SECTION 3

TRACK GEOMETRY

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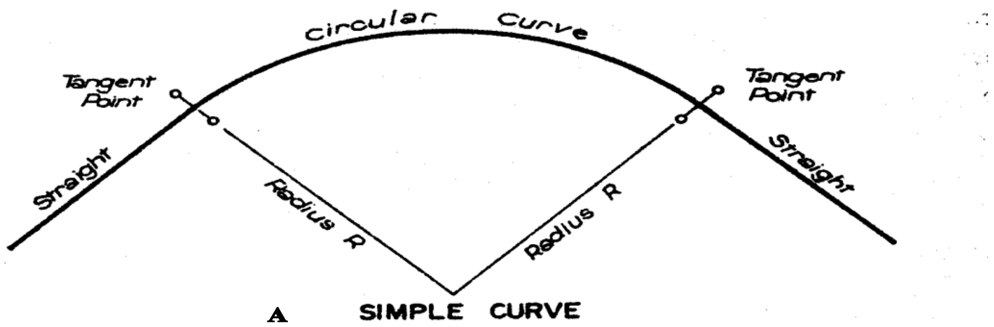
3.1 ALIGNMENT

When a railway vehicle moves on tangent (straight) track, it can be assumed that the flanges are both clear of the rails by about 6 mm and central between them, as in figure 4.2.1. Since a moving vehicle tends to continue in a straight line, any irregularities in the alignment of the running edges of the rails will cause the flanges of the wheels to run against the sides of the rails. This introduces a lateral force between wheel flanges and rail heads and if the irregularity is large, 'rough riding' vehicles, side cutting of rails, wheel flange wear and additional strain on fastenings can result. Therefore tangent track should be maintained as straight as practicable to avoid these undesirable effects on the track.

3.2 CURVES

Where a change in direction of the track is necessary, curves are used to make the change of direction as smooth as possible. Curves are either simple curves or transitioned curves. The size of both types is indicated by their radius which is expressed in metres. A simple curve is really part of the arc of a circle. Because the curve follows the arc of the circle, the rate of change of direction is uniform, i.e. the amount of curvature for a given length is the same (constant) throughout the whole length of the curve. Figure 3.2 shows the essential differences between the layout of simple and transitioned curves.

When a vehicle enters a simple curve, it undergoes a rapid change in direction as it moves from linear (straight) to circular motion. This rapid change becomes more pronounced as speeds increase. To avoid undesirable effects on vehicles and track, transition curves were developed. In a transitioned curve, the central portion of the curve forms the arc of a circle, but special curves or transitions of varying radius are used at each end. These transitions provide a gradual/constant rate of change in direction from the tangent track to the curve proper and avoid the lurch or lateral force at the tangent point. When transitions are used at either end of a curve it is necessary to move the untransitioned circular part of the curve inwards as shown in figure 3.2B.



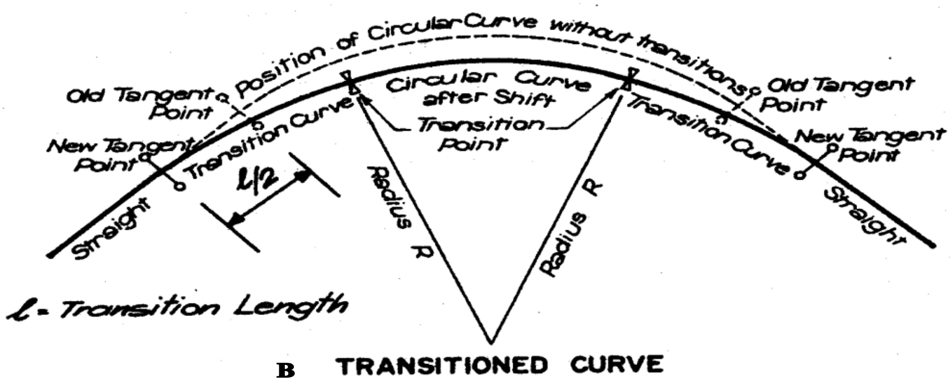


Figure 3.2 Layout of simple and transitioned curves

3.2.1 Curving of rails[1]

Before any single length of rail is used, it should be checked for straightness by sighting because rails are frequently bent during transport and handling. Single rails are curved to the correct radius before laying in track. The most common tool used for this work is a portable press which uses a commercially available hydraulic cylinder and hand pump shown in figure 3.2.1. The press is suited to 31 kg/m and 31 kg/m rails and is frequently used for straightening rails. Where large quantities of rails require curving larger motorised versions are available. These motorised presses are more often used in depot situations.

