS	foresight
Ft	foot (feet)
Ftg	footing
Fwy	freeway
F & C	frame and cover
F & G	frame and grate
FG	finish grade
G	G
G	gutter
Ga	gauge, gage
Galv	galvanized
GL	gas line
GM	guard marker
GR	guard rail
GSP	galvanized steel pipe
GV	gas valve
H	H
H	height
HBP	hot bituminous pavement
Hdwl	headwall
Hl	height of instrument
Horiz	horizontal
HP	hinge point
Hwy	highway
H & T	hub and tack
I	I
IB	imported borrow
In	inch
Inst. Or	instrument or instrument man
Int	intersection
Intch	interchange
Inv	invert

Irr	irrigation
J	J
K	K
L	L
Ln	lane
L	length
LF or Lin.Ft.	linear feet (foot)
Loc	location
Lt	left
M	M
Matl	material
Max	maximum
MB	mail box
MDS	maximum design speed
Med	median
MES	metal end section
MH	manhole
Mi	mile(s)
Min	minimum
Misc	miscellaneous
Mkr	marker
Mod	modified or modify
Mon	monument
MP	mile post(s)
MPH	miles per hour
MS	minor structure
N	N
N	north
NGS	National Geodetic Survey
No. or #	number
✆	note keeper
O	O
Oblr	obliterate
OG	original ground
OH	overhead
O/S	offset
P	P
P	page
PB	pull box

PC	party chief
PCSP	perforated corrugated steel pipe
P & Abn	plug and abandon
Ped	pedestrian
PGL	profile grade line
PK Nail	Parker-Kalon nail
PL	property line
PMBB	plant mix bituminous base
PP	power pole
Proj.	projected, project
PSP	perforated steel pipe
PSS	point of slope selection
Pt	point
Pvmt	pavement
PVPP	polyvinyl plastic pipe
Q	Q
Q	volumetric flow rate
R	R
R	radius
RCP	reinforced concrete pipe
RCPA	reinforced concrete pipe arch
RD	road
Rdwy	roadway
RE	Resident Engineer
Reinf	reinforced
Rel	relocate
Riv	river
ROW	right of way
RP	radius point or reference point
RR	railroad
Rt	right
Rte	route
RW	retaining wall
ϕ	rod man
S	S
S	south
Salv	salvage
San.Swr.	sanitary sewer
SB Fe	sound barrier fence
SD	storm drain
Sec	section
SES	steel end section
SF or Sq. Ft.	square foot (feet)
SG	sub grade

Shld	shoulder
Sht	sheet
S_L	survey line
Sl Coat	seal coat
Spec	special, specification
Sp	spillway
SS	slope stake
Sta	station
Std	standard
St	street
Stm Swr	storm sewer
Str	structure
Surf	surfacing
SW	sidewalk
Swr	sewer
SY or Sq. Yd.	Square yard(s)

T	T
Tan	tangent
Tbr	timber
TCB	traffic control box
Temp	temporary
TP	turning point
Trans	transition
Trav	traverse
TT	transmission tower
TY	type
Typ	typical
Typ.Sec.	typical section

U	U
UD	under drain
USGS	United States Geological Survey

V	V
V	valve
Var	variable
VC	vertical curve
VCP	vitrified clay pipe
Vel	velocity
Vert	vertical
VP	vent pipe

W	W
W	West
WH	weep hole

WL	work line
WM	wire mesh
WSP	welded steel pipe
WV	wing wall

<u>X</u> <u>X</u>

Xing	crossing
X-Sec	cross section

<u>Y</u> <u>Y</u>

<u>Z</u> <u>Z</u>

8.2.17 Weights, Measures & Equivalents

WEIGHTS, MEASURES & EQUIVALENTS

Acre=	43560 square feet 4840 square yards 160 square yards 4047 square meters .4047 hectares 10 square chains
Acre Foot=	43560 cubic feet 325,829 gallons
Acre=	100 square meters
Barrel of Cement=	376 pounds
Celsius=	(C x 9/5) +32 Fahrenheit ^{o}C + 273.18 Kelvin
Centimeter=	.03937 inches .01 meters
Centimeter of Mercury=	.1934 pound/square inch
Chain= (surveyor's)	792 inches 20.12 meters 66 feet 4 rods 22 yards 100 links
Circumference of Circle=	$2 \pi R$
Cubic Centimeter=	3.531×10^{-5} .06102 cubic inches $1 \text{ X } 10^{-6}$ cubic meters 2.642×10^{-4} gallons
Cubic Foot=	28,320 cubic centimeters 1728 cubic inches .02832 cubic meters .03704 cubic yards 7.48052 gallons 62.4 pounds of water
Cubic Foot/Second=	0.646317 million gallons/day .0005787 cubic feet

