the Little Green Book

METRIC EDITION

Compiled by

C.Venter

THE LITTLE GREEN BOOK

FIRST METRIC EDITION

1 500 copies published September 1986

CHIEF CIVIL ENGINEER
(MANPOWER)

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ACKNOWLEDGEMENTS

Thanks are expressed to those draughtsmen who supplied information for inclusion in this book, and also to the individuals who checked all the information for correctness.

C. Venter
February 1985

CONTENTS INDEX

C.V.

CONVERSIONS TO S.I. (METRIC) UNITS.

TO CONVERT FROM	TO	MULTIPLY BY
I. LINEAR MEASURE		
Chain (Gunter's)	Metre (m)	20,1168
Fathom	Metre (m)	1,828 8
Foot (geodetic Cape)	Metre (m)	0,314 855 575 16
Foot (English)	Metre (m)	0,304 797 265 4
Inch	Metre (m)	0,025 4
Light year	Metre (m)	$9{,}460\,55 \times 10^{15}$
Mile	Kilometre (km)	1,609 344
Nautical mile (internat.)	Kilometre (km)	1,852
Perch	Metre (m)	5,029 2
Rood (geodetic Cape)	Metre (m)	3,778 266 9
Yard	Metre (m)	0,914 4
II. SQUARE MEASURE		
Acre	Square metre (m^2)	4 046,86
Morgen	Hectare (ha)	0,856 532
Perch	Square metre (m^2)	25,292 9
Rood	Square metre (m^2)	1 011,715
Square foot (English)	Square metre (m^2)	0,092 903 04
Square inch	Square metre (m^2)	0,000 645 16
Square mile	Square metre (m^2)	2 589 988,00
Square yard	Square metre (m^2)	0,836 127 36
III VOLUME		
Cubic foot (English)	Cubic metre (m^3)	0,028 316 85
Cubic inch	Cubic metre (m^3)	0,000 016 387 064
Gallon	Litre (l)	4,546 09
Ounce	Litre (l)	0,028 413 06
Pint	Litre (l)	0,568 261 3
Quart	Litre (l)	1,136 523

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CONVERSIONS

(Continued)

TO CONVERT FROM	TO	MULTIPLY BY
IV. MASS		
Grain	*Gram (g)*	0,064 798 91
Pound	Kilogram (kg)	0,453 592 37
V. VELOCITY		
Cubic foot per second	Cub. metre /sec. (m^3/s)	0,028 316 85
Mile per hour	Kilometre / hour (km/h)	1,609 344

PLAN INDEXING SUMMARY

NOTE: For detail see C.C.E.'s Diag. Z - 1137

A-Route and land plans.
B-Line plans and sections.
C-Station yard plans.
D-Miscellaneous.
E-Permanent way material.
F-Arches and culverts.
G-River bridges.
H-Foot and highway bridges.
I-Roads and fencing.
J-Water services.
K-Station buildings.
L-Sheds and kraals.
M-Loco and carriage sheds.
N-Workshops.
O-Offices.
P-Housing.
Q-Stores, schools and hospitals.
R-Electrical plants and buildings.
S-Rock, ash and coal plants, turntables.
T-Drainage.
U-Signals.
V-Grain elevators.
W-Abnormal loads.
Y-Rolling stock and tools.
Z-Diagrams and tables.

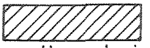
C.V.

USEFUL REFERENCE BOOKS

1. RAILWAY CIVIL ENGINEERING HANDBOOK ("Greenbook").
2. PERMANENT WAY INSTRUCTIONS.
3. PROVISION AND CONSTRUCTION OF PRIVATE SIDINGS.
4. BRIDGE CODE.
5. SAFETY INSTRUCTIONS: HIGH VOLTAGE ELECTRICAL EQUIPMENT (PART 1).
6. WORKS AND ESTATE INSTRUCTIONS.
7. SURVEY HANDBOOK (City Engineer's Department, Durban Corporation).

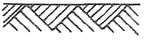
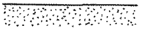
DRAWING SYMBOLS

SYMBOLS FOR MATERIALS IN SECTION

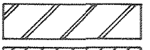
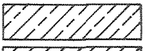
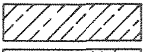
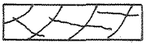


General symbol for all materials in section.

Symbol for areas too thin for line sectioning.

Rock	
Earth	
Sand	
Hardcore	

SYMBOLS FOR MISCELLANEOUS MATERIALS

Brickwork		Vermillion
Masonry		Yellow ochre
Cast or constructed stone		Viridian green
Concrete		Paynes grey
Timber across grain		Burnt sienna

SYMBOLS FOR MATERIALS IN ELEVATION

Corrugated sheeting Galvanized steel Asbestos cement		Prussian blue Paynes grey
Brickwork		Vermillion
Masonry		Yellow ochre

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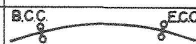
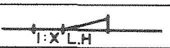
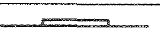
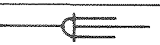
SPECIFIED DRAWING SYMBOLS (AS PER E13)

GENERAL SYMBOLS

DESCRIPTION		SYMBOL
Trigonometrical beacon		△ 473
Survey station		B 1517 ◎ 540
Cadastral or mining beacon		○
Ground control Aerial surveys	Fixed vertically and horizontally	⊕
	Fixed horizontally	⊖
	Fixed vertically	⦶
Bench mark		1314.176
S.A.Transport Services boundary (fenced)		
S.A.Transport Services boundary (unfenced)		
Fence		
Security fence (on boundary)		
Security fence (elsewhere)		
Gate in fence		
Gate across track		
Cattle guards		
Telephone/telegraph route (specify no. of wires)		
Power route (specify no. of wires)		
Surface cable or pipe (specify)		
Underground cable or pipe (specify)		marker
Water valve		C.V.

GENERAL SYMBOLS (continued)

DESCRIPTION	SYMBOL
Water meter	
Fire hydrant	
Water tank (state capacity & height of tower)	
Loco watering point : standpipe	
Loco watering point : gantry	
Existing track	
Beginning and end of circular curve	
Beginning and end of transition	
Stop block	
Sand drag	
Hayes derailer	
Derailing switch	
Scotch block	
Safety set	
Runaway set	
Block joint on one rail	
Block joint on both rails	
Locking bar/safety bar on one rail	
Locking bar/safety bar on both rails	
Splice joint on one rail	
Splice joint on both rails	
Rail and flange lubricator	

GENERAL SYMBOLS (continued)

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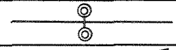
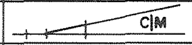
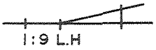
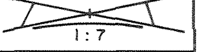
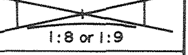
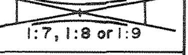
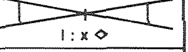
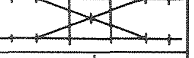
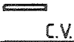
DESCRIPTION	SYMBOL
Axle counter	
Clearance marker	
Telephone	
Turnout (1:9, 1:12 etc)	
Similar flexure turnout	
Contrary flexure turnout	
Equal split	
Unequal split (specify angles θ1 & θ2)	
Single slip (1:7)	
Single slip (1:8, 1:9)	
Double slip (1:7, 1:8, 1:9)	
Diamond crossing	
Scissors crossing	
Semaphore signal	
Colour light signal	
Name board	 or 

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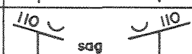
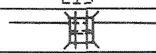
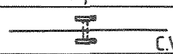
GENERAL SYMBOLS (continued)

DESCRIPTION		SYMBOL
Whistle board		
Notice board		
Watering board		
Warning board		
Stop / notice board		
Speed restriction board		
Speed de-restriction board		
Level crossing signs	Distant	
	Close-up	
	With flashing lights	
Grade posts	Vertical curve 120m or shorter	
	Vertical curve longer than 120m	
	Vertical curve longer than 120m	
Kilometre post		
Mile post		
Ash or examination pit		
Weighbridge		
Building or structure		
Bridge for road over rail (km distance)		
Bridge for rail over road or waterway (km)		
Box culvert (span × height, km distance)		
Pipe culvert (ϕ , km distance)		

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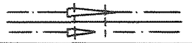
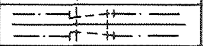
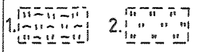
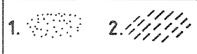
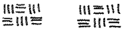
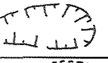
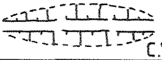
GENERAL SYMBOLS (continued)

DESCRIPTION	SYMBOL
Level crossing with lifting booms	
Level crossing with swinging booms	
Open level crossing	
Cemetery	
Plantation, trees / orchard	
Bush	
1. Irrigated land 2. Dry land	
1. Sandy soil 2. Clayey soil	
Gravel	
Loose boulders	
Rock outcrop	
Cliff	
Marsh, vlei	
Dam / lake, pan	
Quarry	
Dump, earth mound	
Embankment	

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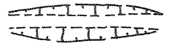
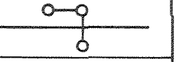
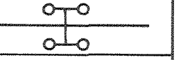
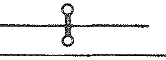
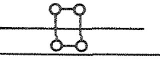
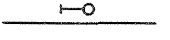
GENERAL SYMBOLS (continued)

DESCRIPTION	SYMBOL
Cutting	
Surface erosion / donga	
Cantilever mast	
Pull-off mast	
Double boom	
Double boom with raking leg	
A-frame tension bridge	
Bridge mast (lattice bridge)	
Switch structure	
Anchor mast	

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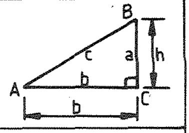
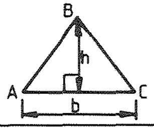
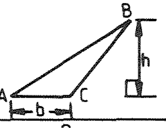
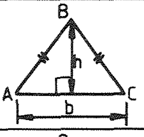
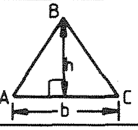
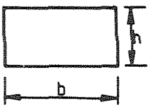
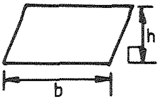
AREAS AND VOLUMES OF GEOMETRIC FIGURES

DESCRIPTION	SKETCH	AREA
Right-angled triangle		i) $\frac{1}{2} b \times h$
Acute-angled triangle		ii) $\frac{1}{2}$ ab Sin C $\frac{1}{2}$ bc Sin A $\frac{1}{2}$ ac Sin B
Obtuse-angled triangle		iii) $\frac{1}{2} a^2 \frac{\text{Sin B. Sin C}}{\text{Sin A}}$ $\frac{1}{2} b^2 \frac{\text{Sin A. Sin C}}{\text{Sin B}}$
Isosceles triangle		$\frac{1}{2} c^2 \frac{\text{Sin A. Sin B}}{\text{Sin C}}$
Equilateral triangle		iv) $\sqrt{s(s-a)(s-b)(s-c)}$ where : a,b,c, = sides $s = \frac{1}{2}$ sum of sides
Rectangle		b × h
Parallelogram		

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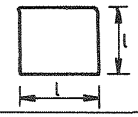
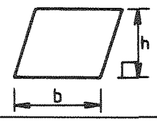
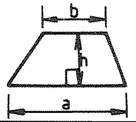
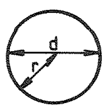
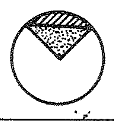
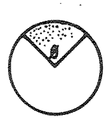
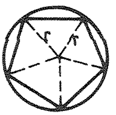
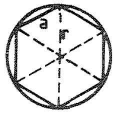
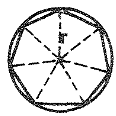
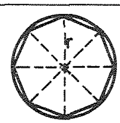
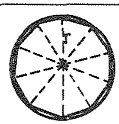
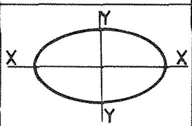
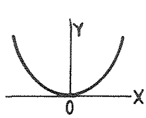
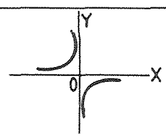
AREAS AND VOLUMES OF GEOMETRIC FIGURES

DESCRIPTION	SKETCH	AREA
Square		l^2
Rhombus Parallelogram		$b \times h$
Trapezium		h × ½ sum of two parallel sides or: $h \times \frac{a+b}{2}$
Circle $x^2 + y^2 = r^2$		$d^2 \times 0{,}785\ 398\ 164$ or: $\frac{\pi d^2}{4}$ or: πr^2
Segment of circle		Area of sector—Area of Δ
Sector of circle		$\frac{ø}{360} \times \pi r^2$ or: Radius $\times \frac{1}{2}$ arc or: Arc $\times \frac{1}{4}$ dia
Pentagon (5)		$\frac{5}{2} r^2 \times \sin 72°$ $\frac{5}{2} r^2 \times 0{,}951\ 056\ 5$ $r^2 \times 2{,}377\ 641\ 3$

C.V.

AREAS AND VOLUMES OF GEOMETRIC FIGURES

DESCRIPTION	SKETCH	AREA
Hexagon (6)		$\frac{6}{2} r^2 \times \text{Sin } 60°$ $3\ r^2 \times 0{,}866\ 025\ 4$ $r^2 \times 2{,}598\ 076\ 2$ $a = r$
Heptagon (7)		$\frac{7}{2} r^2 \times \text{Sin } 51° 25' 42{,}86''$ $\frac{7}{2} r^2 \times 0{,}781\ 831\ 5$ $r^2 \times 2{,}736\ 410\ 2$
Octagon (8)		$\frac{8}{2} r^2 \times \text{Sin } 45°$ $r^2 \times 2{,}828\ 427\ 1$
Decagon (10)		$\frac{10}{2} r^2 \times \text{Sin } 36°$ $r^2 \times 2{,}938\ 926\ 3$
The ellipse $\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$		$\frac{1}{2}$ Maj. axis $\times \frac{1}{2}$ minor axis $\times \pi$ or: Maj. $\times$ minor $\times \frac{\pi}{4}$
Parabola $ax^2 + bx + c = y$ $y = x^2$		Containing rectangle $\times \frac{2}{3}$
Hyperbola $\frac{1}{x} = y$		

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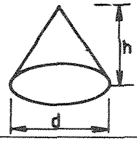
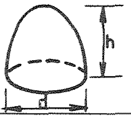
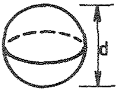
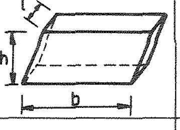
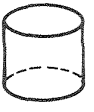
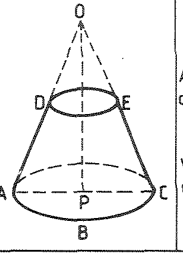
AREAS AND VOLUMES OF GEOMETRIC FIGURES

DESCRIPTION	SKETCH	AREA / VOLUME
Cone		Vol. = $\frac{1}{3}\left(\frac{\pi d^2 h}{4}\right)$ or: $\frac{1}{3}\pi r^2 h$
Paraboloid of revolution		Vol. = $\frac{1}{2}\left(\frac{\pi d^2 h}{4}\right)$ or: $\frac{1}{2}$ vol. of circumscribed circle.
Sphere		Vol. = $\frac{\pi d^3}{6}$ or: $\frac{4}{3}\pi r^3$
Rhomboid		Vol. = $l \times b \times h$ Surface area = area of 6 parallelograms
Cylinder		Vol. = $\pi r^2 h$ Surface area = $2(\pi r h + \pi r^2)$
Frustum of cone or any geometric pyramid		Area of frustum = area of cone OABC – area of cone ODE Vol. of frustum = vol. of cone OABC – vol. of cone ODE

