Appendix

J

Oregon Department of Transportation
Traffic/Roadway Section
4040 Fairview Industrial Drive SE
Salem, OR 97302-1142
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ALIGNMENT GUIDE & DESIGN AIDS

ODOT standard horizontal alignments use transition spirals. Appendix J presents basic information on the ODOT Standard Highway Spiral and solutions to common situations that arise in applying them. The information on Pages J-5 thru J-19 is taken directly from the August 1973 version of the "Standard Highway Spiral" book.

Appendix J also contains numerous Tables, Formulas, and Figures to aid in fitting horizontal and vertical alignments, and information on intersection design. In addition, ODOT design staff have developed an Excel spreadsheet named "Espiral 2011" tool to aid in solving alignments.

For assistance on using this tool, contact the Interchange Engineer at (503) 986-3560.

The example solutions for exit and entrance ramps on curves cover the most common cases that occur in new construction and retrofit situations. They are intended to serve as a template for how to approach individual conditions, not as absolute standards. Standards for spiral length are located in HDM Chapter 3 and Chapter 9 (for ramps).

Since it is not possible to cover every potential situation in this Appendix, designers are strongly encouraged to contact the Roadway Unit for assistance in applying any of these helps.

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TABLE OF CONTENTS

CIRCULAR CURVE DEFINITIONS J-1

SPIRAL CURVE DEFINITIONS AND NOMENCLATURE J-2

BASIC FORMULAS J-5

STANDARD SPIRAL NOTES J-7

TYPICAL SPIRAL CURVE SOLUTIONS J-8

Example I: Solution of spiral elements and deflection angle- (Curve with spirals of equal length) J-8

Example II: Intermediate setup on spiral with deflections J-9

Example III: Deflections to spiral from the P.S.C. or the P.C.S. J-10

Example IV: Fitting a spiral between two parts of a compound curve with spiral transitions at each end J-11

Example V: Semi-tangents for curve with spirals of unequal length J-12

Example VI: Fitting existing circular curve alignment with spiral curves requiring a minimum shift of alignment J-13

Example VII: Offsets from circular curve alignments to spiraled alignment using same radius of curve and original tangents J-14

Example VIII: Standard method of showing alignment on maps J-15

Example IX: Method Of Computing Semi-tangents of curve with spiral at one end only J-16

Example X: Fitting compound curve with three spirals J-17

Example XI: Determining U, V and C distances for segment of a spiral J-18

Example XII: Computing offset spirals J-19

Example XIII: Solution Of Offset spiral intersecting with property line J-20

VERTICAL CURVE J-22

HORIZONTAL CURVES J-24

Parallel Tangents – Equal Length Reversing Curve J-24

Parallel Tangents – Unequal Length Reversing Curves J-25

Two-Centered Corner Radii Graphical Solution J-26

Two-Centered Corner Radii Mathematical Solution J-27

Ramp Fitting Data - One Lane Ramps – 70 mph Highway J-28

Ramp Fitting Data - One Lane Ramps – 60 mph Highway J-29
Ramp Curve Fitting Details J-30
Loop Ramp Fitting Details - Single Lane Loops..... J-31
Loop Ramp Fitting Details - Two Lane Loops J-32
Minimum AASHTO Acceleration & Deceleration Lengths for Ramps J-33
Truck Deceleration J-34
Single Point Interchanges Preferred Intersection Details.....J-35
Single Point Interchanges Minimum J-36
Cross Slope Development at Gores -(Exit and Entrance).....J-37
AASHTO Basic Freeway Lane Drop Hierarchy..... J-38
Establishing Local Tangent On Horizontal Curves..... J-39
Establishing Ramp Takeoff/Touchdown Points And Ramp Angles From Local Tangent J-40
Using Spiral Segment in Compound Horizontal Curve Situations J-41
Establishing Spiral Segment Control Points (in conjunction with ESpiral 2011 spreadsheet.....J-42
Example of Spiral Segment in a Mainline Alignment Situation J-43

RAMPS ON CURVED ALIGNMENTS..... J-44

Exit Ramp on the Inside of Curve – Takeoff Point located along Circular Curve J-44
Typical Treatment For Exit Ramp on the Inside of Circular Curve Takeoff Point located along Circular Curve when 415' or less from PCS of Highway alignment J-45
Typical Treatment for Exit Ramp on the Inside of Curve Takeoff Point located along leading Spiral..... J-46
Exit Ramp on the Inside of Curve Takeoff Point located along Trailing Spiral J-47
Exit Ramp on the Outside of Curve – Takeoff Point located along Circular Curve J-48
Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along leading Spiral..... J-49
Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along Trailing Spiral..... J-50
Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Circular Curve J-51
Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along leading Spiral.....J-52
Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Trailing Spiral.....J-53
Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Circular Curve J-54

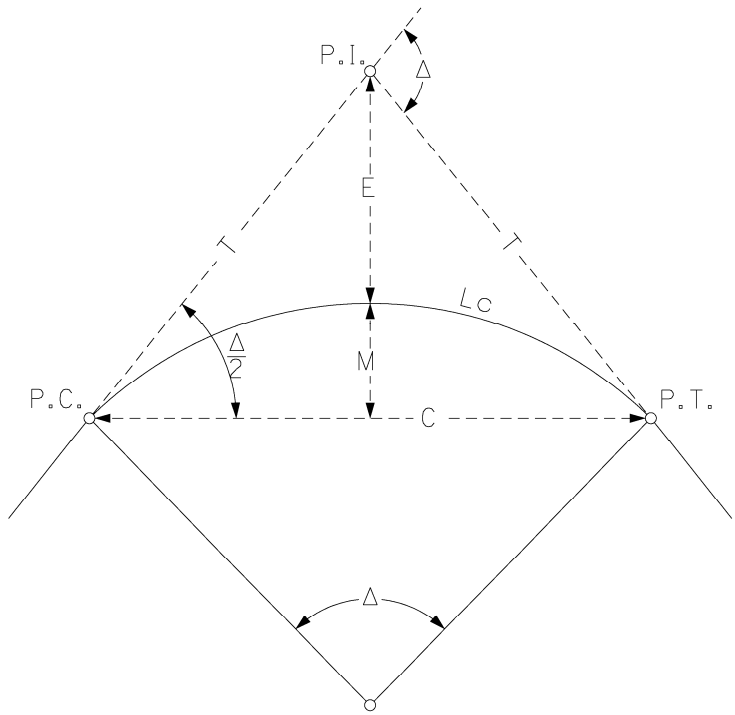
Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along leading Spiral J-55

Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Trailing Spiral J-56

TABLE OF FIGURES

Figure J-1: Parallel Tangents – Equal Length Reversing Curve J-24
Figure J-2: Parallel Tangents – Unequal Length Reversing Curves J-25
Figure J-3: Two-Centered Corner Radii Graphical Solution J-26
Figure J-4: Two-Centered Corner Radii Mathematical Solution J-27
Figure J-5: Ramp Fitting Data - One Lane Ramps – 70 mph Highway J-28
Figure J-6: Ramp Fitting Data - One Lane Ramps – 60 mph Highway J-29
Figure J-7: Ramp Curve Fitting Details J-30
Figure J-8: Loop Ramp Fitting Details - Single Lane Loops J-31
Figure J-9: Loop Ramp Fitting Details - Two Lane Loops J-32
Figure J-10: Minimum AASHTO Acceleration & Deceleration Lengths for Ramps J-33
Figure J-11: Truck Deceleration J-34
Figure J-12: Preferred Design Values For Single Point Interchanges J-35
Figure J-13: Minimum Design Value For Single Point Intersection Design J-36
Figure J-14: Cross Slope Development at Gores - (Exit and Entrance) J-37
Figure J-15: AASHTO Basic Freeway Lane Drop Hierarchy J-38
Figure J-16: Establishing Local Tangent on Horizontal Curves J-39
Figure J-17: Establishing Ramp Takeoff/Touchdown Points And Ramp Angles From Local Tangent J-40
Figure J-18: Using Spiral Segment in Compound Horizontal Curve Situations J-41
Figure J-19: Establishing Spiral Segment Control Points (in conjunction with ESpiral 2011 spreadsheet) J-42
Figure J-20: Example of Spiral Segment in a Mainline Alignment Situation J-43
Figure J-21: Typical Treatment For Exit Ramp on the Inside of Circular Curve J-44
Figure J-22: Typical Treatment For Exit Ramp on the Inside of Circular Curve Takeoff Point located along Circular Curve when 415' or less from PCS of Highway alignment J-45
Figure J-23: Typical Treatment for Exit Ramp on the Inside of Curve Takeoff Point located along leading Spiral J-46
Figure J-24: Typical Treatment for Exit Ramp on the Inside of Curve Takeoff Point located along Trailing Spiral J-47
Figure J-25: Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along Circular Curve J-48
Figure J-26: Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along leading Spiral J-49
Figure J-27: Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along Trailing Spiral J-50
Figure J-28: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Circular Curve J-51
Figure J-29: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along leading Spiral J-52
Figure J-30: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Trailing Spiral J-53
Figure J-31: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Circular Curve J-54
Figure J-32: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along leading Spiral J-55
Figure J-33: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Trailing Spiral J-56

CIRCULAR CURVE DEFINITIONS



A circular curve is based on the arc definition using the degree as it's parameter designation.

P.C. = Beginning of curve.

P.I. = Point of intersection of the tangents.

P.T. = End of curve.

Δ = Deflection angle of the tangents at the P.I..