Cubic Meter=	1×10^6 cubic centimeters 35.31 cubic feet 1.308 cubic yards 264.2 gallons
Cubic Yard=	27 cubic feet 0.7646 cubic meters 202 gallons 46,656 cubic inches
Degree=	.0174533 radians 60 minutes 3600 seconds
Fahrenheit (degree)=	(F –32) 5/9 Celsius (F –32) 5/9 + 273.18 Kelvin
Foot (U.S. Survey)=	1200/3937= 0.30480061 meters 304.80061 millimeters 30.480061 centimeters
Foot (International)=	0.3048 meters 3048 millimeters 30.48 centimeters
Foot of Water=	43.35 pounds/square inch
Foot/Second=	.06818 miles/hour 1.097 kilometers/hour
Gallon=	3,785 cubic centimeters .1337 cubic feet 231 cubic inches 3.785 liters 8.337 pounds of water
Gallon/Minute=	.002228 cubic feet/second
Gram=	.002205 pounds .001 kilograms .03527 ounces
Hectare=	2.471 acres 100 acres 10,000 square meters
Inch=	2.54 centimeters .08333 feet

Inch of Mercury=	.4912 pounds/square inch
Kilogram=	2.2046 pounds 35.274 ounces
Kilometer=	1 x 10^3 meters 3281 feet
Link=	7.92 inches .66 feet 1/100 chain
Liter=	1 x 10^3 cubic centimeters .03531 cubic feet 61.02 cubic inches .2642 gallons
Meter=	100 centimeters 3.2808 feet 39.37 inches .001 kilometers .0006214 miles 1.094 yards
Mile=	5280 feet 63360 inches 1760 yards 1609 meters
Mile/Hour=	1.467 feet/second 1.6093 kilometers/hour
Mil=	.001 inches
Minute=	.01667 degrees 60 seconds
Ounce=	28.35 grams .0625 pounds
Ounce (fluid)=	1.805 cubic inches .02957 liters .0078 gallons
Pound=	453.59 grams .0005 tons 16 ounces
Pound of Water=	27.68 cubic inches .1198 gallons

Pound/Square Inch=	2.036 inches of mercury
Quart=	.25 gallons
	.9463 liters
Radian=	57.296 degrees
Rods=	5.5 yards
	16.5 feet
	.003125 miles
Seconds=	.0003778 degrees
	.01667 minutes
Square Centimeter=	.001076 square feet
	.155 square inches
	.0001 square meters
Square Feet=	.1111 square yards
	.0929 square meters
	144 square inches
Square Inch=	.006944 square feet
	6.452 square centimeters
Square Meter=	.0002471 acres
	10.76 square feet
	1.196 square yards
Square Mile=	640 acres
	2.59×10^6 square meters
Square Yard=	.0002066 acres
	9 square feet
	1296 square inches
	.8361 square meters
Ton=	2000 pounds
	907.18 kilograms
Yard=	3 feet
	.9144 meters
	36 inches
	.0005682 miles

8.2.18 Glossary

GLOSSARY

Alignment-	A formation of points, lines, angles, and curves showing the direction and components of the centerline.
Backsight-	The transit or level sight back on survey line. (Stationing decreases back.)
Bench Marks-	A semi-permanent or permanent physical mark or object of known elevation.
Blue Tops-	Grade stakes marked with blue keel, whiskers, or paint denoting top of sub grade.
Blunders-	An unpredictable human mistake.
Centerline or Control line-	The line midway between the sidelines of an alignment, to which the survey is tied.
Chain- (Engineers)	A steel tape, 100 feet in length. The last foot on each end of the tape is divided in tenths of foot. The last tenth is usually calibrated in hundredths of a foot.
Control Monuments (Primary)-	CDOT Type 2 monuments established on the ground as the framework for the Primary Control Survey Network. This includes the existing control monuments used as reference for the establishment of the primary control network, and is used to control all horizontal and vertical components of the survey.
Control Monuments (Secondary)-	Monuments established from the approved Primary Control Monuments. The secondary control monuments are typically established as survey work points in areas that require additional control be set at a lesser accuracy than that of the Primary Control Network.
Control Network (Primary)-	A network of Primary Control Monuments permanently monumented on the ground as the framework for the Primary Control Survey.
Control Points-	Points on an alignment which are necessary to re-establish the alignment.
Control Survey (Primary)-	The survey performed to obtain the final horizontal and vertical data for the Primary Control Monuments used to control all horizontal and vertical components of the survey and any future surveys in and along the highway corridor.
Corner, Lost-	When the original corner cannot be determined beyond reasonable doubt, it is a lost corner.