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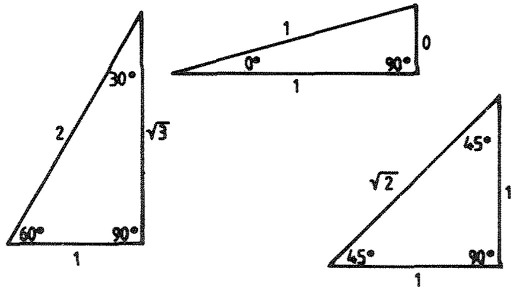
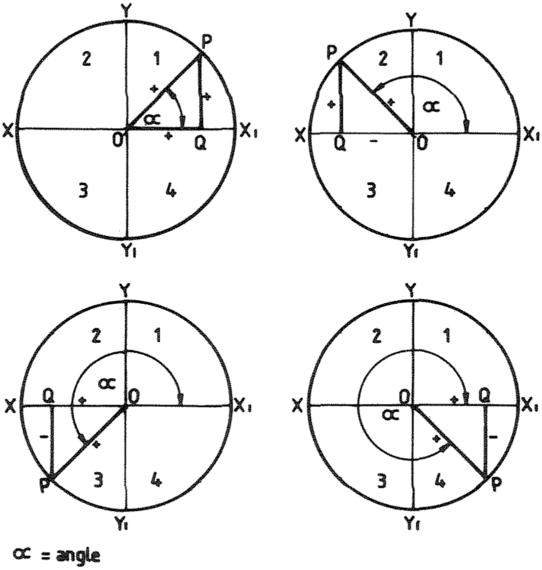
TRIGONOMETRY





∝ = angle

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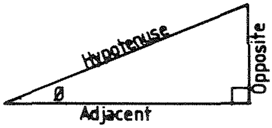
TRIGONOMETRY

I DEFINITIONS (for acute angles)



$\text{Sin } Ø = \dfrac{\text{Opposite}}{\text{Hypotenuse}}$ (Sinoh)

$\text{Cos } Ø = \dfrac{\text{Adjacent}}{\text{Hypotenuse}}$ (Cosah)

$\text{Tan } Ø = \dfrac{\text{Opposite}}{\text{Adjacent}}$ (Tanoa)

II RECIPROCAL FORMULAE

$\text{Sin } Ø = \dfrac{1}{\text{Cosec } Ø}$ $\text{Cosec } Ø = \dfrac{1}{\text{Sin } Ø}$

$\text{Cos } Ø = \dfrac{1}{\text{Sec } Ø}$ $\text{Sec } Ø = \dfrac{1}{\text{Cos } Ø}$

$\text{Tan } Ø = \dfrac{1}{\text{Cot } Ø}$ $\text{Cot } Ø = \dfrac{1}{\text{Tan } Ø}$

III 'S & C' FORMULAE

If Sin Ø = S and Cos Ø = C ;

$\text{Tan } Ø = \dfrac{S}{C}$ $\text{Sec } Ø = \dfrac{1}{C}$ $\text{Cot } Ø = \dfrac{C}{S}$

$\text{Cosec } Ø = \dfrac{1}{S}$ $S^2 + C^2 = 1$

IV "SQUARES" FORMULAE

$\text{Sin}^2 Ø + \text{Cos}^2 Ø = 1$

$\text{Sec}^2 Ø = 1 + \text{Tan}^2 Ø$

$\text{Cosec}^2 Ø = 1 + \text{Cot}^2 Ø$

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TRIGONOMETRY

V. FUNCTIONS OF 0°, 30°, 45°, 60°, 90°, 180°, 270° & 360°

(See page 17 for sketches)

	0°	30°	45°	60°	90°	180°	270°	360°
SIN	0	$\frac{1}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{\sqrt{3}}{2}$	1	0	-1	0
COS	1	$\frac{\sqrt{3}}{2}$	$\frac{1}{\sqrt{2}}$	$\frac{1}{2}$	0	-1	0	1
TAN	0	$\frac{1}{\sqrt{3}}$	1	$\sqrt{3}$	∞	0	∞	0
COT	∞	$\sqrt{3}$	1	$\frac{1}{\sqrt{3}}$	0	∞	0	∞
SEC	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	∞	-1	∞	1
COSEC	∞	2	$\sqrt{2}$	$\frac{2}{\sqrt{3}}$	1	∞	-1	∞

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VI. DEFINITIONS (for any angle).

(See page 17 for sketches)

$\text{SIN } \theta = \frac{QP}{OP}$ $\text{COSEC } \theta = \frac{OP}{QP}$

$\text{COS } \theta = \frac{OQ}{OP}$ $\text{SEC } \theta = \frac{OP}{OQ}$

$\text{TAN } \theta = \frac{QP}{OQ}$ $\text{COT } \theta = \frac{OQ}{QP}$

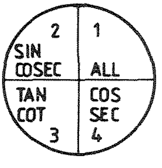
[N.B. (i) OP is always positive.

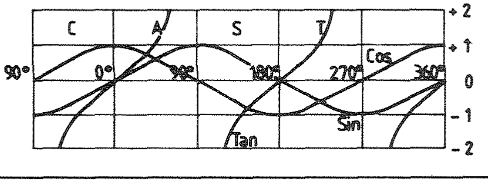
(ii) The signs of QP and OQ are determined according to the usual convention of signs used in graphs.

Any trig. function of $180° \pm \theta$ and $360° - \theta$ is $\pm$ equal to the same function of θ. (1)

Any trig. function of $90° \pm \theta$ and $270° \pm \theta$ is $\pm$ equal to the co-functions of θ. (2)

The choice between the plus and minus signs in (1) and (2) above can be made from a consideration of the following diagrams:





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TRIGONOMETRY

VII. SOLUTION OF TRIANGLES

3 SIDES:

$$\cos A = \frac{b^2 + c^2 - a^2}{2bc}$$

$$\cos B = \frac{a^2 + c^2 - b^2}{2ac}$$

$$\cos C = \frac{a^2 + b^2 - c^2}{2ab}$$

2 SIDES AND THE INCLUDED ANGLE:

$$a^2 = b^2 + c^2 - 2bc \cos A$$

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

$$c^2 = a^2 + b^2 - 2ab \cos C$$

1 SIDE AND 2 ANGLES:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

2 SIDES AND A NON-INCLUDED ANGLE:

No ambiguity if the larger of the given sides is opposite the given angle.

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TRIGONOMETRY

VIII. COMPOUND ANGLE FORMULAE:

$$\text{Sin}(A+B) = \text{Sin}A.\text{Cos}B + \text{Cos}A.\text{Sin}B$$

$$\text{Sin}(A-B) = \text{Sin}A.\text{Cos}B - \text{Cos}A.\text{Sin}B$$

$$\text{Cos}(A+B) = \text{Cos}A.\text{Cos}B - \text{Sin}A.\text{Sin}B$$

$$\text{Cos}(A-B) = \text{Cos}A.\text{Cos}B + \text{Sin}A.\text{Sin}B$$

$$\text{Tan}(A+B) = \frac{\text{Tan}A + \text{Tan}B}{1-\text{Tan}A.\text{Tan}B}$$

$$\text{Tan}(A-B) = \frac{\text{Tan}A - \text{Tan}B}{1+\text{Tan}A.\text{Tan}B}$$

IX. MULTIPLE ANGLE FORMULAE:

$$\text{Sin}\,2A = 2\,\text{Sin}A.\,\text{Cos}A$$

$$\begin{aligned}\text{Cos}\,2A &= \text{Cos}^2A - \text{Sin}^2A \\ &= 2\text{Cos}^2A - 1 \\ &= 1 - 2\text{Sin}^2A\end{aligned}$$

$$\text{Tan}\,2A = \frac{2\,\text{Tan}A}{1-\text{Tan}^2A}$$

$$\text{Sin}\,3A = 3\,\text{Sin}A - 4\,\text{Sin}^3A$$

$$\text{Cos}\,3A = 4\,\text{Cos}^3A - 3\,\text{Cos}A$$

$$\text{Tan}\,3A = \frac{3\,\text{Tan}A - \text{Tan}^3A}{1-\ 3\,\text{Tan}^2A}$$

X. "POWER" FORMULAE

$$\text{Sin}^2A = \frac{1}{2} - \frac{1}{2}\text{Cos}\,2A$$

$$\text{Cos}^2A = \frac{1}{2} + \frac{1}{2}\text{Cos}\,2A$$

$$\text{Sin}^3A = \frac{3}{4}\text{Sin}A - \frac{1}{4}\text{Sin}\,3A$$

$$\text{Cos}^3A = \frac{3}{4}\text{Cos}A + \frac{1}{4}\text{Cos}\,3A$$

XI. SUB-MULTIPLE ANGLE FORMULAE:

$$\text{Sin}\,A = 2\,\text{Sin}\frac{A}{2}.\,\text{Cos}\frac{A}{2}$$

$$\begin{aligned}\text{Cos}\,A &= \text{Cos}^2\frac{A}{2} - \text{Sin}^2\frac{A}{2} \\ &= 2\,\text{Cos}^2\frac{A}{2} - 1 \qquad = 1 - 2\,\text{Sin}^2\frac{A}{2}\end{aligned}$$

$$\text{Tan}\,A = 2\,\text{Tan}\frac{A}{2} \Big/ 1-\text{Tan}^2\frac{A}{2}$$

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TRIGONOMETRY

XII. "t" FORMULAE

If $\tan\frac{X}{2} = t$, then $\tan X = \frac{2t}{1-t^2}$

$$\sin X = \frac{2t}{1+t^2}$$

$$\cos X = \frac{1-t^2}{1+t^2}$$

$$dX = \frac{2dt}{1+t^2}$$

XIII. "SUM AND PRODUCT" FORMULAE:

$$2\sin A.\cos B = \sin(A+B) + \sin(A-B)$$

$$2\cos A.\sin B = \sin(A+B) - \sin(A-B)$$

$$2\cos A.\cos B = \cos(A+B) + \cos(A-B)$$

$$-2\sin A.\sin B = \cos(A+B) - \cos(A-B)$$

$$\sin C + \sin D = 2\sin\frac{C+D}{2}.\cos\frac{C-D}{2}$$

$$\sin C - \sin D = 2\cos\frac{C+D}{2}.\sin\frac{C-D}{2}$$

$$\cos C + \cos D = 2\cos\frac{C+D}{2}.\cos\frac{C-D}{2}$$

$$-(\cos C - \cos D) = 2\sin\frac{C+D}{2}.\sin\frac{C-D}{2}$$

SUMMARY OF "SUM AND PRODUCT"

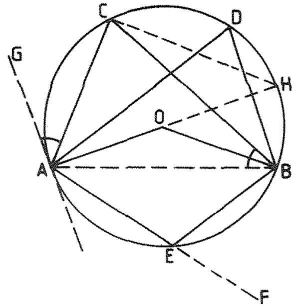
2SC = S + S

2CS = S − S

2CC = C + C

−2SS = C − C

GEOMETRY



1 All angles subtended by a chord, in the same segment of a circle, are equal i.e. $\hat{C} = \hat{D}$.

2 The angle subtended at the centre of a circle, by a chord, is twice the angle subtended by the same chord at the circumference, i.e. $A\hat{O}B = 2\hat{C}$.

3 Angles subtended by the same chord, in opposite segments of a circle, are supplementary, i.e. $\hat{C} + \hat{E} = 180°$.

4 The angle between a tangent and a chord is equal to the angle subtended by the chord in the opposite segment, i.e. $G\hat{A}C = A\hat{B}C$.

5 The exterior angle of a cyclic quadrilateral is equal to the interior opposite angle, i.e. $B\hat{E}F = \hat{C} = \hat{D}$.

6 In any triangle, the exterior angle, formed by producing one of the sides, is equal to the sum of the interior opposite angles, i.e. $B\hat{E}F = E\hat{B}A + B\hat{A}E$.

7 The angle formed at the tangent point, by a tangent and a radius is a right angle, i.e. $G\hat{A}O = 90°$.

8 The angle subtended at the circumference, by a diameter, is a right angle, i.e. $H\hat{C}A = 90°$.

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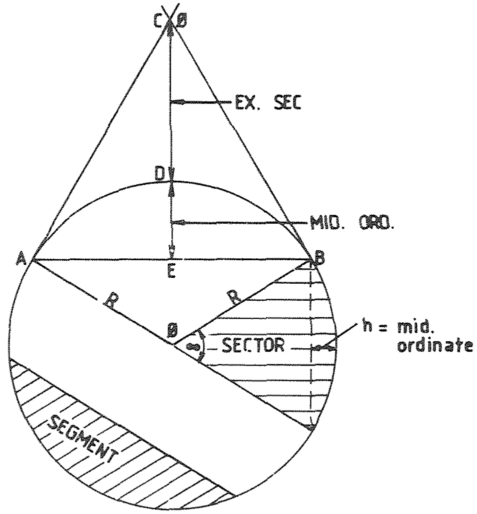
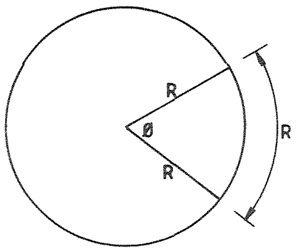
PROPERTIES OF A CIRCLE



Tangent length	$= AC = BC = R.\ \mathrm{Tan}\ \frac{Ø}{2}$
Long chord	$= AB = 2R.\ \mathrm{Sin}\ \frac{Ø}{2} = \sqrt{(8R\ \mathrm{Mid.\ ord.}) - (4\ \mathrm{Mid.\ ord}^2)}$
Mid. ordinate	$= ED = R(1 - \mathrm{Cos}\ \frac{Ø}{2})$
Ex. sec.	$= CD = R(\mathrm{Sec}\ \frac{Ø}{2} - 1)$
Length of curve	$= AB = R.Ø.\frac{\pi}{180}$
Diameter	$= 2R = \frac{\mathrm{Circumference}}{\pi}$
Area of circle	$= \pi.R^2$
Area of sector	$= \frac{\propto}{360}.\pi.R^2 = \mathrm{Rad.} \times \frac{\mathrm{Arc}}{2}$
Angle	$= \propto = 2\ \mathrm{Cos}^{-1}(\frac{R-h}{R})$
Area of segment	= Area of sector − area of triangle

DEGREE OF CURVATURE



Circumference of circle = $2\pi R$ and subtends 360° at the centre

If $2\pi R$ subtends 360°, then :

R will subtend $\frac{360°}{2\pi}$ = 57,29577951

1m will subtend $\frac{57.29577951}{R}$

20 m will subtend $\frac{57.29577951 \times 20}{R}$

30,48m will subtend $\frac{57,29577951 \times 30,48}{R}$

Now angle subtended by 30,48m is the degree of curvature

$$D = \frac{57,29577951 \times 30,48}{R \text{ (in metres)}}$$

1 Radian is the angle subtended at the centre by an arc equal to the length of the radius.

= 57,29577951°

= 57° 17' 44,8063"

<u>NOTE</u>: On some old line plans the radius of curves was given in degrees. The degree curve was defined as the central angle subtended by a 100 foot arc. Today the S.I. system is in use therefore a 20 m arc is used to calculate the degree of curvature.

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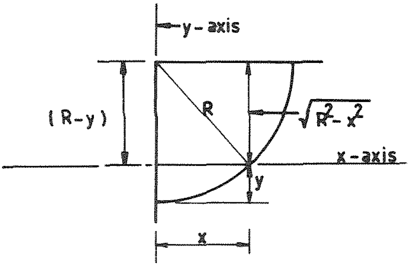
CIRCULAR CURVES



TO CALCULATE OFFSETS FROM TANGENT AT KNOWN DISTANCES ON A CIRCULAR CURVE.

