[RA]ILWAY CURVES

SMITH

RAILWAY CURVES

FOR

Practical Trackmen

BY

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PREFACE.

This book is written for the especial benefit of practical track men, for the purpose of making them acquainted with the elementary principles of railway curves, and to enable them to satisfactorily adjust their curves independent of the civil engineer. For this reason all complicated formulæ or calculations have been eliminated in order to bring the book to the level of the practical man whose education has been limited to that of the public schools, and whose knowledge of arithmetic is limited to the four principal operations, namely: addition, subtraction, multiplication and division.

This book is also a guide for the use of the "Smith" curve lining gauge, whose construction and various applications for the work for which it was designed are fully described.

The author believes that any intelligent section foreman, by the careful study of this little book and the use of the Smith curve lining gauge, should be able to adjust any of his curves, and do it right, with results raising the entire standard of the American railway service.

The problems illustrated in this work are all of a practical character, and cover nearly all the curve work which the track foreman is expected to perform.

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The book is especially designed for a pocket companion of the foreman while out on his work, so he may consult it on a moment's notice. The rules given herein have been deduced by the author in mathematical order, but this has been omitted for the reasons above stated.

Hoping that his efforts will prove of some use to his many friends among American trackmen, the author makes his bow.

RAILWAY CURVES

INTRODUCTORY.

The ideal alignment of a railway is a straight line in a perfectly level surface. Such a road could perform the maximum service for the least expense; its engines could haul the heaviest freight trains with the least work, and its passenger trains could attain very high speed without discomfort to their passengers.

Of course such a road in actual existence is out of the question, except in short stretches, but its theory forms a basis for the best practice in locating roads; that is to say, whenever engineers are first staking out a new road the ideal alignment, namely, the straight line in a level surface, is the standard which is aimed at, and which should be attained as nearly as practicable.

It is obvious that the alignment of practically all railways consists of stretches of straight lines, called tangents, which are connected to each other by curves in order to make the change from one direction to another gradually. Thus in Fig. 1 let *AB* represent the general direction of a road which is to be changed to the direction *BC*. It is evident that this could not be done by simply joining the two straight lines at an abrupt angle, since a train coming along the line *AB* would simply leave the track at *B* going toward *D*. Hence the method pursued is to use a part of a circle, touching line *AB* in *E* and line *BC* in *F*. The distance from *E* to the center of circle *G* is called the radius of the curve and stands always perpendicular to a straight line which touches the circle only in one point; this point is called point of tangency, and the straight line is called a tangent. Thus *AE* is a tangent, also *FC*

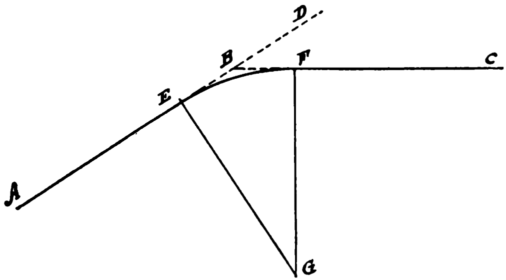

FIG. I.

is a tangent, and the part of the circle between *E* and *F* is called the curve, although its geometrical name is an arc. The straight line from *E* to *F* is called a chord and the angle *EGF* at the center of the circle is called a central angle.

The angle which is formed by the intersection of the two tangents produced at *B*, namely, angle *DBF*, is called the deflection angle and is equal to the central angle *EGF*. The points *F* and *E* are called points of curve or points of tangent, because they are the beginning of curve in one direction and beginning of tangent in the other direction.

The Unit Curve.

Let the circle shown in Fig. 2 have such dimension that a 100-foot chord (*AB*) will span an

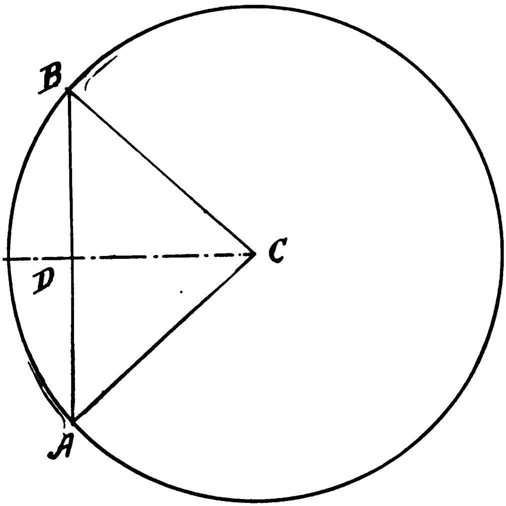

FIG. 2.

angle of one degree at the center *C*; thus if *AB*=100 feet and angle *ACB* equals one degree (or, in other words, if the curve from *A* to *B* is the 360th part of the full circle), then the curve is defined as a one-degree curve. It is quite easy now to determine the length of radius *AC*, for if we draw CD perpendicular to AB it will strike AB in its center and the triangle ACD is right-angled at D, the angle ACD equals 30 minutes and AD equals 50 feet; hence the radius AC of this curve is found by trigonometry as follows:

$AD:AC = \sin. 30'$; substitute values:

$AC = 50 \div .0087265$, or 5729.56 feet.

This is what might be called the unit radius, and is usually taken as 5730 feet long, since the fractional part is a negligible quantity. Considering a full circle of this radius, its length would be $2 \times 5730 \times 3.1416$, or 36001.5 feet; if we would lay in the 360 chords, each 100 feet long, they would measure just 36,000 feet. This shows that the circle is only 18 inches longer than the chords, in the case of the one degree curve.

From this definition any curve may easily be identified. Thus a curve in which a 100-foot chord spans an angle of 2 degrees at the center is called a two-degree curve; if a 100-foot chord spans an angle of 3 degrees at the center it is called a 3-degree curve, and so on. The 100-foot chord is the unit chord, and whatever angle it subtends at the center is the degree of the curve.

The Radii of Curves.

It stands to reason that as the degree of the curvature increases the radius of the curve decreases, and by reference to Fig. 3 this becomes quite plain.

For let AB be a 100-foot chord spanning an angle of 1° at the center (*O*), then the curve (*AB*) is a 1° curve. If we place a 100-foot chord (*DC*) so that it spans an angle of 2° at *O*, then *DC* is a 2° curve, and it is seen that the radius (*OC*) is shorter than *BO*. Suppose the 100-foot chord *FE* be moved so that the center angle would equal 60 degrees, then *FEO* would form an equilateral triangle and the radius would

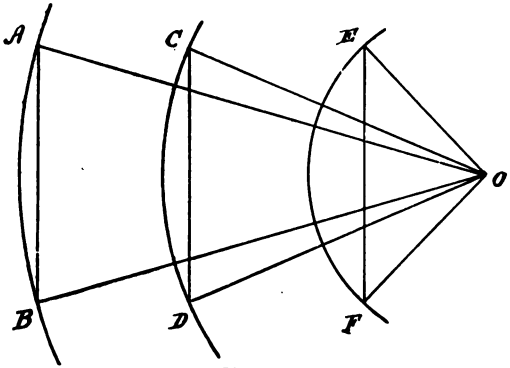

FIG. 3.

equal 100 feet. This shows a variation in radius from 5730 feet to 100 feet, while the curve has grown from 1° to 60°.

Within certain limits, say up to an 8-degree curve, the radius may be assumed to vary inversely as the degree of curve, and the radius may be computed by dividing 5730 by the degree of curve; thus the radius of a 2-degree curve is found by dividing 5730 by 2, making 2865 feet;

the radius of a 3-degree curve equals 5730÷3= 1910 feet; the radius of a 10-degree curve is 573.7 feet, which is .7 feet more than obtained by dividing 5730 by 10. This difference becomes greater as the curvature increases, the radius of a 60-degree curve being 100 feet, while 5730 divided by 60 gives only 95.5 feet.

Following table gives the radii for curves up to 56 degrees:

Curve	Radii	Curve	Radii	Curve	Radii	Curve	Radii
1°	5730	14°	410.3	27°	214.2	40°	146.2
2°	2865	15°	383.1	28°	206.7	41°	142.7
3°	1910	16°	359.3	29°	199.7	42°	139.5
4°	1433	17°	338.3	30°	193.2	43°	136.4
5°	1146	18°	319.6	31°	187.1	44°	133.5
6°	955.4	19°	302.9	32°	181.4	45°	130.7
7°	819.0	20°	287.9	33°	176.0	46°	127.9
8°	716.8	21°	274.4	34°	171.0	47°	125.4
9°	637.3	22°	262.0	35°	166.3	48°	122.9
10°	573.7	23°	250.8	36°	161.8	50°	118.3
11°	521.7	24°	240.5	37°	157.6	52°	114.1
12°	478.3	25°	231.0	38°	153.6	54°	101.3
13°	441.7	26°	222.3	39°	149.8	56°	106.5

To find the radius for any curve by computation: Divide the sine of half the degree of curve into 50 gives the radius of curve. For example, find the radius of a curve of 44 degrees.