D = Degree of Curvature

T = Tangent distance from P.I. to P.C. or P.I. to P.T.

Lc = Length of curve from P.C. to P.T.

E = External distance from the P.I. to midpoint of curve.

M = Middle Ordinate distance from midpoint of chord to midpoint of curve.

C = Chord length from P.C. to P.T.

$$T = R \tan \frac{\Delta}{2}$$

$$Lc = \frac{\pi R \Delta}{180}$$

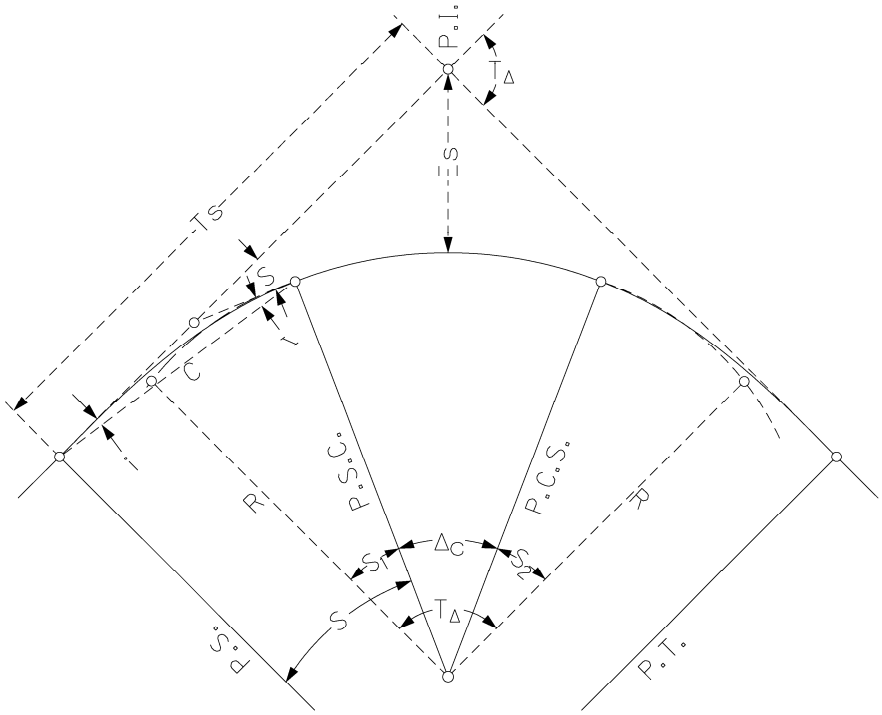
$$E = (R \div \cos \frac{\Delta}{2}) - R$$

$$M = R - (R \cos \frac{\Delta}{2})$$

$$C = 2R \sin \text{deflection} = 2R \sin \frac{\Delta}{2}$$

$$\text{Deflection per foot of arc} = \frac{90}{\pi R}$$

SPIRAL CURVE DEFINITIONS



T_Δ = Deflection angle of the tangents at the P.I.

$\Delta c = T_\Delta - (S_1 + S_2)$ = Central angle of circular curve.

S = The central angle of the whole spiral.

I = The angle from any point on the spiral between the tangent at that point and the chord from that point to the P.S.

i = The angle between the tangent at the P.S. and the chord from the P.S. to any point on the spiral or the deflection angle to any any point on the spiral.

Ts = The semi-tangent distance of the spiraled curve; distance from the P.I. to the P.S. or P.I. to P.T.

Es = External distance, shortest distance from P.I. to the curve assembly.

C = The chord from the P.S. to the P.S.C. or P.C.S. to P.T.

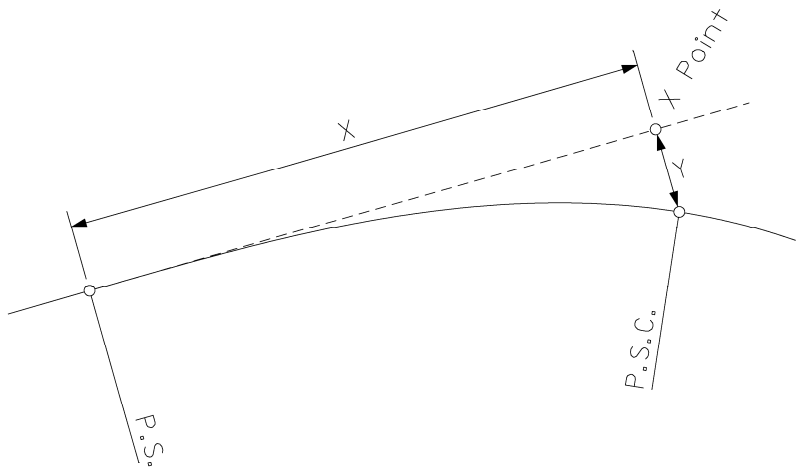
D = The degree of the central circular curve.

Ls = The length of the spiral from the P.S. to the P.S.C. or P.C.S. to P.T.

ℓ = The length of the spiral from the P.S. or P.T. to any given point on the spiral.

a = The rate of increase in degree of curve per station along the spiral (= (100) (D)/Ls).

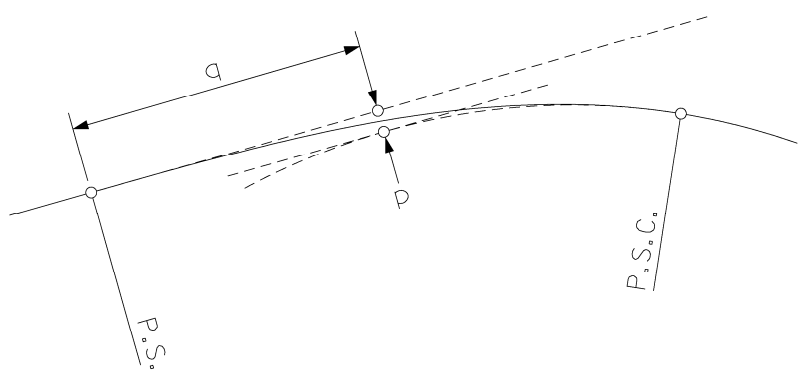
d = The degree of curve at any given point on the spiral.



X = The distance from the P.S. to a point on the tangent perpendicular to the P.S.C.

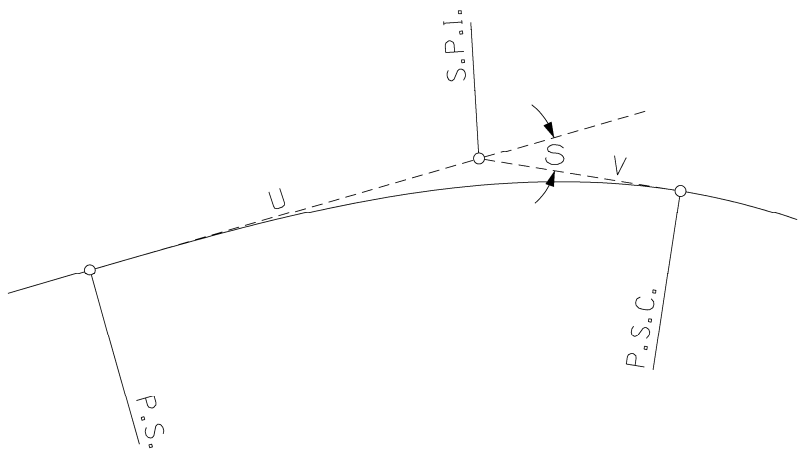
Y = Tangent offset to the spiral at the P.S.C. from semi-tangent.

X Point = Point on the semi-tangent at X distance from the P.S. or P.T. Intersection of X and Y distances.



p = The offset from the semi-tangent to the point where the tangent to the circular curve (produced backward or forward) becomes parallel to the semi-tangent.

q = The distance measured along the semi-tangent from P.S. or P.T. to a point where the tangent to the circular curve (produced backward or forward) becomes parallel to the semi-tangent.



S.P.I. = Intersection of spiral tangents.

U = The distance on the tangent from the P.S. to the intersection with a tangent through the P.S.C.; the longer spiral tangent.

V = The distance on the tangent through the P.S.C. from the P.S.C. to the intersection with the tangent through the P.S.; the shorter spiral tangent.

S = The central angle of the spiral from the P.S. to any given point on the spiral.

NOTATION

P.I. = Point of intersection of tangents.

P.S. = Point of change from spiral to tangent.

P.S.C. = Point of change from spiral to circular curve.

P.C.S. = Point of change from circular curve to spiral.

P.T. = Point of change from spiral to tangent.

P.R.S. = Point of reversing spirals.

P.S.S. = Point of change from spiral to spiral.

P.O.S. = Point on spiral.

P.O.C. = Point on circular curve.

P.O.S.T. = Point on semi-tangent.

P.O.T. = Point on tangent.

BASIC FORMULAS

Spiral Definition

The Standard Highway Spiral is a curve whose degree varies directly with its length, beginning at infinity at the P.S. and reaching a degree of curve equal to the circular curve at the P.S.C.

