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RELATION BETWEEN VERSINE, CHORD AND RADIUS

In Figure 1, ABC is an arc of a circle with centre X and chord AC. The line XDB passing through the centre of the chord at D is a radius of the circle as are AX and CX.

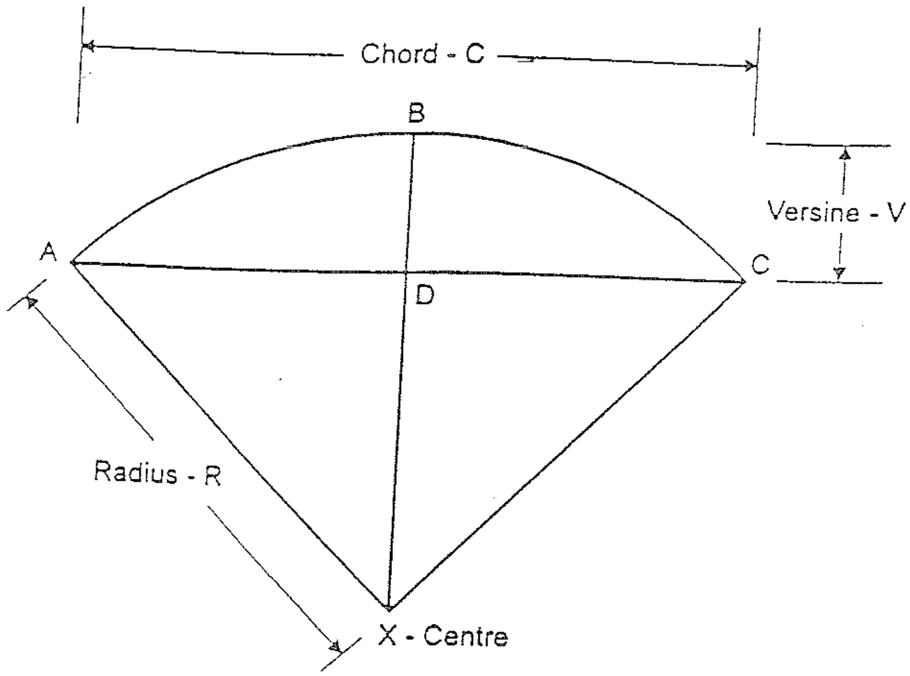


Figure 1

The triangle ADX is right-angled at D, so that:

	(I)	$AX^2 = AD^2 + DX^2$
or	(ii)	$DX^2 = AX^2 - AD^2$
and	(iii)	$DX = \sqrt{(AX^2 - AD^2)}$

The versine BD = BX - DX = v.
BX and AX are the radii of the circle = R.
AD is half the chord C or = $\frac{C}{2}$

By substituting v, R and $\frac{C}{2}$ in (iii)

then $v = R - \sqrt{\left(R^2 - \left(\frac{C}{2}\right)^2\right)}$

from which $R - v = \sqrt{\left(R^2 - \left(\frac{C}{2}\right)^2\right)}$.

Therefore squaring both sides:

$$R^2 - 2Rv + v^2 = R^2 - \left(\frac{C}{2}\right)^2$$

whence $2Rv - v^2 = \left(\frac{C}{2}\right)^2$

$$2R - v = \frac{C^2}{4v}$$

$$2R = \frac{C^2}{4v} + v$$

$$R = \frac{C^2}{8v} + \frac{v}{2}$$

For railway curves the versine is very small in relation to the chord and no practical difference arises through omitting the final $\frac{v}{2}$ in the above, thus the formula becomes:

$$R = \frac{C^2}{8v}$$

or can be transported to the forms:

$v = \frac{C^2}{8R}$ or $C = \sqrt{(8Rv)}$

RELATION BETWEEN VERSINE AND CHANGE OF DIRECTION

In figure 2, ABC is an arc of a circle with centre X and chord AC. The line XDB passing through the centre of the chord at D is a radius of the circle as are AX and CX. The lines AE and CE are tangents to the arc at the chord points A and C respectively. Therefore the change of direction from A to C is measured. In the form of the angle β; That is the total angle turned through.

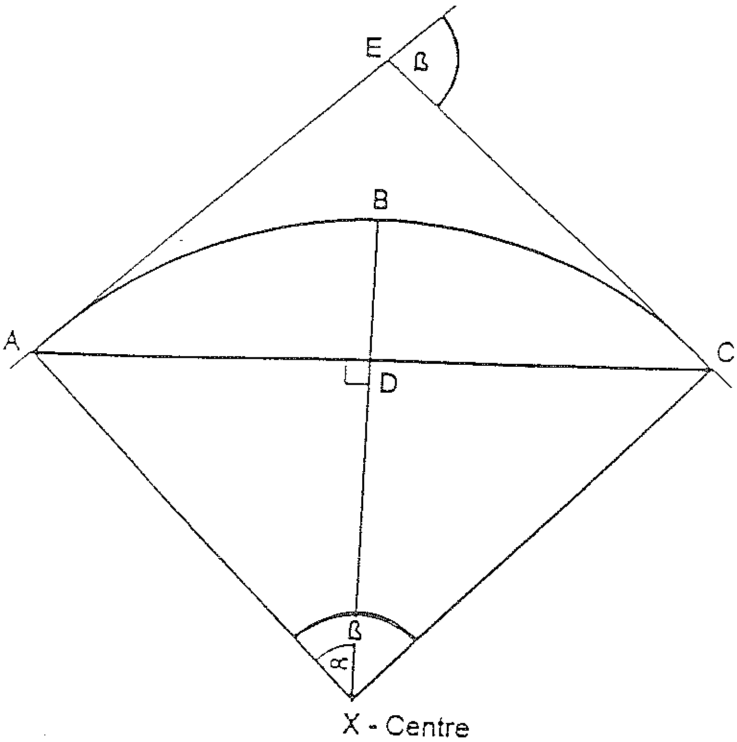


Figure 2.

The triangle ADX is right-angled at D, so that:

(I) $\text{Sin } \alpha = \frac{AD}{AX}$

AD is half the chord = $\frac{C}{2}$ and

AX is the radius of the circle = $R = \frac{C^2}{8v}$ as previously shown and by substituting these values in (I) then:

$$\text{Sin } \alpha = \frac{\frac{C}{2}}{\frac{C^2}{8v}}$$

from which $\text{Sin } \alpha = \frac{C}{2} \times \frac{8v}{C^2}$

whence $\quad \text{Sin}\ \alpha = \frac{4v}{C}$

As previously stated in the relation between versine, chord and radius, the versine is small in relation to the chord, therefore there is no practical difference between the arc and the chord lengths. Hence the angle turned through becomes:

$$\text{Sin}\ \beta = \text{Sin}\ 2\alpha$$

therefore $\quad \text{Sin}\ \beta = \frac{8v}{C}$

That is on chords of constant length the versine will vary directly with the sine of the angle turned through.

RELATION BETWEEN DIFFERENCE OF THE CHANGE OF DIRECTION AND RESULTANT SLUE

In Figure 3, ABC and ABC and ABC, are the existing and proposed areas of the circle. BD and BD, are the existing and proposed versines on the respective chords AC and AC.

It is noted that the areas ABC and ABC, cannot have the same centre X if points A and B are common. However, as the radii of railway curves are usually large it can be assumed that the four points, centre of arc and centre of chord for both existing and proposed curves are collinear. Thus Figure 3 diagrammatically shows the difference in the angle turned through in respect of the common tangent AE.