Solution: 44°÷2=22°; look up the sine of an angle of 22°, which is .3746; divide this into 50 gives 133.5 feet as the radius of a 44-degree curve.

TABLE OF RADII FOR FRACTIONAL CURVES.

Curve	Radii	Curve	Radii	Curve	Radii
15′	22920	2° 00′	2865	4° 30′	1274.6
30′	11460	2° 15′	2549.2	5°	1146
45′	7640	2° 30′	2292	5° 30′	1093.4
1°	5730	2° 45′	2186.8	6°	955.4
1° 15′	4584	3° 00′	1910	6° 30′	883.4
1° 30′	3820	3° 30′	1638	......	....
1° 45′	3276	4°	1433	....	....

Curve Lining Gauge.

Fig. 4 shows an elevation, and Fig. 5 a plan of the tool. It is all made of steel, strong and light, weighing about 7 pounds. The center casting (*C*) has a hole bored through its center (see Fig. 8),

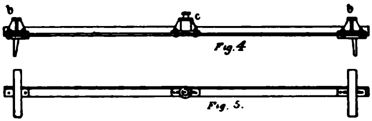

Fig. 4

Fig. 5

Fig. 6

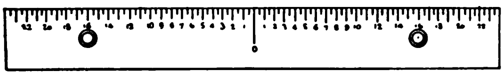

Fig. 7

into which fits center pin (Fig. 9). The raised castings (*b*) on either end of gauge carry each a nickel-plated graduation plate, which is shown in Fig. 7. There is a pair of gauge lugs, shown in Figs. 4 and 6, bolted under the gauge bar (*A*) at either end.

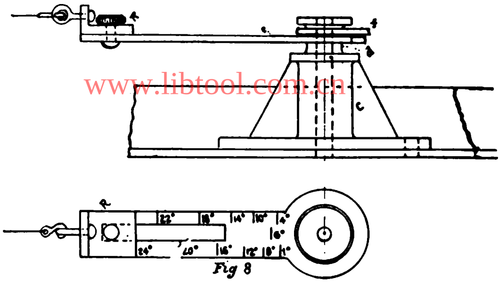

Fig 8

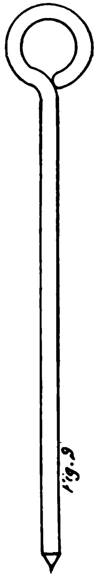

Fig.9

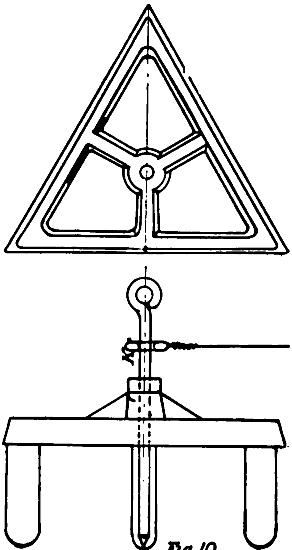

Fig.10

The center casting (*c*) has a collar (*d*), around which two brass end pieces (*e* and *f*) can freely rotate (see Fig. 8). The measuring wires, which are used as chords, are attached to these by suitable swivel hooks. The No. 1 curve gauge is graduated for 25-foot chords, and has a capacity up to 24-degree curves. The free end of the wire terminates in a ring, which fastens to an end pin (*K*), shown in Fig. 10. A graduation on the end piece, in connection with a movable rider (*R*),

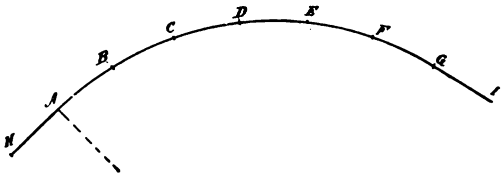

FIG. 11.

shown in Fig. 8, makes it easily adjustable for any curve; for instance, it is shown that the curve under consideration is 12°. the sliding rider (*R*) is moved until edge cuts graduation at 12°.

End pins *K*, which are just like center pin shown in Fig 9, pass through hole in triangular chair when the gauge is in use. Two cast-iron reels are provided to wind up the wire chords, and the whole is securely placed in a well-made wooden box, which may be locked, and which is convenient to carry along on hand or inspection car.

How to Check an Existing Curve.

Three men are required when using the gauge, two end men and one center man. To undo the wires it is best for one end man to attach ring to end pin and, walking toward center, unroll the wire until hook is reached, which is then attached to end piece; he then walks back to his end pin. This brings one end man 25 feet from gauge; the other end man will do the same with other chord, and gauge is now ready for action. Center man lays gauge on top of inner rail of curve, places center pin in position, and moves gauge so that center pin bears against gauge face of rail; the two end men draw their wires taut and hold their pins against gauge face of same rail. The center man will observe that the two wires move over the graduations without binding, yet close enough for accurate reading, and then swing gauge about center pin until one wire crosses graduation at zero. The other wire then indicates the degree of curve.

If there are four men present it is preferable to have the fourth man keep a check by noting down the readings. However, three men can do it very well. A few readings will tell approximately the degree of curve. For instance, if first reading is 3¾°, second reading 4¼°, third reading 4°, the curve may be assumed to be 4°. If the point of curve is not known, the men walk toward the beginning of curve, and when near the beginning, place gauge on rail, as indicated above, and take readings. The P. C. is reached by center man when rear chord on tangent indicates zero and first chord on curve indicates 2° (or just half of curve). This point should be carefully marked on the rail, also drive a stake in middle of track (or tack, if it falls on a tie). Now go over the curve, beginning at point of curve with gauge on top of inner rail, and mark down all the readings, keeping rear line always at zero. Let curve *AG*, Fig. 11, be the gauge line of inside rail, and *A* be the P. C. Then rear man holds his pin at *H*, or 25 feet back on tangent. Center man swings gauge until *AH* crosses zero line, then forward chord indicates curve between *A* and *B*, where it crosses graduation. Since *AB* is first chord of curve, the angle indicated is the tangential deflection, hence if this first reading shows 2° it indicates a 4° curve.

The tally man marks down this reading and center man adjusts the end piece for the 4° curve; forward man marks point *B* with chalk, or in some other suitable way, on the gauge face of rail. Then all three advance, center man goes to *B*, rear man to *A*, and forward man toward *C*; center man adjusts rear end piece for the 4° curve, rear man holds his pin against gauge face of rail at *A*; center man holds center pin against rail at *B*, and swings gauge so rear line crosses graduation at zero, then forward string shows curve between *B* and *C*, when it crosses graduation. If it crosses at 4¼ it is a 4¼° curve between *B* and *C*. The tally man marks this down under the 2° of the preceding reading, front man marks point *C*, and then they advance to the next position, the rear man to *B*, the center man to *C*, and front man to *D*, when the preceding operations are repeated until the end of curve is reached. If *G* is the *PT*, then when center man is at *G* with the curve gauge the rear man's wire crossing zero at the graduation, the front man's wire should cross at 2°, the last deflection being again just half of the curve, and the chord *GI* will be part of tangent.

Now let us suppose that the readings marked down are as follows:

2, 4¼, 4, 4½, 3½, 3¾, 2; add these seven readings together makes 24; there are just six chords on the curve; so divide 24 by 6, gives 4, which is the average degree of curvature.

This is the general method to be followed in checking up any curve. It is, of course, very desirable to have the P. C. fixed by some permanent monument; this simplifies the checking very much.

To Stake Out the Curve.

After the curve is checked up and the P. C. fixed, place gauge in between rails parallel therewith, so the center pin tallies with point *A* (see Fig. 11), assuming *AG* is center line of track; the point *H* is also to be fixed 25 feet back on tangent in the middle of track. The rear man holds the pin over point *H*, center man holds center pin over point *A*; he swings gauge until rear string crosses graduation at zero and lines forward chord until it crosses at 2° (the curve to be staked being a 4° curve). When forward string is in correct alignment, front man drives a stake at *B*, and fixes point *B* by driving a tack in exact point, after the end piece has been adjusted for the 4° curve; then the three men walk ahead the length of a chord; the center man takes gauge to point *B*, rear man goes to *A*, and front man toward *C*. Center man adjusts rear end piece to the 4° curve and rear man brings point of his pin over *A*; center man makes center pin to tally with point *B*, and swings gauge so rear string tallies with zero point, and he then lines in forward string until it crosses graduation at 4°; front man drives a stake at this point and fixes point *C* precisely by driving in a tack. Then the three men walk ahead again, the length of a chord, center man takes gauge to point *C*, rear man goes to *B*, and forward man to *D*, where point *D* is fixed as above. In like manner all points are fixed on curve until P. C. at *G* is fixed, then the point *I* on tangent is fixed in following manner. The three men walk ahead again, center man from *F* to *G*, rear man from *E* to *F*, and front man walks toward *I*. Rear man is lined to zero and forward man to 2° (half of curve being laid); then front man's point indicates point *I*, and chord *GI* is first chord on tangent.