Corner, Meander-	A corner placed at the mean high water mark on a surveyed line, where the body of water is greater than 3 chains in width on the surveyed line.
Corner, Obliterated-	If the monument or marker of the existing corner can not be found, it is obliterated, but not necessarily lost.
Cross Sections-	Profiles at the right angle to the centerline or control line of a survey showing all breaks in grade of the ground line to truly reflect the ground situation.
Differential Leveling-	Used for setting bench marks by determining the differences of elevation between two points of which the first point's elevation is known. Theory and application is expressed as: Elev. A + B.S. = H.I. H.I. – F.S. =Elev. B
Electronic Distance Meter-	An instrument which uses microwaves, modulated light beams or laser light to measure distances.
Error-	The difference (after blunders have been eliminated) between a measured or calculated value of a quantity and the true or established value of the quantity.
Field Notes-	A permanent written or electronic record of the survey including all pertinent information, measurements, calculations and observations made during the course of the survey.
Foresight-	The transit or level sight ahead on survey line. Stationing increases ahead.
Guard-	A stake placed to protect a hub, marked with the information describing the point.
Hand Level-	A small hand instrument with a small bubble periscoped so that it shows in the field of view. The instrument is level when the reflected bubble is on the cross hair.
Height of instrument-	The known elevation of the instrument at the center of the telescope.
Hub-	A stake driven flush or even with the ground, denoting elevation and/or line.
Inverted Transit-	The transit with the telescope reversed and level bubble on top.
Level-	A precision instrument used to establish elevation. Consists of an adjustable telescope with horizontal and vertical cross hairs. A bubble and adjustable tangent screws level the instrument.
Level Rods-	Rod marked in feet, tenths of a foot and hundredths of a foot to be used in conjunction with the level in establishing elevations and stadia.

Normal Transit- Transit telescope in erect position, level bubble below. Sometimes referred to as direct.

0+00- Denotes the starting point or beginning of stationing. Any designation with 00 after it is a full, complete, or even station. Any designation after the + sign is a fraction of a station.

Plus Fifties- (Half Station) The fifty foot interval between stations.

Pole, Range- Also called range rod or picket. A metal or wood pole with a steel point, usually banded in alternate red and white sections, one foot wide. Usually six to eight feet long, range rods are used to give sight to the transit man.

Profile Leveling- Determining existing ground surface elevations along a definite line by means of a level and a direct reading rod. These elevations are then plotted to show a graphical representation of the intersection of a vertical surface. Usually a much larger vertical scale than horizontal scale is used to accentuate the differences of elevation.

Reference Monuments- When two or more monuments are established to accurately perpetuate the true monument they become reference monuments and are set as close as practicable to the true monument, and meet the same physical standards required to set the true monument. (See Witness Corner)

Reference Points- A point that gives information so that another point can be re-established.

Right of Way- Area of land required to construct a road.

Right of Way Monument- CDOT Type 1 monument established on the ground set to define the Departments land boundaries in the field.

Slope Stakes- Stakes set to mark the outside limits of the grading operation giving information as to the construction of the road.

Station- A full chain or steel tape distance of 100 feet. Locations along the alignment are designated as stations. New stationing is consecutively numbered from West to East and from South to North.

Super elevation- Adjusting the slope perpendicular to centerline for the purpose of counteracting centrifugal force.

Tangent- The straight line of a survey.

Tangent of a Curve- The distance from the P.I. to the P.C. and P.T. or T.S. and S.T.

Theodolite/ Transit- Precision instruments used for the establishment and location of lines upon the earth’s surface. They consist of an adjustable telescope with horizontal and vertical cross hairs, stadia hairs and vertical and horizontal vernier plates for determining the angular measurements. The term “transit” is limited to an instrument which has open verniers that must be read directly with the naked eye or with the aid of a hand held magnifier. Theodolites have closed, optical reading verniers.

Topography- A surveying process in which the positions with respect to the horizontal control line and description of the natural and artificial features of a given locality are obtained and recorded.

Turning Point- A point used between bench marks as a temporary turning elevation.

Vernier- A device used to obtain readings smaller than the smallest division on a scale.