1 In railway terminology the action of providing a permanent set in a rail for a curve is called ‘pressing

The large cumbersome screw operated Jim Crows (generally shortened to 'Crows') and eccentric benders have now been superseded by the hydraulic benders.

Figure 3.2.1 Portable hydraulic cylinder and hand pump press.

The process of curving a rail involves putting a permanent set in it at several points along its length until the required radius is reached. Pressing starts at one end of the rail moves incrementally along the rail to the other end. Several small sets repeated several times at each point along the rail produces a far smoother curve than a few large sets.

Tables 3.2.1.1 and 3.2.1.2 give the correct offsets for curving rails of various lengths. A fine string is stretched along the rail head for its full length and the offsets from the string to the curved rail at the middle point and the two quarter points should be in fairly close agreement with those given in this table.

Part worn rails removed from curved track may be straightened or recurved to suit another curve and then placed in sidings. Rails should not be recurved in the opposite direction but may be transposed as discussed in section 3.2.2.

Rails should not be over-curved. If overcurving occurs the actual radius should be reduced to one less than the required radius and then recurved to the required radius. This is essential if good curve geometry is to be maintained.

The approximate ordinate or offset for curving rails to any given radius is given by the formula:

$$V_1 = \frac{125L^2}{R}$$

where V =ordinate or offset (in millimetres),
L =length of rail being curved (in metres), and
R =radius of curve (in metres).

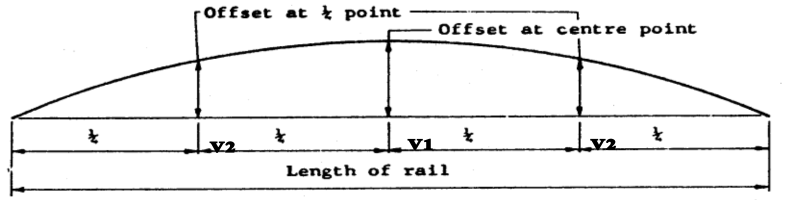
The approximate offset at the quarter point of the rail is:

$$V_2 = \frac{3}{4}V_1$$

Example:

For 200 metre radius curve the offset at the centre point of a 12.2 m rail is 93 mm and at the quarter point 70 mm. (Table 3.2.1.1).

Table 3.2.1.1 Table of offsets for curving rails



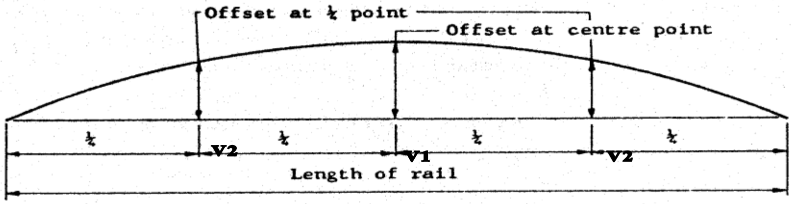
Cord to be stretched for full length of rail and held against side of rail head.

Approximate formula:

$$V_1 = \frac{125L^2}{R} \qquad V_2 = \frac{3}{4} V_1$$

Radius (metres)	12.20 m (40') rails		9.15 m (30') rails		Radius (metres)
	Offset at centre (V_1) mm	Offset at 1/4 point (V_2) mm	Offset at centre (V_1) mm	Offset at 1/4 point (V_2) mm	
50	372	279	209	157	50
60	310	232	174	131	60
80	232	174	131	98	80
100	186	140	105	78	100
120	155	116	87	65	120
140	132	99	75	56	140
160	116	87	65	49	160
180	103	77	58	44	180
200	93	70	52	39	200
220	84	63	48	36	220
240	77	58	44	33	240
260	72	54	40	30	260
280	66	50	37	28	280
300	62	46	35	26	300
400	46	34	26	20	400
500	37	28	21	16	500
600	31	23	17	13	600
700	27	20	15	11	700
800	23	17	13	10	800
900	21	16	12	9	900
1000	19	14	10	8	1000