R = Radius

x = Distance on x-axis

y = Distance on y-axis

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

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

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

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

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

USING CALCULATOR (Versine method)

$\sin \emptyset = \frac{x}{Rad}$

$\therefore x = R.\sin \emptyset$

$y = R.\text{vers}.\emptyset$ or $R(1 - \cos \emptyset)$

USING LOG. BOOK

Determine the value of $\frac{x}{Rad}$. Find this value in the natural Sin tables (do not look up the value in degrees). Follow the line through to heading 'Versine' and read of the value and multiply by the radius.

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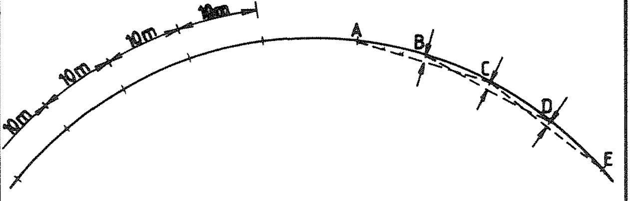
CIRCULAR CURVES

TO FIND THE APPROX. RADIUS OF A CURVE BY THE STRINGLINING METHOD.



PROCEDURE TO BE FOLLOWED:

1. Mark rail at 10m intervals.
2. Measure mid. ordinates in mm. (every 10m)
3. Calculate average mid. ordinate.
4. *Radius in metres* $= \dfrac{125 \times \text{chord length}^2}{\text{Average mid. ordinate}}$

NOTE:

A standard chord of 20m should be used, but as the chords must overlap, the rail is marked at 10m intervals.

The rails should be marked on the inside of the high leg, but the outside of the low leg can also be used.

To measure the mid. ordinates, fishing line is most suitable. The line should be firmly held against the side of the railhead and the ordinate measured at mid. span.

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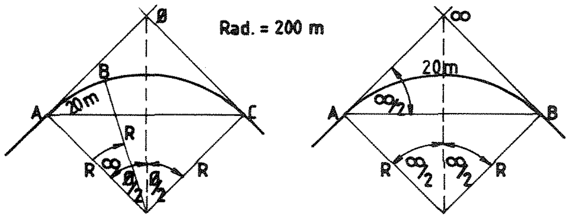
CIRCULAR CURVES

METHOD OF CALCULATING THE TANGENTIAL ANGLE OF PORTION OF A CIRCULAR CURVE OF WHICH THE ARC LENGTH IS KNOWN.



Arc length = Radius × circular measure ∞

$\therefore \infty = \dfrac{\text{Arc length}}{\text{Radius}} \times 1 \text{ radian}$ (1 radian = 57,295 779 51°)

$= \dfrac{20}{200} \times 57{,}295\ 779\ 51°$

$= 5{,}729\ 577\ 951°$

$= 5°\ 43'\ 46{,}48''$

$\therefore \dfrac{\infty}{2} = 2°\ 51'\ 53{,}24''$ = tangential angle for 20 m arc.

So : tangential angle $= \dfrac{l}{R} \times \dfrac{1 \text{ radian}}{2}$ (in degrees)

or $= \dfrac{\text{Arc} \times 28{,}647\ 889\ 76}{\text{Radius}}$ (degrees)

or $= \dfrac{\text{Arc} \times 1\ 718{,}873\ 386}{\text{Radius}}$ (minutes)

Chord length $= 2R.\text{Sin}\dfrac{\infty}{2}$

$= 2 \times 200 \times \text{Sin } 2°\ 51'\ 53{,}24''$

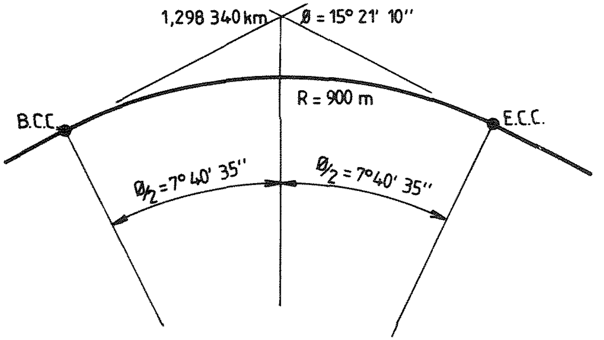
$= 19{,}992$ m

CIRCULAR CURVES

SETTING OUT WITH TANGENTIAL ANGLES

EXAMPLE

It is required to connect two straights whose deflection angle is 15° 21' 10" with a circular curve of radius 900 m. Use the tangential angle method. The kilometre distance of the point of intersection is 1,298 340 km. Use chord lengths of 20 m and sub-chords at the beginning and end of the curve to ensure that all intermediate pegs are placed at exactly 20 m intervals.



i) Curve no. 27

ii) Curve to the right

iii) Radius = 900 m

iv) Deflection angle = 15° 21' 10"

v) Tangent length $= R.\tan\frac{Ø}{2}$

$= 900 \times \tan 7° 40' 35''$

$= 121,307$ m

vi) Arc length $= R \times Ø$ (radians)

$= 900 \times 0,267\,957$

$= 241,161$ m

vii) Kilometre distances of:

B.C.C. = 1,298 340 − 0,121 307 = 1,177 033 km

E.C.C. = 1,177 033 + 0,241 161 = 1,418 194 km

Crown peg $= 1,177\,033 + \frac{0,241\,161}{2} = 1,297\,614$ km

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CIRCULAR CURVES

EXAMPLE (continued)

viii) P.I. to crown peg = $R(\mathrm{Sec}\frac{\emptyset}{2} - 1)$

$= 8{,}183$ m

Direction P.I. to C.P. = $360° - (\frac{180 - 15° 21' 10''}{2})$

$= 277° 40' 35''$

As this is a curve to the right, the tangential angles for the first half of the curve must be added to the orientation angle (0° 00' 00") and the tangential angles for the second half must be subtracted from the orientation angle (360°00' 00").

NOTE:

1. To limit the closing error, the curve must be staked from the B.C.C. and E.C.C. and work towards the crown peg.
2. Pegs are required on full 20 m distances to a full 20 m distance after the crown peg.

A KILOMETRE DISTANCE	B DISTANCE FOR PURPOSE OF CALCULATING TANGENTIAL ANGLES FROM B.C.C.	C TANGENTIAL ANGLE (α)	D DISTANCE FOR STAKING PURPOSES (MEASURED FROM PRE STAKED PEG)
B.C.C. 1,177 033			
1,180	2,967	00° 05' 40"	2,967
1,200	22,967	00° 43' 52"	20
1,220	42,967	01° 22' 04"	20
1,240	62,967	02° 00' 15"	20
1,260	82,967	02° 38' 27"	20
1,280	102,967	03° 16' 39"	20
1,297 614	120,581	03 50 18	17,614
1,300	122,967	03 54 51	2,386

see next page

C.V.

CIRCULAR CURVES

EXAMPLE (continued)

Tabulation of tangential angles from E.C.C. to 1280.

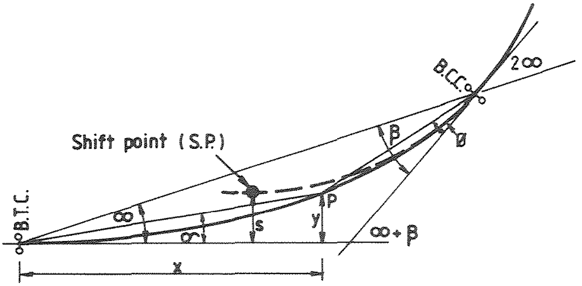
A	B	C	D	E
E.C.C. 1,418 194			360° 00' 00"	
1,400	18,194	00° 34' 45"	359° 25' 15"	18,194
1,380	38,194	01° 12' 57"	358° 47' 03"	20
1,360	58,194	01° 51' 09"	358° 08' 51"	20
1,340	78,194	02° 29' 20"	357° 30' 40"	20
1,320	98,194	03° 07' 32"	356° 52' 28"	20
1,300	118,194	03° 45' 44"	356° 14' 16"	20
1,297 614	120,580	03° 50' 17"	356° 09' 43"	2,386
1,280	138,194	04° 23' 56"	355° 36' 04"	17,614

Check:

Equal distances will have equal angles, therefore the tangential angle at B.C.C. to crown peg is equal to the tangential angle at E.C.C. to crown peg. Considering that the distance to the crown peg was rounded off, a difference of 1 mm causes a difference of 1".

(3° 50' 18" + 3° 50' 17") 2 = Deflection angle = 15° 21' 10"

THE TRANSITION CURVE



If L = Total length of transition
l = B.T.C. to any point P
R = Radius of circular curve
s = Shift of circular curve from tangent
P = Any point on transition
x & y = Ordinates (offsets) of P
∞ = Deflection from tangent from B.T.C. to B.C.C.
β = Deflection from tangent at B.C.C. to B.T.C.
σ = Deflection from tangent from B.T.C. to P
ø = Deflection from tangent at B.C.C. to P

Then:

$$s = \frac{L^2}{24R}$$

$$\beta = 2\infty$$

$$\emptyset = \frac{57.296}{6R}\left[2L - \frac{l^2}{L} - l\right]$$

$$\infty = \frac{57.296\,L}{6R}$$

$$\sigma = \frac{57.296\,l^2}{6RL}$$

$$x = l\left(1 - \frac{l^4}{40R^2L^2}\right)$$

$$y = \frac{l^3}{6RL}$$

y-offset at shift point = $\frac{s}{2}$

y-offset at B.C.C. = $4 \times s$

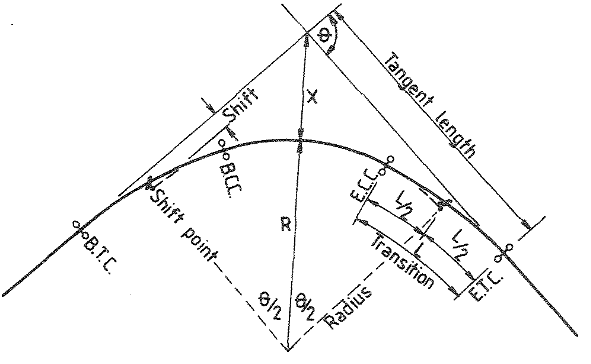
C.V

TRANSITIONED CURVES

All curves on running lines must be provided with transitioned ends.

On curves of 300 m radius and sharper, the length of transition provided must be 60 m.

On curves flatter than 300 m radius, the length of transition provided must be 80 m.



$$\text{Shift} = \frac{L^2}{24R}$$

$$\text{Tangent length} = (R+S)\,\text{Tan}\frac{\theta}{2} + \frac{L}{2}$$

Where: L = Length of transition
R = Radius of curve
S = Shift
θ = Deflection angle

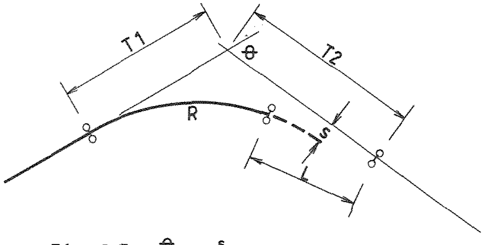
$$\text{Total length of curve} = R \times \theta\,(\text{in radians}) + L$$

$$X = (R+S)(\text{Sec}\,\frac{\theta}{2}) - R$$

C.V.

TRANSITIONED CURVES

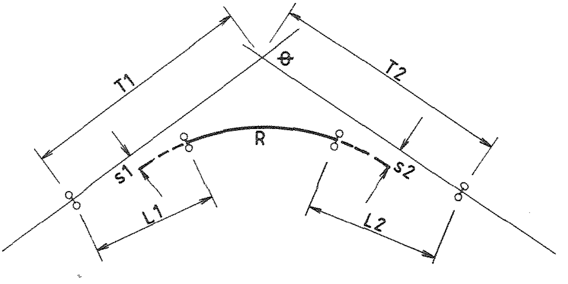
I. ONE TRANSITION



$$T1 = R.\mathrm{Tan}\frac{\theta}{2} + \frac{s}{\mathrm{Sin}\,\theta}$$

$$T2 = \left(R.\mathrm{Tan}\frac{\theta}{2} - \frac{s}{\mathrm{Tan}\,\theta}\right) + \frac{L}{2}$$

II. UNEQUAL TRANSITIONS

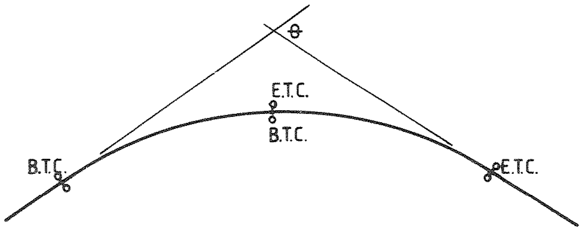


$$T1 = R.\mathrm{Tan}\frac{\theta}{2} + \left(\frac{s2}{\mathrm{Sin}\,\theta} - \frac{s1}{\mathrm{Tan}\,\theta}\right) + \frac{L1}{2}$$

$$T2 = R.\mathrm{Tan}\frac{\theta}{2} + \left(\frac{s1}{\mathrm{Sin}\,\theta} - \frac{s2}{\mathrm{Tan}\,\theta}\right) + \frac{L2}{2}$$

C.V.

BUTTING TRANSITIONS



$$\text{Radius} = \frac{L}{\theta r}$$

or

$$\text{Radius} = \frac{TL}{[1 + \frac{(\theta r)^2}{24}]\,\text{Tan}\,\frac{\theta}{2} + \frac{\theta r}{2}}$$

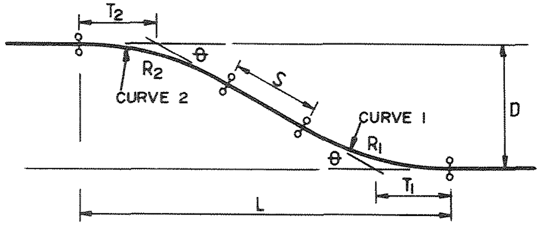
$$\text{Tangent length (TL)} = R[(1 + \frac{\theta r}{24})\,\text{Tan}\,\frac{\theta}{2} + \frac{\theta r}{2}]$$

where : L = length of transition curve
R = radius
θ = Deflection angle
θr = Deflection angle (in radians)

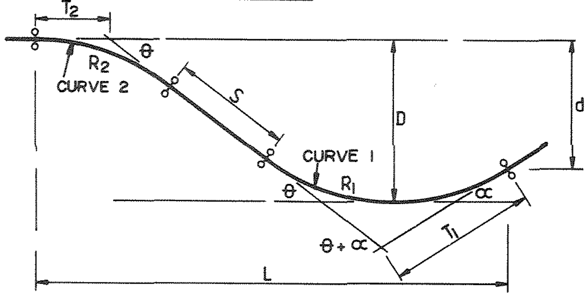
REVERSE CURVES

(For equations see next page)

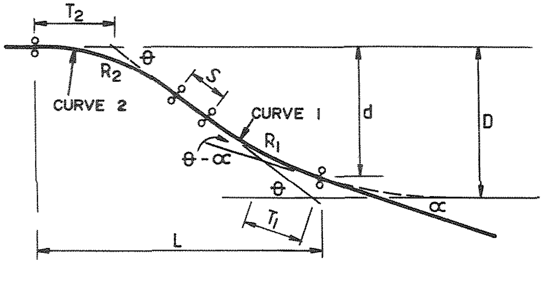
I PARALLEL LINES ($\alpha = 0$)



II CONVERGING LINES ($\alpha = +$)



III DIVERGING LINES ($\alpha = -$)



C.V.

REVERSE CURVES

(For sketches see previous page)

These equations are applicable for the following cases :

I Parallel lines

II Converging lines

III Diverging lines

Each case can be with or without intervening straight. Please note that for track layouts a minimum length of straight track (40 m—P.W.I. 503.9) is required between reverse curves. Both curves can be circular or transitioned , or have one curve circular and one curve transitioned.

These equations are not applicable if one of the curves has only one end transitioned.