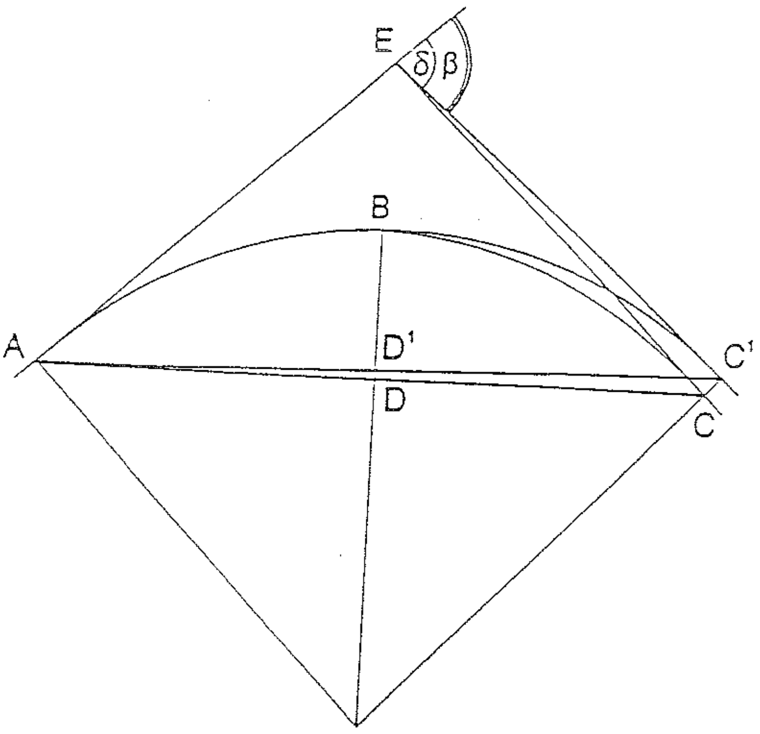


Figure 3

As the versine BD has been amended to BD, then, as stated in the relation between versine and change of direction, the sine of the angle turned through will vary directly with the versine, thus point C will move to C, when points A and B and tangent AE are common to both existing and proposed curves.

Let, u_1 = existing versine BD
v_1 = proposed versine BD
and d_1 = difference in versine DD
then $d_1 = u_1 - v_1$

Let, δ= existing angle turned through
β = proposed angle turned through
and θ = difference in angle turned through
then $\theta = \delta - \beta$

As $\sin \delta = \frac{8u_1}{C}$ where C = chord

and $\sin \beta = \frac{8v_1}{C}$

then $\sin \theta = \frac{8u_1}{C} - \frac{8v_1}{C}$ (for railway curves)

or: $\sin \theta = \frac{8}{C}(u_1 - v_1)$

from which the difference in versine is:

$$d_1 = (u_1 - v_1) = \frac{C.\ \sin \theta}{8}$$

Consider the triangle ACC_1, the versines are at the centre of the chord i.e $\frac{C}{2}$, therefore by similar triangles:

$$CC_1 = 2.DD_1$$

or slue = $2.d_1$

That is the slue due to a change of versine on a chord of the constant length is twice the difference in versines.

By substituting the difference in angle turned through for the difference in versine, then:

$$\text{slue} = 2\ \frac{(C.\ \sin \theta)}{8}$$

hence $\text{slue} = \frac{C.\ \sin \theta}{4}$

That is the slue due to a change of versine on a chord of constant length will vary directly with the Sine of the difference in angles turned through.

DEFINITION OF A 'MOMENT' ON A 'CHORD SURVEY'

If it necessary to examine a railway curve using the aforementioned properties of a circle, then the single or even several unconnected measurements are not likely to give a correct picture of that curve unless it is in perfect alignment. Therefore it is desirable to connect the measurements in such a manner as to provide a series of readings which are geometrically related.

This is achieved by the overlapping the chords so that the chord points of a particular chord form the half-chord points of the adjacent chords, as shown in figure 4.

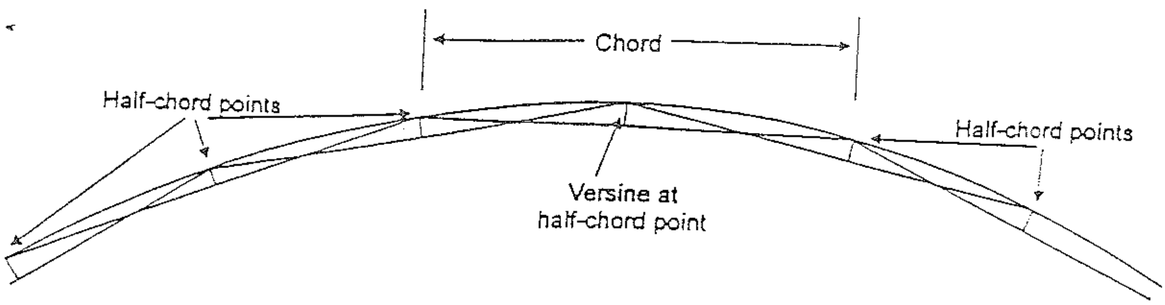


Figure 4

By overlapping the chords in this way all the geometric information necessary to enable curve re-alignment to be effected is obtained. There are various methods available to procure the curve adjustments, but all are based on the 'chord survey' of the curve, that the measurement of versines on overlapping chords.

It is generally considered that where clearance problems, such as those presented bridges, tunnels and platforms form an integral part of the re-alignment or where speed improvement is sought, the best mode of calculating the re-alignment scheme is by the 'Moment' method.

The 'Moment' method is an arithmetic between the proposed curve adjustments (slues) by accumulating the effects of the differences in change of direction made to each chord.

As previously stated, the difference between the existing and designed versines on a chord is a function of the difference in angles turned through which is directly related to the slue due to such change. Therefore by accumulating the effects, the slue at any half-chord point is the summation of the sums of the differences in change of direction made by amending the versines on all previous chords.

So that, $\text{slue}_\eta = \Sigma \text{ of } \Sigma \dfrac{C. \sin\theta}{4}$ (o to n-l)

as $d = \dfrac{C. \sin\theta}{8}$

then, slue n = 2Σ of Σ d (o to n -l)

In the above expression the variable term "2Σ of Σ d (o to n - l)" is known as a 'Moment'. That is the 'Moment' at any half-chord point is the sum of the running totals of the differences in versine made to all previous chords. The slue at that point is TWICE the value of the 'Moment'.

THE PROPERTIES OF THE 'HALLADE' METHOD

Of the various systems available for effecting curve re-alignment using the Moment principle the 'Hallade' method is probably the most generally used.

The 'Hallade' method is based upon the application of four basic rules:

1. The curve handed, that is the direction of the curve is to the left or right in the direction of the curve is to the left or right in the direction of the survey.

2. All versines measured on a 'handed' chord survey are defined as positive in value.

3. The designed versine line is the datum for arithmetic calculations. That is the sign and value of the difference in the versine is obtained by subtracting the existing versine from the designed.

4. Direction of slue determined by fixed sign convention, that is outward slues are always of positive value and inward slues are always of negative value.

By applying these rules to the diagram shown in Figure 3, the following observations can be made:

As the existing versine BD is larger than the designed versine BD_1 then the difference in versine DD_1 will be of a negative value. Thus the designed angle turned through, β, is less than that of the existing angle δ, which has the effect of the moving point C outwards to C_1. That is the slue CC_1 will be of positive value. Conversely, if the difference in versine DD_1 was of positive value then the slue CC_1 would be of negative value.

As previously stated the slue is twice the Moment, therefore, to maintain equilibrium with the 'Hallade' sign conventions the constant in the above relation must be of negative value.

Therefore the slue is minus twice the Moment.

RELATION BETWEEN "MOMENTS" AND SLUES ON A HALLADE SCHEME

The justification for calling the 'Moments' minus one-half of the slues and also for applying that slue at the half-chord point following the amendment in versine is shown below.

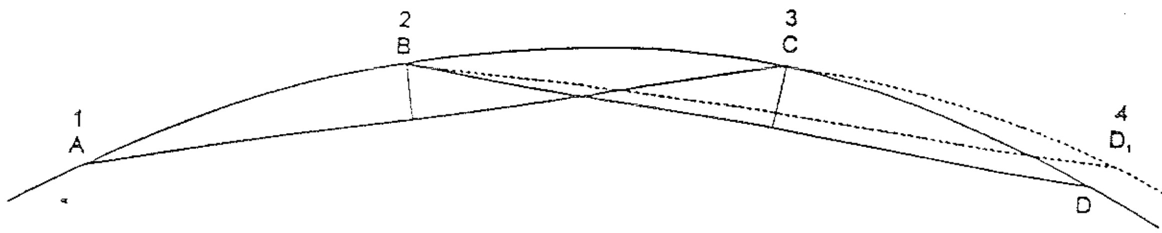


Figure 5

Consider the portion of curve ABCD as shown in Figure 5. AB, BC and CD are half-chords, the half-chord points being numbered for convenience. The existing curve is shown by a full line and the designed curve by a dotted line.