π = 3.1415926536

1 Radian = 57.295779513

a = [(100)(D)/Ls]

D = [(a)(Ls)/100] = [(200)(S)/Ls]

Ls = (100)(D)/a = (200)(S)/D

S = Spiral Angle in Degrees

$S = (D)(Ls)/200 = (a)(Ls^2)/20{,}000 = (D^2)/(2)(a)$

R=5729.5779513/D=(5729.5779513)(Ls)/(200)(S)=(28.647889757)(Ls)/S

$$\frac{X}{Ls} = \sum\left(\frac{\theta^{2n-2}}{(2n-2)!\,(4n-3)\,(-1)^{n+1}}\right)$$

$$\frac{Y}{Ls} = \sum\left(\frac{\theta^{2n-1}}{(2n-1)!\,(4n-1)\,(-1)^{n+1}}\right)$$

Following is the expanded form for values to n = 8 ("n" is not equal to 0)

θ = S in Radians

$$X = Ls\left(1 - \frac{\theta^2}{10} + \frac{\theta^4}{216} - \frac{\theta^6}{9360} + \frac{\theta^8}{685{,}440} - \frac{\theta^{10}}{76{,}204{,}800} + \frac{\theta^{12}}{11{,}975{,}040{,}000} - \frac{\theta^{14}}{2{,}528{,}170{,}444{,}800}\right)$$

Note: Designations of X and Y (from the 1973 Standard Highway Spiral) have been reversed to match most software. Tabulated Spiral Book values are accurate, but reversed.

$$Y = Ls\left(\frac{\theta}{3} - \frac{\theta^3}{42} + \frac{\theta^5}{1320} - \frac{\theta^7}{75{,}600} + \frac{\theta^9}{6{,}894{,}720} - \frac{\theta^{11}}{918{,}086{,}400} + \frac{\theta^{13}}{168{,}129{,}561{,}600} - \frac{\theta^{15}}{40{,}537{,}905{,}408{,}000} - - -\right)$$

$$\text{Tan } i = \frac{Y}{X}$$

$$I = S - i$$

$$q = X - R \sin S = X - \frac{28.647\,889\,757\ Ls}{S} \sin S$$

$$p = Y - R\ (1 - \text{Cos } S) = Y - \frac{28.647\,889\,757\ Ls}{S} (1 - \text{Cos } S)$$

$$U = X - \frac{Y}{\tan S}$$

$$V = \frac{Y}{\sin S}$$

$$C = \sqrt{X^2 + Y^2}$$

$$Ts = q + (R + p) \tan \frac{T\triangle}{2}$$

$$Es = \frac{R + p}{\text{Cos} \frac{T\triangle}{2}} - R$$

$$Lc = \text{Length of circular curve} = \frac{\pi R \triangle c}{180} = \frac{\pi R\ (T_\triangle - S_1 - S_2)}{180}$$

Note: Designations of X and Y have been reversed to match most software. The ODOT Standard Highway Spiral Book values for X and Y are still accurate, just reversed.

STANDARD SPIRAL NOTES

All curves of one degree or sharper shall be spiraled, using an approximation of the Talbot Spiral based on the arc definition for radius of the curve. Standard lengths for spirals are found in HDM Chapter 3, Tables 3-2, 3-3 and 3-4. Standard spiral lengths are based on the number of lanes being rotated and the super rate for the curve. Standard spirals for ramp alignments are found in Figures 9-11 and 9-12 (HDM Chapter 9)

Design exceptions are required when using spirals that are less than standard. Using longer spirals than standard does not require an exception. Using unequal spiral lengths is not an exception if both meet or exceed standards. This arrangement is most commonly found on ramps. Designers always need to consider potential operational effects and the roadway context in making alignment decisions.

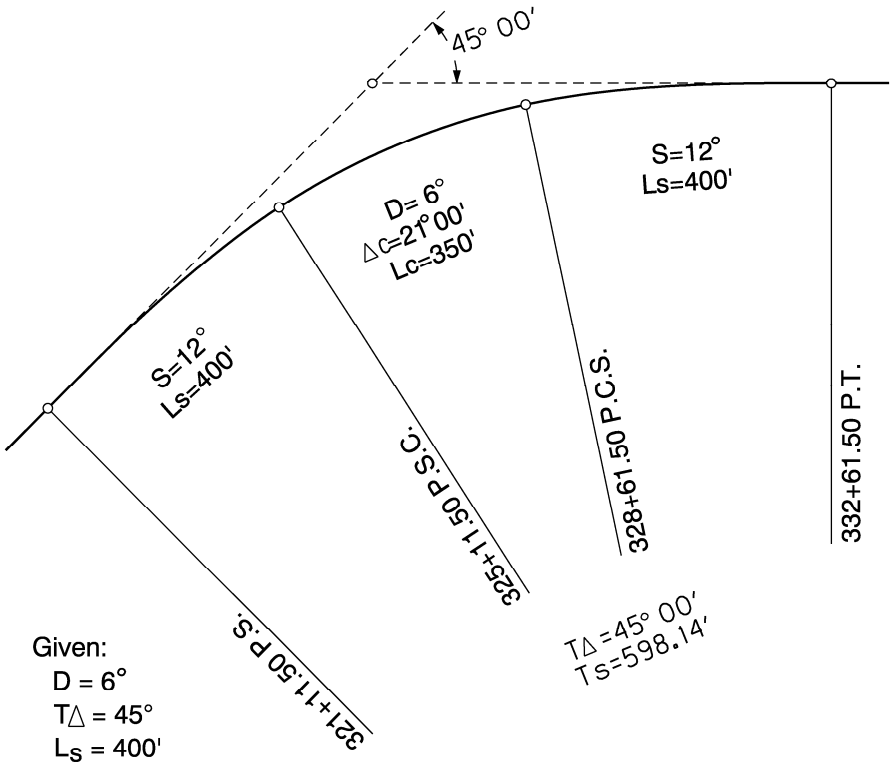
Prior versions of design standards were based on using inside edge super rotation. Current standards allow for using other rotation points when developing superelevation.

Ramp profile grades are typically carried at the ramp alignment and rotated about that point.

It's common for ramp alignments in the "terminal area" (where the ramp meets the crossroad) to have a spiral on one end only. The portion of the curve closest to the crossroad typically has to have reduced or no super in order to get intersection grades to work. A spiraled alignment in this situation isn't usually too beneficial. EXAMPLE IX on Page J-16 and HDM Figure 9-19 illustrates this condition. An exception is not required for this situation.

EXAMPLE I

TYPICAL SOLUTION OF SPIRAL ELEMENTS AND DEFLECTION ANGLES
(Curve with spirals of equal length)



Given:
- D = 6°
- T△ = 45°
- L_S = 400'
- Station of P.S. = 321 + 11.50

Find:

Elements of spiral and main curve and to determine deflection angles from P.S. to points on the spiral.

Solution:

a = (100)(D)/Ls = 600/400 = 1.5

S = (D)(Ls)/200 = (6)(400')/200 = 12°00'

$$i = \text{ArcTan}\,\frac{Y}{X} = 4°26'36''$$

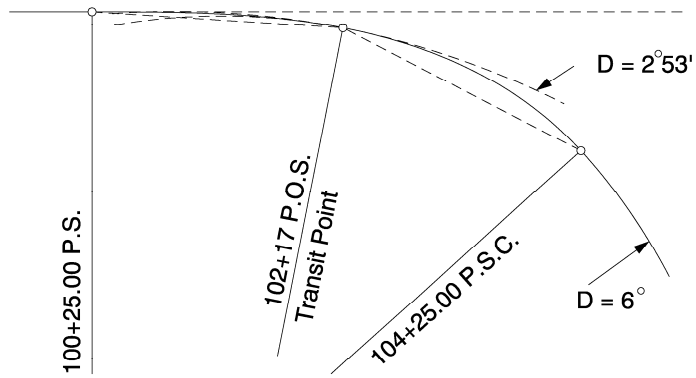
$$Ts = q + (R+p)\,\text{Tan}\,\frac{T\Delta}{2} = 598.14'$$

From Formula

X = 398.25'
Y = 27.84'
C = 399.22'
U = 267.28'
V = 133.89'
p = 6.97'
q = 119.71'

EXAMPLE II

INTERMEDIATE SETUP ON SPIRAL WITH DEFLECTIONS



Given:

S = 12° 00'
D = 6°
a = 1.5
Ls = 400'
P.S. = 100 + 25.00
P.S.C. = 104 + 25.00

Find:

Assume it is necessary to make intermediate setup at station 102 + 17

Solution:

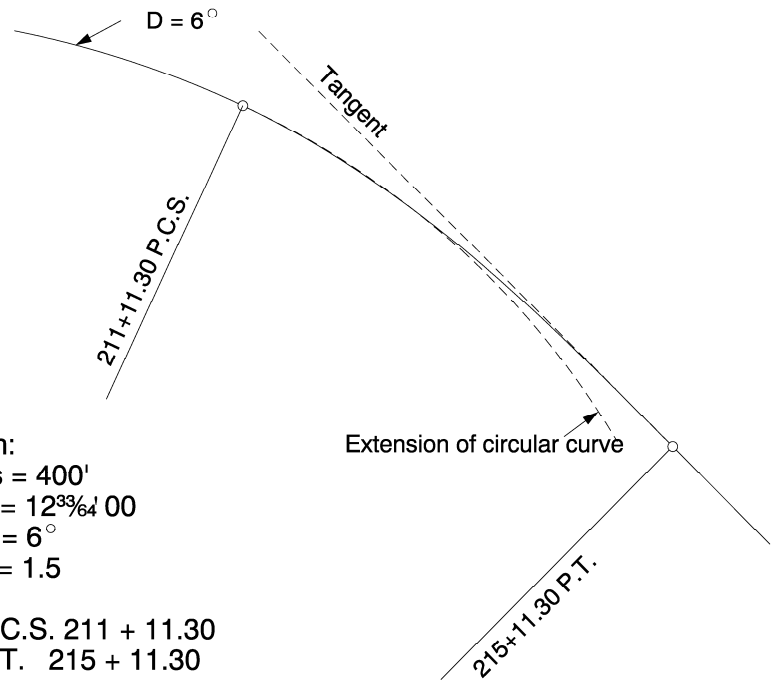
RULE: A spiral deviates from the circular curve common to it at any point at the same rate as it deviates from the tangent at the P.S. Therefore, at any point on the spiral the deflection angle from the tangent at that point to any other point on the spiral is equal to the deflection angle for a circular curve of the same radius as the spiral at the intermediate setup plus or minus the deflection from tangent at the P.S. to a point at an equivalent distance from the P. S. thus:

* Degree of curve at point of intermediate setup Sta. 102+17 $= \frac{(a)(x)}{100} = \frac{(1.5)(192)}{100} = 2^\circ\ 52'\ 48''$

	Simple Curve Deflection		Spiral Deflection		Deflection (Instr. at Sta. 102+17)
P.S. 100 + 25.0	2°45'54"	-	0°55'18"	=	1°50'36"
+ 50	2°24'18"	-	0°41'48"	=	1°42'30"
101 + 00	1°41'12"	-	0°20'30"	=	1°20'36"
+ 50	0°57'54"	-	0°06'42"	=	0°51'12"
102 + 00	0°14'42"	-	0°00'24"	=	0°14'21"
Transit Pt. + 17	0°00'00"	-	0°00'00"	=	0°00'00"
+ 50	0°28'30"	+	0°01'36"	=	0°30'06"
103 + 00	1°11'42"	+	0°10'18"	=	1°22'00"
+ 50	1°54'54"	+	0°26'30"	=	2°21'24"
104 + 00	2°38'06"	+	0°50'12"	=	3°28'18"
P.S.C. 104 + 25.0	2°59'42"	+	1°04'54"	=	4°04'36"

EXAMPLE III

DEFLECTIONS TO SPIRAL FROM P.S.C. OR P.C.S.



Given:

Ls = 400'
S = 12 33/64' 00
D = 6°
a = 1.5

P.C.S. 211 + 11.30
P.T. 215 + 11.30

Find:

Deflections angles from the tangent to the curve at P.C.S.

Solution:

To back the spiral in from P.C.S.:

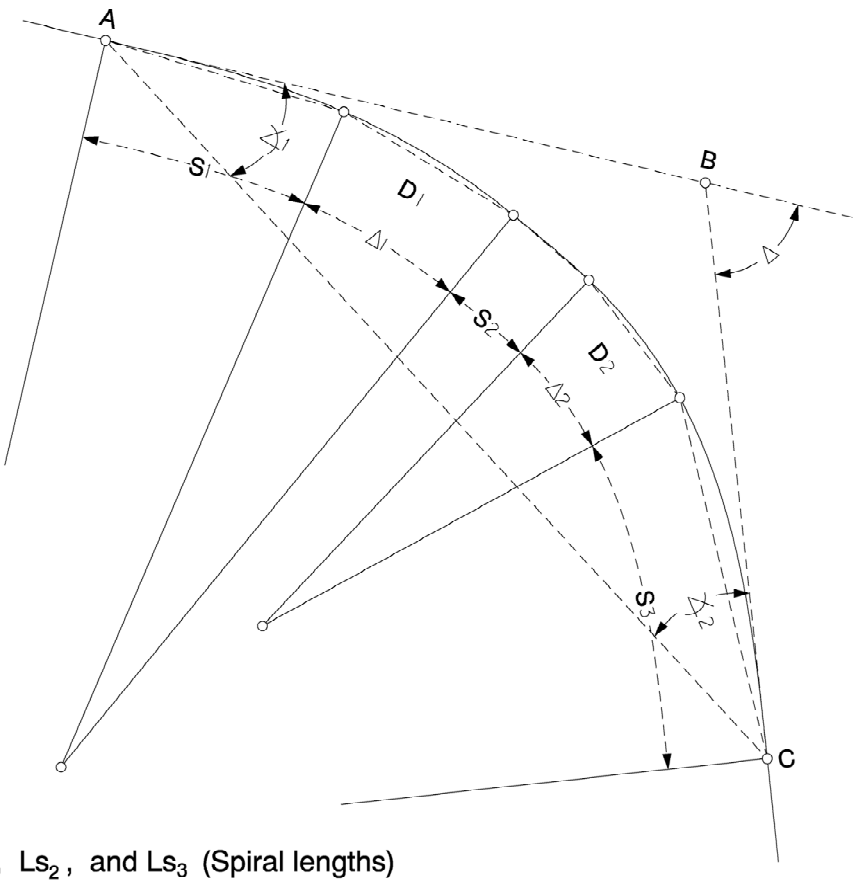
RULE: A spiral curve and a circular curve which coincide at any point (as at the P.C.S.) deviate from each other at the same rate as the spiral does from the tangent at the P.S.

Therefore, to obtain deflection angles from the tangent to the curve at the P.C.S. to the spiral, compute deflection angles to the circular curve and subtract therefrom the deflection angles to the spiral at corresponding distances from the P.S.

STATION	Simple Curve Deflection (D = 6°)	—	Spiral Deflection	=	Deflections (Instrument Setup at P.C.S.)
P.C.S.211+11.30	0°00'00"	—	0°00'00"	=	0°00'00"
211+50	1°09'42"	—	0°02'12"	=	1°07'30"
211+75	1°57'42"	—	0°06'06"	=	1°48'36"
212+00	2°39'42"	—	0°11'48"	=	2°27'54"
212+35	3°42'42"	—	0°23'00"	=	3°19'42"
212+80	5°03'42"	—	0°42'42"	=	4°21'00"
213+20	6°15'42"	—	1°05'18"	=	5°10'24"
213+50	7°09'42"		1°25'30"	=	5°44'12"
214+00	8°39'42"	—	2°05'00"	=	6°34'42"
214+50	10°09'42"	—	2°52'06"	=	7°17'36"
215+00	11°39'42"	—	3°46'36"	=	7°53'06"
P.T. 215+11.30	12°00'00"	—	4°00'00"		8°00'00"

EXAMPLE IV

FITTING A SPIRAL BETWEEN TWO PARTS OF A COMPOUND CURVE WITH SPIRAL TRANSITIONS AT EACH END



Given:

Δ
D_1
D_2
Ls_1, Ls_2, and Ls_3 (Spiral lengths)

Find:

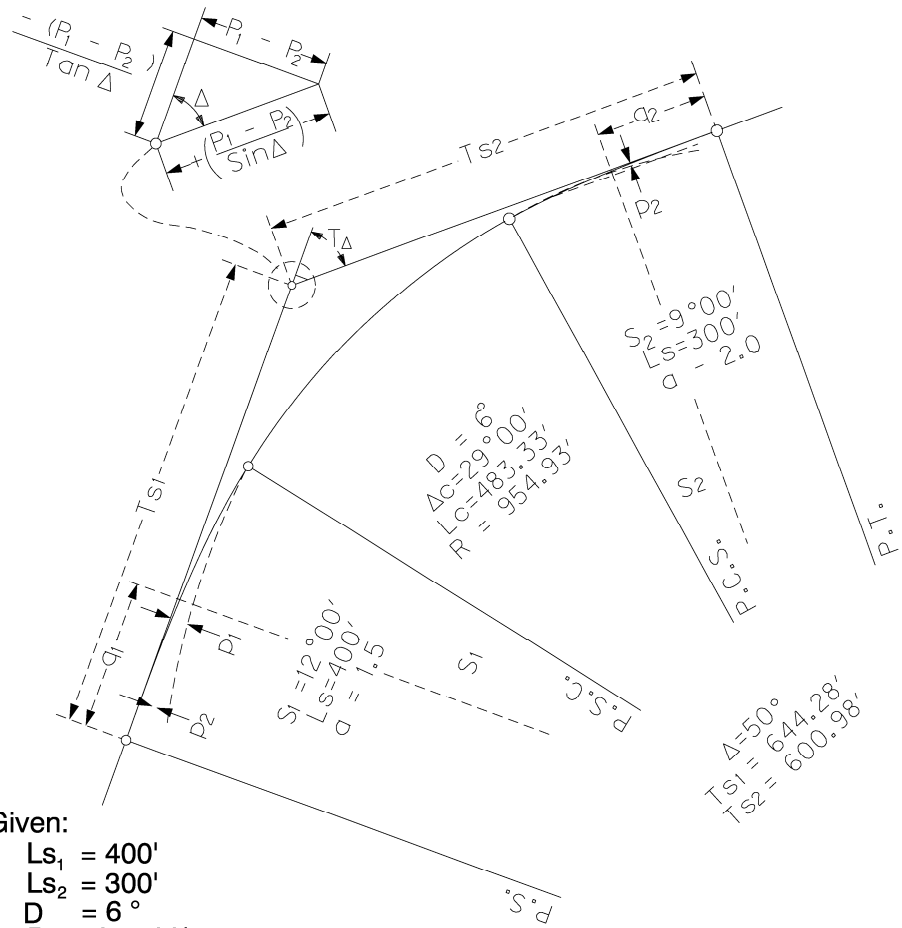
Semi-tangents

Solution:

(1) Ascertain Δ_1 (by assumption or measurement).
(2) Then $\Delta_2 = \Delta - \Delta_1 - S_1, - S_2, - S_3$.
(3) Find long chords for circular curves and spirals.
(4) Figure bearings for chords.
(5) Compute coordinates for point C.
(6) Compute length and bearing of long chord A - C.
(7) Then $\measuredangle_2 = \Delta - \measuredangle_1$:
(8) Solve triangle ABC for semi-tangents AB and BC. (Three angles and one side known).
(9) Spiral S_2 may be used to connect curves D_1 and D_2 by choosing that portion of the spiral having curvature intermediate between the radius of the two circular curves: thus if $D = 3°$ and $D_2 = 10°$ the connecting spiral will have a varied radius from 3° to 10° omitting the portion of the spiral below 3°.
Deflection angles from P.C.S. or P.S.C. may be computed in the same manner as an intermediate setup on the spiral (see Example II).