For curve no. 1

L_1 = length of transition

$$\emptyset_1 = \frac{180\,L_1}{2\pi R_1}$$

$$X_1 = L_1 - \frac{(L_1)^3}{40(R_1)^2}$$

$$Y_1 = \frac{(L_1)^2}{6R_1} - \frac{(L_1)^4}{336(R_1)^3}$$

$$K_1 = Y_1 - R_1(1-\cos\emptyset_1) = \text{shift}$$

$$Q_1 = X_1 - R_1\sin\emptyset_1$$

$$Z_1 = R_1 + K_1$$

For curve no. 2

L_2 = length of transition

$$\emptyset_2 = \frac{180\,L_2}{2\pi R_2}$$

$$X_2 = L_2 - \frac{(L_2)^3}{40(R_2)^2}$$

$$Y_2 = \frac{(L_2)^2}{6R_2} - \frac{(L_2)^4}{336(R_2)^3}$$

$$K_2 = Y_2 - R_2(1-\cos\emptyset_2) = \text{shift}$$

$$Q_2 = X_2 - R_2\sin\emptyset_2$$

$$Z_2 = R_2 + K_2$$

For no transitions : $L_1 = \emptyset_1 = X_1 = Y_1 = K_1 = Q_1 = 0$ and $Z_1 = R_1$

For no transitions : $L_2 = \emptyset_2 = X_2 = Y_2 = K_2 = Q_2 = 0$ and $Z_2 = R_2$

$D = d + Z_1(1-\cos\alpha) + Q_1\sin\alpha$ (not necessary for parallel lines)

$M = S + Q_1 + Q_2$

$x = Z_1 + Z_2$

$y = x - D$

$A = M^2 + x^2$

$B = 2yM$

$C = y^2 - x^2$

$$\theta = \sin^{-1}\left[\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right]$$

$$T_1 = Q_1 + Z_1\tan\frac{\theta+\alpha}{2} \qquad T_2 = Q_2 + Z_2\tan\frac{\theta}{2}$$

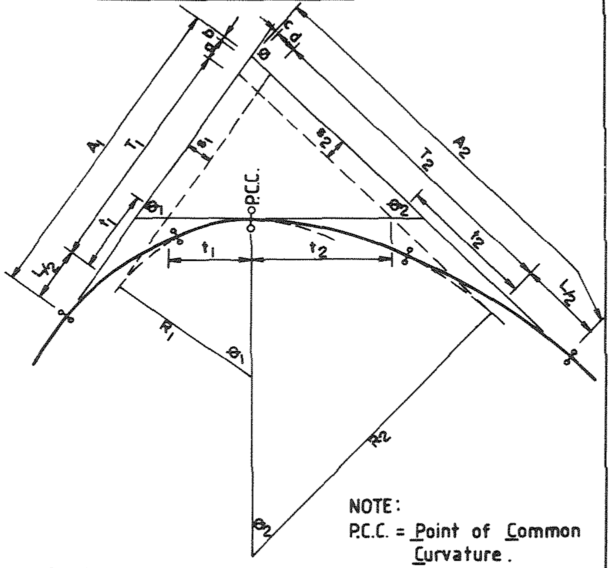
$$L = x\sin\theta + M\cos\theta + Z_1\sin\alpha + Q_1\cos\alpha + Q_2$$

C.V.

COMPOUND CURVES

WITH TRANSITIONS

CHANGE OF DIRECTION >90°



NOTE:
P.C.C. = Point of Common Curvature.

$$\theta = \theta_1 + \theta_2$$

$$\theta_1 = \cos^{-1}\left[1 - \frac{R_2(1-\cos\theta) - T_2\sin\theta}{R_2 - R_1}\right]$$

$$\theta_2 = \cos^{-1}\left[1 - \frac{T_1\sin\theta - R_1(1-\cos\theta)}{R_2 - R_1}\right]$$

$$T_1 = \frac{R_1(1-\cos\theta) + (R_2 - R_1)(1-\cos\theta_2)}{\sin\theta}$$

$$T_2 = \frac{R_2(1-\cos\theta) - (R_2 - R_1)(1-\cos\theta_1)}{\sin\theta}$$

$$a = \frac{s_2}{\cos(\theta - 90°)}$$

$$c = s_2\tan(\theta - 90°)$$

$$b = s_1\tan(\theta - 90°)$$

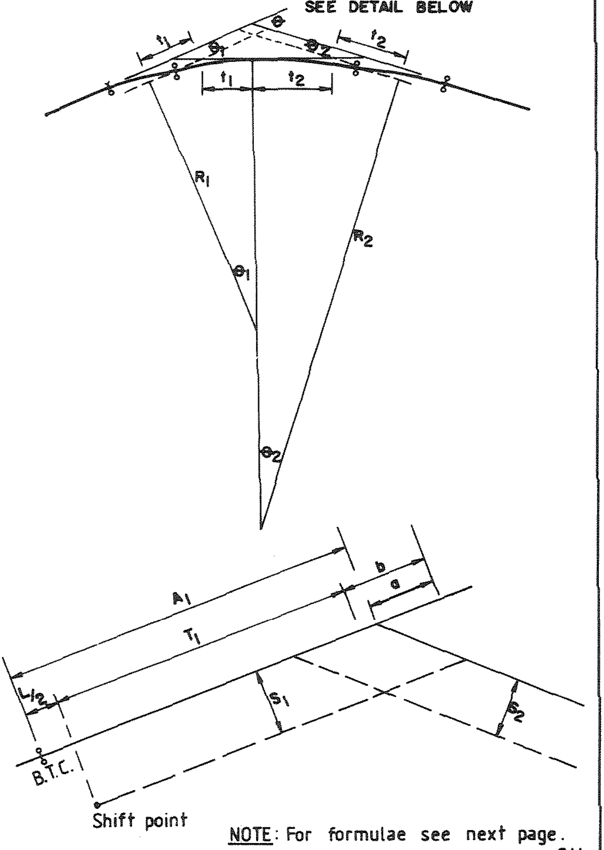
$$d = \frac{s_1}{\cos(\theta - 90°)}$$

C.V.

COMPOUND CURVES

WITH TRANSITIONS

CHANGE OF DIRECTION < 90°



NOTE: For formulae see next page.

C.V.

COMPOUND CURVES

(continued)

$$\theta = \theta_1 + \theta_2$$

$$\theta_1 = \cos^{-1}[1 - \frac{R_2(1-\cos\theta) - T_2 \sin\theta}{R_2 - R_1}]$$

$$\theta_2 = \cos^{-1}[1 - \frac{T_1 \sin\theta - R_1(1-\cos\theta)}{R_2 - R_1}]$$

$$T_1 = \frac{R_1(1-\cos\theta) + (R_2 - R_1)(1-\cos\theta_2)}{\sin\theta}$$

$$T_2 = \frac{R_2(1-\cos\theta) - (R_2 - R_1)(1-\cos\theta_1)}{\sin\theta}$$

$$a = \frac{S_1}{\tan\theta} \qquad c = \frac{S_1}{\sin\theta}$$

$$b = \frac{S_2}{\sin\theta} \qquad d = \frac{S_2}{\tan\theta}$$

$$A_1 = \frac{L}{2} + T_1 + b - a$$

$$A_2 = \frac{L}{2} + T_2 + c - d$$

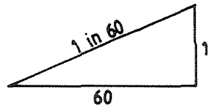
L = Length of transition

C.V.

GRADES

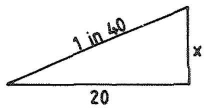
DIFFERENT METHODS OF EXPRESSING A GRADE OR SLOPE.

PER UNIT RISE



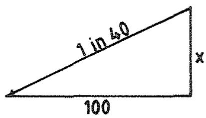
1 in 60

IN METRES PER 20 m



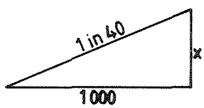
$x = \frac{20}{40} = 0{,}5\ m/20\ m$

IN PERCENT



$x = \frac{100}{40} = 2{,}5\%$

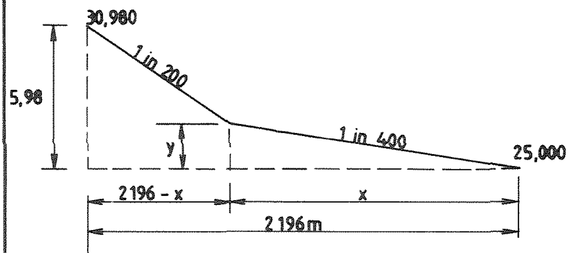
IN MILLIGRADE



$x = \frac{1000}{40} = 25‰$

GRADE INTERSECTIONS

When two grades are known with their respective levels at intersections, and distance between the grade posts, the point where the two grades intersect can be calculated as follows:



Now: $y = \frac{x}{400}$ $\quad \therefore \; x = 400y$

And $\frac{2196 - x}{200} = 5{,}98 - y$

$$\frac{2196 - 400y}{200} = 5{,}98 - y$$

$$2196 - 400y = 1196 - 200y$$

$$2196 - 1196 = 400y - 200y$$

$$\therefore \quad 200y = 1000$$

$$y = 5\text{m}$$

$$x = 400 \times 5$$

$$= 2000\text{m}$$

$\therefore$ Elevation at x $= 30{,}000$

Check:

$$30{,}980 - \left(\frac{196}{200}\right) = 30{,}000$$

$$25{,}000 + \left(\frac{2000}{400}\right) = 30{,}000$$

DEPARTURE GRADES

Where trains are likely to be stopped it is necessary to have a section of track on a grade less than the ruling grade to permit easier starting of trains and to avoid damaging the rails by the locomotive wheels spinning.

Originally this applied to the approaches to stations and halts and was known as "pre-station grades". With the introduction of longer and heavier trains, as well as centralised traffic control (C.T.C.), it has become necessary in addition to reduce grades at other places on the main lines. The term "departure grades" has been adopted to cover these as well as the pre-station grades.

In the case of air-braked trains the departure grades should not be steeper than 1:200.

For other trains the formula for arriving at departure grades is:

Departure grade $DG = (0,75\,RG) - 0,06\ \%$

where RG = ruling grade expressed as a percentage.

It is desirable that the departure grade be maintained for a minimum length of 610 m on both sides of a station or halt. This length may be varied depending on the load and length of trains.

Where it is impractical to obtain this length without excessive expenditure, the proposals must be submitted to the C.C.E. before too much detailed work is carried out.

Departure grades of 610 m length may be required at the following signals:

departure or starting, semaphore type home, intermediate home (for C.T.C.) but not with simultaneous entry, block, and also at entry sets without signals.

C.V.

COMPENSATION OF GRADES FOR CURVATURE

Because of additional resistance caused by wheel flanges on curves, it is necessary to reduce the grade on curved track in order to keep the total effective grade within the limit of the ruling grade.

The necessary amount of grade compensation is calculated by the equation $C = \frac{14}{R}$ m / 20 m, where R is the radius of the curve.

To obtain the compensated grade for a curve of radius = R metres on a ruling grade of $1 : x$, consider two points 20 m apart on the ruling grade :

Amount of elevation for ruling grade = $\frac{20}{x}$ m / 20 m

Reduction in elevation for compensation = $\frac{14}{R}$ m / 20 m

So, amount of elevation for compensated ruling grade

$$= \left[\frac{20}{x} - \frac{14}{R}\right] \text{ m/20 m}$$

$$\therefore \quad \boxed{\text{Compensated grade is } 1 : \frac{20}{\left[\frac{20}{x} - \frac{14}{R}\right]}}$$

NOTE: This compensation for curvature must be applied over the whole length of a circular curve and in the case of a curve with transitioned ends, from shift point to shift point, which is the minimum distance allowed for compensation on such a curve. A change of grade usually falls on a full 20 m unit before BCC or shift point to the first full 20 m unit after E.C.C. or shift point on the other end of the curve.

If the grade calculated is steeper than, or equal to the actual grade, no compensation of the actual grade is required.

(For examples see next page)

COMPENSATION OF GRADES FOR CURVATURE

EXAMPLES

1. What is the steepest grade that can be used on a curve of 250 m radius on a line with a ruling grade of 1:50?

   a) Amount of elevation for ruling grade $= \frac{20}{50}$ m / 20 m
   $= 0{,}400$ m / 20 m

   b) Reduction in elevation for compensation $= \frac{14}{250}$ m / 20 m
   $= 0{,}056$ m / 20 m

   c) Amount of elevation for compensated grade
   $= 0{,}400 - 0{,}056$ m / 20 m
   $= 0{,}344$ m / 20 m

   d) Compensated grade $= \frac{20}{0{,}344}$ = 1 : 58,14

2. The compensated grade on a 250 m radius curve is 1:58,14. Calculate the ruling grade of this line.

   a) Reduction in elevation for compensation $= \frac{14}{250}$ m / 20 m
   $= 0{,}056$ m / 20 m

   b) Elevation for compensated grade $= \frac{20}{58{,}14}$ m / 20 m
   $= 0{,}344$ m / 20 m

   c) Amount of elevation for ruling grade $= 0{,}344 + 0{,}056$ m / 20 m
   $= 0{,}400$ m / 20 m

   d) Ruling grade $= \frac{20}{0{,}400}$ = 1 : 50

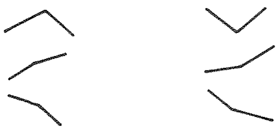
C.V.

VERTICAL CURVES

Generally whenever there is a change in grade of the track it is necessary to introduce a vertical curve to ensure smooth running of trains. This curve should be of a parabolic form since with this curve an even rate of change is ensured.

PERMISSIBLE RATES OF CHANGE : (maximum)

Summits Sags



The rates of change are the same for both summits and sags and must not exceed :

1 For running lines --- 0,040 m / 20 m / 20 m
2 For traffic yards --- 0,150 m / 20 m / 20 m
3 For loco depots ----- 0,240 m / 20 m / 20 m
4 For special cases such as humps in gravity marshalling yards the standards will be specially determined for each case.

Note :
The above standards are as per C.C.E.'s letter W48 (R 283) of 21 - 03 - 74.

NARROW GAUGE (610 mm)

The rates of change are the same for both summits and sags and must not exceed :

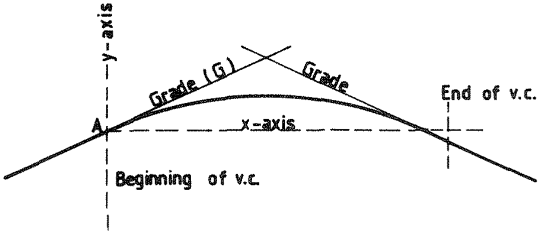
1. For running lines ______ 0,300 m / 20 m / 20 m
2. For yards ____________ 0,600 m / 20 m / 20 m

VERTICAL CURVES

The equation of a parabolic form vertical curve :

$$Y = \frac{1}{2} r x^2 + Gx + H$$

Where :- x = distance along x-axis in 20 m units
y = distance along y-axis in metres.
G = grade in m/20 m of grade passing through A
r = rate of change of grade in m/20 m/20 m
H = Elevation of point A in metres.



NOTE

G is positive on an up grade and negative on a down grade.
r is negative on a summit and positive on a sag.

VERTICAL CURVES

CALCULATING LENGTH OF V.C. REQUIRED.

Length of v.c. = $\dfrac{\text{Algebraic difference}}{\text{Permissible rate of change}}$

EXAMPLE :

1 in 100 = −0,200 m / 20 m

1 in 66 = +0,303 m / 20 m

Algebraic difference = −0,503 m / 20 m

Max. permissible rate of change = 0,040 m / 20 m / 20 m

∴ Length of v.c. required = $\dfrac{0{,}503}{0{,}040}$

= 12,576 × 20 m units

When space is limited (clearance) in a layout, the calculated length of v.c. can be used, but if space is no problem, then use the next higher even length of v.c. In example above it would be 14 × 20 m units (280 m).