Let, the existing versines at B and C be u_2 and u_2.
The designed versines at B and C be v_2.and v_3.
The differences in versine at B and C be d_2.and d_3.
and the slues at B, C and D be S_2, S_3 and S_4.

If the arc ABC is of the correct curvature but the arc BCD is not, then the existing versine at B, U_2, is of the desired value but the existing versine at C, u_3, is not. Any attempt to correct the versine u_3 by moving point C or B would change the existing versine at B, u_3, and thus the curvature of the arc ABC would be incorrect. Therefore the only way to correct the versine u_3, is to move point D to D_1, thus the existing versine u_3 at point C will be amended to v_3.

That is, by applying the appropriate slue to the next half-chord point, any desired alteration to any versine can be obtained without interfering with the previous versine. Or, conversely, the Moment or slue, due to any desired difference of the versine at any half-chord point, is to be applied at the next half chord point.

As previously stated, the centre of arc and centre of chord for both the existing and designed curves can be assumed to be collinear and, as previously shown, the slues at points B and C are zero, that is $S_2 = S_3 = O$.

Consider the triangle BDD_1 the versines u_3 and v_3 are at the mid-points of the chords BD and BD_1 respectively. Therefore by similar triangles:

$$u_3 - v_3 = \frac{DD_1}{2}$$

$$u_3 - v_3 = \frac{S_4}{2}$$

However, for curve design calculations using the Hallade sign conventions, the difference in versine is the designed versine minus the existing versine, that is:

therefore $d_3 = (v_3 - u_3)$ or $-(u_3 - v_3)$

$$2(u_3 - v_3) = S_4$$

whence $S_4 = -2d_3$

As previously stated, the 'Moment' at any half-chord point is minus one half of the slue at the same point, therefore:

$M_4 = d_3$ in this example.

DEFINITION OF COLUMNS ON A HALLADE CALCULATION SHEET

Figure 6 shows part of the Hallade calculation sheet and the columns 'A' to 'L' are defined below.

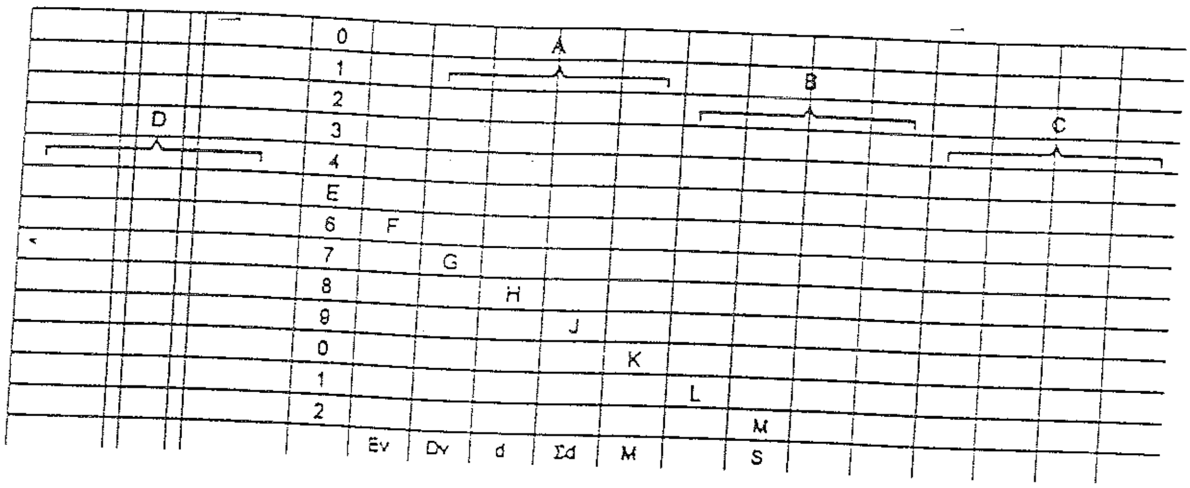


Figure 6

The calculation sheet is ruled horizontally with each line representing a half-chord point and is divided into three sets of four columns, as shown marked 'A', 'B' and 'C'. As the process of curve design is somewhat trial and error, the three sets of columns will allow the designer to make corrections/amendments to the design without erasing any relevant intermediate calculations. However, the final Hallade scheme need only show those calculations applicable to the final design tabled in the first set of columns, that is column 'A'. the remaining columns can then be used to show Quarter Chords, Track Intervals, Cant, Radii and speed functions applicable to the design.

Column 'D' Survey Details. This column has been pre-ruled with four vertical lines representing the gauge rails of two tracks. All the relevant information gained from the site survey is shown diagrammatically on the sheets so that the various obstructions/limitations can be kept well in view by the designer.

Column 'E' Half Chord Numbers, (H/C N). This column has been repetitively pre-printed with numbers from 1 to 9 thus only the 'tens' and 'hundreds' units need to be inserted. As previously stated each horizontal line represents a half-chord point and the relevant H/C No is shown in the space above. When a Hallade scheme exceeds fifty half-chords that is more than one calculation sheet, the last H/C No on a sheet be repeated at the commencement of the succeeding sheet to facilitate an overlap for continuous design.

Column 'F' Existing Versines, (Ev). The existing rail versines as measured on a chord survey are tabled in this column. As previously stated, the measured versines on a handed curve are always considered to be positive, thus it is not necessary to show the 'positive' sign. However, it is necessary to show 'negative' versines, which may occur on straight sections of track and at misalignments on flat or reverse curves, as such.

Column 'G' Design Versines, (Dv). This column is also known as the Amended Versines, that is the proposed versines to achieve the designed alignment are tabled in this column.

Column 'H' Differences, (d). The arithmetic difference between the designed and existing versines at each half-chord point is calculated and tabled in this column. the value (+ve or -ve) being obtained by subtracting the existing versines from the proposed versines. As previously shown, the existing and designed versines are a function of the angle turned through by their respective arcs, thus a ' Difference' is a function of the difference of angle turned through. From which, a positive 'Difference' signifies an increase of angle turned through which results in the curve being sharpened, thus the slue at the next half-chord point will be inwards or at least an outward slue will be either reduced or arrested. Conversely, a negative 'Difference' is a decrease of angle turned through.

Column 'J' Summation of Difference, (Σd). An arithmetic running total of the 'Differences' as calculated and tabled in this column. The summation of the differences is an intermediate step between a change of versine at any point and the resultant slue at the next. Therefore the Σd value should not be entered either on the line where an amendment to versine has been made or on the next line where the slue is effected, but in-between. That is, one half space lower than the difference in versine. As a 'Difference' is a function of the difference of angles turned through, then the value of the Σd at any point is a function of the total difference between the angles turned through by the designed and existing curves at that point. The sign (+ve or -ve) of the summation of the differences at any point will indicate whether the total angle turned through by the designed curve is greater or lesser than that of the existing curve at the point. Thus a zero value of Σd means the total change of direction of the designed curve is the same as that of the existing curve.

Column 'K' Moments, (M). An arithmetic running total of the summation of differences is calculated and tabled in this column. A Moment is minus one-half of the total effect the summation of differences make to the slue at any point.

Column 'M' Slues, (S). The slues are the track adjustments necessary to achieve the designed alignment, and as previously stated are minus twice the respective Moment value. By Hallade rule positive slues are outwards, that is away from the centre of curve and negative slues are inwards. All slues are applied radically.

METHOD OF WORKING HALLADE CALCULATIONS

Figure 7 shows part of the typical Hallade realignment scheme, which demonstrates the method of calculating the slues required to obtain the designed alignment, the procedure for which is described below.

After entering the existing versines in ink onto a calculation sheet it is advisable to study the versine pattern to ascertain the average versine line.

	6	Ev	Dv	d	Σd	M	S			
	7									
	8									
	9					0	—			
	10	25	25	0	0	0	—			
	1	24	25	0	0	0	—			
	2	29	25	-3	+1	+1	-2			
	3	28	25	-6	-3	-2	+4			
	4	22	25	-3	-6	-8	+16			
	5	25			-3	-11	+22			
	6	23								
	7	27								
	8	23								
	9	24								
	20									

Figure 7

At the beginning and end of any Hallade scheme, the proposed alignment must be tangential to the existing alignment. Therefore, the first designed versine on a Hallade scheme must be the same as the existing and designed curves have a common chord and arc. Thus the track at three half-chord points will not require slue to achieve the proposed alignment. the same principle applies at the end of a Hallade scheme.