Fractional Chords.

If the last chord is fractional, *i. e.*, less than 25, feet, for instance, in Fig. 12, let *D* be *PT* of a 6° curve, and let *BC* be the last full 25-foot chord; let $CD=9$ feet, then the deflection angle (*ECD*) is found by adding fractional chord 9 to 25; multiply by twice the degree of curve and divide by 100; so in this case add 9 to 25, making 34; multiply 6 by 2=12; multiply 12 by 34=408; divide by 100 = 4.08°; so turn off 4 1-12° at *C*, which gives correct direction of *CD;* then the rear man will take a tape line and measure the

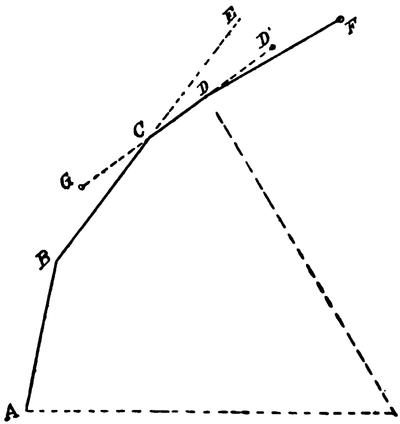

FIG. 12.

9 feet from *C* to *D;* this fixes point *D;* to fix first chord (*DF*) on tangent the angle *D*, *DF* must be turned at *D*. This is found by multiplying fractional chord by twice degree of curve, and divide by 100; in this case 9×2×6 divided by 100 =1.08°. So the gauge is placed at point *D*, rear string passing over *C*, extending to *G;* place rear

string at zero, then forward string is deflected 1.08°, which fixes point *F* on tangent.

In the case of the 8-100 part of a degree, it will be near enough to take the nearest quarter of a degree, so that in this case 1° should be used, a little stiff, since the 8-100 is nearly 1-12 of a degree.

Easements for the Ends of Curves.

In Fig. 13 is shown an application for easing the ends of a curve. We will assume that we have a 4° curve, correctly center staked, as shown in preceding paragraph. Let it now be required to ease it off on either end. Let *A* be P. C. of 4° curve and *C* the center, and let *B* be the *P. C. C.*, (point of circular curve), and the beginning of spiral. From *B* toward *A* the curve will have to be made sharper, say a 5° curve with center at *D* and *PC* at *E*. At *B*, however, both curves have common tangent *BG,* and tangent *EI* is parallel to *F A*. To make the work easy find point *B,* so that there will be no fractional chord between *B* and *E,* and assume four chords, for instance, of 5° curve. This makes central angles at *D* and at *C* = 5°, and arc *AB* equals .017 × angle × radius, or .017 × 5 × 1433, or 121.8 feet. This means 5 full 25 ft. chords less 3.2 feet. So if *M* is 5 chords from *A*, measure 3.2 back from point *M* to *B;* at *B* turn off a tangent *BG,* as explained above, and then stake in the 5° curve, *BE* putting stakes at *N, O, P, E* and *I*. The distance from *E* to *F* is called the offset, and the spiral must pass through its middle *H*. Also the beginning of spiral *S* is just as far to the right of *H* as the end *B* is to the left; so measure 4 full 25 ft. chords from *F* to *S*, setting stakes at *Q*, *R*, *U* and *S*. The spiral is finished by measuring ordinates at *Q*, *R* and *U*, also at *P*, *O* and *N*. The length of these ordinates depend upon the length *FH*, which is readily measured on the ground. In this case *FH* = 6.42 inches; the ordinate *UU* equals the 64th part of

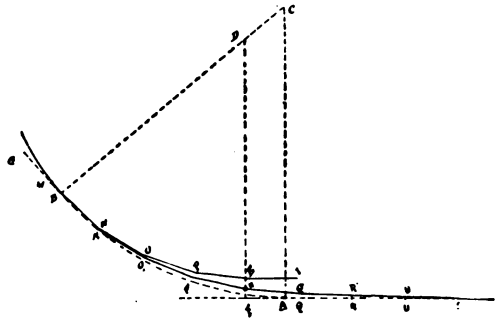

FIG. 13.

F H, or 3-32 inches. *R R* equals the 8th part of 6.42, or ¾-inch *Q Q* is 27 times as big as *UU*, or 81-32, or 2 17-32 inches. The ordinate *PP* = *QQ*, *OO* = *RR*, and *NN* = *UU*. These ordinates are easily measured on the ground, those between *F* and *S* are measured square to the tangent, and those between *E* and *B* are measured from the inner curve. A good way to do this is to stretch a cotton string along the stakes from *B* to *N, O, P* and *E;* this brings out the points where the ordinates are to be measured. This kind of easement-curve is recommended in all cases where it is not desirable to disturb the old curve through its entire length.

For the assistance of the track man who wants to apply this method we will give following hints:

First. Put entire curve into good line, leaving the centers visible at each end and the P. C.

Second. Decide on length of easement. This had best depend on the full elevation of the outer rail, because the track must be level at *S* and must have full elevation at *B;* so the spiral must be long enough to permit of having the elevation put in gradually. Ordinarily this requires about 50 feet per inch of elevation.

Third. One-half of spiral is on the curve.

To illustrate: Suppose *AB* is a 5° curve with 6 inches elevation at *B;* then allowing 50 feet easement per inch of elevation, $SB=300$ feet. This makes the curve $BE=150$ feet long; the degree of the curve *BE* is 6°, so that the central angle $BDE=9°$; this is also the case with angle $BCA=9°$, and, therefore, *AB* is found by multiplying $.017 \times 9 \times 1146=180$ feet (the general rule is: multiply central angle with radius and .017); then measure 180 feet from *A* toward *B;* this means six full 25-feet chords and 5 feet; this 5 feet fractional chord is staked out as shown in Fig. 12, and common tangent (*BG*) is fixed.

Then, with GB as common tangent, stake out six full 25-ft. chords of 6° curve to point E; then measure from E to F, which produces the offset. A cotton thread stretched from B to E, touching the intermediate points, is very useful.

Fourth. From point F measure 6 chords 25 feet long to S, placing stakes or tacks at each point and stretch a thread along these points, which all are in the same straight line.

Fifth. Figure the ordinates for these points. They are found from the distance FH or half of EF. If you have six chords, as in this case, divide FH by $6 \times 6 \times 6$ or 216; this distance is measured at the first point to the left of S and also at the first point to the right of B; the next ordinate is eight times as big; so multiply first measurement by 8 and measure square from tangent at the second chord point to the left of S, and also at second point to the right of B.

The third ordinate is 27 times as long as the first, so multiply first ordinate by 27 and measure from third chord to the left of S, and also from third chord to the right of B.

The fourth ordinate is 64 times the first and is measured at the fourth chord to the left from S and at the fourth to the right from B.

The fifth ordinate is 125 times the first and is measured at the fifth chord to the left from S and to the right from B. This in the case under consideration brings us to within one chord length of H, which is the middle of spiral.

After all the center points have thus been fixed it is easy to throw the track to them and the easement is complete.

Compound Curves.