EXAMPLE :

To calculate a corresponding grade, given one grade.

Max. permissible rate of change = 0,040 m / 20 m / 20 m

Length of v.c. required = 8 × 20m units (160 m).

Now permissible algebraic difference = 8 × 0,040

= 0,320 m / 20 m

1 in 100 = 0,200 m / 20 m

∴ Grade required = 0,320 − 0,200

= 0,120 m / 20 m

= 1 in 166,667

A. If grades cross dotted line, subtract.

B. If grades do not cross dotted line, add.

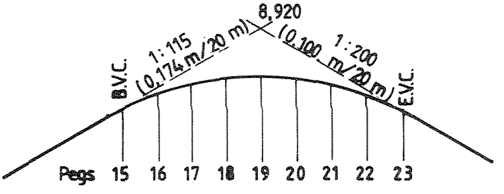
VERTICAL CURVES

TO CALCULATE THE LEVELS OF THE INTERMEDIATE PEGS ON THE VERTICAL CURVE.

EXAMPLE: (for even unit v.c. only).

a 1 in 115 up grade and a 1 in 200 down grade intersect at peg no. 19, the P.i. level of which is 8,920.

Rate of change of grade not to exceed 0,040 m/20 m/20 m



Algebraic difference = $-0{,}100 - 0{,}174 = -0{,}274$ m / 20 m

Theoretical length of v.c. = $\frac{0{,}274}{0{,}040}$ = $6{,}848 \times 20$ m units

∴ Use an 8×20 m unit v.c.

Formation level at beginning of v.c. = $8{,}920 - (4 \times 0{,}174) = 8{,}224$

Formation level at end of v.c = $8{,}920 - (4 \times 0{,}100) = 8{,}520$

Let G = grade in m/20 m passing through B.V.C. = +0,174 m/20 m

r = rate of change in m/20 m = $\frac{-0{,}274}{8}$

= $-0{,}034$ m/20 m/20 m

G is positive on an up grade and negative on a down grade.

r is negative on a summit and positive on a sag.

Now level at any full 20 m peg on v.c. = G + Nr

∴ G is positive and r is negative

∴ Equation becomes :- lev = G − Nr

where N is always equal to $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$ etc.

VERTICAL CURVES

EXAMPLE (continued)

$r = -0,034$	$\frac{1}{2}r = -0,017$	$1\frac{1}{2}r = -0,051$
$2\frac{1}{2}r = -0,086$	$3\frac{1}{2}r = -0,120$	$4\frac{1}{2}r = -0,154$
$5\frac{1}{2}r = -0,188$	$6\frac{1}{2}r = -0,223$	$7\frac{1}{2}r = -0,257$

Level at peg 15 = 8,224
+0,174
= 8,394
−0,017
Level at peg 16 = 8,381
+0,174
= 8,555
−0,051
Level at peg 17 = 8,504
+0,174
= 8,678
−0,086
Level at peg 18 = 8,592
+0,174
= 8,766
−0,120
Level at peg 19 = 8,646
+0,174
= 8,820
−0,154
Level at peg 20 = 8,666
+0,174
= 8,840
−0,188
Level at peg 21 = 8,652
+0,174
= 8,826
−0,223
Level at peg 22 = 8,603
+0,174
= 8,777
−0,257
Level at peg 23 = 8,520

VERTICAL CURVES

EXAMPLE (continued)

SUMMARY OF CALCULATIONS

PEG NO.	G − Nr WHERE N = $\frac{1}{2}, 1\frac{1}{2}, 2\frac{1}{2}$, ETC.	LEVEL OF PEG
15		8,224
16	0,174 − 0,017 = 0,157	8,381
17	0,174 − 0,051 = 0,123	8,504
18	0,174 − 0,086 = 0,088	8,592
19	0,174 − 0,120 = 0,054	8,646
20	0,174 − 0,154 = 0,020	8,666
21	0,174 − 0,188 = −0,014	8,652
22	0,174 − 0,223 = −0,049	8,603
23	0,174 − 0,257 = −0,083	8,520

TO CALCULATE THE LEVEL AT ANY POINT ON THE V.C.

EXAMPLE:

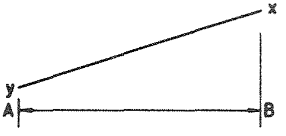
$$Y = \frac{1}{2} r x^2 + Gx + H$$

Level at peg 17.

where x = 2, G = 0,174 m/20 m, r = 0,034 m/20 m/20 m and H = 8,224

∴ Level at peg 17 = $-(0{,}5 \times 0{,}034 \times 2^2) + (0{,}174 \times 2) + 8{,}224$
= 8,504

HYDRAULIC GRADIENT



$$\text{Hydraulic gradient} = \frac{\text{Difference in levels x \& y}}{\text{Distance AB in metres}}\ \%$$

EXAMPLE

Difference in level = 6,580 m

Distance = 1 396 m

$$\text{Hydraulic gradient} = \frac{6,580}{1396} \times \frac{100}{1} = 0,471\%$$

$$= \frac{100}{0,471} = 1 \text{ in } 212,16$$

$$\text{Velocity} = C\sqrt{R.I}$$

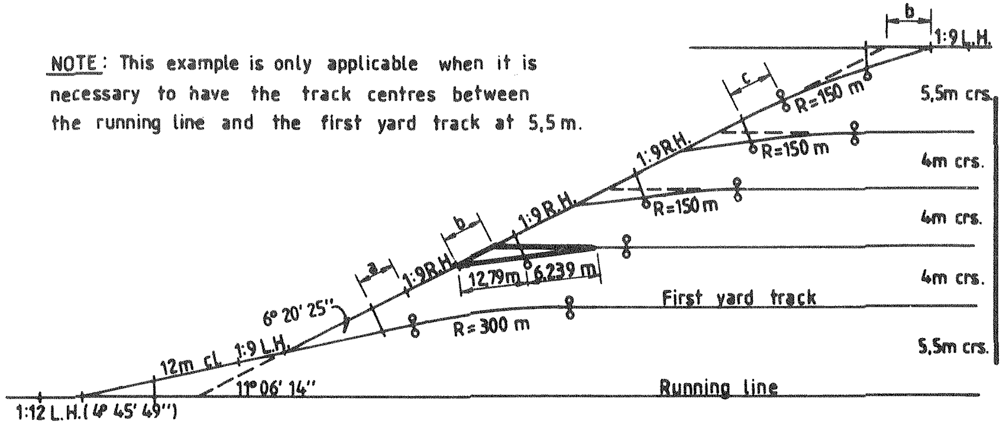
where:- C = coefficient of function

$$R = \frac{\text{cross-sectional area of pipe}}{\text{circumference of pipe}}$$

$$I = \frac{\text{difference in height}}{\text{distance}}$$

C.V.

NOTE: This example is only applicable when it is necessary to have the track centres between the running line and the first yard track at 5,5 m.



MAXIMUM GATHERING ANGLE EXAMPLE

$$\text{SIN } \emptyset = \frac{\text{MIN. TRACK CENTRES IN YARD}}{\text{LENGTH OF YARD SET}}$$

C.V.

TRACKWORK

MAXIMUM GATHERING ANGLE

Calculations required:

1. Maximum gathering angle: $\sin \theta = \frac{\text{Min. track centres in yard}}{\text{Length of yard set}}$

$$= \frac{4}{20{,}718} = 0{,}193\ 068\ 8$$

$$\therefore\ \theta = 11^\circ\ 07'\ 55''$$

2. Tangent length for 300 m radius curve:

$$T = R.\tan\frac{\theta}{2}$$
$$= 300.\tan 2^\circ\ 22'\ 54{,}5''$$
$$= 12{,}478\ \text{m}$$

3. Tangent length for 150 m radius curve:

$$T = R.\tan\frac{\theta}{2}$$
$$= 150.\tan 2^\circ\ 22'\ 54{,}5''$$
$$= 6{,}239\ \text{m}$$

4. Dimension "b":

$$\frac{b}{\sin 4^\circ\ 45'\ 49''} = \frac{19{,}029}{\sin 11^\circ\ 07'\ 55''}$$

$$\therefore\ b = \frac{\sin 4^\circ\ 45'\ 49'' \times 19{,}029}{\sin 11^\circ 07'\ 55''}$$

$$= 8{,}185\ \text{m}$$

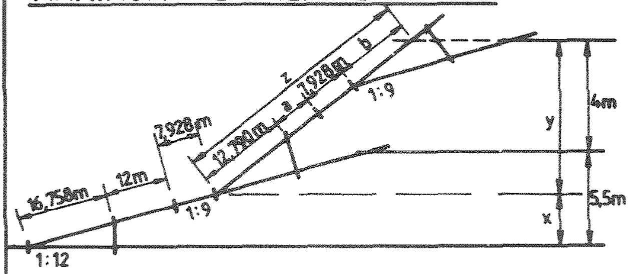
NOTE

The true maximum gathering angle is 11° 07' 55", but 11° 06' 14" is used as this is the angle of a 1 in 9 + 1 in 12 sets. The difference is too small to matter much in practice. (See Green Book section 7 page 12)

C.V.

TRACKWORK

MAXIMUM GATHERING ANGLE



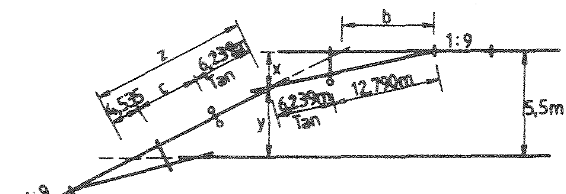
$\sin 4°45'49'' = \frac{x}{36{,}686}$ $\quad\therefore\ x = 3{,}047\ m$

$\therefore\ y = 9{,}5 - 3{,}047 = 6{,}453\ m$

Now $\sin 11°06'14'' = \frac{6{,}453}{z}$ $\quad\therefore\ z = 33{,}509\ m$

$\therefore\ a = 33{,}509 - 12{,}790 - 7{,}928 - b$ (b = 8,185 see calcs.)

$= 4{,}606\ m$



$\sin 6°20'25'' = \frac{x}{19{,}029}$

$\therefore x = 2{,}101\ m$

$y = 5{,}5 - 2{,}101 = 3{,}399\ m$

$\sin 11°06'14'' = \frac{y}{z}$

$\therefore\ z = \frac{3{,}399}{\sin 11°06'14''} = 17{,}647\ m$

$c = 17{,}647 - 10{,}874$

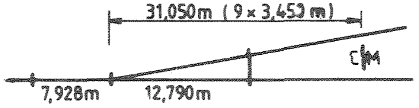
$= 6{,}773\ m$

C.V.

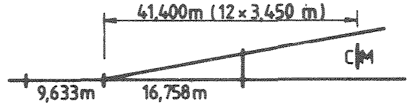
TRACKWORK

NOTES:

1. Centres of tracks at clearance markers = 3,450 m



1 in 9 turnout



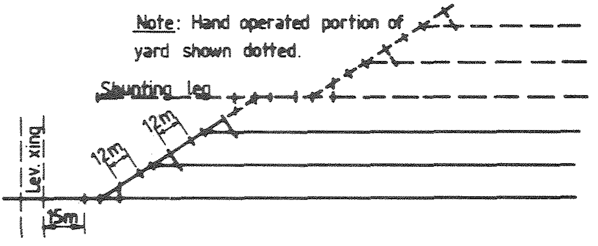
1 in 12 turnout

2. Centres of tracks at safety set = 3,650 m
3. Minimum track centres = 4 m
4. Centres of tracks having water column or parachute tank between = 5,500 m
5. To provide for erection of electric light poles, electrification masts and future masts, not more than four tracks should be spaced at 4 m centres and the fifth track at 5,500 m centres.
6. In yards curves should normally not be sharper than 140 m radius. If a sharper radius is permitted by the C.C.E. the absolute minimum will be 100 m.
7. Curves of 150m radius and sharper in running lines must be provided with check rails.
8. Hayes derail or scotch block to be a minimum of 2 m inside the clearance marker.
9. S.R.J. to be 15m from edge of level crossing to allow for a 12 m locking bar.

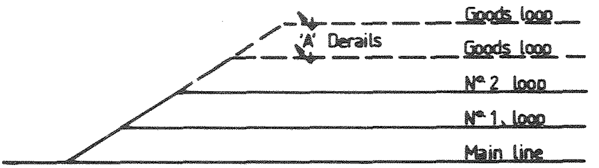
(continued) C.V.

TRACKWORK

10. On all signalled roads a minimum closure of 12 m is to be allowed for a locking bar. Not required where points are track locked

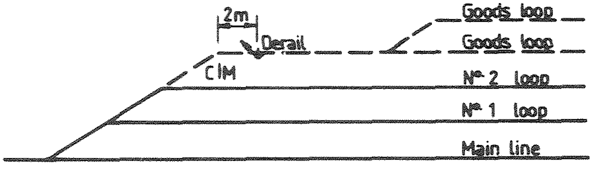


11.



Vehicles derailed at 'A' may be rerailed at vee of next set.

BAD LAYOUT

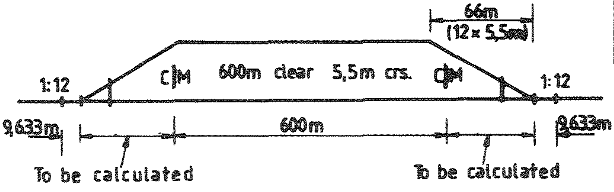


GOOD LAYOUT

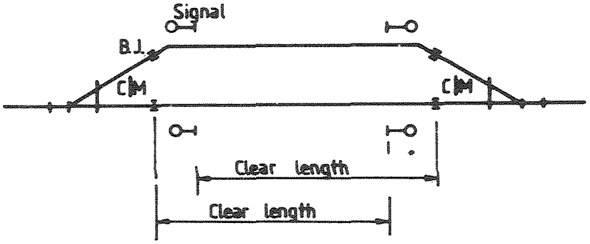
(continued) C.V.

TRACKWORK

12. EXAMPLE OF CLEARANCE ON UNSIGNALLED ROADS.

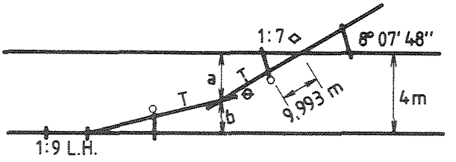


13. EXAMPLE OF CLEARANCE ON SIGNALLED ROADS.



TRACKWORK

14. Calculate minimum radius



$a + b = 4\,m$

$a = (9{,}993 + T)\ \sin 8°\,07'\,48''$

$b = (12{,}790 + T)\ \sin 6°\,20'\,25''$

$\therefore (9{,}993 + T)\sin 8°\,07'\,48'' + (12{,}790 + T)\sin 6°\,20'\,25'' = 4$

$1{,}413\ 206 + T.\sin 8°\,07'\,48'' + 1{,}412\ 438 + T.\sin 6°\,20'\,25'' = 4$

$0{,}141\ 420\ T + 0{,}110\ 433\ T = 4 - 1{,}413\ 206 - 1{,}412\ 438$

$0{,}251\ 853\ T = 1{,}174\ 356$

$T = 4{,}662\ m$

$= R.\tan\frac{\theta}{2}$

$\therefore R = \dfrac{T}{\tan\frac{\theta}{2}} \quad (\theta = 8°\,07'\,48'' - 6°\,20'\,25'')$

$= 298{,}410\ m$

Check

$a = (4{,}662 + 9{,}995)\ \sin 8°\,07'\,48''$

$= 2{,}073\ m$

$b = (4{,}662 + 12{,}790)\ \sin 6°\,20'\,25''$

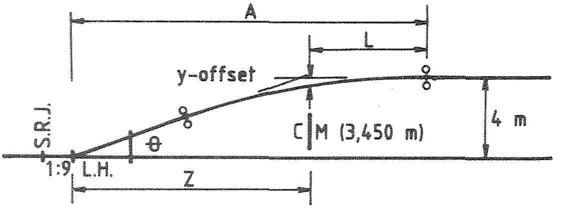
$= 1{,}927\ m$

$a + b = 4\ m$

$2{,}073 + 1{,}927 = 4\,m$

TRACKWORK

15. Calculation of position of clearance marker on curved track.



NOTE: Before "Z" is calculated, check whether clearance marker falls within curve.