Witness Monument- When only one reference monument is established to perpetuate the location of the true monument, it becomes a witness monument and is to be set within 660 feet, preferably in one of the surveyed lines leading to the true monument location. However, the witness monument can be set in any direction within a distance of 330 feet. (See Reference Corner)

8.2.19 Conversion Tables

CONVERSION TABLES

MINUTES		SECONDS		MINUTES		SECONDS	
0'	0°000000	0''	0°000000	30	0.500000	30	0.008333
1	016667	1	00278	31	516667	31	08611
2	033333	2	00556	32	533333	32	08889
3	050000	3	00833	33	550000	33	09167
4	066667	4	01111	34	566667	34	09444
5	083333	5	01389	35	583333	35	09722
6	100000	6	01667	36	600000	36	10000
7	116667	7	01944	37	616667	37	10278
8	133333	8	02222	38	633333	38	10556
9	150000	9	02500	39	650000	39	10833
10	0.166667	10	0.002778	40	0.666667	40	0.011111
11	183333	11	03056	41	683333	41	11389
12	200000	12	03333	42	700000	42	11667
13	216667	13	03611	43	716667	43	11944
14	233333	14	03889	44	733333	44	12222
15	250000	15	04167	45	750000	45	12500
16	266667	16	04444	46	766667	46	12778
17	283333	17	04722	47	783333	47	13056
18	300000	18	05000	48	800000	48	13333
19	316667	19	05278	49	816667	49	13611
20	0.333333	20	0.005556	50	0.833333	50	0.013889
21	350000	21	05833	51	850000	51	14167
22	366667	22	06111	52	866667	52	14444
23	383333	23	06389	53	883333	53	14722
24	400000	24	06667	54	900000	54	15000
25	416667	25	06944	55	916667	55	15278
26	433333	26	07222	56	933333	56	15556
27	450000	27	07500	57	950000	57	15833
28	466667	28	07778	58	966667	58	16111
29	483333	29	08056	59	983333	59	16389