By a process of trial and error, but being guided by the average line of the existing versines a uniform, or uniformly increasing/decreasing, series of proposed versines is then written in the designed versines column.

The existing versines value is subtracted from the design and the algebraic result is entered in the 'differences' column. In the 'summation of differences' (Σd) column, but as previously stated, one half-space below the line, is next entered into the running total of these 'differences'. In the 'Moments' column and a further half-space down, that is on the next half-chord line, is put into the running total of these sums.

It is not a useful policy to try to fill in the designed versines too far ahead, but to enter only a few values at a time and to work through to the Moments. It is thus possible to keep a check on this value and hence a slew. The way in which the Σd values vary is an indication of how the proposed alteration of alignment is likely to build-up a large residual one-way slue that cannot conveniently be lost before the end of the scheme. Therefore if the Σd values can be kept small and varying from positive and negative quantities, then the curve adjustments are likely to be satisfactory divided between inward and outward slues. It is not advisable to calculate and enter the slue as the scheme is progressively worked through, as it may later be necessary to amend the primary. The whole of the proposed alignment is worked through to the end of the Hallade scheme where the designed curve should be tangential to the existing, as previously stated.

The total angle turned through by the designed curve must be the same as that turned through by the existing curve. As versines are a function of the angle turned through by each chord, then the totals of the existing and designed versines must be the same. Therefore the final Σd value must be zero if the proposed curve has been correctly designed.

DESIGN REQUIREMENTS AND TOLERANCES

CIRCULAR CURVES

By definition a circular curve is one which has a constant radius, therefore the versines on overlapping chords of equal length must also be of constant value.

For railway curves, a change of versine of 2mm is not considered to be a change of radius when measured on 30m chords. Care must be taken with a 2mm tolerance when working with lesser chord lengths. A design tolerance of +/-1mm or within a range of 2mm is acceptable on circular curves, as shown below.

Dv	Dv	Dv
57	58	58
↕	↕	↕
57	↕	↕
56	58	58
56	60	56
57	↕	↕
58	↕	↕
↕	↕	↕
58	↕	↕
57	60	56
↕	58	58
↕	↕	↕
57	58	58
↕	↕	↕
(+/-1 tolerance)	(-2/+0 tolerance)	(2/-0 tolerance)

To calculate the radius of a circular curve which incorporates a design tolerance the average versine should be used in the general formula:-

$$R = C^2 / 8v$$

Where R = radius)
C = chord length) All must have the same common unit, i.e. metres.
and v = versine)

TRANSITIONS

A similar tolerance/allowance is acceptable in the design of transitions. Whilst keeping the slope of the versine line constant a SINGLE variation of +/-1 is allowed in the design transition versine rise (or fall). If the design is being worked in ½mm then this statement still applies but the variation will be +/- ½mm.

At a direct transition reverse (Left hand to Right hand or vise versa) this allowance can be considered on both sides of the reverse point.

In all cases, after the application of the +/-1 on the transition versine rise (or fall), you must revert to the original rise (or fall), if you do not you will have changed the slope of the original transition and this is not permitted at a direct reverse.

PROCEDURE TO CLOSE A HALLADE SCHEME

From the tabulated existing versines (Figure 8) the apparent circular curve versine is 25 and the resultant scheme is as shown on the part sample calculation sheet below.

5	STAGE 1					STAGE 2				STAGE 3			
6													
7													
8	Ev	Dv	d	Σd	M								
9													
40	26	25	-1	0	0								
1	24		+1	-1	-1								
2	29		-4	0	-1								
3	28		-3	-4	-5					25	-3		
4	18		+7	-7	-12					26	+8	-7	-12
5	22		+3	0	-12						+4	+1	-11
6	25		0	+3	-9					26	+1	+5	-6
7	23		+2	+3	-6					25	+2	+6	0
8	29		-4	+5	-1						-4	+8	+8
9	30		-5	+1	0						-5	+4	+12
50	23		+2	-4	-4					25	+2	-1	+11
1	32		-7	-2	-6					24	-8	+1	+12
2	25		0	-9	-15						-1	-7	+5
3	17		+8	-9	-24	25	+8				+7	-8	-3
4	20		+5	-1	25	24	+4	-1	-25		+4	-1	-4
5	26		-1	+4	-21		-2	+3	-22		-2	+3	-1
6	25	25	0	+3	-18	24	-1	+1	-21	24	-1	+1	0
7				+3	-15			0	-21			0	0
8													

Figure 8

Since the calculations do not zero out the curve has not been correctly designed in Stage 1.

The final value " Σd " is positive which indicates that the total angle turned through by the designed curve is greater than that turned through by the existing curve. The positive SLUE at the end of the scheme indicates an "overshot" design. This means that the curve will converge to the existing curve because of this excess angle turned through as shown diagrammatically in Figure 9.

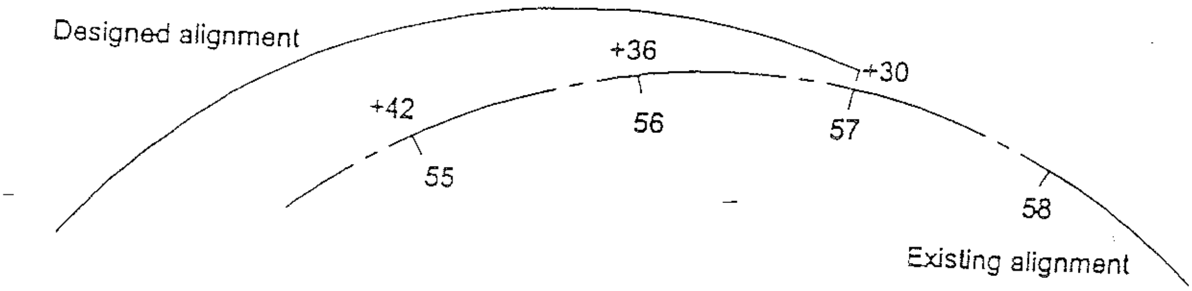


Figure 9

The primary objective in correcting Stage 1 is to make the total angle turned through by the designed curve match that turned through by the existing curve. Thus the final "Σd" value must be zero.

EXAMPLE OF PROCEDURE TO CLOSE A HALLADE SCHEME

In this example the angular difference is represented by the factor +3. It is necessary to reduce the total of the designed versines by this amount, and in such a manner that the amended versines remain within the allowable tolerance for the circular curves. It follows that no single versine can be reduced by 3mm, hence 2 but in this case preferably 3 design versines must be amended.

It must be appreciated that the further away from the end of the scheme an amendment to the design versine is made, the greater will be the change in "Moment" values.

In Figure 10 it can now be seen that the total angle turned through by the proposed alignment is now equal to that of the existing alignment because the final summation of differences is zero. However, there are still Moments, and hence slues, at the last 3 HC points. The designed curve is therefore displaced from, but parallel to, the existing alignment.

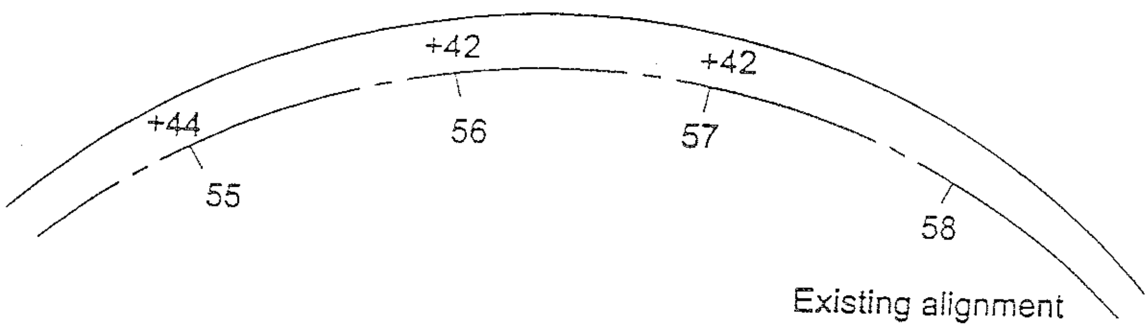


Figure 10

To force the design line to meet the existing line tangentially it is necessary to alter the sequence in which the individual difference of angle turned through per Half Chord point is made whilst maintaining the same total angle turned through by the whole curve.