EXAMPLE V

COMPUTING SEMI-TANGENTS FOR CURVES WITH SPIRALS OF UNEQUAL LENGTH



Given:

Ls_1 = 400'
Ls_2 = 300'
D = 6 °
R = 954.93'
Δ = 50° 00'

Find: Semi-tangents (Ts_1 and Ts_2) and external (Es_1 or Es_2).

Solution:

To compute semi-tangents ascertain the spiral elements.

Then

$$Ts_1 = q_1 + (R + p_2)\ \text{Tan}\ \frac{T\Delta}{2} - \frac{p_1 - p_2}{\text{Tan}\ T\Delta} \qquad Ts_2 = q_2 + (R + p_2)\ \text{Tan}\ \frac{T\Delta}{2} + \frac{p_1 - p_2}{\text{Sin}\ T\Delta}$$

Es_1 and Es_2 formulas are valid only if S_1 and S_2 are equal to or less than ½ Δ.

$$Es_1 = \sqrt{(Ts_1 - q_1)^2 + (R + p_1)^2} - R \qquad Es_2 = \sqrt{(Ts_2 - q_2)^2 + (R + p_2)^2} - R$$

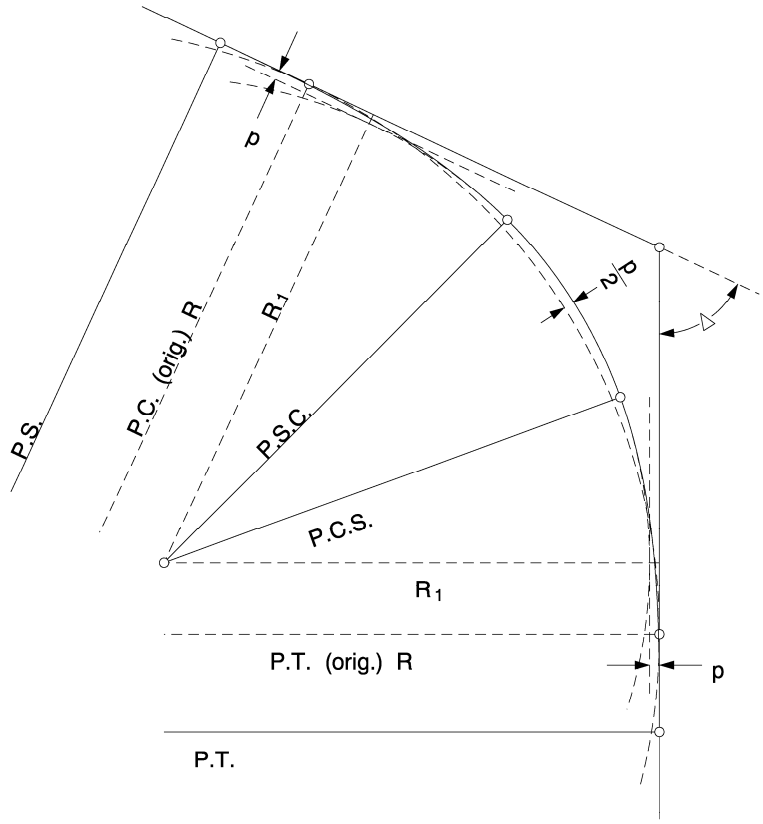
$$Ts_1 = 199.71' + (954.93' + 3.92') \times 0.466\ 307\ 7 - \frac{(6.97' - 3.92')}{1.191\ 754} = 644.28'$$

$$Ts_2 = 149.88' + (954.93' + 3.92') \times 0.466\ 307\ 7 + \frac{(6.97' - 3.92')}{0.766\ 044} = 600.98'$$

Rule: Ls_1 = Longer spiral

EXAMPLE VI

FITTING EXISTING CIRCULAR CURVE ALIGNMENT WITH SPIRALED CURVES REQUIRING A MINIMUM SHIFT OF ALIGNMENT



Given:

R

Δ

Ls

Find: R_1

Solution:

To retain present tangents and fit spiraled alignment with least possible shift of circular curve.

The new curve will be sharper and it should lay outside of the old curve at the vertex, and the distance between the vertexes of the two curves should be equal to half the spiral offsets, $\frac{p}{2}$

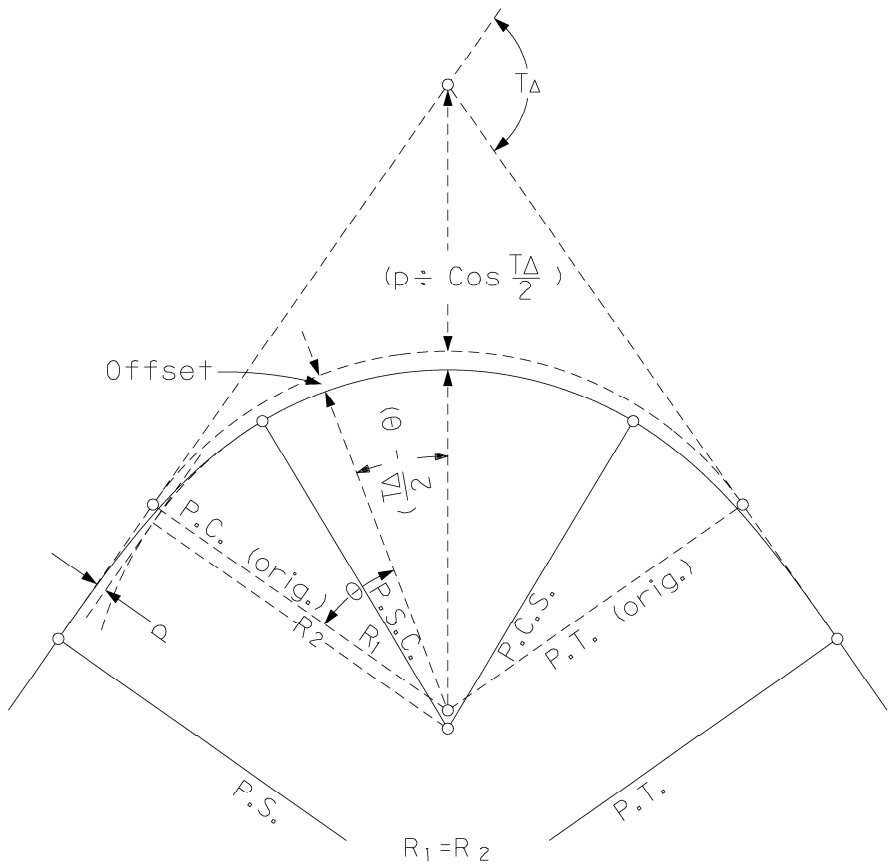
$$\text{Then } R_1 = R - \frac{p + \frac{p}{2}\cos\frac{\Delta}{2}}{1 - \cos\frac{\Delta}{2}}$$

In solving this equation, first assume a value for "p" slighty greater than the value of "p" for a radius of curve equal to the original curve. Base the assumption on an estimate of the new curve radius required.

Then revise the value of "p" to fit alignment.