8.2.20 Temperature Correction Table Chaining

TEMPERATURE CORRECTION TABLE

- CHAIN IS SHORT + CHAIN IS LONG

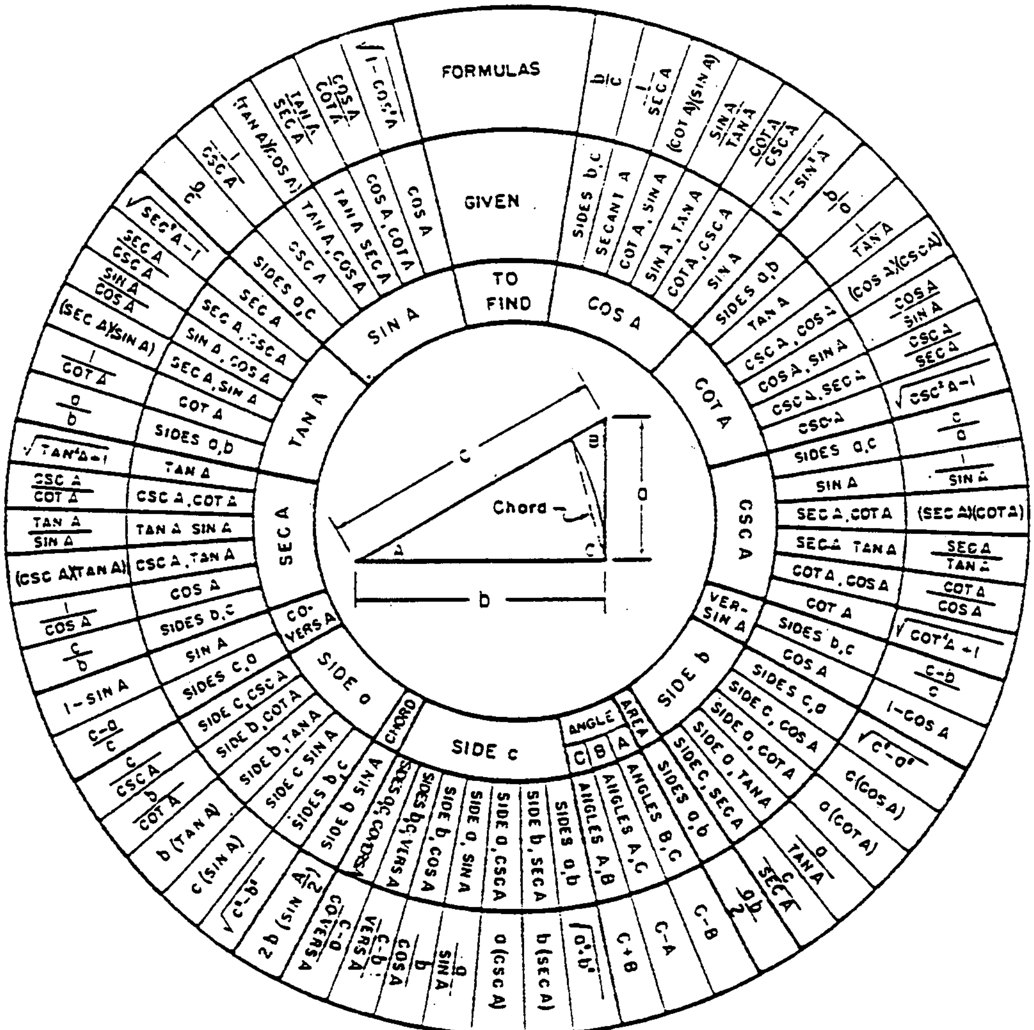
Temp.	Correction	Temp.	Correction	Temp.	Correction
-10	-.050	28	-.026	66	-.001
- 9	-.050	29	-.025	67	-.001
- 8	-.049	30	-.025	68	.000
- 7	-.048	31	-.024	69	+.001
- 6	-.048	32	-.023	70	+.001
- 5	-.047	33	-.023	71	+.002
- 4	-.046	34	-.022	72	+.003
- 3	-.046	35	-.021	73	+.003
- 2	-.045	36	-.021	74	+.004
- 1	-.045	37	-.020	75	+.005
0	-.044	38	-.019	76	+.005
1	-.043	39	-.019	77	+.006
2	-.043	40	-.018	78	+.006
3	-.042	41	-.017	79	+.007
4	-.042	42	-.017	80	+.008
5	-.041	43	-.016	81	+.008
6	-.040	44	-.015	82	+.009
7	-.039	45	-.015	83	+.010
8	-.039	46	-.014	84	+.010
9	-.038	47	-.014	85	+.011
10	-.037	48	-.013	86	+.012
11	-.037	49	-.012	87	+.012
12	-.036	50	-.012	88	+.013
13	-.036	51	-.011	89	+.014
14	-.035	52	-.010	90	+.014
15	-.034	53	-.010	91	+.015
16	-.034	54	-.009	92	+.015
17	-.033	55	-.008	93	+.016
18	-.032	56	-.008	94	+.017
19	-.032	57	-.007	95	+.017
20	-.031	58	-.006	96	+.018
21	-.030	59	-.006	97	+.019
22	-.030	60	-.005	98	+.019
23	-.029	61	-.005	99	+.020
24	-.028	62	-.004	100	+.021
25	-.028	63	-.003	101	+.021
26	-.027	64	-.003	102	+.022
27	-.026	65	-.002	103	+.023

Temperature Correction Normal 68 Degrees.

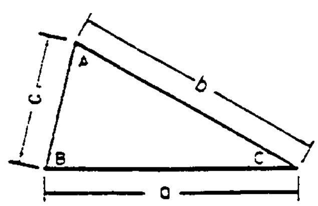
Tape Temperature Correction
for each Degree 0.000645 per 100 ft.