This can be achieved by applying a half (or semi) couple. This is a symmetrical change to the proposed design versine line. In this example the final "Moment" is negative (-21). It is therefore necessary to increase some of the design versines and follow them by an equal reduction of other designed versines.

As a "Rule of Thumb" the method of determining how far apart the increases and decreases should be is;

Moment value to be eliminated = A x B
(Where A and B are whole numbers)

Thus 3 x 7 = 21

By applying three consecutive amendments of 1 and letting each run for 7 Half Chords, to be cancelled out by three consecutive amendments of -1, the resultant amendment will give a "Moment" value of +21 but will maintain a zero value in the "Σd" column. The result is illustrated as Stage 3 in Figure 8.

TRANSITION DESIGN

On most railway administrations, transition curves are designed to the equation of the cubic parabola as shown in Figure 11.
The general cubic parabola formula is:

$y = kx^3$

It can be shown that for this curve the curvature at any point along the transition is proportional to the distance along the transition from its origin. Thus the versine throughout a transition which is designed to a cubic parabola will increase uniformly from the origin.

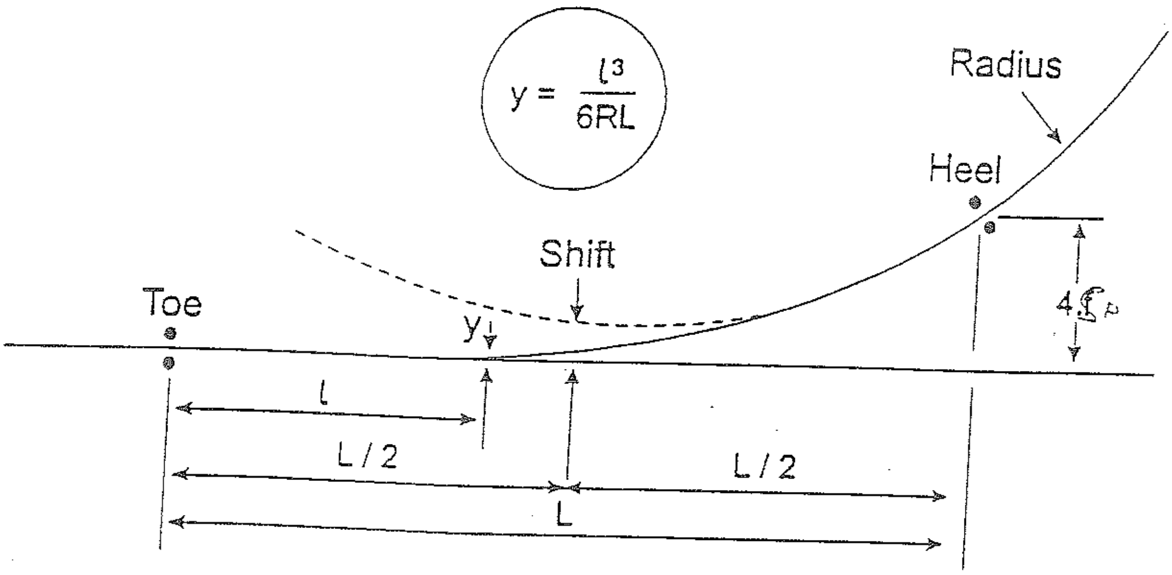


Figure 11

ROUNDING OFF AT A TOP & BOTTOM OF TRANSITION

CASE 1 When the transition starts or finishes at a Half Chord point.

The first/last versines are modified by adding or subtracting 1/6th times the full versine rise per Half Chord. **This is a factual value of the geometric design at the tangent point.** It is applicable to any transition between either straight to circular curve or between two circular curves of the same hand or between circular curve to straight.

TRANSITIONS

Without a correct "Rounding Off" the design versines for this type of transition would be:

HC No.	Dv
0	0
1	0
2	12
3	24
4	36
5	48

(R.Off = 1/6 x 12 = 2)

However it can be seen in Figure 12 that there will be a measurable versine at HC1. which is the offset due to one end of the chord being on the transition - this versine is the Rounding Off and its numerical value is as previously stated, i.e. 1/6 x full transition rise per HC.

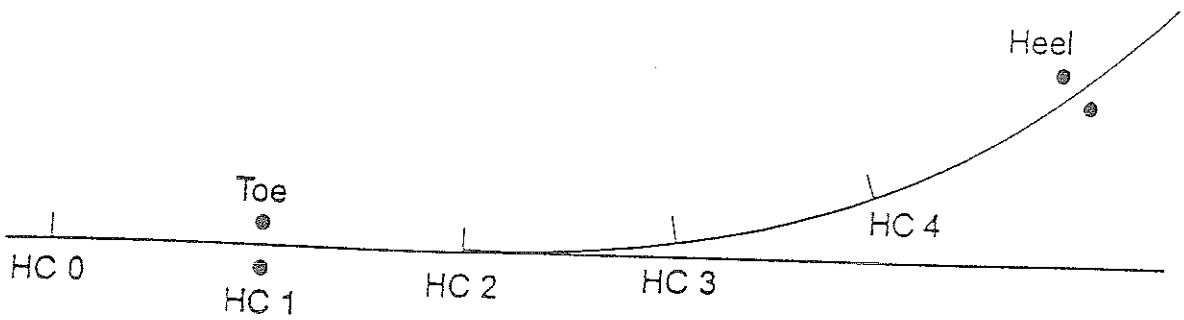


Figure 12.

CASE 2 When the transition starts or finished exactly midway between two half chord points.

Here again it is possible to see that there will be a versine at the HC point in front of the transition origin on the straight. In this case the numerical value of the "Rounding Off" is equal to (1/48 x the full transition rise) per Half Chord. Unless the transition rise is large it is generally taken that in this case the rounding off is zero.

CASE 3 Intermediate type transitions.

There will occur situations which will not coincide with a HC point or be exactly half way between two HC points. These are "intermediate" type transitions and the Rounding Off factor varies with the position of the end of the transition within the half chord length.

HC No.	CASE-1	Intermediate			Case 2
10	0	0	0	0	0
1	4	3	2	1	0
2	24	21	18	15	12
3	48	45	42	39	36
4	72	69	66	63	60
15	96	93	90	87	84

ROUNDING OFF - PART STEPS

When the Part Step is greater than a Half Step of the full transition rise then:

Rounding off =

$$\frac{[\text{part step} - \text{half step}]}{\text{half step}} \times \left(\frac{\text{rise}}{6} - \frac{\text{rise}}{48} \right) + \frac{\text{rise}}{48}$$

When the part step is less than a Half Step of the full transition rise then:

Rounding off =

$$\frac{\text{part step}}{\text{half step}} - \frac{\text{rise}}{48}$$

The "Rounding Off" is applied to the final straight/circular curve versine consistant to a transition, and is ADDED at the FLATTER end and SUBTRACTED at the SHARPER end.

The "Rounding Off" must never be applied to the true transition versine as illustrated in the following examples.

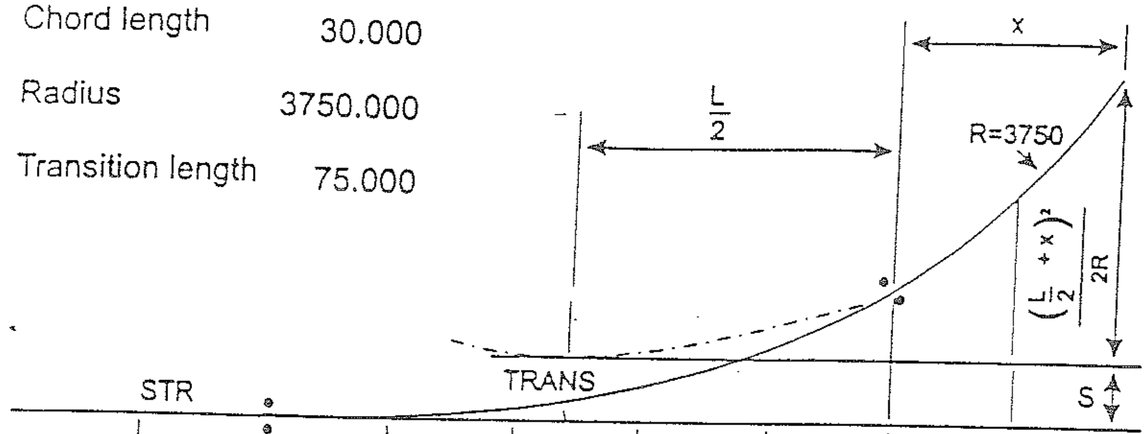
Using a Chord length of 30m and the versines in 1/2mm.