A compound curve is one in which two or more curves of different degrees and tending in the same direction join without intervening tangent. Thus in Fig. 14 let *AT* be a tangent and *TC* nor-

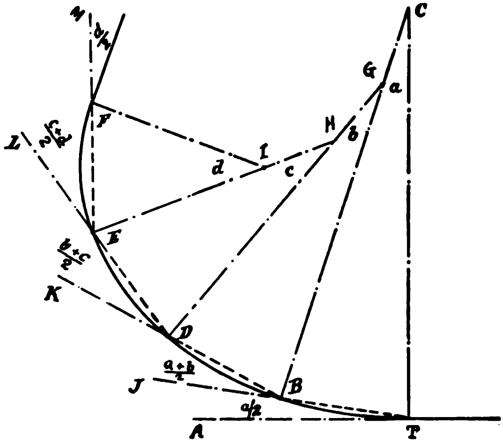

FIG. 14.

mal to *AT* at point *T*. Let the compound curve start at *T* with a curve of *a* Degrees for one chord to *B;* here let it compound to a *b* Degree curve to *D,* then to a *c*° curve to *E* and to a *d*° curve from *E* to *F;* at *F* turn to tangent. Let

C, G, H, and *I* be the respective centers of curve elements. The first deflection angle $ATB = \frac{1}{2}$ of central angle, $BCT = a \div 2$; this fixes point *B*. The curve from *B* to *D* is of *b* degrees, or angle $BGD = b$; hence the second deflection angle $JBD = (a+b) \div 2$; by a like deduction it can be proven that the deflection angle for chord $DE = (b+c) \div 2$, and for chord *EF* the deflection is $(c+d) \div 2$; turning back on tangent at *F*, the last deflection, of course, equals $d \div 2$. A convenient check for the correctness of this principle is that the total sum of deflection angles must equal the total sum of central angles. Thus if, for instance, we have a curve in which the first chord is a 1° curve, the second chord is a 2°, the third chord is a 3°, and the fourth chord a 4° curve, then the first deflection from *T* to *B* should be ½ degree; from *B* to *D* should be: $(1 + 2) \div 2 = 3 \div 2$ or 1½°; from *D* to *E* should be: $(2 + 3) \div 2 = 5 \div 2 = 2\frac{1}{2}°$; from *E* to *F* should be: $(3 + 4) \div 2 = 7 \div 2 = 3\frac{1}{2}°$; if this curve turns back to tangent at *F*, then the last deflection from *F* to tangent should be: $4° \div 2 = 2°$.

To check this back, add up all the angles at the centers, as follows:

At $C = 1°$
" $G = 2°$
" $H = 3°$
" $I = 4°$

Total 10°

Now add sum of deflection angles:

At T = ½°
" B = 1½°
" D = 2½°
" E = 3½°
" F = 2 °

Total 10°

Turnouts.

Switches are devices for joining two or more lines of track. In Fig. 15 let *A* and *B* be main line rails and *C* and *D* turnout rails—where rail *C* crosses *B* is point of frog *F*. It is seen that

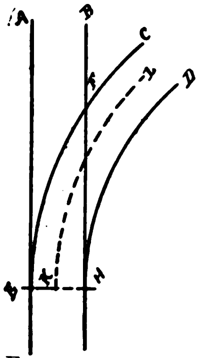

FIG. 15.

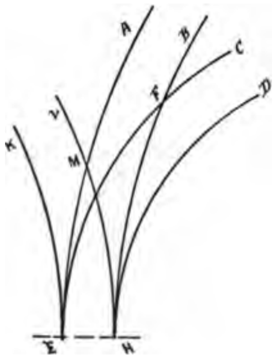

FIG. 16.

rails *C* and *D* are curved, and, generally speaking, main track rail *A* is a tangent to rail *C* at *E*. This curve (*EC*) varies with angle of frog *F* and gauge of track $E\ H$, and we append a table showing degree of curves for different frogs, both for standard and 3-foot gauges.

To stake out a turnout for a No. 9 frog, for instance, on a standard gauge road we see from table the curve $E\ C$ is about 7½°. Hence we use K as P. C. and stake out a 7½° curve along center line (KL); point of frog F is found by squaring over from center line of turnout curve ($K\ L$), point F being exactly ½ of gauge from $L\ K$.

If turnout $C\ E$ is taken off from a curved main track (AE) Fig. 16, the degree of curve of main track is added to that of turnout if both tend in the same direction; thus, if $A\ E$ is a 3° curve, and F is a No. 9 frog, then curve $E\ C$ = 3 plus 7.5 = 10½° curve. If turnout is, however, opposite to main track curve, like $H\ L$, then turnout curve equals difference of curvature. (See Fig. 16.)

TABLE OF TURNOUT CURVES.

Frog No.	Frog Angle	Degree of Curve for 4′ 8½″ Gauge	Degree of Curve for 3-foot Gauge
5	11° 25′	24° 3′	37° 44′
6	9° 32′	16° 40′	26° 10′
7	8° 10′	12° 17′	19° 16′
8	7° 9′	9° 23′	14° 44′
9	6° 22′	7° 25′	11° 45′
10	5° 44′	6° 1′	9° 26′
11	5° 12′	4° 58′	7° 48′
12	4° 46′	4° 10′	6° 33′
14	4° 5′	3° 4′	4° 49′
15	3° 50′	2° 40′	4° 11′
18	3° 11′	1° 52′	2° 56′

In the above case, when $E\ A = 3°$ curve, frog $M =$ No. 9, then curve $L\ H = 7.5$ minus $3° = 4\frac{1}{2}°$ curve. So turnout $L\ H$ would be put in by staking out a $4\frac{1}{2}°$ curve.

The foregoing gives a general idea of how to use the curve lining gauge for the true alignment of curves. The No. 1 Gauge is intended for general track work; the No. 2 Gauge having a capacity of 48° curvature, is for all such track work as is not included in the No. 1 Gauge. For special purposes special gauges are made.

Staking Out Curves on New Track.

This work will quite naturally be done by civil engineers, particularly the establishment of the sub-grade. After the grade, however, is finished, center stakes can be given for the curves with the above curve lining gauge quite satisfactorily. Let Fig. 17 represent the grade of a new road, the bed being graded to a general 5° curve; let the curve *A B*, which joins the tangents, be 800 feet long. In grading such a new road, provision must be made to shift the roadbed inwardly the width of the offset required for the easement, which is shown by the shifted full lines. This should be selected according to the length of spiral, and the latter according to the speed of trains, or elevation of outer rail, as explained above. Assume elevation of curve is 5 inches, then length of easement should be 200 feet at each end, and the offset suitable will be about 20 inches. Let *A T* and *B P* be the joining tangents; the roadbed should be graded between *A* and *B* so that it makes an offset of 20 inches toward the inside of curve, as shown in full lines. Then stake the curve *C D* = 32 chords of the 5° curve; mark stakes at *A*, *B*, *C* and *D*, and drive stakes half way between *A* and *C* at *M*, also between *B* and *D* at *N*; these are the middle points of the spirals. Assume each spiral is 250 feet long—half of this is on curve and half on tangent; so, beginning at *C*, going along on curve toward *D*, use 5—25 foot chords to point *E*, and from *A* going

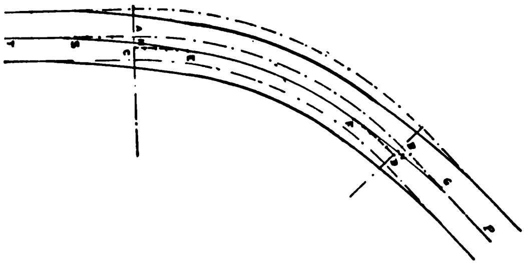

FIG. 17.

toward *T* on tangent stake out five chords to point *S*. Then the spiral begins at *S*, passes through *M*, and at *E* joins the regular 5° curve. The intermediate points are found as above in the section on Easements for the Ends of Curves. There are five chords; the smallest ordinate is equal to $A\ M \div 5 \times 5 \times 5$. Since $A\ M = 10$, the first ordinate is $10 \div 125$, or about 1-12th inch. The second ordinate is eight times as big, or two-third inches; the third ordinate is 27 times as big, or 2¼ inches; the fourth ordinate is 64 times as big, or 5 1-3 inches; the fifth is *A M*, which is 10 inches.

Between *C* and *E* the same ordinates are used and stakes set every 25 feet; then the track can be laid to these stakes. The same operation is performed at the other end of the curve by fixing five chords on the curve *D C* to *F;* also on tangent *B P* to *G*, and then measuring in the ordinates, as explained above, and putting in the stakes.

This method should have been employed when curves were first laid out; but railway construction is a practical science and has been developed gradually, by eliminating mistakes made by pioneer railway builders.

The Easement of Compound Curves.

When checking up a curve, the characteristics of which are not known, great care must be exercised not to confound compound curves with simple curves in bad alignment. For instance, a curve being checked gives following readings: 3°, 3½°, 2¾°, 3¾°, 3¼°, 4°, 3°, 3½°, it is correct to assume that the curve is a simple one, but that it is out of line.

But suppose the readings run as follows: 2½° 3°, 3°, 2¾°, 3½°, 3°, 3°, 3¼°, 2¾°, 5½°, 8°, 7¾°, 8¼°, 8°, 8°, 7¾°, 8°, 8¼°, etc.; then it is easily seen that the first 9 chords are parts of a 3° curve, while the other 9 chords form parts of an 8° curve, consequently it is a compound curve, and there should be an easement put in between them.