8.2.21 Trigonometric Formulas & Functions

TRIGONOMETRIC FORMULAS & FUNCTIONS



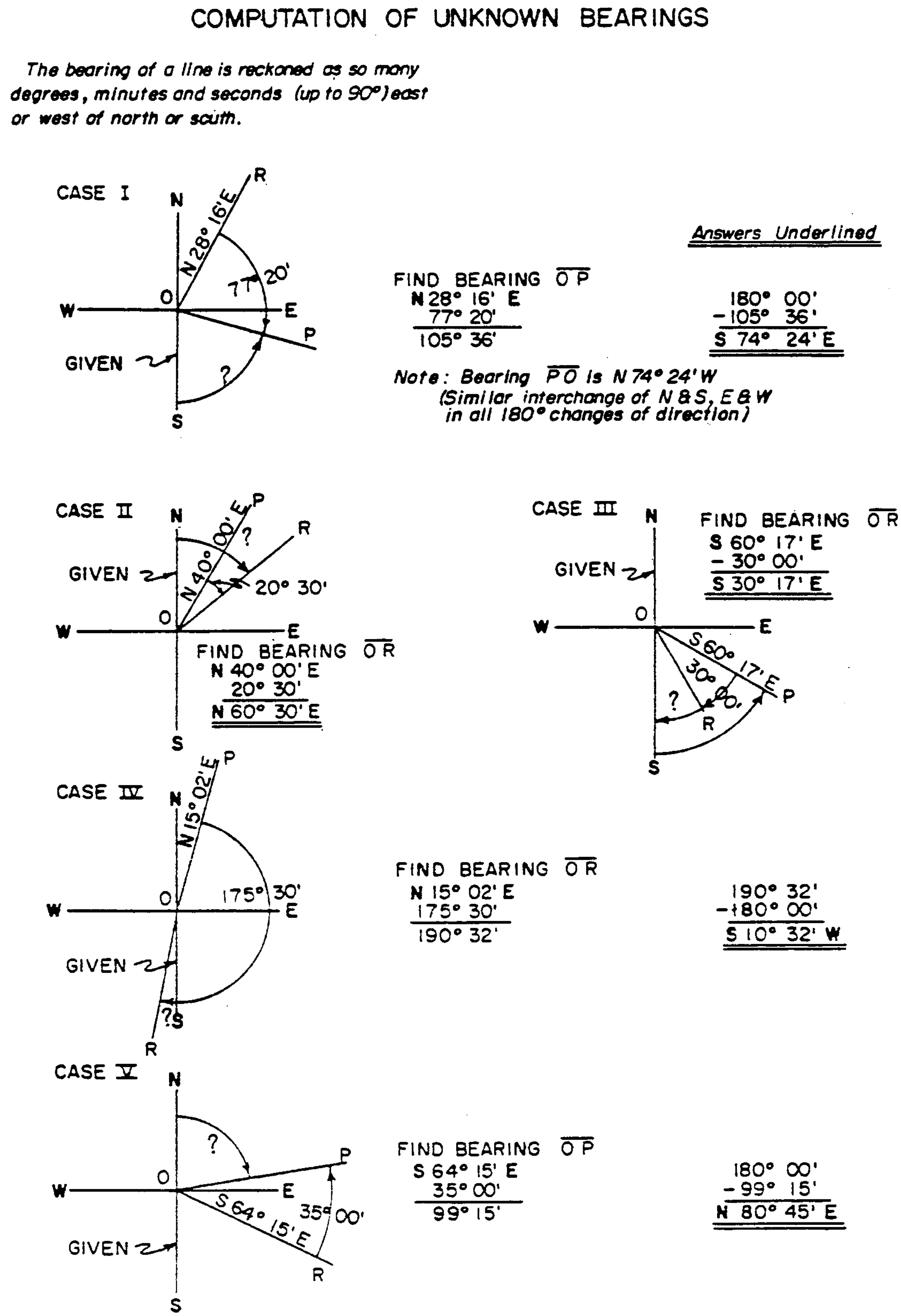
TO FIND	GIVEN	FORMULA
A	B, C	180°−(B+C)
TAN A	a,b,C	$\frac{a \sin C}{b-a \cos C}$
COS A	a,b,c	$\frac{b^2+c^2-a^2}{2bc}$
SIN A	a,c,C	$\frac{a \sin C}{c}$
SIN A	a,b,B	$\frac{a \sin B}{b}$
TAN A	a,c,B	$\frac{a \sin B}{c-(a \cos B)}$
B	A,C	180°−(A+C)
SIN B	a,b,A	$\frac{b \sin A}{a}$
COS B	a,b,c	$\frac{c^2+a^2-b^2}{2ac}$
TAN B	b,c,A	$\frac{b \sin A}{c-b \cos A}$
SIN B	b,c,C	$\frac{b \sin C}{c}$