(4 x 9) - tangent length $\leqslant$ 9 x 3,450

Determine "Z"

At clearance marker = 3,450 m
Track centres = 4 m
Radius of curve = 400 m
1 in 9 set: θ = 6° 20' 25"

A = (9 x 4) + tangent length of curve
= 36 + (400 x Tan 3° 10' 13")
= 36 + 22,155
= 58,155 m

Offset y = 4 - 3,450
= 0,550 m

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

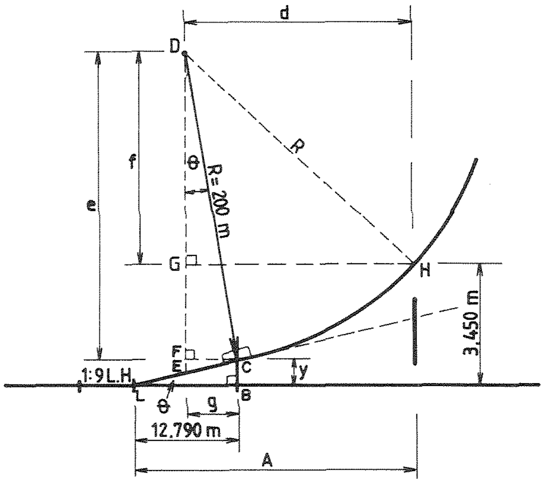
$= \sqrt{400^2 - (400 - 0{,}550)^2}$

= 20,969 m

Now Z = A - L
= 58,155 - 20,969
= 37,186 m

TRACKWORK

16. Calculation of position of clearance marker on curved track.



i. $A = d - g + 12{,}790$ m

ii. ΔLCB and ΔEDC are similar triangles.
because: $L\hat{C}B = C\hat{E}D$ ($CB \parallel DE$)
$C\hat{B}L = DCE = 90°$ ($CB \perp LB$ and $DC \perp LC$)
$\therefore B\hat{L}C = E\hat{D}C = 6° 20' 25''$

iii. $e = R.\cos\theta = 200 \times \cos 6° 20' 25'' = 198{,}777$ m
$y = LB.\tan\theta = 12{,}790 \times \tan 6° 20' 25'' = 1{,}421$ m
$\therefore f = e + y - 3{,}450 = 198{,}777 + 1{,}421 - 3{,}450 = 196{,}748$ m

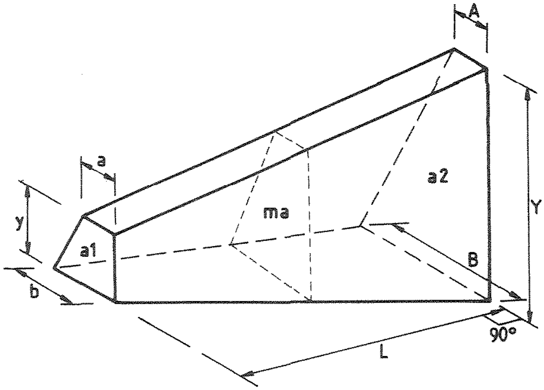
iv. $g = R.\sin\theta = 200 \times \sin 6° 20' 25'' = 22{,}087$ m
$d = \sqrt{R^2 - f^2} = \sqrt{200^2 - 196{,}748^2} = 35{,}920$ m
Now $A = 35{,}920 - 22{,}087 + 12{,}790 = \underline{26{,}623 \text{ m}}$

C.V.

WING WALLS

TO CALCULATE VOLUME

PRISMOIDAL EQUATION



The Prismoidal equation is : $V = \frac{L}{6}(a_1 + a_2 + 4ma)$

where a_1 = area of small end
a_2 = area of large end
ma = middle area

By substituting, the equation becomes :

$$VOL = \frac{L}{12}\left[y(a+b) + Y(A+B) + (a+b+A+B)(y+Y)\right]$$

VOLUMES

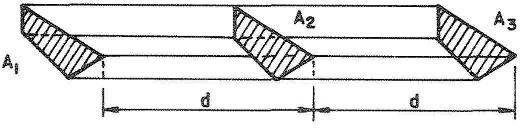
1. When earthwork quantities are required for estimating purposes , it can be calculated from cross-sections or longitudinal sections using any one of the following methods
   i) Prismoidal
   ii) Simpsons rule
   iii) End area

2. When earthwork quantities are required for tender or payment purposes , it must be calculated from cross-sections which are levelled (no interpolation allowed) and using Simpsons rule for volumes.

VOLUMES

VOLUMES FROM CROSS SECTIONS

I. END AREAS METHOD



If two cross sectional areas A_1 and A_2 are horizontal distance d apart, the volume contained between the two cross sections is :

$$V_1 = d_1 \frac{(A_1 + A_2)}{2}$$

This leads to the general equation for a series of n cross sections.

$$V = V_1 + V_2 + V_3 + \ldots + V_{n-1}$$

$$= d_1 \frac{(A_1 + A_2)}{2} + d_2 \frac{(A_2 + A_3)}{2} + d_3 \frac{(A_3 + A_4)}{2} \ldots + d_{n-1} \frac{(A_{n-1} + A_n)}{2}$$

If $d_1 = d_2 = d_3 = d_{n-1} = d$

$$\therefore \text{VOLUME} = d\left[\frac{(A_1 + A_n)}{2} + A_2 + A_3 + \ldots A_{n-1}\right]$$

This equation is comparable to the trapezoidal rule for areas.

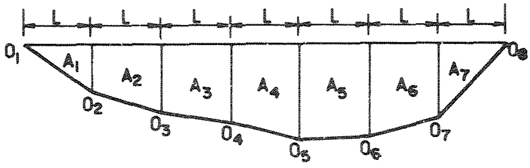
II SIMPSONS RULE FOR VOLUMES

$$\text{VOLUME} = \frac{d}{3}[A_1 + A_n + 4 \text{ (even areas)} + 2 \text{ (remaining odd areas)}]$$

C.V.

AREAS

TRAPEZOIDAL RULE



The figure shows an area bounded by a survey line and a boundary. The survey line is divided into a number of small equal intercepts of length L and the offsets O_1 to O_8 are measured on the ground or scaled off the plan. If L is small enough the boundary line between offsets can be assumed to be a straight line and the area can therefore be considered to be made up of a series of trapezoids.

Area of trapezoid 1 $= \left(\frac{O_1 + O_2}{2}\right) \times L$

Area of trapezoid 2 $= \left(\frac{O_2 + O_3}{2}\right) \times L$

Area of trapezoid 6 $= \left(\frac{O_6 + O_7}{2}\right) \times L$

$\therefore$ Area $= \frac{L}{2}(O_1 + 2O_2 + 2O_3 + \ldots\ldots\ldots\ldots + O_7)$

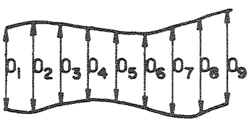
In general with n offsets :

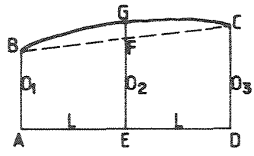
$$\text{AREA} = L\left[\left(\frac{O_1 + O_n}{2}\right) + O_2 + O_3 + \ldots\ldots\ldots\ldots + O_{n-1}\right]$$

AREAS

SIMPSONS RULE

This method gives more accurate results than the trapezoidal method. In this method it is assumed that the irregular boundary is made up of a series of parabolic arcs. In this method the area must be divided into an even number of equal width strips.





ENLARGEMENT

The area between offset O_1 and O_3 which is ABGCDEA

$$= \text{trapezoid ABFCDEA} + \text{area BGCFB}$$

$$= \left(\frac{O_1+O_3}{2}\right)2L + \frac{2}{3}\text{area of circumscribing parallelogram}$$

$$= \left(\frac{O_1+O_3}{2}\right)2L + \frac{2}{3}2L\left[O_2 - \left(\frac{O_1+O_3}{2}\right)\right]$$

$$= \frac{L}{3}(3O_1 + 3O_3 + 4O_2 - 2O_1 - 2O_3)$$

$$= \frac{L}{3}(O_1 + 4O_2 + O_3)$$

For the area between offsets O_3 and O_5

$$\text{Area} = \frac{L}{3}(O_3 + 4O_4 + O_5)$$

For the area between offsets O_5 and O_7

$$\text{Area} = \frac{L}{3}(O_5 + 4O_6 + O_7)$$

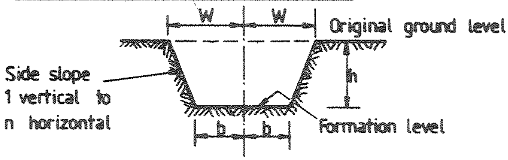
$$\therefore \text{Total area} = \frac{L}{3}[(O_1 + O_7) + 2(O_3 + O_5) + 4(O_2 + O_4 + O_6) + \dots\dots]$$

In the general case :

> AREA $= \frac{L}{3}$ [sum of the first and last intercept + 2 (sum of the odd numbered offsets) + 4 (sum of the even numbered offsets)]

AREAS

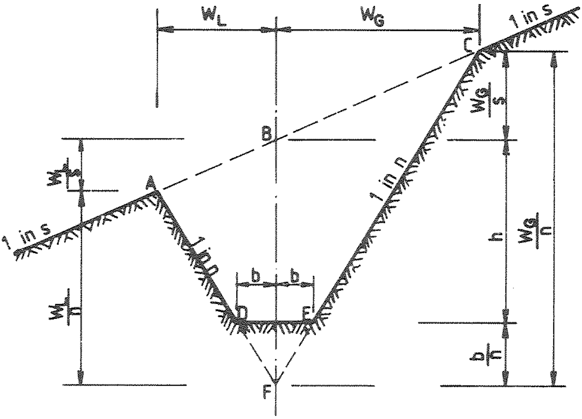
1. EXISTING GROUND LEVEL HORIZONTAL



Area of cross section = $h(2b + nh)$

For an embankment the diagram is inverted and the same equation apply.

2. EXISTING GROUND LEVEL SLOPING



Area = Area ABF + Area BCF − Area DEF

$$A = \frac{s^2(2bh + nh^2) + nb^2}{s^2 - n^2}$$

$$WL = \frac{s(b + nh)}{s + n} \quad \text{and} \quad WG = \frac{s(b + nh)}{s - n}$$

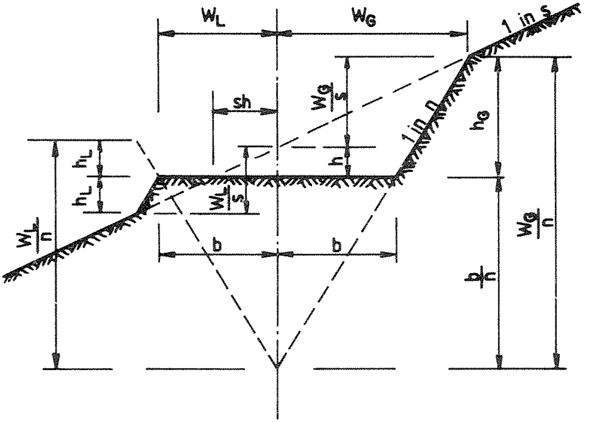
For an embankment the figure is inverted and the same equation applies.

(continued) C.V.

AREAS

(continued)

3. CROSS SECTIONS INVOLVING CUT AND FILL



Lesser area $= \dfrac{(b-hs)^2}{2(s-n)}$

Greater area $= \dfrac{(b+hs)^2}{2(s-n)}$

If the fill area is greater than the cut area then use the greater area equation for the fill and the lesser area equation for the cut which is the reverse of the example in the figure.

ENGINEERING SURVEY STANDARDS OF ACCURACY

STAKING (E13 - 1985)

LIMITS OF ALLOWABLE ERROR	STRAIGHTS OR CURVES	DISTANCE MEASUREMENT	ALIGNMENT
		$\not>$ 30 mm / 100 m	$\not>$ 10 mm
ACCURACY	Co-ordinates of staking pegs to be calculated to nearest 0,01 m		
TRANSITIONS	Radius $\leqslant$ 300 m ——— 60 m transition Radius $>$ 300 m ——— 80 m transition		
DISTANCE	STRAIGHTS : Distance pegs or marks on rail at 20 m intervals. RADIUS $>$ 140 m : Distance pegs at 20 m intervals. RADIUS $\leqslant$ 140 m : Distance pegs at 10 m intervals.		
ALIGNMENT	Line pegs to be provided at every half km.		

C.V.

ENGINEERING SURVEY STANDARDS OF ACCURACY

TRIANGULATION (E13 - 1985)

		DIRECTIONS			LIMITS OF ALLOWABLE ERROR
		RECORDING	MIN. NO. OF ARCS	MISCLOSURE	
RECCE & ANCILLARY SURVEY	Rays > 1000m	Nearest 10″	One	$\ngtr$ 10″	$D \ngtr 3(0{,}3 + \frac{17\,000}{3S + 1000})$ seconds
	Rays < 1000m	Nearest 20″	One	$\ngtr$ 20″	eg. $D \ngtr 40''$ where $S = 1000$ m
LINE & STRIP SURVEY	Rays > 1000m Rays < 1000m	Nearest 1″ Nearest 10″			$D \ngtr 1{,}5(0{,}3 + \frac{17\,000}{3S + 1000})$ seconds
	Rays > 3000m Rays < 3000m		Two One	$\ngtr$ 5″	Fixing angles must lie between 30° & 150°

NOTE : D = difference between observed and calculated values of any direction used in determining the position of the unknown point.

S = distance between known and unknown point in metres.

Arc = an 'arc' of observations is the mean of two rounds of observations one clockwise (⊙L) and one anti-clockwise (⊙R). Both must close on R.O.

C.V.

ENGINEERING SURVEY STANDARDS OF ACCURACY

TRAVERSES & DETAILED SURVEY (LEVELLING) (E13 – 1985)

	TRIGONOMETRICAL LEVELLING	SPIRIT LEVELING
RECCE & ANCILLARY SURVEY	Read vertical angle to nearest 10". Reduce levels to nearest 0,1 m. Take 2 sets min. $\Delta m \ngtr 10''$ $\Delta L \ngtr$ 1 in 10 000	May be used provided the accuracy is proven.
LINE, STRIP & STATION YARD SURVEYS	Permitted only in exceptional circumstances with C.C.E.'s permission.	Read levels to nearest 2 mm. Between through and check levelling: $0{,}030\sqrt{S}$ in km. Between BM's: $0{,}009 + 0{,}000\ 3\sqrt{S}$ in m.

NOTE : Δm = difference between means of sets.

set = a set of observations consists of vertical readings taken in each of the ⊙L and ⊙R positions.

ΔL = closing error in levelling.

S = sum of legs of traverse in metres or distance to nearest benchmark in metres.

C.V.