EXAMPLE VII

OFFSETS FROM CIRCULAR CURVE ALIGNMENT TO SPIRALED ALIGNMENT USING SAME RADIUS OF CURVE AND ORIGINAL TANGENTS



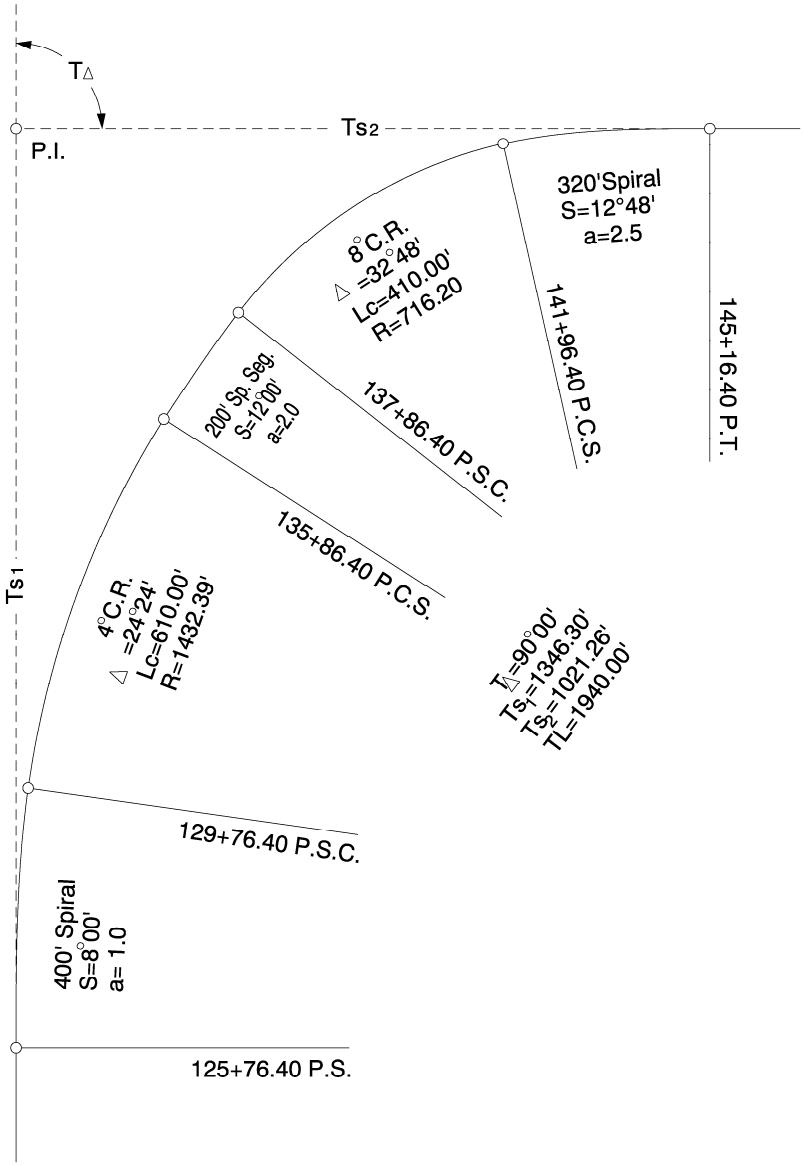
In fitting spiraled alignment to existing circular curve alignment, while retaining the same degree of main curve and the original tangents, it will be found that the new main curve will not be concentric with nor parallel to the original curve. The offset varies from a value of "p" as shown on the sketch to a value of (p ÷ Cos T_Δ ÷ 2) at the vertex. Between the point where the value of "p" applies to the P.S.C., the offsets from the original alignment to the new alignment may be found by obtaining the X coordinate to the point in question on the spiral and making correction for the offset to the original circular curve where that is necessary. Beyond the P.S.C. the following approximate formula will give values of the offset sufficiently close for practical purposes.

$$\text{Offset} = p \div \text{Cos}\frac{T_\Delta}{2}\left[\cos\left(\frac{T_\Delta}{2} - \theta\right)\right] \quad \text{Approximately}$$

Where θ = angle from the P.C. or P.T. of original circular curve to the point desired.

EXAMPLE VIII

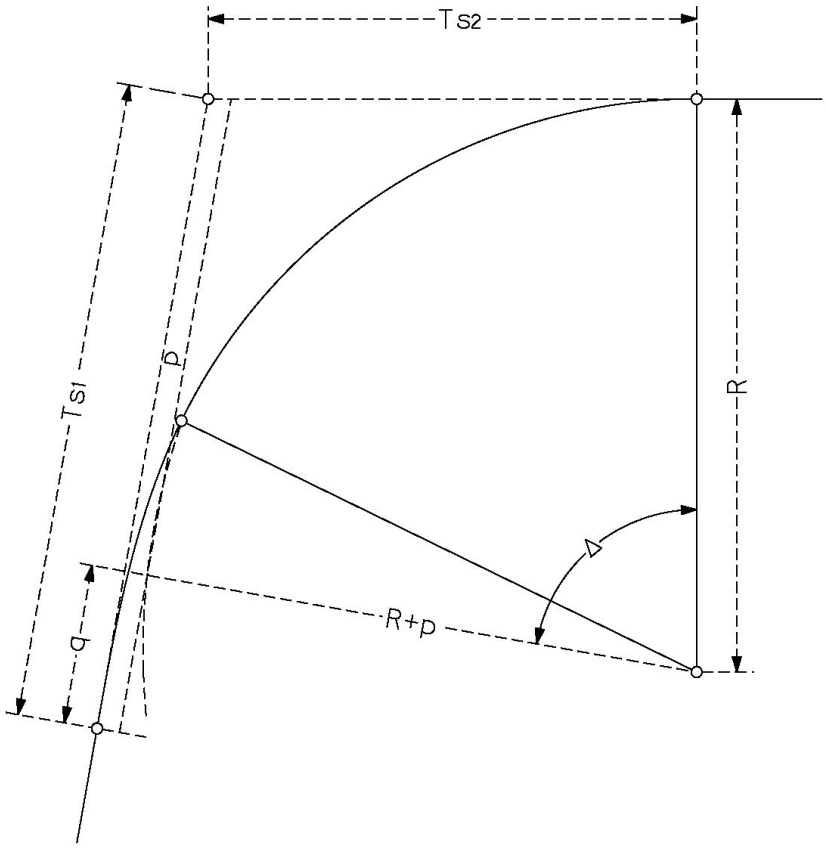
STANDARD METHOD OF SHOWING ALIGNMENT ON MAPS



Show stationing to the nearest hundredth of a foot. Show angles and bearings to the nearest second. When calculating the "S" angle, carry at least four places so coordinates are accurate to three places.

EXAMPLE IX

METHOD OF COMPUTING SEMI-TANGENTS OF CURVE WITH SPIRAL AT ONE END ONLY



Given:
Δ, R, p. and q.

Find:
Semi-Tangents.

Solution:

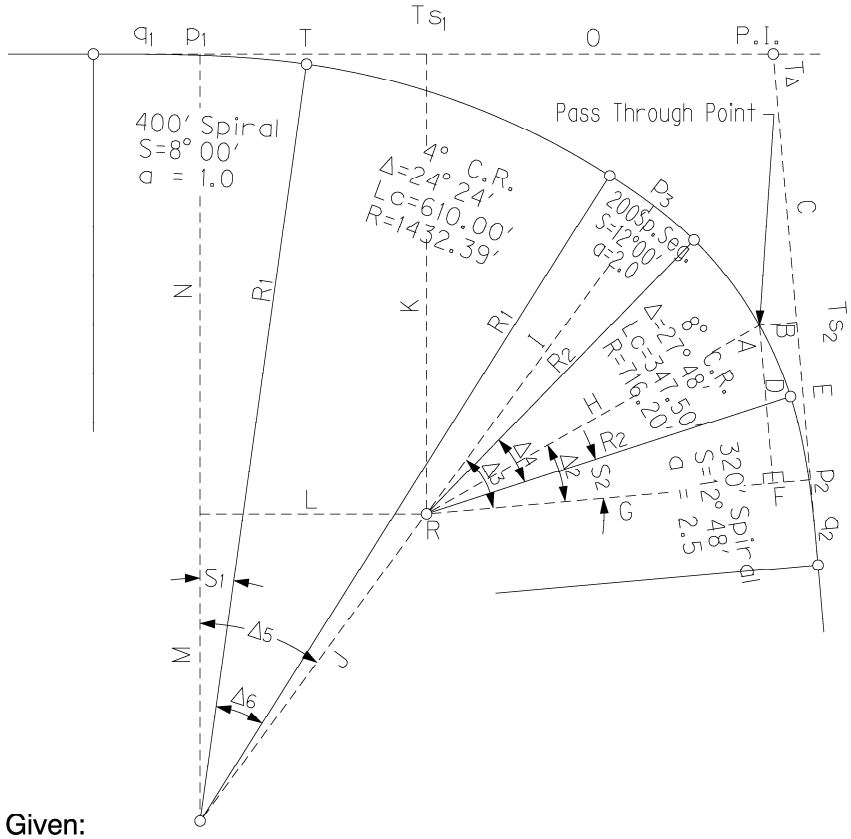
$$Ts_1 = \frac{R - (R + p)\cos\Delta}{\sin\Delta} + q$$

$$Ts_2 = \frac{(R + p) - (R\cos\Delta)}{\sin\Delta}$$

When Δ is over 90°, the cosine function has a negative value.

EXAMPLE X

FITTING COMPOUND CURVE WITH THREE SPIRALS



Given:

With a fixed pass through point or a given or assumed semi-tangent (Ts_2), known P.I., $T\Delta$, R_1 and R_2, spiral lengths.

Find:

Ts_2 (for fixed point) or Ts_1 (for known Ts_2)

Solution:

FIXED PASS THROUGH POINT

Calculate C and B along and perpendicular to the Ts semi-tangent tangent Then ....

$B = F$, $G = (R_2 + p_2) - F$, $H = R_2$, $\cos\Delta_2 = \frac{G}{H}$, $D = H \sin\Delta_2$,

$E = D$ and $Ts_2 = C + E + q_2$

GIVEN OR ASSUMED SEMI-TANGENT (Ts_2)

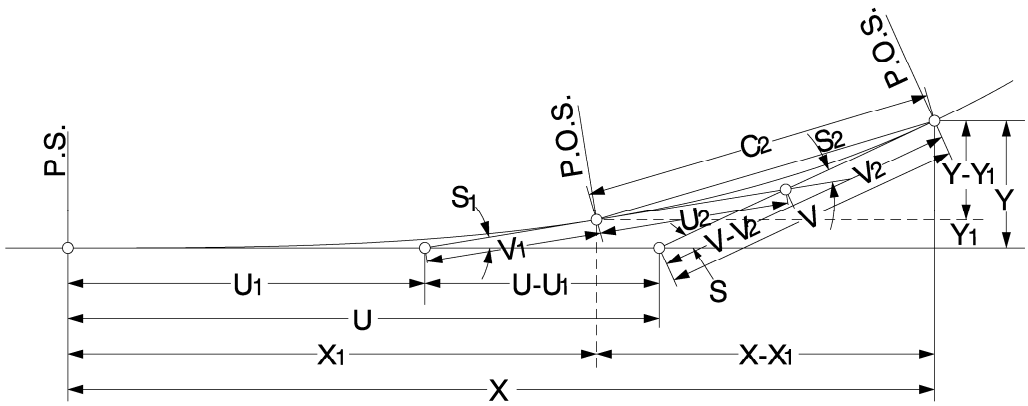
Calculate coordinates for the radius point of " R_2 " from Ts_2. Calculate O and K along and perpendicular to the Ts_1, semi-tangent. 'p_3' is the perpendicular distance between R_1 and R_2, when tangent to each other. Then $I = R_2 + p_3$.