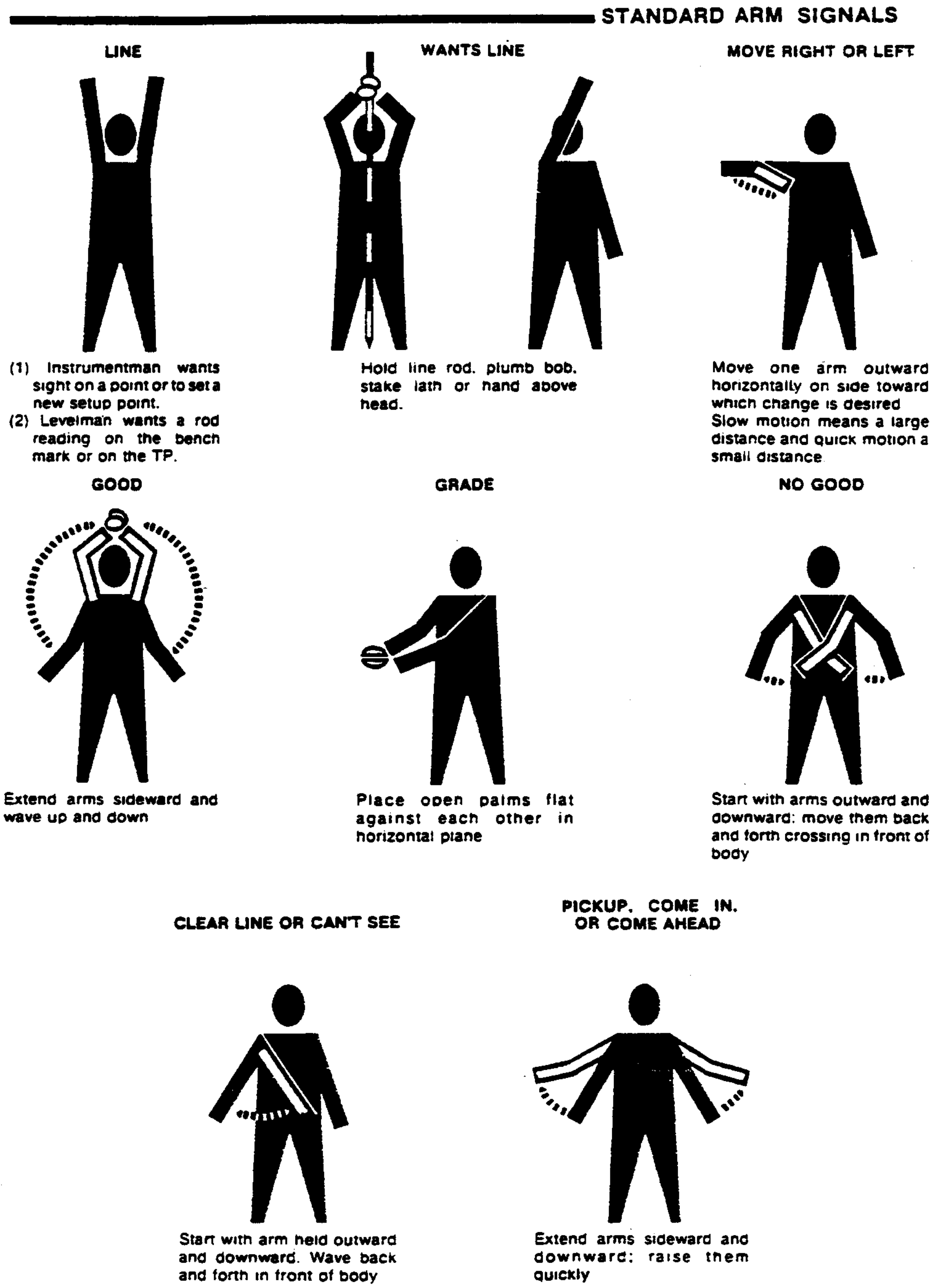
TO FIND	GIVEN	FORMULAS	FORMULAS	GIVEN	TO FIND
a	c,A,C	$\frac{c \sin A}{\sin C}$	$\frac{a \sin B}{\sin A}$	a,A,B	b
a	b,A,B	$\frac{b \sin A}{\sin B}$	$\frac{c \sin B}{\sin C}$	c,B,C	b
a	b,c,A	$\sqrt{b^2+c^2-2bc \cos A}$	$\sqrt{c^2+a^2-2ac \cos B}$	a,c,B	b