HC No.	Dv		Dv	
10	0		131.5	
1	0		131.5	
2	0		131.5	
3	0		131.5	
4	6.5	@HC4+0.000	131.5	@HC4+8.250
5	39.0	Trans	120.5	
6	78.0		96.0	Trans
7	117.0	@HC7+7.500	71.5	
8	136.0		47.0	@HC8+9.796
9	136.5		33.5	
20	136.5		31.0	
1	136.5		31.0	
2	136.5		31.0	
3	136.5		31.0	

It should be appreciated that using 1/2mm versines greatly enhances the theoretical design accuracy of a Hallade scheme.

Cubic Parabola Transition Design Example

Chord length	30.000
Radius	3750.000
Transition length	75.000



HC	1	2	3	4	5	6	7	8	9
Offset	0 mm	0	2	16	54	128	250	430	670
Versine	0 mm	1	6	12	18	24	129	30	

REVERSE CURVES

When a curve reverses from one hand to the other then in order to maintain the Hallade sign convention it is necessary to change the sign of the "Σd" value and the Moment value on the Half Chord past the reverse point.

The point at which the surveyor has reversed the wire holders when carrying out the versine survey is indicated by a thick line drawn below the HC versine at that point. It should be noted that thepoint of reversal of the wire holders may not necessarily be the actual point of the reverse of the two curves. (The surveyor must pay special attention to the sign of the versines at or near the reverse point. An error here will have a disastrous effect on the alignment design).

By adopting this course of action it avoids the necessity of showing all the versines on the second curve as negative values in the survey book or on the survey sheets, or indeed on the Hallade calculation sheet itself.

Because of this change of sign a positive change in the Moment on the first curve, if carried through the reverse, will result in a negative change in Moment on the second curve.

Transition rises MUST BE CONSTANT through the whole length of the reversed transition (see also tolerances page 20). The ONLY exception to this rule is where there is a length of true straight track not less than 45m long, between the toes of the transitions forming the reverse. In this instance the reversed transitions may be considered as single unconnected transitions and can be designed accordingly.

When designing reverse transitions the resultant slue can be affected by the transition slope as well as its actual position relative to the existing versines. It is always prudent to calculate from circular curve to circular curve before considering what, if any, corrective action needs to be taken.

QUARTER CHORDING TRANSITION CURVE ALIGNMENT

Because the transition is the most important part of any curve then it must be most meticulously designed and carefully maintained.

The present system of pegging at HC stations only is not satisfactory, especially where high speed running is concerned.

If the normal chord of 30m is used the distance between pegs is such that alignment errors which are outside acceptable track alignment tolerances can easily creep in. Whilst these may go undetected on circular curves the misalignment, if in a transition, will manifest itself by poor ride quality very quickly.

The disadvantages attached to the use of a short chord survey however far outweigh the advantages of a long chord survey using additional calculated closer control points. In the first place, the versines are small in comparison with the equivalent speed chord versines, and in consequence, the measurement errors are greatly magnified. Secondly the smaller versines adversely effect the flexibility of the design and the chance of obtaining the optimum transition curve.

To overcome the disadvantages of both methods the normal long chord is used and the transitions pegged at quarter chord intervals in addition to the half chord points.

On curves which have been permanently pegged, without quarter chord pegs in the transitions, the additional pegs will be set at the same distance from rail as the previously pegged scheme and adjusted by checking the rail versines through the transition.

For new alignment schemes the survey will be made in the normal way and the quarter chord pegs fixed in accordance with the design information given on the scheme plan.

The quarter chord offsets will be measured starting with those on the first full chord which is entirely on the transition. (Note: if the theoretical starting point of the transition is less than a quarter chord length beyond any station the transition may be considered to start at that station for the purpose of calculating quarter chord values). Quarter chord pegs are set using OFFSETS from the wire stretched over a full chord. You must never try to versine the quarter chord pegs as if on a short chord.

On the first full chord three measurements are taken i.e. at the quarter, half and three-quarter points.

The three-quarter point is ALWAYS to be taken as that nearest to the circular curve. In the case of compound curves on similar flexure the "circular curve" is the sharper of the two radii. Remember always calculate quarter chord values from the FLAT END of the transition towards the SHARP END of the transition.

Quarter chord pegs need not be provided on the transition between two curves if there is no change in the value of the applied cant.

QUARTER CHORDS

At a direct reverse the quarter/three quarter chord values are calculated outwards towards each circular curve from the point of reverse.

The design versine having the minimum numerical value is ignored for this calculation. Should it happen that both versines are identical at the point of reverse a note on the calculation sheet must clearly indicate which HC number has been ignored.

On the remaining chords, which must be wholly on the transition, only half and three quarter chord points will be measured.

For a cubic parabola transition the values of these points are given by the equations below. The equations apply equally to transitions from straight to circular curve and transitions between two circular curves whether the same or opposite hand.

If vn = versine at HC "n"
and r = transition rise per HC

then offset at 1/4 chord point on 1st chord = 3/4.v1 - r/8
offset at 3/4 chord point on 1st chord = 3/4.v1 + r/8
offset at 3/4 chord point on nth chord = 3/4.vn + r/8

To adjust the three quarter chord pegs it is first necessary to adjust and correct the half chord pegs by regulation in the usual way.

The correction of the offset "n" will then be the algebraic sum of:
Error in offset "n" + 3/4 x adjustment to peg (n+1) + 1/4 x adjustment to peg (n-1)

The values of the quarter chord <u>offsets</u> are always quoted on the final realignment scheme rounded to the nearest whole number on versines measured in millimetres and to the nearest 0.5 on versines measured in 1/2 millimetres - the desirable standard.

QUARTER CHORD EXAMPLES

HC	Dv	Calculation	1/4 chd Number	1/4 chd Value
1	0.0			
2	1.0	3/4 x 6 - 1/8 x 6 = 4.5 - 0.75	2A	4.0
3	6.0	3/4 x 6 + 1/8 x 6 = 4.5 + 0.75	3A	5.0
4	12.0	3/4 x 12 + 1/8 x 6 = 9.0 + 0.75	4A	10.0
5	18.0	3/4 x 18 + 1/8 x 6 = 13.5 + 0.75	5A	14.0
6	24.0	3/4 x 24 + 1/8 x 6 = 18.0 + 0.75	6A	19.0
7	30.0	3/4 x 30 + 1/8 x 6 = 22.5 + 0.75	7A	23.0
8	35.0			
9	36.0			

26	25.5			
27	25.5			
28	25.0	3/4x21.0+1/8x4.5=15.75+0.56	28A	16.5
29	21.0	3/4x16.5+1/8x4.5=12.38+0.56	29A	13.0
30	16.5	3/4x12.0+1/8x4.5=9.00+0.56	30A	9.5
31	12.0	3/4x7.5+1/8x4.5=5.63+0.56	31A	6.0
32	7.5	3/4x3.0+1/8x4.5=2.25+0.56	32A	3.0
REV 33	3.0	3/4x3.0-1/8x4.5=2.25-0.56	33A	2.0
34	1.5	3/4x6.0-1/8x4.5=4.50-0.56	34A	4.0
35	6.0	3/4x6.0+1/8x4.5=4.50+0.56	35A	5.0
36	10.5	3/4x10.5+1/8x4.5=7.88+0.56	36A	8.5
37	15.0	3/4x15.0+1/8x4.5=11.25+0.56	37A	12.0
38	19.5	not required because full rise not used		
39	21.5			
40	21.5			
41	21.5			

INDEPENDENT ALIGNMENT DESIGN

VERSINE METHOD

After producing an alignment on the "Through" line:-

1. Deduce the amended "Sixfoot" spaces after the "Through" line has been slued to the proposed design alignment.

2. Deduce the required slues to set the Independent alignment parallel to the Through line at the standard "Sixfoot" space (1830), or to whatever space your design may require.