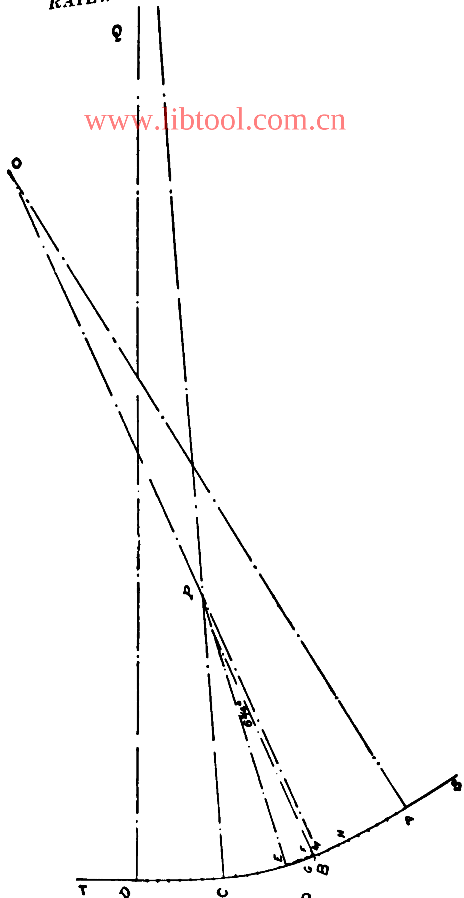

FIG. 18.

Let Fig. 18 represent such a curve; let *A* be the P.C. of the 3° curve, *B* the point where the 3° curve compounds to an 8° curve. Let *O* be the center of 3° and *P* the center of the 8° curve. The first thing to do in order to put this curve into good condition will be to check it carefully all around, beginning with P.C. at *A* and running back into tangent at *D*. Let us suppose we find nine 25 foot chords of 3° curve, from *A* to *B*, 9 chords of 8° curve from *B* to *C*, and 8 chords of 2° curve from *C* to *D*; center stakes should then be driven all around from *A* to *D*. It is plain that the speed around the 8° curve will naturally be limited, and the elevation of outer rail on the 3° curve will probably be only 2 inches; thus the easement between tangent and 3° curve will not need to be more than 100 feet, but might be made 150 feet if there is enough room. Stake out the easement curves for the two ends at *A* and *D* as shown on page 17.

To put in a transition curve between the 3° and 8° curve, let us suppose the elevation of outer rail on the 8° is 5 inches, and on the 3° is 2 inches; this makes a difference of 3 inches in elevation, which should require an easement of 150 feet; of this we would take 3 chords on the 3° and 3 chords on the 8° curve—the 3 chords on the 8° curve must be for 9°; this makes a central angle of 6¾° at point *P* (center of 8° curve). To find point *E* where transition terminates, figure arc *B E* for an 8° curve and 6¾° central angle; this makes: .017 × 716.8 × 6¾ = 82.25 feet;

so from *B* toward *E* stake out 82.25 feet of 8° curve, which fixes point *E;* from *E* toward *F* stake out 3 chords of 9° curve; this fixes point *F*. Measure square across from *F* to *G* on extended 3° curve; then *F G* is the offset, and spiral passes through its middle *M*. Then from *G* toward *A* stake out 3 chords of 3° curve to point *H*, which is the beginning of transition curve. The ordinates are figured as explained on page 16, from half of the distance *F G*, the smallest one being the 27th part of that distance. Stakes are then set for the easement between *E* and *H*. Similar transition is put in between the 2° and 8° curve at *C;* this easement should be 200 feet long; when this is done the curve is finally lined to these center points.

Many compound curves do not require any easements, for instance: when the change in curvature is only 2 or 3 degrees. The conditions of traffic will regulate this to a considerable extent; thus on roads of very fast traffic easements may be put in where the change in curvature is only 2°, while on roads of slow traffic a change of 4° may be permitted. The heads of maintenance of way departments will regulate this on the various roads.

Reverse Curves.

Strictly speaking, there is no such thing as a reverse curve to be tolerated in railway work; but quite often curves are termed reverse curves which in reality are two simple curves with a short tangent between them.

A true reverse curve is one in which two circular curves of opposite direction join without any straight track between them, as shown in dotted lines in Fig. 19. It is plain that with a curve like this in a track it would be impossible to run trains safely around it at a greater speed than 10 miles per hour, even if the curve was of a long radius. Let in Fig. 19 point *A* be the P.C., *B* be the point of reverse, and *C* be the *P. T.;* let *O* be the center of first and *P* the center of second part of reverse curve. In order to fix a curve of this nature, it is necessary to put between them a tangent of sufficient length to permit the proper elevation of the outer rail. The problem involved is a rather complex one, and should be handled by the engineering department, but for illustration we will show a simple case, in which the two curves have the same radius and the same central angle. Let the curve be a 3°, then the radius = 1910 feet; and let each curve be 600 feet long, then central angle $m=18°$. Let *I* and *K* be the intersections of the sub-tangents with the common tangent, and *P O* the line joining the two centers; then the curves lie symmetrical above and below the line *P O*. We can now calculate the tangents *C E, I B, B K,* and *K A,* which are all equal to each other. If we draw *P I* and *O K* the angle *m* is bisected, and we find:

$CI : PC =$ tangent $m \div 2$; from which we get:

$CI = PC \times tg\ (m \div 2)$; if we insert the figures we have:

$CI=1910 \times tg\ 9°$; look up the tangent for 9° in the table and substitute:

$CI=1910 \times .1584=302.54$ feet.

Consequently, since $CI=BI=BK=AK$, each of these is 302.54 feet long.

In order to interpolate a tangent *HN* between the curves, we must employ curves of shorter radii, as *CM* and *AQ*, beginning the curves at the same points as old curves. A simple way of doing this is to divide the tangents *CI* and *AK* at *E* and *D*, draw *ED* and make $EN=CE$, also $DH=AD$; then by drawing *MN* perpendicular to *EN*, and *HQ* perpendicular to *DH*, we obtain the centers of the new curves, and *MC* and *QA* are the radii.

Since *CI* is known, we know *IE*, and the angle $EIB=180°-18°=162°$, so in the triangle *EIB* we know two sides $EI=151.27$, $IB=302.54$, and the enclosed angle$=162°$; so we can find the angle *BEI* and the side *BE*. Call angle $BEI=x$ and angle $EBI=y$, then we have by trigonometry: $302.54+151.27 : 302.54-151.27=$tangent $9° \div$ tangent $(x\text{-}y)\div 2$; from this we get: tangent $(x\text{-}y)\div 2=151.27 \times .1584 \div 453.81$.

Figuring this out, we find tangent $(x\text{-}y)\div 2=.0529$.

This makes angle $(x\text{-}y)\div 2=3°$; angle $(x+y)\div 2$ is 9°; so by adding the two together we get $x=12°$, and by subtracting we get $y=6°$.

This checks out all right, since the sum of the 3 angles of any triangle must make 180°, we have: $162+12+6=180°$.

It must not be assumed that the relation of the angles x and y is always as simple as it happens in the case under consideration, where the angles are both small and the two adjacent sides have a

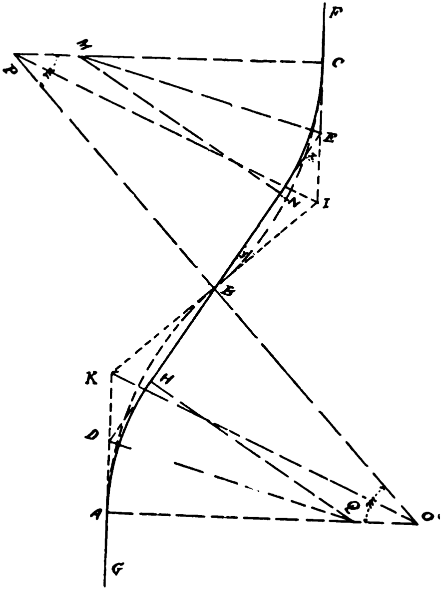

FIG. 19.

simple ratio to each other, one being twice as long as the other.

The principle shown in the solution of this problem can be extended, however, to almost any case.

The side *EB* is found now by simple proportion:

EB : 302.54 = sine 18° : sine 12°. Look up the sines in the table and substitute *EB* : 302.54 = .3090 : .2079.

Hence $EB = 302.54 \times .3090 \div .2079$.

$EB = 449.66$ feet.

Since *EN* will be on the new curve, subtract 151.27 from 449.66 leaves 298.39 feet of tangent above line *PO;* since *BH* is equal to *BN* we have a tangent of nearly 600 feet between the two curves.

Now let us get at the new curves. We know *CE* and *EN*, also angle x, then angle $CEN = 180 - x = 168°$; then angle $MEC = 84°$, and angle $CME = 6°$; hence the radius of curve may be found as follows: $CE \div MC = tg\ 6°$, from which we get:

$MC = CE \div \text{tg}\ 6°$.