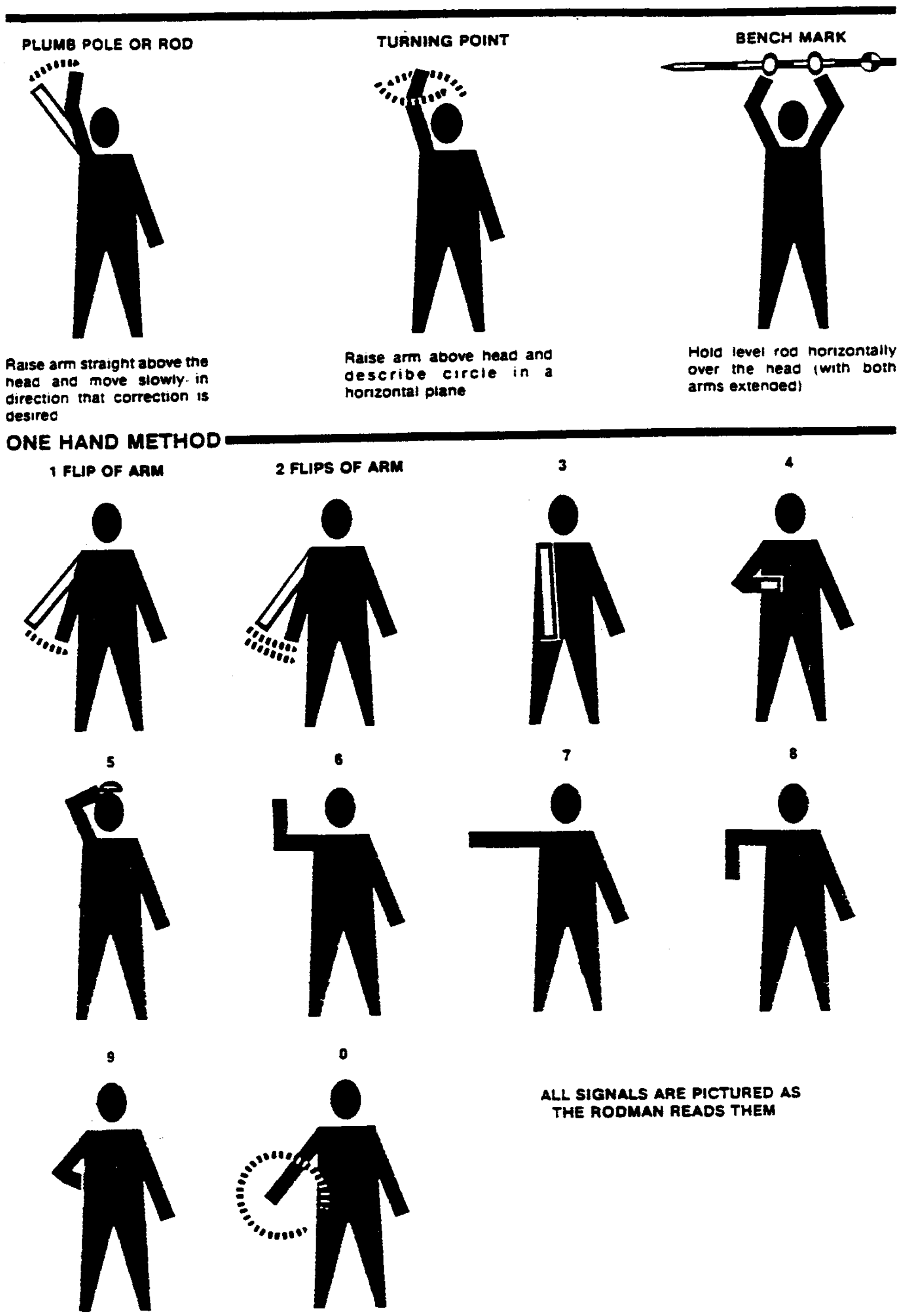
FORMULA	GIVEN	TO FIND
180°−(A+B)	A,B	C
$\frac{c \sin A}{a}$	a,c,A	SIN C
$\frac{c \sin A}{b-(c \cos A)}$	b,c,A	TAN C
$\frac{c \sin B}{b}$	b,c,B	SIN C
$\frac{c \sin B}{a-(c \cos B)}$	a,c,B	TAN C
$\frac{a^2+b^2-c^2}{2ab}$	a,b,c	COS C
$\frac{a \sin C}{\sin A}$	a,A,C	c
$\sqrt{a^2+b^2-2ab \cos C}$	a,b,C	c
$\frac{b \sin C}{\sin B}$	b,B,C	c
$\frac{ab \sin C}{2}$	a,b,C	AREA
$\sqrt{s(s-a)(s-b)(s-c)}$	a,b,c	$(s = \frac{a+b+c}{2})$

8.2.22 Computation of Unknown Bearings



8.2.23 Standard Arm Signals




PLUMB POLE OR ROD
TURNING POINT
BENCH MARK
Raise arm straight above the head and move slowly in direction that correction is desired
Raise arm above head and describe circle in a horizontal plane
Hold level rod horizontally over the head (with both arms extended)
ONE HAND METHOD
1 FLIP OF ARM
2 FLIPS OF ARM
3
4
5
6
7
8
9
0
ALL SIGNALS ARE PICTURED AS THE RODMAN READS THEM

8.3 References

CDOT Survey Manual – CDOT, 1992

CDOT Survey Manual – CDOT, 1984

CDOT Survey Manual – CDOT, 1966

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