$J = R_1 - I$, $K = N$, $M = (R_1 + p_1) - N$, $\cos\Delta_5 = \frac{M}{J}$, $L = J \sin\Delta_5$,

$T = L$, $\Delta_6 = \Delta_5 - (S_1 + \Delta$ for D_1 for ½ length of intermediate spiral), $\Delta_3 = T\Delta - \Delta_5$, $\Delta_4 = \Delta_3 - (S_3 + \Delta$ for R_2 for ½ length of intermediate spiral) $Ts_1 = O + T + q_1$; the use of ½ the length of the intermediate spiral is a close approximation of the true answer.

EXAMPLE XI

DETERMINING U, V, AND C DISTANCES FOR SEGMENT OF A SPIRAL



Given:

200' spiral segment, a=1.0, connecting 3° curve to 5° curve.

Find:

S, U, C, and V distances for that spiral segment.

Solution:

The given spiral segment is that portion of the Standard Highway Spiral , a=1.0, between the P.O.S. at Ls = 300' and the P.O.S. at Ls = 500'. In the solution of the given problem S,U,V, X, and Y are values for L = 500', S_1,U_1,V_1 ,X_1, and Y_1 are values for L = 300' m and S_2,U_2, C_2 and V_2 are the values to be found for the given spiral segment.

Ls = 500', S = 12° 30' , U = 334.17', V = 167.43', Y = 36.24'
X = 497.63'

Ls = 300', S_1 = 4° 30' , U_1= 200.06', V_1= 100.06', Y_1= 7.85'
X_1 = 299.81'

$$S_2 = S - S_1 \qquad V_2 = V - \frac{(U - U_1)\text{Sin } S_1}{\text{Sin } S_2}$$

$$U_2 = \frac{(U - U_1)\text{ Sin } S}{\text{Sin } S_2} - V_1 \qquad C_2 = \sqrt{(X_1 - X)2 + (Y_1 - Y)2}$$

$$S_2 = 12° 30' - 4° 30' = 8° 00'$$

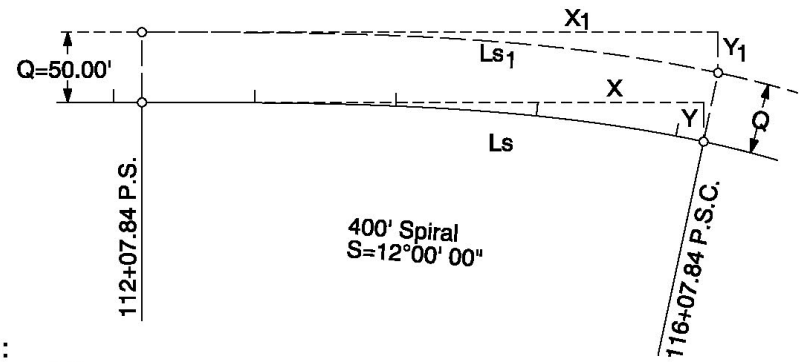
$$U_2 = \frac{(334.17' - 200.06')\text{ Sin } 12°30'}{\text{Sin } 8°00'} - 100.06' = 108.506'$$

$$V_2 = 167.43' - \frac{(334.17' - 200.06')\text{ Sin } 4°30'}{\text{Sin } 8°00'} = 91.83'$$

$$C_2 = \sqrt{(36.24' - 7.85')\ 2 + (497.63' - 299.81')\ 2} = 199.847'$$

EXAMPLE XII

COMPUTING OFFSET SPIRALS



Given:

Ls = 400'
a = 1.5
S = 12° 00' 00"
Q = 50.00' (Outside offset)

NOTE:
The offset spiral is not related to the Standard Highway Spiral. Therefore use the following method.

Find:

Offset spiral.

Solution:

θ = S (in radians) for the base spiral = $\frac{S}{57.29578}$

Q = Offset in feet

$Ls_1 = Ls \pm Q(\theta)$ (+) for outside offset

$X_1 = X \pm Q \sin S$ (-) for inside offset

$Y_1 = Y \pm Q(1 - \cos S)$ Use (+) for outside offset

To compute the spiral offset as it would be run in the field; setting stakes at right angles to and "Q" offset from the corresponding stations on the base spiral with transit setup at the P.S. or P.T. of the offset spiral:

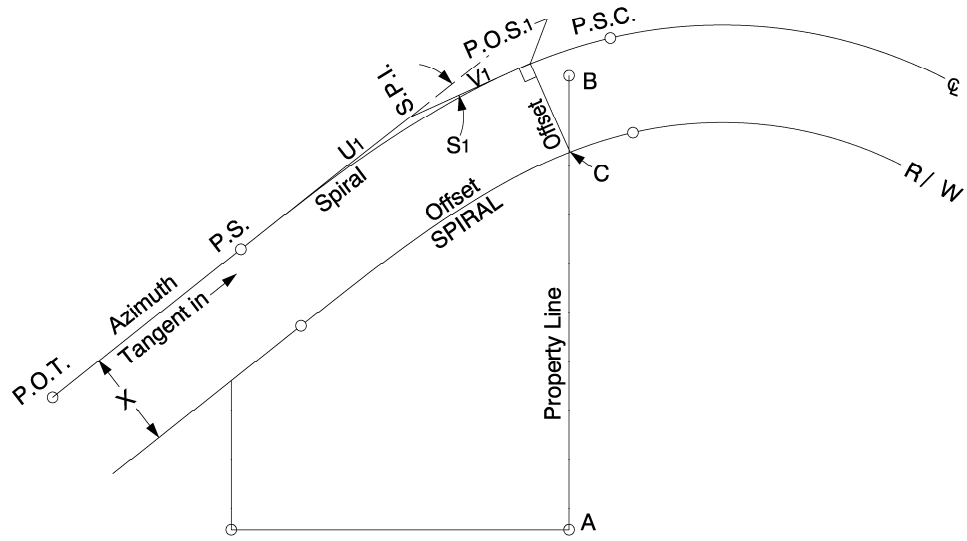
(1) Find the S angle for each station.
(2) Determine length of the offset spiral, Ls_1, from P.S. or P.T. to each station.
(3) Using S angles found in step 1, determine the corresponding X and Y values for each station of the base spiral.
(4) Determine the X_1 and Y_1 values for the offset spiral.
(5) Determine the offset spiral deflections from $\tan i = \frac{Y_1}{X_1}$
(6) Calculate chords using formula in example XI.

TABULATION OF RESULTS FOR ABOVE DATA

STATION	Ls	S	L1	Y	X	Y1	X1	i1	C1
112+07.84 P.S.	0.00	0°00'00"	0.00	0.00	0.00	0.00	0.00	0°00'00"	0.00
112+50	42.16	0°08'00"	42.28	0.03	42.16	0.03	42.28	0°02'24"	42.28
113+00	92.16	0°38'13"	92.72	0.34	92.16	.034	92.72	0°12'36"	50.44
113+50	142.16	1°30'57"	143.48	1.25	142.15	1.27	143..47	0°30'36"	50.76
114+00	192.16	2°46'10"	194.58	3.10	192.12	3.16	194.54	0°55'48"	51.10
114+50	242.16	4°23'53"	246.00	6.20	242..01	6.35	245.84	1°28'48"	51.39
115+00	292.16	6°24'07"	297.75	10.88	291.79	11.19	297.36	2°09'18"	51.75
115+50	342.16	8°46'50"	349.82	17.45	341.35	18.04	348.98	2°57'30"	52.07
116+00	392.16	11°32'03"	402.23	26.25	390.57	27.26	400.57	3°53'36"	52.41
116+07.84 P.S.C.	400.00	12°00'00"	410.47	27.84	398.25	28.93	408.65	4°03'00"	8.24

EXAMPLE XIII

SOLUTION OF OFFSET SPIRAL INTERSECTING WITH PROPERTY LINE



Given:

Centerline geometry, offset value, coordinate of P.O.T. on tangent in, azimuth of tangent in, coords of point A and B or coords of A or B and azimuth to the other. "Lg" is a generic value representing the guess length of spiral to offset point.

Find:

Coordinate of intersect point C.

Solution:

This problem has no direct solution. It can be solved by iteration. This is not as difficult as it seems.

Begin at the P.S. of the spiral and guess an "Lg" length. Using the "Lg" and the "a" value generate "U_1" and "V_1" and "S " values for trial solution. The solution is to coordinate from the P.S. to the S.P.I. to the P.S.C. of the P.O.S. along the spiral. Next coordinate a point "C" from the P.O.S.$_1$ 90° off the tangent between the S.P.I. and P.O.S. out the offset distance "X". Finally inverse between point "C" and point "A" and determine the azimuth of point "C" to "A". Compare this azimuth to the azimuth between point "B" to "A". When azimuths are identical you have solved for the intersect.