Table 3.2.1.2 Table of offsets for curving rail



Cord to be stretched for full length of rail and held against side of rail head.
Approximate formula:

$$V_1 = \frac{125L^2}{R} \qquad V_2 = \frac{3}{4}V_1$$

Radius (metres)	7.92 m (26') rails		7.30 m (24') rails		Radius (metres)
	Offset at centre (V_1) mm	Offset at 1/4 point (V_2) mm	Offset at centre (V_1) mm	Offset at 1/4 point (V_2) mm	
50	157	118	134	100	50
60	131	98	112	84	60
80	98	73	84	63	80
100	78	59	67	50	100
120	65	49	56	42	120
140	56	42	48	36	140
160	49	37	42	31	160
180	44	33	37	28	180
200	39	29	33	25	200
220	36	27	30	23	220
240	33	24	28	21	240
260	30	23	26	19	260
280	28	21	24	18	280
300	26	20	22	17	300
400	20	15	17	13	400
500	16	12	13	10	500
600	13	10	11	8	600
700	11	8	10	7	700
800	10	7	8	6	800
900	9	7	7	6	900
1000	8	6	7	5	1000

3.2.2 Transposing rails

Where the high rail of the curve has been worn beyond safe limits on the running or gauge face, common practice is to transpose both rails of the curve. In this way the low rail is moved to the outside or high rail position in the curve and the worn high rail is moved to the low rail position. Thus the life of both rails can be extended because the most severe running face wear invariably occurs on the high or outside rail. Transposition of rails is sound practice provided excess table wear has not occurred on either rail head. Table wear or head wear is caused by the action of the wheels or wagons and locomotives on the top running surface of the rail. Excess table wear could result in the wheel flanges striking the top edge of the fish plates, fish bolt nuts or other track fastenings.

3.3 EFFECT OF AUTOMATIC TAMPING ON LINE AND LEVEL

3.3.1 Introduction

Tamping machines incorporating facilities for automatic correction of track geometry are now used to maintain line and level of track. With repeated application this procedure can have detrimental effects on the geometry of both vertical and horizontal curves.

This section explains the origin of these effects and draws attention to the need for caution in the repeated application of such machines.

3.3.2 Vertical curves

Machine principles

The principle embodied in automatic lifting devices fitted to tamping machines is to lift the rails at the point of tamping (lifting point) to a straight line defined by a point behind (rear reference point) where the track has already been tamped and a point ahead of the machine (forward reference point) which is assumed to be at the desired level for the track at that point. That assumption is justified by the facility to adjust the forward reference point relative to the rails.

The distance from the lifting point to the forward reference point is greater than that from the rear reference point to the lifting point. The ratio of these distances (correction factor) is four to one for cane railway production tamping machines. Continuous adjustment of the forward reference point is therefore not necessary as, although track irregularities at the front reference point are repeated in form at the lifting point, their magnitude is reduced in proportion to the correction factor.

This system of 'smoothing' is ideal for track which is intended to be level or on a uniform grade. The effect on vertical curves, however, needs further consideration.

Effect on vertical curves

To illustrate the effect on vertical curves the case of a sag type rounding between two opposing grades is discussed. The geometry of such a rounding is important for the safe handling of long trains.

Until the forward reference point reaches the start of the rounding at the entry end, the system is working on track of uniform grade. At this point the forward reference point begins to rise above the grade line and the commencement of the vertical curve is moved back to the lifting point. The total effects of tamping through the rounding can be analysed mathematically if the geometry of the existing track and the machine system is defined. For general purposes it can be said that:

a) The entry end of the rounding will be lengthened significantly;

b) the low point of the rounding will be moved towards the entry end;

c) the exit end of the rounding will be lengthened dramatically;

d) an excessive lift will occur at the low point of the rounding and for some distance towards the exit end; and

e) repeated passages will aggravate the effects.

Alternatives available

For any particular rounding and machine geometry it is feasible to calculate the continuous adjustment of the forward reference point necessary to reproduce the desired parabolic curve in its correct longitudinal location. The requirements are complex and the approach is not practical for general application.