ENGINEERING SURVEY STANDARDS OF ACCURACY

TRAVERSES & DETAILED SURVEY (E13 - 1985)

		DIRECTIONS			DISTANCES	CO-ORD. CALCS.
		RECORDING	MIN. NO. OF ARCS	MISCLOSURE		
RECCE & ANCILLARY SURVEY		Nearest 20″	One	$\ngtr$ 20″	By tache to nearest 0,1 m. $\Delta s \ngtr$ 1 in 600 $E \ngtr$ 1 in 1000	Nearest 0,5 m
LINE, STRIP & STATION YARD SURVEYS	Leg > 3 000 m Leg < 3000 m	Nearest 1″	Two One	$\ngtr$ 5″	By tape to nearest 0,01 m $E \ngtr 1{,}5(0{,}005 + \frac{S}{24\,000})$ eg. S = 1000 m ∴ E = 0,29 m	Nearest 0,01 m

NOTE : Δs = difference between two tache measurements

E = closing error = $\sqrt{(X\ error)^2 + (Y\ error)^2}$

S = sum of legs of traverse in metres

Arc = an 'arc' of observations is the mean of two rounds of observations, one clockwise (⊙L) and one anti-clockwise (⊙R). Both must close on R.O.

LEVEL BOOK

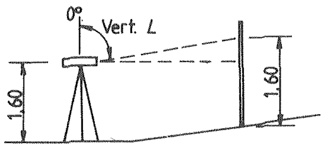
BACK SIGHT	INTER. SIGHT	FORE SIGHT	RISE +	FALL -	REDUCED LEVEL	FINAL LEVEL	DISTANCE	REMARKS
(Leave first line blank for entering last reading of previous page)								
2,975	(Set up instrument and take reading on B.M.24)					18,340		B.M.24 (existing level)
	2,564		0,411			18,751	6,100	Edge formation
	2,585			0,021		18,730	7,900	Top bank
	3,030			0,445		18,285	9,400	Bottom bank
	3,094			0,064		18,221	13,000	Spot
	1,673		1,421			19,642	16,000	Spot
	1,390		0,283			19,925	18,500	Spot
	3,840		5,230			25,155	22,170	Underside bridge
	1,311			5,151		20,004	24,300	Spot
	~~1,097~~	1,097	0,214			20,218	27,500	Spot
2,975		1,097	7,559	5,681		20,218		
-1,097			-5,681			- 18,340		
= 1,878			= 1,878			= 1,878		

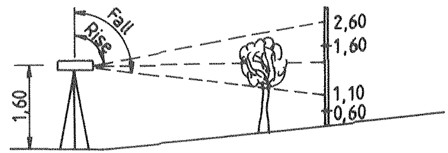
When reading is less than previous one, difference is a rise.
When reading is greater than previous one, difference is a fall.

C.V.

TACHEOMETER BOOK

STATION & INST. HT.	HOR. ANGLE	VERT. ANGLE	STADIA READING	HOR. DISTANCE	RISE	FALL	ALTITUDE	REMARKS
A. H.I. 1,60							99,88	
	285° 25′	93° 23′		200		11,78	88,10	Invert furrow
	308° 47′	86° 28′		210	12,92		112,80	Top bank
2,60	358° 09′	105° 15′		~~80~~ 74,47		~~20,30~~ 21,30	78,58	Invert manhole
	203° 28′	73° 00′		~~65~~ 59,44	18,17		118,05	Top bank
1,10	3° 52′	86° 42′		83	~~4,77~~ 5,27		105,15	Top retaining wall
0,60	18° 21′	92° 30′		163		~~7,10~~ 6,10	93,78	Cattle kraal cnr.





When vertical angle is less than 90°, rise.
When vertical angle is more than 90°, fall.

Rise or fall $= d.\frac{1}{2} \sin 2A$ (d = slope distance)

Corrected distance (hor. distance) $= d.\cos^2 A$ (d = slope distance)

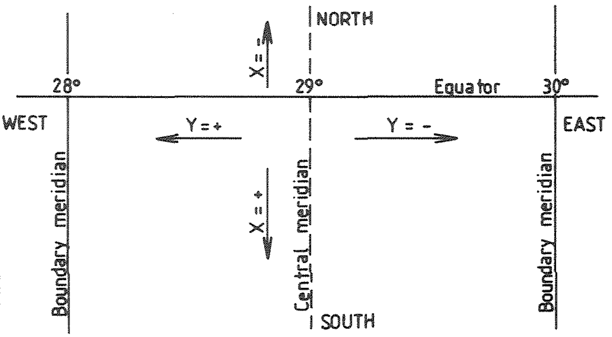
C.V.

CO-ORDINATES

THE SOUTH AFRICAN CO-ORDINATE SYSTEM

The South African co-ordinate system is based upon the Gauss Conform Projection (also known as the Transverse Mercator Projection).

The system consists of belts running north and south, 2° of longitude wide, the central meridian being every odd meridian, i.e., 15°, 17°, 21°......33°.... Each belt is referred to as Lo 15°, Lo 27°, Lo 31°, etc.

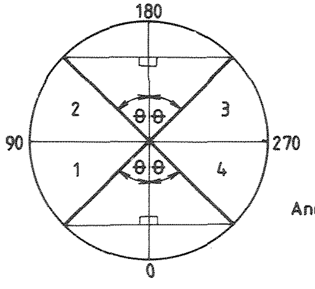


If a survey falls on or near the boundary meridian, it is usual to do the entire survey in the belt in which the greater portion of the area falls. For this purpose the co-ordinates of trig. beacons falling within an overlap area of 15 minutes of longitude on either side of the boundary meridian, are given on both co-ordinate systems.

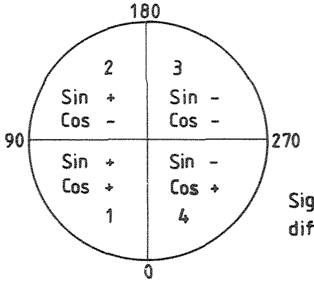
The S.A. co-ordinate system (Lo system) has 0° to south and angles are always measured in a clockwise direction.

C.V.

CO-ORDINATES

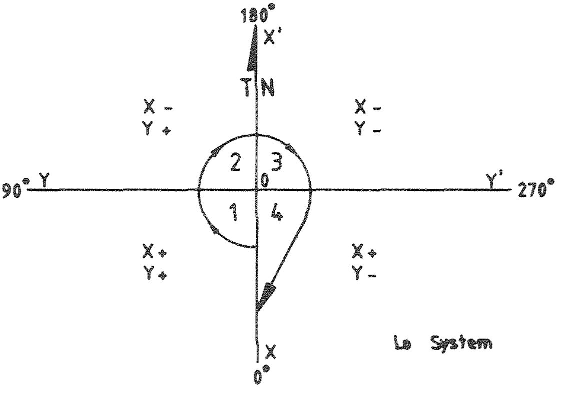


Angle to be looked up = θ

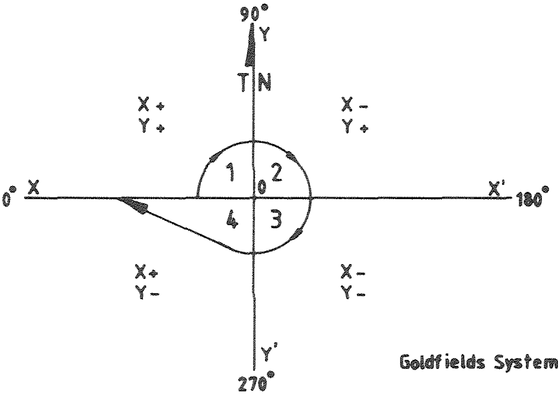


Signs of angles in different quadrants

CO-ORDINATE SYSTEM



Lo System

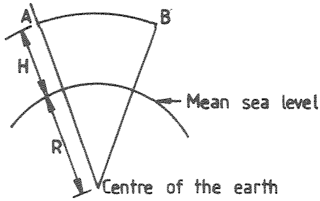


Goldfields System

C.V.

CO-ORDINATES

SCALE ENLARGEMENT AND REDUCTION TO SEA LEVEL.



The figure indicates how a line AB, measured at height H above mean sea level, is longer than its projected distance at mean sea level. As the triangulation system is based upon distances as they would be measured at mean sea level, a correction must be applied to measured distances, for accurate work.

When working far from the central meridian of a co-ordinate system, it is necessary for accurate work, to apply a scale enlargement factor, to compensate for the difference between a spheroidal distance and its equivalent on the projection.

The formula allowing for both these corrections is :

$$\text{Correction factor} = \frac{H+R}{R} - \frac{Y^2}{2R^2}$$

where : H = mean height above sea level
Y = mean Y co-ordinate (in metres)
R = radius of the earth (6 367 000 m)

The correction factor so obtained must be applied to to all distances used in co-ordinate calculations. All distances must be at mean sea level (M.S.L.).

$$\text{M.S.L. distance} = \frac{\text{measured distance}}{\text{correction factor}}$$

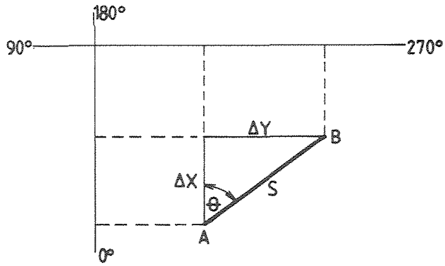
Distance to be measured = M.S.L. distance × factor .

C.V.

CO-ORDINATES

CALCULATION OF THE JOIN

To calculate the distance and direction between two points, the co-ordinates of which are known.



STA.	DIRECTION DISTANCE	ΔY	ΔX	Y	X
A				± YA	± XA
	D √ S	ΔY (check)	ΔX (check)		
B				± YB	± XB
				ΔY	ΔX

1. To find ΔY and ΔX change the signs of YA and XA and add.
2. $\theta = \text{Tan}^{-1}$ or Cot^{-1} of $\frac{\text{Lesser } \Delta}{\text{Greater } \Delta}$ ($\frac{\Delta Y}{\Delta X} = \text{Tan}\,\theta$ & $\frac{\Delta X}{\Delta Y} = \text{Cot}\,\theta$)
3. D = direction AB = 180 + θ (for this example).
4. S = distance AB = $\sqrt{\Delta Y^2 + \Delta X^2}$

EXAMPLE

A				- 1 058,47	+310 248,17
	√ 213° 27' 35" 1141,868 m	-629,570	-952,630		
B				- 1 688,04	+309 295,54
				- 629,57	- 952,63

NOTE: The √ sign in the second column indicates that the join has been checked.

(see next page)

C.V.

CO-ORDINATES

CALCULATION OF THE JOIN

(continued)

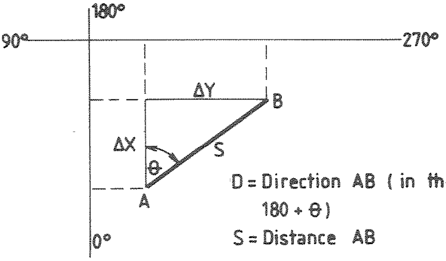
After the join has been calculated, the calculation must be checked. The only complete check of a join is to calculate a polar from A to B, i.e., the co-ordinates of B are calculated from A by using the direction and distance obtained in the original calculation. The check ΔY and ΔX must be added to YA and XA to check if the answer is the same as the original YB and XB. The fact that the ΔY's and ΔX's are the same, is not a check.

The method in this example is at present being taught at the Chief Civil Engineer's training centre for draughtsmen

CO-ORDINATES

CALCULATION OF THE POLAR

To calculate the co-ordinates of an unknown point, by distance and direction, from a known point.



D = Direction AB (in this case — 180 + θ)
S = Distance AB

STA.	DIRECTION DISTANCE	ΔY	ΔX	Y	X
A				± YA	± XA
	D° S	ΔY S. Sin D°	ΔX S. Cos D°		
B				√ ± YB	√ ± XB
				ΔY (check)	ΔX (check)

1. When using an electronic calculator to calculate ΔY and ΔX, the algebraic signs will be given by the calculator as part of the answer.
2. When not using a calculator, the algebraic signs of ΔY and ΔX can be determined by checking into which quadrant the direction AB falls.

EXAMPLE

A				-1058,47	+310 248,17
	213° 27' 34" 1141,87	-629,57	-952,63		
B				√ -1688,04	√ +309 295,54
				- 629,57	- 952,63

The √ sign indicates that the co-ordinates of B have been checked.

(see next page)

C.V.

CO-ORDINATES

CALCULATION OF THE POLAR

(continued)

A polar which is not part of a traverse or which is not checked by another polar from a different point, is very dangerous and is virtually never used. The only really satisfactory check of a single polar is to calculate a join between the two points, using only the co-ordinates obtained from the original calculation. The check ΔY and ΔX must be used to check the distance and direction. The fact that the $\Delta Y'$ and $\Delta X'$ are the same, is not a check.

The method in this example is at present being taught at the Chief Civil Engineer's training centre for draughtsmen

CO-ORDINATES

TRAVERSE CALCULATIONS

To calculate the co-ordinates of stations in a traverse. The co-ordinates of the start and end points are known as well as the angles of direction and distances from station to station are known.

EXAMPLE

STA	DIRECTION DISTANCE	CO-ORD. DIFFERENCES ΔY	ΔX	CO-ORDINATES Y	X
A				−11 757,300	+ 125,300
	299° 09'00"	−484,649	− 32,615		
	458,710	+ 0,019	− 0,020		
B		−484,595	− 32,633	−12241,895	+ 92,667
	257° 31' 51"	−275,848	− 60,998		
	282,512	+ 0,011	− 0,011		
C		−275,837	− 61,009	−12 517,732	+ 31,658
	337° 36' 22"	−232,139	+563,383		
	609,210	+ 0,024	− 0,025		
D		−232,068	+563,242	−12 749,800	+ 594,900

S=1 377,432

	− 992,554	+ 469,656	(sum of ΔY & ΔX)
	− 992,500	+ 469,600	(D − A)
Closing error	+ 0,054	− 0,056	

Allowable closing error $E = 1{,}5\left(0{,}005 + \frac{1\,377{,}432}{24\,000}\right)$

$= 0{,}094$ m

Closing error $E = \sqrt{0{,}054^2 + 0{,}056^2}$

$= 0{,}078$ m

The traverse closing error must be distributed proportionally over the traverse legs.

$$\frac{dy}{S} = \frac{0{,}054}{1\,377{,}432} = 0{,}039\ 203 \text{ m per } 1000 \text{ m}$$

$$\frac{dx}{S} = \frac{0{,}056}{1\,377{,}432} = 0{,}040\ 655 \text{ m per } 1000 \text{ m}$$

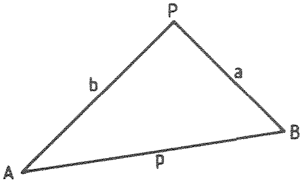
The co-ordinates are adjusted with these differences.

C.V.

CO-ORDINATES

TRIANGULATION CALCULATION

To calculate the co-ordinates of an unknown point if the co-ordinates of two points are known as well as the directions from the known points to the unknown point.



i) Calculate the join between A and B.

ii) Calculate length of sides 'a' and 'b' by using Sin formula : $\frac{a}{\text{Sin A}} = \frac{p}{\text{Sin P}}$ $\frac{b}{\text{Sin B}} = \frac{p}{\text{Sin P}}$

iii) Calculate co-ordinates of P by two polar calculations, one from A and one from B. The two sets of co-ordinates so obtained should be the same.
If the co-ordinates of P were calculated from A, then the calculation from B is the check. The join between A & P and between B & P do not have to be calculated for a check.