Substitute values: $MC = 151.27 \div .1051$.

$MC = 1439.3$ feet, which is radius of new curve; this divided into 5730 gives the degree of curve = 3.29°, or 3° 18′ nearly.

The length of the curve from *C* to *N* is: $.017 \times 1439 \times 12 = 293.22$ feet.

We can now stake out the curve with the above curve lining gauge, beginning at point *C* and staking out 293.22 feet of 3° 18′ curve; then we do the same, beginning at point *A* to *H;* continue staking out the tangent from *H* toward *N*, where it should coincide with the tangent to curve *CN*.

The proper easements can now be put in and the piece of track from *A* to *F* may be made good for a speed of 50 miles per hour.

This method preserves the general alignment of the road and does not change the approach from either end. It is easily seen that by varying the length *CE* the tangents between the two curves may be increased or diminished; thus, if *CE* is made shorter, the common tangent is made longer and the radius of curve gets shorter, which means increased curvature. If *CE* is made longer the common tangent is made shorter and radius of curve becomes longer.

The Easement Considered as a Compound Curve.

While theoretically the cubic parabola, which is used extensively as an easement for the ends of circular curves, is a curve differing from a circle in that it begins with a radius of infinite length, and approaches with constantly decreasing radius that of the circular curve at the end of the easement, it may be shown that in reality such easement is nothing more or less than an aggregation of circular curves compounded. To show this the case treated on page 16 will be considered, and reference had to Fig. 20. Let *ST* represent the tangent, *S* being the beginning of spiral, and let *F* be the middle of spiral, *FH* being the offset. Let *Q*, *R* and *U* be points on the tangent dividing *FS* into 4 equal parts, each 25 ft. long. The spiral ordinates are as shown on page 16, as follows: $UU' = 3/32$ in.; $RR' = 3/4$ in.; $QQ' = 81$-32 inches, and $HF = 6.42$ inches. Reducing these to fractions of feet we get: $UU' = .0078$, $RR' = .0625$, $QQ_1 = .211$, and $FH = .535$ ft.

Consider triangle SUU'; the deflection angle USU' can be determined, since the base $US = 25$,

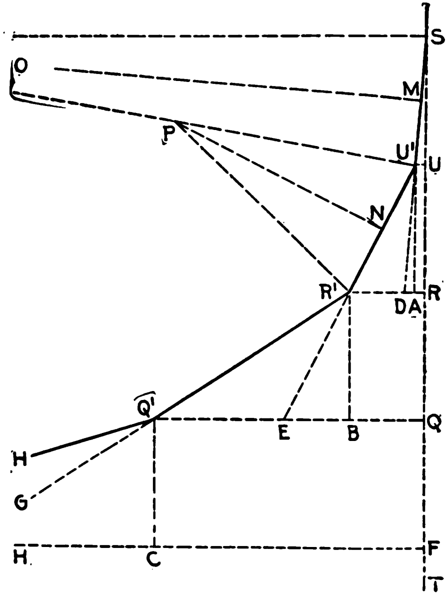

FIG. 20.

and $UU' = .0078$ are known; hence tangent $USU' = .0078 \div 25 = .00031$; the angle corresponding to this tangent is slightly larger than

1 minute; if M is center of $U'S$ and MO is normal to $U'S$ and OS is normal to FS, then O will be center of a circle tangent to FS in S and passing through U_1. (In the figure point O lies beyond the paper, but is indicated by an arrow.)

Since $U'S$ practically equals US = 25 ft., SM = 12.5, and angle MOS = 1 min. Radius SO = 12.5 ÷ tang. 1′ = 40,022 ft. This corresponds to a .14 degree curve, or nearly an 8½ minute curve, reduced to the 100 ft. chord.

It is plain, then, that no matter how carefully a stake might be set for the point U' and how carefully the track men line their curve, there is actually a 25 ft. piece of circular curve of about 40,000 ft. radius joining the tangent at S_1.

Going to the next chord $U'R'$ and drawing $U'A$ parallel to tangent SF, the triangle $U'AR'$ can be computed. AU' = 25 ft. and AR = RR' — UU' = .0625 — .0078 = .0547; hence angle $R'U'A$ is found as follows: tangent $R'U'A$ = .0547 ÷ 25 = .00219.

This gives an angle of nearly 8 min. for $R'U'A$; the extension of SU' strikes RR' in D and angle $AU'D$ = 1′; subtract this from 8 leaves angle $RU'D$ = 7 minutes. Since $R'U'$ virtually equals 25 ft., the Radius for Curve passing through $U'R'$ may be readily computed by Trigonometry, or by the Rule shown on page 20. Using the latter, then angle x (at Center P) equals 12′, which would make the circular curve from U' to R' equal to 48′, or 4/5 degree.

Treating chord $R'Q'$ in like manner, triangle $Q'R'B$ may be computed:

$R'B = 25$ ft.; $Q'B = .2110 - .0625 = .1485$; hence

Tangent of angle $Q'R'B = .1485 \div 25 = .00594$.

This makes angle $Q'R'B = 20$ minutes.

Subtract angle $ER'B = 8'$, leaves angle $Q'R'E = 12'$.

From this we can deduce center angle opposite the chord $Q'R'$, for let x = center angle opposite $Q'R'$, then according to Analysis of Compound Curves:

$20' = (x \div 2) + 6$; from this we find $x = 28'$; this would make the degree of curve from U' to R' equal to $4 \times 28' = 1° 53'$; applying the same reasoning to chord $Q'H$ we find in triangle $HQ'C$ the base $Q'C = 25$ ft., and $HC = HF - CF = .535 - .211 = .324$ ft.; hence tangent of angle $HQ'C = .01296$, making angle $HQ'C = 44'$.

Subtract angle $HQ'C \div$ angle $Q'R'B = 20'$, leaves angle $HQ'G = 44' - 20' = 24'$. Hence central angle opposite chord $HQ' = 36'$, making circular curve passing through $Q'H$ equal to $4 \times 36 = 2° 24'$.

Without extending this any farther it is seen that this easement under consideration consists successively of curves of 8½ minutes, 48 minutes, 1° 53′ and 2° 24′. Hence a compound curve of gradually increasing curvature will have the same effect as the theoretical parabola.

This illustration shows that, while the ordinates, as figured according to the rules of the cubic parabola, give the best values for the varying curvature, the trackman should not think that he has supernatural conditions before him, but merely several ordinary circular curves which gradually melt into the main curve.

The above deductions and conclusions can be arrived at in another way as follows: Since all the angles under consideration are very small, and the radii of circles comparatively large, the angles may be measured directly on the circumference of the circles. Thus, measuring angle USU' where $SU = 25$ ft. and $UU' = .0078$: if a circle be described with SU as a Radius, its circumference equals $2 \times 25 \times 3.14159 = 157.0795$ ft.; divide this by 360, would give the length of arc opposite one degree of central angle; this makes .43633 ft.; divide this by 60 gives .00726 ft. per minute; divide this into .0078 gives 1.08 minutes.

The Radius SO may be found by simple proportion:

$MO : MS = SU = UU'$. Substitute values:

$MO : 12.5 = 25 : .0078$. Hence

$MO = 12.5 \times 25 \div .0078$.

$MO = 40{,}064$ ft.

It is seen this agrees pretty well with the answer found above. This method does not require any trigonometrical tables, but cannot be used for angles greater than 4 degrees with any degree of accuracy.

The Elevation of Outer Rail.

It is not enough that railway curves are in true alignment, and that the curvature is produced gradually by spiraling the ends of same. There is a mechanical requirement to keep the cars from leaving the rails, when they go around a curve at high speed. Everyone is familiar with the fact that when a body is traveling freely it will do so in a straight line; hence, if we want to have it perform any other motion, we must apply force; thus, cars going around a curve can be made to do so satisfactorily only by providing means to overcome their tendency to travel in a straight line. The wheel flanges perform this duty satisfactorily when cars are traveling slow and when the curvature is light; but when the speed of the trains reaches above 15 miles per hour there would be grave danger of flanges breaking, or the train tipping over. This tendency of a train rounding a curve to leave the rails and travel in a straight line is called centrifugal force, or tangential force, and it is counterbalanced by the centripetal force which acts in the opposite direction. This latter force is generated by the raising of the outer rail above the level of the inner one; this makes an inclined plane out of the track, and the force of gravity pulls on the train toward the center of the curve. This elevation should be so proportioned that the pull toward the center of the curve is exactly equal to the centrifugal force.

The centrifugal force varies directly as the square of the velocity, and inversely as the radius.