In practice it is normal for the operators to adjust the forward reference point so as to maintain a reasonable height of lift at the lifting point. By this action, however, control over the geometric shape of the rounding is lost. Generally depending on the finesse of the operator, a sharpening of the rounding on the exit side of the low point will result.

The implications are not serious for a limited number of such treatments for a particular rounding. In time, however, the vertical geometry can be seriously affected.

A very much reduced distortion of the vertical curve will occur if the distance of the forward reference point is reduced to provide a correction ratio of about two and the tamping done in two or three passes. The last pass only need include the tamping of all sleepers. The previous pass or passes need only include the tamping of alternate or every third sleeper but should provide for the greater part of the total lift required.

Ultimate requirement

To limit the extent of deterioration of the geometry of vertical roundings it is necessary periodically to resort to regrading by normal surveying techniques and re-establish a proper rounding by lifting to a pegged grade line.

It is recommended that no more than three automatic tampings be undertaken through vertical roundings without re-establishment of a proper grading.

3.3.3 Horizontal alignment

General

Traditionally railway track alignment was controlled by slewing to centre line pegs periodically re-established from data used at the time of construction of the line. Over the last forty years it has become practice to maintain acceptable alignment in a local sense without reference to the original design geometry. It is again a ‘smoothing’ approach. Alignment equipment fitted to tamping machines provides for this approach to realignment.

Machine principles

There are two principles commonly used:

a) To slew to a point a fixed distance from a straight line joining a rear and a forward reference point; and

b) to slew to a point which lies on a circular curve defined by two rear and one forward reference points.

In both cases a straight line or uniformly circular curve would result if the forward reference point was following such a path. The irregularities introduced by the non-uniformity of the path of the forward reference point are reduced by slewing point being much closer to the rear reference than to the forward reference. They are also displaced by the distance between the slewing point and the forward reference point.

Implications on straight track

Generally the magnitude and the rate of application of a misalignment are the accepted criteria for the need for realignment. Smoothing techniques fully meet the needs in this regard.

Critical variation in alignment, however, can occur with displacements of relatively small magnitude occurring at regular intervals which may match natural frequencies of vehicle motions within the operating speed range. Smoothing techniques do not eliminate but merely reduce the amplitude of such cyclic misalignments. Even though reduced in amplitude they will grow rapidly under traffic.

If such conditions do exist it is necessary to resort to correction techniques other than normal smoothing. One approach is to align towards a forward reference point temporarily fixed at points between those of maximum misalignment.

Implications on curved track

The misalignment of a curve can be considered as an uncontrolled change in radius. Again smoothing techniques will reduce and displace such irregularities.

An important consideration in curves apart from the actual curvature is the relationship between superelevation and curvature and particularly the rate of change of this relationship. The rate of change of unbalanced superelevation can be likened to a measure of ‘jerk’.

When tamping curves a uniform superelevation is restored. If also aligned by smoothing techniques significant rates of change of unbalanced superelevation may still exist.

Preventive procedures

If gross misalignment is present in a curve then it is desirable to undertake preliminary correction prior to any general smoothing run by track packing and lining machines.

Some machines are fitted with recording and control systems which largely overcome the problem.

An alternative is to check and correct for gross misalignments prior to tamping using stringlining or similar techniques described in section 3.4.2.

3.4 Realignment of curves

It is often desirable to be able to realign a curve or part thereof without resorting to the use of conventional surveying techniques. An example of this need is referred to in section 3.3 dealing with the long term effects of automatic lining processes.

There are two methods which are easy to apply and for which the procedures are described below.

3.4.1 Chord/deflection angle method

(1) Application

This method is very quick and requires a minimum of calculations. It does however require the simple use of a theodolite. It is particularly suitable when part only of a curve requires realignment.

(2) Mathematical basis

The method relies on the fact that the deflection angle measured from a point (X) on a circular curve between any two other points (Y + Z) on that same curve is directly related to the distance between the second two points as shown in figure 3.4.1.

It follows that the deflection angle is constant for chords of equal length irrespective of the relative location of the observation point and the chord within the curve.