(see next page for example)

CO-ORDINATES

TRIANGULATION CALCULATION

EXAMPLE

(Refer to sketch on previous page)

a) Co-ordinates A − 5 610,610 + 11 643,681
B − 5 832,810 + 11 511,430

b) Angles of direction AP 205° 30′ 20″
BP 132° 20′ 10″

Calculate the co-ordinates of P.

i) Calculation of join AB :

A	√ 239° 14′ 22″ 258,579 m	−222,200	−132,251	− 5 610,610	+ 11 643,681
B				− 5 832,810	+ 11 511,430
				− 222,200	− 132,251

ii) Calculate lengths of sides AP and BP :

$B\hat{A}P = (239°14'\,22'' - 205°\,30'\,20'') = 33°\,44'\,02''$

$P\hat{B}A = (132°\,20'\,10'' - 59°\,14'\,22'') = 73°\,05'\,48''$

$A\hat{P}B = 180° - (33°\,44'\,02'' + 73°\,05'\,48'') = 73°\,10'\,10''$

$$\frac{a}{\text{Sin A}} = \frac{b}{\text{Sin B}} = \frac{p}{\text{Sin P}}$$

$$a = \frac{p\,\text{Sin A}}{\text{Sin P}} = 150{,}025 \text{ m}$$

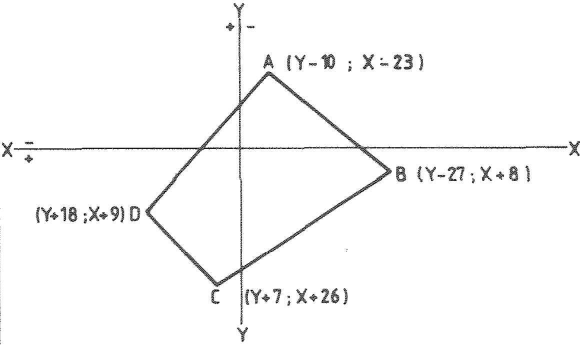
$$b = \frac{p\,\text{Sin B}}{\text{Sin P}} = 258{,}479 \text{ m}$$

iii) Calculation of co-ordinates of P :

A	205° 30′ 20″ 258,479 m	−111,301	−233,289	− 5 610,610	+ 11 643,681
P				− 5 721,911	+ 11 410,392
B	132° 20′ 10″ 150,025 m	+110,899	−101,038	− 5 832,810	+ 11 511,430
P				− 5 721,911	+ 11 410,392

C.V.

AREAS BY CO-ORDINATES



$$AREA = \frac{1}{2}[(Ay+By)(Ax-Bx)+(By+Cy)(Bx-Cx)+(Cy+Dy)(Cx-Dx) + (Dy+Ay)(Dx-Ax)]$$

EXAMPLE

$(Ay+By)(Ax-Bx)$ $= (-10-27)(-23-8)$ $= (-37)(-31)$ $= +1\,147$	$(By+Cy)(Bx-Cx)$ $= (-27+7)(8-26)$ $= (-20)(-18)$ $= +360$
$(Cy+Dy)(Cx-Dx)$ $= (7+18)(26-9)$ $= (25)(17)$ $= +425$	$(Dy+Ay)(Dx-Ax)$ $= (18-10)(9+23)$ $= (8)(32)$ $= +256$

$$AREA = \frac{1}{2}(1147 + 360 + 425 + 256)$$
$$= 1\,094 \ m^2$$

NOTE:
The calculation must be checked by repeating with the difference of the y's and the sum of the x's. The result will now be negative.

C.V.

BRICKWORK

USEFUL QUANTITIES FOR ESTIMATING PURPOSES

MATERIAL IN 10 SQUARE METRES OF BRICKWORK - 5 % ADDED FOR WASTAGE

BEDS AND JOINTS = 10mm.

SIZE OF BRICKS APPROX 222 x 106 x 73 mm
MORTAR 4:1

TYPE OF WALL	No. BRICKS COMMON	No. BRICKS FACE	CEMENT 50kg pkts.	SAND m^3
1/2 BRICK COMMON OR FACE	550		2 pkts	0,27
1 BRICK COMMON	1 100		4 pkts	0,54
1 BRICK FACE ONE SIDE (F. I. S.)	550	550	4 pkts	0,54
1 BRICK FACE TWO SIDES (F. 2. S)		1 100	4 pkts	0,54
280 mm CAVITY COMMON	1 100		4 pkts	0,54
280 mm CAVITY FACE ONE SIDE (F.I.S)	550	550	4 pkts	0,54
280mm CAVITY FACE TWO SIDES (F. 2.S)		1 150	4 pkts	0,54
1 1/2 BRICK COMMON	1 650		6 pkts	0,81
1 1/2 BRICK FACE ONE SIDE (F.I.S) ENGLISH BOND.	825	825	6 pkts	0,81
1 1/2 BRICK FACE ONE SIDE (F.I.S) STRETCHER BOND.	1 100	550	6 pkts	0,81
1 1/2 BRICK FACE TWO SIDES (F.2.S)		1 650	6 pkts	0,81
2 BRICK COMMON	2 200		8 pkts	1,08
2 BRICK FACE ONE SIDE (F.I.S.) ENGLISH BOND	1 375	825	8 pkts	1,08
2 BRICK FACE ONE SIDE (F.I.S) STRETCHER BOND	1 650	550	8 pkts	1,08
2 BRICK FACE TWO SIDES (F.2.S) ENGLISH BOND	550	1 650	8 pkts	1,08
2 BRICK FACE TWO SIDES (F.2.S) STRETCHER BOND	1 100	1 100	8 pkts	1,08

TYPE OF WALL	No. BRICKS COMMON	No. BRICKS FACE	CEMENT 50kg pkts	SAND m^3
2 ½ BRICK COMMON	2 750		10 pkts	1,35
2 ½ BRICK FACE ONE SIDE (F.I.S.) ENGLISH BOND	1 925	825	10 pkts	1,35
2 ½ BRICK FACE ONE SIDE (F.I.S.) STRETCHER BOND	2 200	550	10 pkts	1,35
2 ½ BRICK FACE TWO SIDES (F.2.S) ENGLISH BOND	685	2 065	10 pkts	1,35
2 ½ BRICK FACE TWO SIDES (F.2.S) STRETCHER BOND	1 650	1 100	10 pkts	1,35

CEMENT REQUIREMENTS FOR VARIOUS MIXES

THE NUMBER OF 50kg POCKETS OF CEMENT REQUIRED IS THE NUMBER OF m^3 OF SAND SHOWN IN THE ABOVE TABLES MULTIPLIED BY:

15,09 for 2:1 cement mortar
10,06 for 3:1 cement mortar
7,55 for 4:1 cement mortar
6,04 for 5:1 cement mortar

CEMENT WORK

USEFUL QUANTITIES FOR ESTIMATING PURPOSES

MATERIAL REQUIRED FOR ONE CUBIC METRE (m^3) OF CONCRETE

MIX	CEMENT 50kg PACKETS	SAND	STONE 20mm	REMARKS
1 - 1½ - 3	8,6 pkts	0,42 m^3	0,85 m^3	5% ADDED FOR WASTAGE
1 - 2 - 3	7,9 pkts	0,52 m^3	0,78 m^3	
1 - 2 - 4	6,7 pkts	0,44 m^3	0,89 m^3	THESE QUANTITIES ARE NOT
1 - 3 - 4	5,9 pkts	0,59 m^3	0,78 m^3	SUITABLE WHERE VERY ACCURATE
1 - 3 - 5	5,3 pkts	0,52 m^3	0,79 m^3	CONTROL OF MIXES IS DESIRED
1 - 4 - 6	4,3 pkts	0,57 m^3	0,84 m^3	10 m^2 = 1 DECIARE (da)
				1 pkt. CEMENT = 33 LITRES

FOR CONCRETE SLABS AND FLOORS, THE DEPTH OR THICKNESS OF FLOOR IN MILLIMETRES (mm) MULTIPLIED BY 10 SQUARE METRES GIVES YOU THE QUANTITY OF CONCRETE REQUIRED FOR ONE DECIARE (da), NAMELY, A SLAB 75mm THICK = 0,075 x 10 = 0,75 m^3 OF CONCRETE REQUIRED PER (da.) AND USING THE ABOVE TABLE, THE QUANTITIES OF CEMENT SAND AND STONE ARE EASILY CALCULATED

EXAMPLE: A CONCRETE SLAB 75mm THICK 1-3-5 CONCRETE MIX 0,75 m^3 OF CONCRETE PER (da)

THEREFORE CEMENT = 0,75 x 5,3 = 4 pkts PER (da)

SAND = 0,75 x 0,52 = 0,39 m^3 STONE = 0,75 x 0,79 = 0,59 m^3

CEMENT TOPPING TO FLOORS

1 PART CEMENT TO 2 ½ PARTS SAND. APPROXIMATELY 16 mm THICK
= 1,5 pkts CEMENT AND 0,17 m^3 SAND PER (da)

FOR GRANOLITHIC FLOORS

2,5 kg OF DRY OXIDE IS REQUIRED PER (da) OF FLOOR

NOTE MIXTURE: IMPORTED 1-OXIDE 4 CEMENT
LOCAL 1-OXIDE 2 CEMENT

CEMENT PLASTER

QUANTITIES REQUIRED FOR 10 m^2 APPROXIMATELY 13mm THICK

MIX	CEMENT 50kg PACKETS	SAND
3 - 1	1,3	0,15 m^3
4 - 1	1,0	0,15 m^3
5 - 1	0,75	0,15 m^3
6 - 1	0,65	0,15 m^3

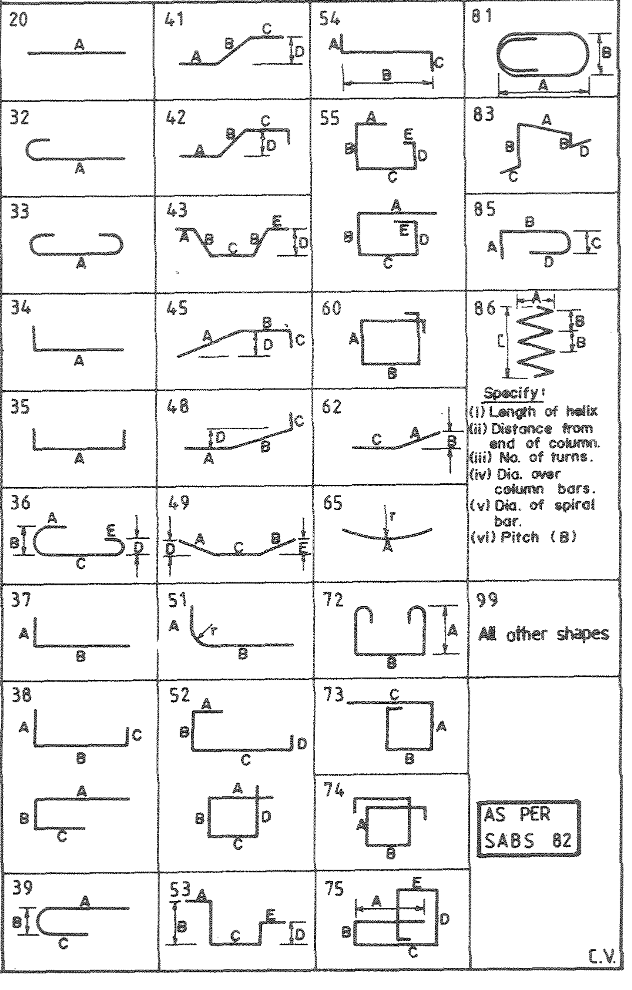
STEEL BARS FOR THE REINFORCEMENT OF CONCRETE

CROSS SECTIONAL AREAS AND MASSES

SIZE mm	CROSS SECTIONAL AREA mm^2	MASS kg/m
6	28,3	0,222
8	50,3	0,395
10	78,5	0,616
12	113,1	0,888
16	201,1	1,579
20	314,2	2,466
25	490,9	3,854
32	804,2	6,313
40	1256,6	9,864
50	1963,5	15,413

C.V.

REINFORCING.
STANDARD SHAPE CODES



REINFORCING.

CALCULATED LENGTHS

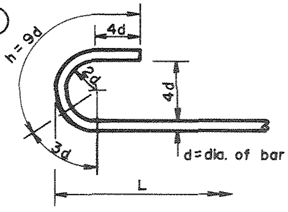
20 A	41 A + B + C	54 A + B + C − r − 2d	81 2A + 3B + 5d
32 A + h	42 If angle with horz. is 45° or less A + B + C + n	55 A + B + C + D + E − 2r − 4d	83 A + 2B + C + D − 2r − 4d
33 A + 2h	43 If angle with horz. is 45° or less A + 2B + C + E		85 A + B + 0,57C + D − ½r − 2,57d
34 A + n	45 A + B + C − ½r − d	60 2 (A + B) + 2n	86 Where B does not exceed $\frac{A}{5}$, the length is $\frac{C}{B}\pi(A-d) + 8d$ where : A = External dia. N = No. of turns B = Pitch of helix d = Nom. dia. of bar
35 A + 2n	48 A + B + C	62 If angle with horz. is 45° or less A + C	
36 (A + C + E) + 0,57(B + D) − 3,14d	49 If angle with horz. is 45° or less A + B + C	65 A	
37 A + B − ½r − d If r is non-standard use shape code 51.	51 A + B − ½r − d If r is standard use shape code 37	72 2A + B + 2h	99
38 A + B + C − r − 2d	52 A + B + C + D − 1½r − 3d	73 2A + B + C + n	AS PER SABS 82
		74 2A + 3B + 2n	
39 A + 0,57B + C − 1,57d	53 A + B + C + D + E − 2r − 4d	75 A + B + C + 2D + E	C.V.

REINFORCING.

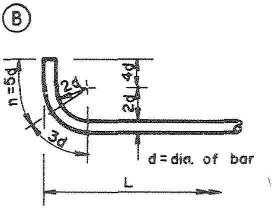
MINIMUM HOOKS AND BENDS.

I. MILD STEEL BARS. (R)

(A)



(B)



(A) = SEMI-CIRCULAR HOOKS (Shape codes 32, 33 and 72)

h = Hook allowance = 9d (min.) taken to the nearest 10 mm over, or not less than 100 mm to be added to dimension L.

(B) = BENDS FORMING END ANCHORAGES (Shape codes 34, 35 and 42)

n = Bend allowance = 5d (min.) taken to the nearest 10 mm over, or not less than 100 mm added to dimension L.

Size of bar, mm	d	8	10	12	16	20	25	32	40
Hook allowance,	h	100	140	170	190	210	240	290	360
Bend allowance,	n	100	100	100	120	130	150	180	200

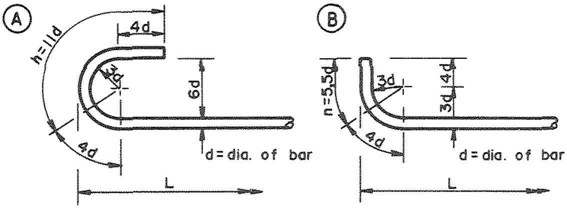
AS PER SABS 82

C.V.

REINFORCING.

MINIMUM HOOKS AND BENDS.

II. HIGH YIELD STRESS STEEL BARS. (Y)



(A) = SEMI-CIRCULAR HOOKS (Shape codes 32, 33 and 72)

h = Hook allowance = 11d (min.) taken to the nearest 10mm over, or not less than 180 mm to be added to dimension L.

(B) = BENDS FORMING END ANCHORAGES (Shape codes 34, 35 and 42)

n = Bend allowance = 5,5d (min.) taken to the nearest 10mm over, or not less than 130 mm to be added to dimension L.

Size of bar, mm	d	8	10	12	16	20	25	32	40
Hook allowance	h	150	180	210	240	280	340	400	480
Bend allowance	n	100	130	130	150	170	190	220	250

AS PER SABS 82

C.V.