3. Deduce the Independent alignment design versines by the working the Hallade scheme backwards from the deduced slues.

4. Establish the best place to start the design of the Independent alignment. This is where 3 consecutive slues give the required space and a Design versine that is within the tolerance of the Design versines of the Through line at those points.

5. Use the same procedures to close the Independent alignment design to be parallel to the existing alignment of the Through line designed alignment. (You will note here that it is unlikely that the independent alignment design will close to zero difference and/or zero moment).

This method is generally used for the widening of the standard track interval especially where a long obstacle is present between the two tracks in question. This could be an island station platform, long bridge piers or bridge centre girders for example.

Great care should be taken with the survey for Independent alignment schemes. In the design of the alignment after your chosen "kicking off point" you must ensure that the alignment does not slue the opposite way to that which is required. Always check this point before sending your final scheme to site for pegging.

INTERVAL METHOD

1. Determine the amount of reduction (or widening) you require to the standard space, or whatever parallel space is present or required.

2. Deduce the required "Moment" and its algebraic sign.

3. Apply a "half couple" to the Through line designed alignment to achieve the desired "Moment", making due note of the allowable versine tolerances and the speed required over the Independent alignment.

This method is used for tightening standard intervals, for example through tight arched overbridges, or for widening the standard interval to accommodate bridge centre girders. This method can only be used where it is possible to measure the final track interval at <u>EVERY</u> Half Chord point.

HIGH CANT DEFICIENCY RULES FOR SPEED ON CURVES

When detailing alignment designs for curves laid in Continuous Welded PLAIN LINE the following rules must be applied:

RULE 1: Only the Railtrack Civil Engineer has the authority to permit cant deficiency in excess of 110mm but to a maximum of 150mm may be used on curves where BOTH of the following conditions are satisfied.

a) Rate of change of cant deficiency complies with rules set out in sheet B3.3 of the Track Design Manual, i.e. Max RgD=55mm/sec.

(You should note that in exceptional circumstances and only at the discretion of the Railtrack Civil Engineer this value can be increased to 70mm/sec.)

b) No switch & crossing work, catch points, adjustment switches, level crossings, must be located on either the transition curves or on the circular curve itself.

RULE 2: Actual cant must not be built into the track with a gradient steeper than 1 in 400 or flatter than 1 in 1500 or with a rate of change of cant greater than 55mm/sec.

(You should note that in exceptional circumstances and only at the discretion of the Railtrack Civil Engineer this value can be increased to 85mm/sec providing that the actual cant gradient does not fall outside the minimum requirement of 1 in 400).

RULE 3: After calculating the actual cant plus cant deficiency required for a particular speed on a given curve the proportion cant to cant deficiency should be no more than 50%, i.e. cant deficiency should be equal to or preferably less than actual cant.

RULE 4: After calculating the permitted maximum speed in "kph" the speed must then be converted to "mph" and rounded DOWN or UP to the nearest 5mph – this then becomes the maximum permitted speed on that curve. The final details of actual cant deficiency and rates of change must now be recalculated using this maximum speed in "mph" converted to "kph".

ALL THE ABOVE CHANGES TO THE CURVE DESIGN PARATMETERS ARE INCLUDED IN RT/CE/S/049, PAGE TDM B3.3

THE HALLADE CHORD SURVEY REQUIREMENTS

SURVEY EQUIPMENT

1 No. Hallade wire and reel (60m plus)
1 No. Pair of handles (or boomerangs)
1 No. Hallade scale graduated in 1mm intervals reading to 150mm
1 No. 30m fibron or steel tape
1 No. 3m or 5m pocket tape
1 No. Plumb line and/or platform gauge
1 No. Cant or crosslevel gauge
Bridge profile rods
Survey chalk or paint sticks
Survey book or survey sheets and clip board
Pens, pencils, pencil sharpener and erasers.

SURVEY REQUIREMENTS

Track Measurements

Half chord stations, marked out consecutively with the mileage and facing traffic.
Versines.
"Sixfoot" spaces at least every 5HCs measured to Outer Edges.
Cant to be taken at least every 5HCs on BOTH roads at every HC in transitions, platforms and other restrictive locations.

Locations

All mile posts.
Platform ramps, top and bottom and station name.
Lineside structures.
Signal posts/gantries with the signal numbers if they have them.
OHLE masts where present and their location plate details.
Toes of Switches and tied timber positions in S&C work.
Catchpits and signal troughing, especially if in the "Sixfoot".
Level crossings whether timber, concrete, tarmac or bowmac type.

Clearances

All clearance measurements are taken to Outside Edges of nearest rail and must include the height above rail where applicable.
Platform edges (include coping overhang where present).
Lineside structures within 2500mm from nearest rail.
Catchpits and bridge centre girders (an indication of the amount of sleeper movement actually possible should be given)
OHLE masts - to be compared with agreed records.

General Observations

Hand of starting curve (Left or Right).
Whether in cutting, on embankment or level.
Type of track on both roads (CWR, jointed, flat bottomed or bull head rail, concrete or wood sleepers).
Track gradient where indicated together with trackside signs.
AWS magnets in 4ft and neutral section magnets where present.
Adjustment switches, catch and trap points.
Type of rail fastenings and position relative to edge of longitudinal timbers together with relative position of chairs/baseplates to the edge of the timber.
The length and width of EACH longitudinal timber.

TRACK ALIGNMENT SURVEY EQUIPMENT

A set of "Track alignment survey equipment" consists of three items, colloquially known as "Boomerangs". There is a Left and Right hand handle plus a third which has a sliding scale. The left hand handle has a rubber strip (to protect the scale from the Hallade wire) on its left edge when viewed from the thin end. The right hand handle has the rubber strip on the right side. All three handles are fitted with spirit bubble levels.

The general use of this equipment is as follows:-

The three boomerang handles are placed at Half Chord intervals on the inside of the curve with the metal block against the survey rail and the smaller overhang being placed on the rail head. Each boomerang handle is then leveled and used in one of the following ways, depending upon requirements.

1 Used To Read Versines, Slues Not Included

The wire is placed through the brass clips on the outside of both left and right hand handles (normally these clips are folded down). The sliding scale on the central boomerang is positioned so that the zero coincides with the zero on the fixed scale. The versine can then be read off, being the reading at which the wire crosses the versine scale.

2. Used To Read Design Versines, Slue Included

a) When all slues are less than 150mm. (the length of the scale).
The slues at the left and right hand half chords are set by holding the wire at the slue on the boomerang scales, and the slue at the central-half chord is set by positioning the moving scale so that the zero on the moveable scale is opposite the slue on the fixed scale. The versine is then read off as before. See example 2 on page 39.

b) One or more slues greater than 150mm i.e. too large to read on one or more of the scales.
All three slues must first be reduced (or increased if negative) by equal amounts such that the largest can be read on the scale. The method of use is then as in (a) above. See example 3 on Page 39.

c) Two or more slues too large to read directly on the scales, with overall differences greater than 300mm.

All three slues need to be reduced but reduction by equal amounts is not possible. Instead they are reduced in proportion to their size, i.e the largest is reduced by the most etc., again so that all slues can be read on the scales. The versine is read off as before. See example 4 on page 39.

d) Slues at left and right half chords too large and in different directions.

The slues at left and right chords are altered so that both are nearer zero. The alterations being of the same amount and of sufficient value that the larger slue can be read on the scale. The slue at the central half chord remains unaltered, and the versine is read off in the usual way. See example 5 on Page 39

e) Slues at left and right half chords too large and in different directions, with average of these slues also too large.

A combination of two cases must be used here and the versine read off in the usual way. See example 6 on page 39.