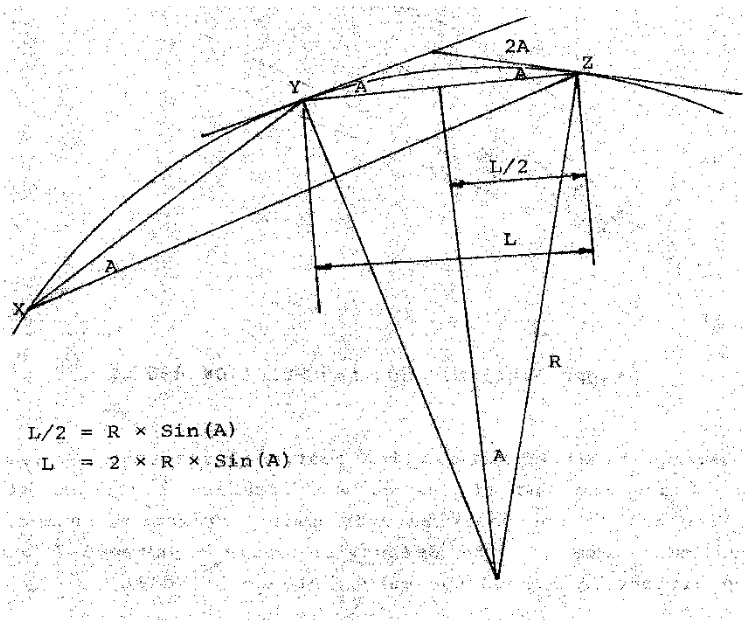
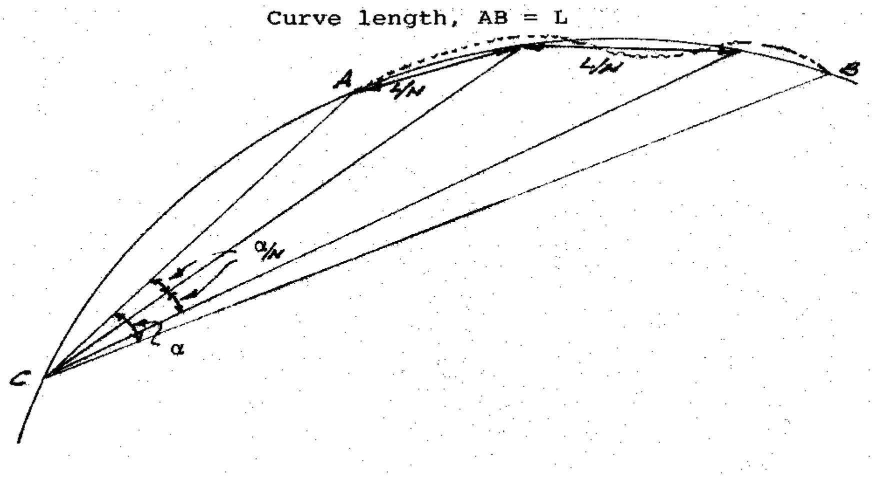


Figure 3.4.1 Simple curve geometry.

(3) Procedure

Assume that the length of track A to B in figure 3.4.2 is the portion of the total curve required to be realigned.

Figure 3.4.2



Curve/deflection angles.

Set up the theodolite on the centre of the track at point C between A and the end of the curve. Precise levelling of the theodolite is not necessary as only small horizontal angles will be involved. Measure the deflection angle α between A and B. Measure distance L around the curve between A and B.

Divide L by a number N to give a convenient chord length L/N (say five or ten metres) depending on the radius of the curve.

Divide the angle α by the same number N to give an angle α/N.

Proceed to peg or slew the curve from A to B by using chords of length L/N and deflection angle increments of α/N.

3.4.2 String lining method

(1) Application

The method is also known as the Plus and Minus method and has been used throughout the railway world. It can be used to realign the whole or part only of a curve including transition curves to any degree of accuracy desired.

The equipment required is simple. The arithmetic procedures are basically simple but can become tedious and time consuming. This aspect can be exaggerated by the trial and error principles involved.

Analog calculating machines have been used in the past to expedite the calculations. The development of a suitable interactive program for use with a minicomputer would enable more regular and beneficial use of string lining techniques.