The mechanical formula for the elevation of outer rail is:

$$e = gv^2 \div 32.2\ r.$$

In this formula e represents the elevation, g

the gauge, v the velocity in feet per second, and r the radius, all in feet. The author, some time ago, modified this rather difficult formula to one which is much easier of application, namely:

$$e = 66\ ds^2 \div 100{,}000.$$

In this formula e represents the elevation of outer rail in inches, d is the degree of curve, and s is the speed of train in miles per hour.

To show that the two formulæ reach practically the same result, a problem will be worked by both methods.

Problem. Find the elevation of the outer rail of a 6° curve on a standard gauge road for a speed of 40 miles per hour.

Solution. 40 miles per hour means .667 miles per minute, or 59 feet per second; the radius of a 6° curve is 955 feet; the standard gauge = 4.71; so the numerator is found by multiplying 4.71 × 59 × 59, and the denominator by multiplying 32.2 with 955; this gives:

$$e = 16395.51 \div 30751.0.$$
$$e = .533 \text{ feet.}$$

Multiply this by 12, gives 6.40 inches, and reduce the .40 inches gives 13-32″, so that the elevation of the outer rail should be 6 13-32″ for this case.

Using the second formula, we just multiply 66 × 6 × 40 × 40 and point off 5 numbers from right to left, thus: $e = 66 \times 6 \times 40 \times 40 =$ 6.33600, or

$e = 6.34$ inches.

Hence it is seen that the results are practically the same.

If the track gauge is different from 4′ 8½″, the constant 66 must be changed to 42 for a 3 foot gauge.

So if the above problem was to be solved for a 3 foot gauge, we would say:

$e = 42 \times 6 \times 40 \times 40 \div 100{,}000.$
$e = 4.03$ inches, which would be 4 1-32 inches.

As to the limits of extreme elevation, the head of maintenance of way on each road will give special instruction. Ordinarily no curve should be elevated more than 7 inches on standard. nor more than 4 inches on 3 foot gauge track.

Practical Examples.

1. Change 4′ 8½″ to a decimal fraction.

There are 4 full feet, so place 4 down with the point back of it, thus: 4.; then 8½ inches can be written 8.5 inches, and if we divide this by 12 will reduce it to feet; this gives .708; put this back of the 4. and you have 4.708, which generally is shortened to 4.71. This is the Standard Gauge of Track.

Another method: Change the whole number to inches and divide by 12. Thus, 4 feet equals 48 inches, and 8.5 inches makes 56.5. Divide by 12 gives = 4.708 feet.

2. Change a decimal fraction of feet to feet and inches; for instance:

Change 4.708 to feet and inches.

There are 4 full feet, so put them aside as part of the answer; the remainder, .708, is less than a foot, and is reduced to inches by multiplying by 12; this gives 8.496 inches, which is 8½ inches; attach this to the full 4 feet above, and the answer is 4′ 8½″.

3. Rule for changing the decimal fraction of an inch to the nearest 32d of an inch: Take the nearest 1-100 of an inch; if less than 12-100 divide by 3 for the nearest 32d. If between 12-100 and 37-100 subtract 1 from the number of hundredths and divide by 3; if between 38-100 and 62-100 subtract 2 and divide by 3; if between 63-100 and 87-100 subtract 3 and divide by 3; if between 87-100 and 100-100 subtract 4 and divide by 3 for the nearest 32d of an inch.

Application: Change .12 inches to 32ds. Divide 12 by 3, gives 4-32 or ⅛ inch.

Change .28 inches. Subtract 1, leaves 27; divide by 3, gives 9-32 inches.

Change .48 inches. Subtract 2, leaves 46; divide by 3, gives 15-32 inches.

Change .71 inches. Subtract 3, leaves 68; divide by 3, gives 23-32 inches.

Change .93 inches to 32ds. Subtract 4, leaves .89; divide by 3, gives 30-32 (always take the nearest full number); this can be reduced to 15-16 inches.

When the division with 3 does not go up without a remainder, like in the last application, take the nearest full number; thus, if you divide 16 by 3, the answer is 5; but if you divide 17 by 3, use 6; this will give you the nearest 32d of an inch every time with the least figuring.

4. Find the length of a 7 degree curve opposite an angle of 12° at the center. (This example would have to be figured if you want to ease the ends of a 7° curve), see page 18.

The radius of the 7° curve = 5730 ÷ 7 = 819 feet. (This can also be looked up in table on page 6.) Then the length of curve equals .017 × 12 × 819; this brings 167.076 feet; the fractional part can either be neglected or can be turned into inches by multiplying with 12; if we do the latter we obtain .912 inches. Reducing this as stated above: Subtract 4 from 91, leaves 87; divide by 3, gives 29-32 inches.

Of course, when putting in the easement, this fractional inch will be neglected; but when it comes to comparing the length of the eased curve with that of the original curve, the fraction must be taken account of.

General Directions.

If there is considerable wind the man in charge must be sure that wires are not deflected from a straight line. Ordinarily the tool is protected by the rails from the action of the wind, but if the wind is bad enough to deflect the wires operation must be suspended, as no accurate work can be done unless they stretch to absolute straight lines.

See that center pin works freely. When working in center of track, where there is considerable elevation of the outer rail, the curve gauge frame adjusts itself parallel to the plane of roadbed and center pin will stand normal to said plane. Hence the two end pins must be held so as to also stand normal to plane of roadbed, which is assured by the triangular stools.

See that the chord graduation is properly adjusted; the end pieces of the No. 1 gauge have a capacity up to and including 24-degree curves. For intermediate degrees not marked use proportional lengths; thus for a 9-degree curve, for instance, move rider until index is half-way between 8° and 10°

Test the curve gauge frequently, particularly if you have let it fall heavily and for any other cause which may have injured its alignment. The best way for testing it is to take a straight-edge, hold one end of it at the zero point of one end graduation touching center casting and observe point on other end graduation where straight-edge intersects; do the same from the other side of center casting, and again observe where straight-edge strikes end graduation. The two observed intersections should be equidistant from zero point.

When using gauge the center man should carry a wedge-shaped board about 3″ x 8″, having one edge about ¼″ and other edge ¾″ thick. This will be very handy if the four gauge lugs don't touch the ground firmly; then he can slip the wedge under one of the lugs to make gauge stand firm; also if it is necessary to either raise or depress one end of gauge slightly, it can readily be done by slipping wedge under one set of gauge lugs.

To fix points between rails in middle of track the front man uses stakes when the points fall between ties, and tacks or nails when they fall upon wooden ties. To use the gauge upon an open-deck bridge where there is no ballast the points which fall between the ties must be fixed as follows: the front man must carry some boards about 6" x 10", ½" thick, reaching from one tie to the other, and nail it securely to both ties at about the place where the point is to be fixed. Then when point is exactly fixed drive a tack. Of course if point falls on tie, just drive a tack. On steel ties or concrete ties the exact point is to be marked either with crayon or a chisel.

In the case the head of rail is very broad and the curve is sharp, it may be found when checking up curve that there is not sufficient room between the gauge lugs to let the rear wire cross graduation at zero. This is not necessary; place the gauge on top of rail any way at all and just add the indicated curvatures together; for instance, if rear wire shows 5° and forward 7° it is a 12° curve; only watch that both read from the same side of zero marks, and that pins properly touch gauge face.

If for any reason the gauge cannot be placed on top of rail it may be placed alongside of base of rail; by using points an equal distance from the base of rail, say the length of the pin, the curve may be checked up without any trouble.

The observant user will discover many ways in which to overcome little difficulties—when the ballast is rough it may have to be smoothed slightly to give the lugs under gauge and the triangular stools parallel bearings. The stakes should be like those used by surveyors, and should be driven firmly, and before the tack is put in, the points should be carefully checked.

Middle Ordinates for Curving Rails.

When laying new track, or when renewing rails around curves of 2° or over, the rails should be curved to conform to the degree of curve. When a rail is curved for a certain degree curve its middle will lie a certain distance from a straight line connecting the ends; this distance is called the middle ordinate, and it is used to check the rail after curving, whether it will fit into the curve. A table giving the middle ordinates for curves up to 24°, and for rails from 18 feet to 33 feet is appended to this paragraph. But as it may become necessary for the man in charge of switch work or other track work to find out the middle ordinate for other cases than the ones covered in this table, we give the rule which is to be followed. This general rule may be stated thus:

The middle ordinate for any rail in any curve is found by subtracting the square of half the rail length from the square of the radius, extract the square root and subtract from the radius:

Applied Problem: Find middle ordinate for a 33 foot rail in a 24° curve:

Solution: The radius of a 24° curve is 241; divide 33 by 2 gives 16.5. Square 241 = 58081;

square 16.5 = 272.25; subtract 272.25 from 58081 = 57808.75; extract the square root from this number gives 240.434; subtract this from 241 leaves .566 feet; reduce this to inches by multiplying by 12 gives 6.79 inches, and change .79 inches to the nearest 32d. Subtract 3 and divide by 3: 76÷3=25-32 inches—hence the middle ordinate measures 6 25-32 inches; 6¾ inches will be sufficiently accurate.