NOTES

1. In (b) and (e) above changes in the proposed slue are for versine reading purposes only.
2. All slues measured on the boomerang are positive away from and negative towards the operator.
3. If an obstruction prevents normal usage, the boomerangs can be used with the metal block against the outer edge of the rail, but ALL THREE must be used in this manner.
4. At a reverse curve, at the point where the holders are transferred to the opposite edge of the rail, the left and right holders must be exchanged so that the rubber strips remain outermost.

EXAMPLES

SHEET NO ______

ROUTE ______ LOCATION ______ LINE ______

CURVE No. ______ MILEAGE ______ TO ______ MP ______ CHORD ______

P.S.R. ______ M.D.A. ______ L.S.A. ______ DATE SURVEYED ______ DATE ISSUED ______

SURVEYED BY ______ DESIGNED BY ______ CHECKED ______ APPROVED ______

	design	slue		ALTERATIONS NECESSARY TO MAKE SLUES READABLE ON BOOMERANGS		
0	year					
1						
2	0	-70				
3	2	-44				
4	18	-6	]	0		
5	38	+6	] EXAMPLE 2	0		
6	58	-32	]	0		
7	78	-106				
8	98	-172				
9	119	-238	]	+200		
10	129	-296	] EXAMPLE 3	+200		
1	130	-238	]	+200		
2	129	-62				
3	112	+130	]	-100		
4	92	+254	] EXAMPLE 4	-200		
5	72	+330	]	-300		
6	52	+406				
7	31	+446				
8	21	+514				
9	21	+556				
20	21	+556				
1	22	+542				
2	23	+492				
3	23	+402				
4	27	+308				
5	42	+224				
6	57	+158				
7	72	+158				
8	87	+170				
9	102	+176				
30	117	+152				
1	132	+80				
2	147	+22				
3	151	-94				
4		-172				
5	151	-186				
6	149	-56				
7	144	-12				
8	139	+68				
9	134	+60				
40	129	-112				
1	124	+232				
2	119	-228	]			
3	114	-72	] EXAMPLE 5	+100		
4		+154	]	0		
5		+224		-100		
6		+282				
7		+358	]	+150		-100
8		+42	] EXAMPLE 6	0	THEN	-100
9		-160	]	-150		-100
50	114	-194				

CURVE DEFINITIONS

CIRCULAR CURVE: a curve of constant radius.

TRANSITION CURVE: a curve of linearly varying curvature. It is normally provided between two circular curves of differing radii, or between a circular curve and a straight. It is normally of cubic parabola form.

COMPOUND CURVE: a curve formed of two similar flexure circular curves of differing radii, which may be connected by a transition curve.

REVERSE CURVE: a curve formed by two circular curves of opposite hand, which may be joined by a transition curve.

CANT: (superelevation) is the difference in height relative to the horizontal of the two rails of one track at a particular location measured at the centrelines of the heads of the rails. It is POSITIVE when the outer rail on a curve is raised above the inner rail, and NEGATIVE when the inner rail on a curve is raised above the outer rail. (Negative cant may be unavoidable in switches and crossings on canted main lines where the turnout is curving in a contra flexure direction from the main line, or at the plain line immediately adjoining the turnout).

EQUILIBRIUM SPEED: is the speed of a vehicle on a curve such that the resultant force of the weight of the vehicle and the effect of centrifugal force is perpendicular to the running plane of the rails. The vehicle is then said to be in equilibrium.

EQUILIBRIUM CANT: is that cant at a particular speed at which the vehicle will have a resultant force perpendicular to the running plane of the rails.

CANT OF DEFICIENCY: is the difference between the applied cant on the track and the equilibrium cant for the vehicle at the particular stated speed.

MAXIMUM PERMISSIBLE SPEED: is the highest speed which may be permitted on a curve with associated transitions when radius, cant, cant deficiency, cant gradient, and rates of change of cant and cant deficiency have all been taken into consideration. When the maximum permissible speed of the curve or part of the curve is less than the line speed limit it will be necessary to impose a lower "permanent speed restriction".

LINE (ROUTE) SPEED LIMIT: is the maximum speed at which traffic is allowed to run on a line (route) or on sections of a line. The line speed limit is usually established after taking into consideration the incidence of permanent speed restrictions and the type of traffic on the line.

CANT GRADIENT: indicates the amount by which cant is increased or decreased in a given length of track e.g. 1 in 1,200 means that a cant of 1mm is gained or list in 1,200mm length of track.

RATE OF CHANGE OFCANT OR CANT DEFICIENCY: is the rate at which cant or cant deficiency is increased or decreased, relative to the maximum speed of a vehicle passing over the transition curve, e.g. 35mm/sec means that a vehicle when travelling at the maximum speed permitted will experience a change of cant or cant deficiency of 35mm for every second it travels over the length of the transition.

CURVE FORMULAE

SYMBOLS:

Vmax	=	maximum speed in km/h
Ve	=	equilibrium speed in km/h
R	=	radius of curve in m
E	=	cant in mm
D	=	cant deficiency in mm

MAXIMUM SPEED on circular curve:

$$V_{max} = \sqrt{\frac{R\,(E+D)}{11.82}} = 0.29\sqrt{R\,(E+D)}$$

∴ EQUILIBRIUM:

$$0.29\sqrt{RE}$$

SWITCHES – EFFECTIVE RADIUS:

To calculate the theoretical cant deficiency at the toes of switches, an effective radius is used. It is calculated by placing a 12.2 m chord centred on the switch toe, and using the versine v measured at the toe:

$$R = \frac{C^2}{8v}$$

$$\text{Then } D = \frac{11.82\ V^2}{R}$$

For formulae, relating radius to tangent length, chord length, offset, versine, etc., see sheet 6.

THE "HALLADE" SURVEY REQUIREMENTS.

TRACK MEASUREMENTS.

Half Chord stations - to be marked out with the mileage, facing traffic

Versines (to the 1/2mm)

"Sixfoot" intervals between parallel tracks measured to the outside edge of the rails at least every 5 HCs on straights and circular curves but EVERY HC in transitions, long bridges, platforms, tunnels, through Switch and crossing work or other obstructions which may affect your designed realignment.

Cant measurements, ON BOTH ROADS as for "Sixfoot" intervals.

Full information of longitudinal timbers at underbridges.

LOCATIONS.

Mile Posts, Top (TOR) and Bottom (BOR) of platform ramps.

Lineside structures - Bridges, Tunnels etc.

Signal posts with their numbers if they have them together with any overhang toward the track at the aspect level.

O.H.L.E. masts where present together with their M.& E.E. number.

Level crossings and whether timber, concrete or tarmac.

Catchpits or cable manholes especially if in the "Sixfoot".

Toes of switches and position of tied timbers in S & C work.

CLEARANCES.

All clearance measurements are to the outside edge of the nearest rail and should state the height above rail (HOR) where relevant.

Platform copings - also note the overhang if any.

Lineside structures within approximately 2,500 from rail.

Signal posts and ladders where present.

O.H.L.E. masts to the steelwork unless the concrete foundation is more than 2,000 above rail level.

Bridge centre girders and catchpits noting the ammount of movement that can be achieved at the sleeper ends.

THE "HALLADE" SURVEY REQUIREMENTS.

GENERAL OBSERVATIONS.

Hand of staring curve (Left or Right)

Physical features - cutting, embankment or level.

Type of track, in both roads - CWR, Jointed, FB, BH, wood or concrete sleepers.

Track gradient posts where present.

Trackside signs, Warning indicators, speed restriction signs etc.

AWS magnets in "4ft." and Neutral section magnets on sleeper ends.

Rail expansion joints (Breather /Adjustment switches), catch or trap points stating whether hand operated, motor operated or sprung.

Cable troughing that is "close" to the sleeper ends.

Type of rail fastening and its position relative to one edge of longitudinal timbers.

The length and width of EACH longitudinal timber under EACH rail.

THE "HALLADE" CHORD SURVEY.

SURVEY EQUIPMENT.

1 No. Hallade reel of wire (approx 60m length)

1 No. Pair Hallde handles (or "boomerangs")

1 No. 1mm interval Hallade scale

1 No. 30m fibron and/or steel tape.

1 No. 3m or 5m tape.

1 No. Plumb line or Platform Gauge.

Survey chalk

Hallade calculation sheets and survey book or sheets.

Clip board, pencils and rubbers.

Cant gauge (cross level)

Bridge profile rod.