(2) Mathematical basis

The method uses a measuring chord of length twice the distance between required successive measuring points as shown in figure 3.4.3 and relies on the following principles:

(a) for a circular curve, the versine for a fixed length chord is constant;

(b) for a transition curve, the versine at successive measuring points increases or decreases by equal increments;

(c) a slew at one measuring point will vary the versine at the adjacent measuring point by half of the amount of the slew;

(d) the sum of the versines will be the same for any two curves between the same two tangents;

(e) if a curve is slewed in such a way that the sum of the slews (positive and negative) is equal to zero, the length of the curve (and therefore the length of the rails) will remain the same.

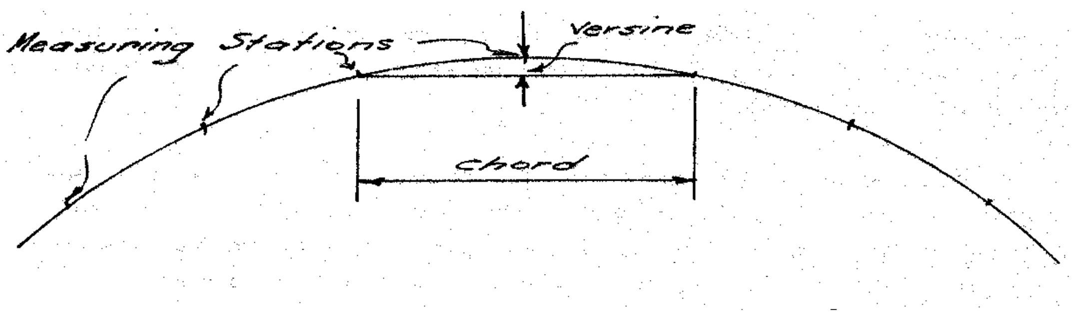


Figure 3.4.3 Method of string lining curves.

(3) Equipment required

The only equipment required is a rule graduated in millimetres and a string line of twice the length of the required measuring station interval. The string line requires a knot at its mid point and a cube of timber of say 50 millimetre side at each end so that versines of both positive and negative sign may be measured.

(4) Measuring procedure

The procedure is best illustrated in conjunction with an example of the tabulation required.

The example used assumes a chord length of 10 metres with measuring stations at five metre intervals and a curve radius of approximately 200 metres as shown in figure 3.4.4.

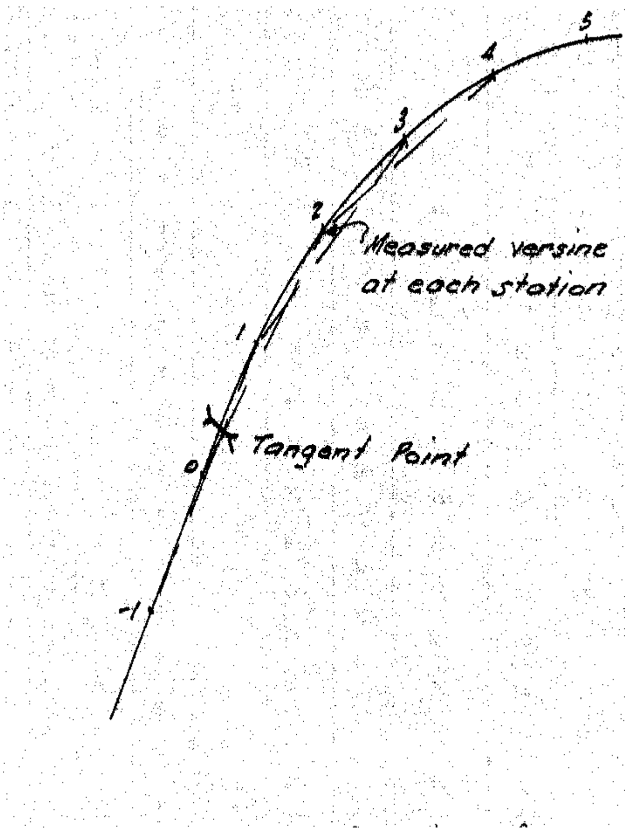


Figure 3.4.4 Method for string lining curves.