Another Rule, although not absolutely correct for very sharp curves and long chords, but useful for regular track work, is as follows: Square the length of rail and divide by 8 times the radius.

If we apply this Rule for the above problem we have:

$$33 \times 33 \div 8 \times 241.$$

$$1089 \div 1928 = .565.$$

It is seen that this answer corresponds to the one found above with much less figuring.

Table of Middle Ordinates in Inches.

Curve.	18-ft. Rail.	20-ft. Rail.	22-ft. Rail.	24-ft. Rail.	26-ft. Rail.	28-ft, Rail.	30-ft. Rail.	33-ft. Rail.
1°....	3/32	3/32	1/8	5/32	3/16	7/32	1/4	1/4
2°....	5/32	3/16	5/16	11/32	3/8	13/32	7/16	5/8
3°....	1/4	5/16	13/32	7/16	17/32	5/8	11/16	7/8
4°....	13/32	7/16	1/2	5/8	3/4	7/8	15/16	1 1/8
5°....	7/16	1/2	19/32	3/4	15/16	1 1/16	1 3/16	1 3/8
6°....	1/2	5/8	3/4	7/8	1 1/16	1 1/4	1 13/32	1 3/4
7°....	9/17	11/16	5/8	1	1 1/4	1 7/16	1 21/32	2
8°....	21/32	13/16	1	1 3/16	1 7/16	1 9/16	1 7/8	2 1/4
9°....	3/4	29/32	1 3/32	1 11/32	1 5/8	1 3/4	2 3/32	2 1/2
10°....	27/32	1	1 3/8	1 11/16	2	2 5/32	2 11/32	2 7/8
12°....	1 3/32	1 5/16	1 1/2	1 13/16	2 1/8	2 7/16	2 23/32	3 3/8
14°....	1 3/16	1 1/2	1 3/4	2 1/16	2 9/16	2 15/16	3 5/16	4
16°....	1 3/8	1 11/16	2 1/16	2 3/8	2 7/8	3 5/16	3 3/4	4 5/8
18°....	1 17/32	1 15/16	2 3/16	2 11/16	3 3/16	3 11/16	4 7/32	5
20°....	1 7/8	2 1/16	2 9/32	2 7/8	3 1/2	4 1/16	4 11/16	5 1/2
22°....	2 1/32	2 11/32	2 21/32	3 1/4	3 27/32	4 1/2	5 1/16	6
24°....	2 9/32	2 1/2	3	3 5/8	4 11/32	5	5 28/32	6 3/4

Table of Sines and Tangents of Angles.

Angle.		Sine.	Tangent.	Angle.		Sine.	Tangent.
0	00	.0000	.0000	18	00	.3090	.3249
	30	.0087	.0087		30	.3173	.3346
1	00	.0175	.0175	19	00	.3256	.3443
	30	.0262	.0262		30	.3338	.3541
2	00	.0349	.0349	20	00	.3420	.3640
	30	.0436	.0437		30	.3502	.3739
3	00	.0523	.0524	21	00	.3584	.3839
	30	.0610	.0612		30	.3665	.3939
4	00	.0698	.0699	22	00	.3746	.4040
	30	.0785	.0787		30	.3278	.4142
5	00	.0872	.0875	23	00	.3907	.4245
	30	.0958	.0963		30	.3988	.4348
6	00	.1045	.1051	24	00	.4067	.4452
	30	.1132	.1139		30	.4147	.4557
7	00	.1219	.1228	25	00	.4226	.4663
	30	.1305	.1317		30	.4305	.4770
8	00	.1392	.1405	26	00	.4384	.4877
	30	.1478	.1495		30	.4462	.4986
9	00	.1564	.1584	27	00	.4540	.5095
	30	.1650	.1673		30	.4618	.5206
10	00	.1736	.1763	28	00	.4695	.5317
	30	.1822	.1853		30	.4772	.5430
11	00	.1908	.1944	29	00	.4848	.5543
	30	.1994	.2035		30	.4924	.5658
12	00	.2079	.2126	30	00	.5000	.5774
	30	.2164	.2217		30	.5075	.5890
13	00	.2250	.2309	31	00	.5150	.6009
	30	.2334	.2401		30	.5225	.6128
14	00	.2409	.2493	32	00	.5299	.6249
	30	.2504	.2586		30	.5373	.6371
15	00	.2588	.2679	33	00	.5446	.6494
	30	.2672	.2773		30	.5519	.6619
16	00	.2756	.2867	34	00	.5592	.6745
	30	.2840	.2962		30	.5664	.6873
17	00	.2924	.3057	35	00	.5736	.7002
	30	.3007	.3153		30	.5807	.7133

Table of Sines and Tangents of Angles.—Continued.

Angle.		Sine.	Tangent.	Angle.		Sine.	Tangent.
36	00	.5878	.7265	**54**	00	.8090	1.3764
	30	.5948	.7400		30	.8141	1.4019
37	00	.6018	.7536	**55**	00	.8192	1.4281
	30	.6088	.7673		30	.8241	1.4550
38	00	.6157	.7813	**56**	00	.8290	1.4826
	30	.6225	.7954		30	.8339	1.5108
39	00	.6293	.8098	**57**	00	.8387	1.5399
	30	.6361	.8243		30	.8434	1.5697
40	00	.6428	.8391	**58**	00	.8480	1.6003
	30	.6494	.8541		30	.8526	1.6319
41	00	.6561	.8693	**59**	00	.8572	1.6643
	30	.6626	.8847		30	.8616	1.6977
42	00	.6691	.9004	**60**	00	.8660	1.7321
	30	.6756	.9163		30	.8704	1.7675
43	00	.6820	.9325	**61**	00	.8746	1.8040
	30	.6884	.9490		30	.8788	1.8418
44	co	.6947	.9657	**62**	00	.8829	1.8807
	30	.7009	.9827		30	.8870	1.9210
45	00	.7071	1.0000	**63**	00	.8910	1.9626
	30	.7133	1.0176		30	.8949	2.0057
46	00	.7193	1.0355	**64**	00	.8988	2.0503
	30	.7254	1.0538		30	.9026	2.0965
47	00	.7314	1.0724	**65**	00	.9063	2.1445
	30	.7373	1.0913		30	.9100	2.1943
48	00	.7431	1.1106	**66**	00	.9135	2.2460
	30	.7490	1.1303		30	.9171	2.2998
49	00	.7547	1.1504	**67**	00	.9205	2.3559
	30	.7604	1.1708		30	.9237	2.4141
50	00	.7606	1.1918	**68**	00	.9272	2.4751
	30	.7716	1.2131		30	.9304	2.5386
51	00	.7771	1.2349	**69**	00	.9336	2.6051
	30	.7826	1.2572		30	.9367	2.6746
52	00	.7880	1.2799	**70**	00	.9397	2.7475
	30	.7934	1.3032		30	.9426	2.8239
53	00	.7986	1.3270	**71**	00	.9455	2.9042
	30	.8039	1.3514		30	.9483	2.9887

Table of Sines and Tangents of Angles.—Continued.

Angle.	Sine.	Tangent.	Angle.	Sine.	Tangent.
72 00	.9511	3.0777	82 00	.9903	7.1154
30	.9537	3.1716	30	.9914	7.5958
73 00	.9563	3.2709	83 00	.9925	8.1443
30	.9588	3.3759	30	.9936	8.7769
74 00	.9613	3.4874	84 00	.9945	9.5144
30	.9636	3.6059	30	.9954	10.3854
75 00	.9659	3.7321	85 00	.9962	11.430
30	.9681	3.8667	30	.9969	12.706
76 00	.9703	4.0108	86 00	.9976	14.301
30	.9724	4.1653	30	.9981	16.350
77 00	.9744	4.3315	87 00	.9986	19.081
30	.9763	4.5107	30	.9990	22.904
78 00	.9781	4.7046	88 00	.9994	28.636
30	.9799	4.9152	30	.9997	38.188
79 00	.9816	5.1446	89 00	.9998	57.290
30	.9833	5.3955	30	1.0000	114.589
80 00	.9848	5.6713	90 00	1.0000	Infinite
30	.9863	5.9758			
81 00	.9877	6.3138			
30	.9890	6.6912			

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