Table 3.4.2 is then compiled as follows:

Table 3.4.2 String lining of curves

1	2	3	4	5	6	7	8	9	10	11	12	13
Station number	Versine						Correction					
	Mid string distance	Actual	Trial	Difference	Sum 1	Sum 2	Versine	Sum 1	Sum 2	Half slew	Full slew	New versine
0	53	3	4	1	1			0				4
1	51	1	12	11	12	1		0	0	1	2	12
2	74	24	24	0	12	13		0	0	13	26	24
3	111	61	36	-25	-13	25		0	0	25	50	26
4	105	55	48	-7	-20	12		0	0	12	24	48
5	110	60	60	0	-20	-8		0	0	-8	-16	60
6	86	36	60	24	4	-28		0	0	-28	-56	60
7	88	38	60	22	26	-24		0	0	-24	-48	60
8	116	66	60	-6	20	2	4	4	0	2	4	64
9	102	52	60	8	28	22	4	8	4	26	52	64
10	134	84	60	-24	4	50		8	12	62	124	60
11	125	75	60	-15	-11	54		8	20	74	148	60
12	107	57	60	3	-8	43		8	28	71	142	60
13	121	71	60	-11	-19	35		8	36	71	142	60
14	135	85	60	-25	-44	16		8	44	60	120	60
15	86	36	60	24	-20	-28		8	52	24	48	60
16	102	52	60	8	-12	-48		8	60	12	24	60
17	100	50	60	10	-2	-60		8	68	8	16	60
18	104	54	60	6	4	-62		8	76	14	28	60
19	114	64	60	-4	0	-58		8	84	26	52	60
20	132	82	60	-22	-22	-58		8	92	34	68	60
21	108	58	60	2	-20	-80		8	100	20	40	60
22	94	44	60	16	-4	-100	-4	4	108	8	16	56
23	105	55	60	5	1	-104	-4	0	112	8	16	56
24	99	49	60	11	12	-103		0	112	9	18	60
25	134	84	60	-24	-12	-91		0	112	21	42	60
26	87	37	48	11	-1	-103		0	112	9	18	48
27	85	35	36	1	0	-104		0	112	8	16	36
28	78	28	24	-4	-4	-104		0	112	8	16	24
29	62	12	12	0	-4	-108		0	112	4	8	12
30	50	0	4	4	0	-112		0	112	0	0	4
TOTALS		1508	1508									1508

- Column 1 represents the number of stations entered;

- Column 2 is the versine at each station measured with the string line taut between the stations each side of that being measured. Normally the running face of the outer rail of the curve is used as the reference and positive versines and slews are considered to be away from the centre of the curve;

- Column 3 is completed by subtraction of the size of the offset block (suggested as 50 mm) from the values of Column 2;

- Column 4 is compiled by trial and error providing a transition (as discussed in section 3.4.2, 2(b)) at each end and a circular curve (as discussed in section 3.4.2, 2(a)) between the transitions such that the totals of Columns 3 and 4 are equal thus satisfying section 3.4.2, 2(d);

- Column 5 is derived directly by subtracting the values in Column 3 from those in Column 4;

- Column 6 is a progressive summation of Column 5;

- Column 7 is a progressive summation of Column 6 and in fact represents half of the slew necessary at each station to achieve the versines suggested in Column 4. The implied half slew of 112 mm at the last station is unacceptable and must be made equal to zero or close thereto. The same applies at any intermediate stations where clearances or other considerations may limit the allowable slew;

- Column 8 is the corrective versine applied by trial and error at spacings and of magnitude such that the sum of the values in Column 9 is zero and the second progressive summation of Column 10 produces values cancelling out the unacceptable values in Column 7. It is this particular operation which may prove time consuming but which will be greatly simplified by experience with the technique;

- Column 11 represents the half slews derived by the addition of the values in Columns 7 and 10;

- Column 12 gives the full slews required which are merely double the values in Column 11;

- Column 13 shows the new versines which are derived as the sum of the values in Columns 4 and 8. The arithmetic sum of Column 13 must be checked against the total of Column 3 to ensure consistency of the arithmetic work.

The values of Column 12 can be used to slew or peg the curve.

The arithmetic sum of the values in Column 12 will indicate whether the length of the curve has been lengthened or shortened. Rail conditions may dictate a further revision of the proposed realignment or the adjustment of the rails themselves. Normally the best overall result is achieved by optimising the alignment as indicated in the example and subsequently adjusting the rail lengths.