ALGORITHM FOR ITERATION

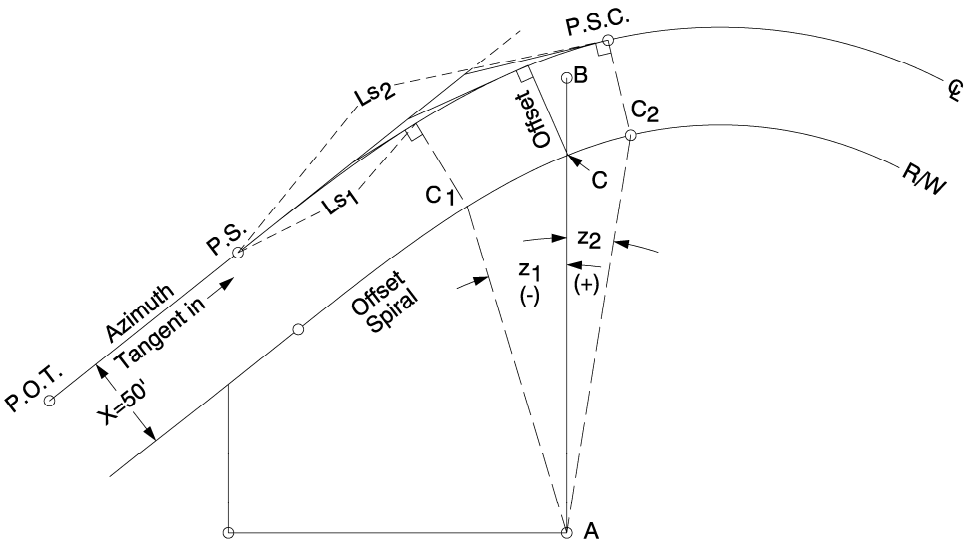
Lg_1 = $Guess_1$ = Length of spiral for Trial #1
Lg_2 = $Guess_2$ = Length of spiral for Trial #2
Ls_3 = ? = Projected length from linear regression

"Equation" is all calculations to produce difference in azimuths (d_1 , d_2).

Solve "equation" using Lg_1 - result is z_1
Solve "equation" using Lg_2 - result is z_2

Given Lg_1 , z_1 , Lg_2 , z_2 , compute Ls_3:

$Ls_3 = Lg_2 - (z_2 (Lg_1 - Lg_2) / (z_1 - z_2))$



Given:

Centerline geometry, D - 8, Spiral 400', offset 50', coordinate of P.O.T. on tangent in, azimuth of tangent in, coords of point "A" and "B" or coords of (A or B) and azimuth to the other.

Find:

Coordinate of intersect point C.

Solution:

Lg_1 = $Guess_1$ = 300' Lg_2 = $Guess_2$ = 400'

Calculate "z_1" by assuming a "Ls_1" length and computing for "U_1", "V_1" and "S_1". Turn a 90° and "X" distance from "V_1" tangent at point on spiral to offset spiral. Inverse between point "C_1" and "A" for azimuth. Take the difference between "C " to "A" and "B" to "A" and this is angle z_1. Repeat steps for z_2.

Note:

To reduce the number of iterations select "Lg_1" and "Lg_2" as close as possible to point "C". Keep in mind the positive and negative "z" values.

Ls_3 = 400' - (8.9151 (300' - 400') / (-3.3458- 8.9151) = 327.28839'

Ls_3 = 327.28839' - (0.299(400' - 327.28839') / (8.9151- 0.299) = 324.76512'

Ls_3 = 324.76512' - (-0.0276(327.28839' - 324.76512') / (0.299 - (- 0.0276)) = 324.97835'

Ls_3 = 324.97835' - (0.0001 (324.76512' - 324.97835') / (-0.0276 - (0.0001)) = 324.97758'

In this example the L_3 starts to repeat itself to significant figures, & it is solved.

Flow Diagram for "Lg" in Ls_3 equation

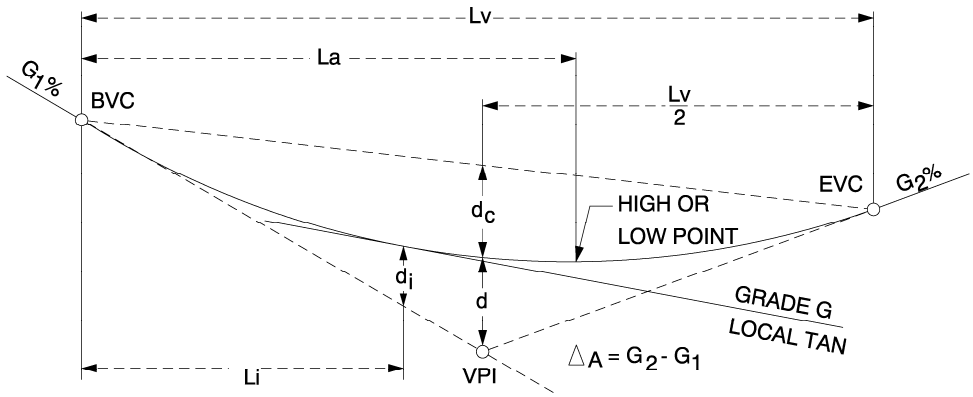
Lg_1 Lg_2 Ls_3

Lg_1 Lg_2 Ls_3 Lg_2 becomes new Lg_1, and Ls_3 becomes, new Lg_2.

Lg_1 Lg_2 Ls_3

VERTICAL CURVES

VERTICAL CURVE SYMMETRICAL PARABOLIC



L_i = Distance from beginning point of vertical curve to any point along the curve.

G_1, G_2 = Tangent grades in percent, positive for ascending forward, negative for decending forward.

K = Ls / △A = feet to affect a 1% change in grade.

△A = algebraic difference in grades, percent.

Lv = Length of vertical curve in feet, measured horizontally.

d = Vertical offset from the vertex (called PI) to the middle of curve.

d_i = Vertical offset from a tangent to the vertical curve vary as the square of the distance from the PC.

d_c = Vertical offset from the chord to the vertical curve.

$$\triangle_A = G_2 - G_1 \qquad K = \frac{Lv}{\triangle_A}$$

$$d = d_c = \frac{\triangle_A Lv}{800} = \frac{K \triangle_A^2}{800}$$

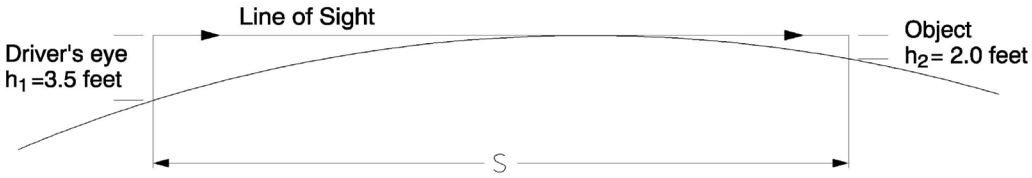
$$d_i = \frac{L_i^2}{\left(\frac{Lv}{2}\right)^2} \qquad d = \frac{\triangle_A L_i^2}{200\ Lv} = \frac{L_i^2}{200\ K}$$

$$G = G_1 - \frac{L_i}{K} \qquad L_a = G_1 K$$

Note: Distances Lv, d, d_c, L_a, L_i, d_i, are in feet.
Grades G_1, G_2, △A, G are in percent.

CREST CURVATURE

Design Speed (V) mph	25	30	35	40	45	50	55	60	65	70
Design (K)	12	19	29	44	61	84	114	151	193	247



$$K = \frac{S^2}{200\ h_1\ (1 + \sqrt{h_2 / h_1})\ 2}$$

Stopping Sight Distance (S) is derived from this formula:

$S = 1.47Vt + (1.075)(V^2/a)$

where:

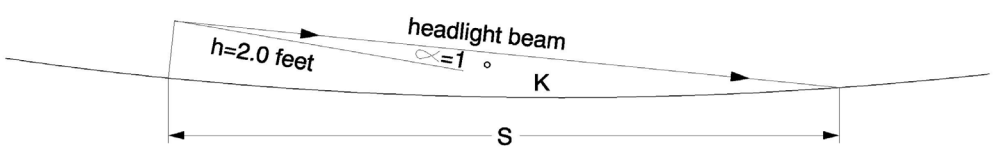
t = brake reaction time, 2.5 seconds;

V = design speed, mph;

a = deceleration rate - 11.2 ft/s

SAG CURVATURE

Design Speed (V) mph	25	30	35	40	45	50	55	60	65	70
Design (K)	17	26	37	49	64	79	96	115	136	181



Where the length of curve exceeds the stopping sight distance, K is given.

S Less Than or Equal to Lv $\quad K = \dfrac{S^2}{200\ (h + S\ \tan\alpha)}$

Where the stopping sight distance exceeds the curve length, K is given.

S > Lv $\quad K = \dfrac{2\,S}{\Delta A} - \dfrac{200\,h_1(1 + \sqrt{h_2 / h_1})\ 2}{\Delta A^2}$ where:
A = Algebraic Difference in Grades

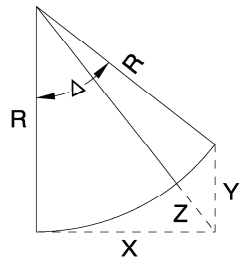
Minimum sag vertical curvature for comfort critera, illumination may be required.

$$L = \frac{AV^2}{46.5}$$

where:
A = Algebraic Difference in Grades

HORIZONTAL CURVES

TANGENT LAYOUT OF CURVE



$Z = R - \sqrt{R^2 + X^2}$

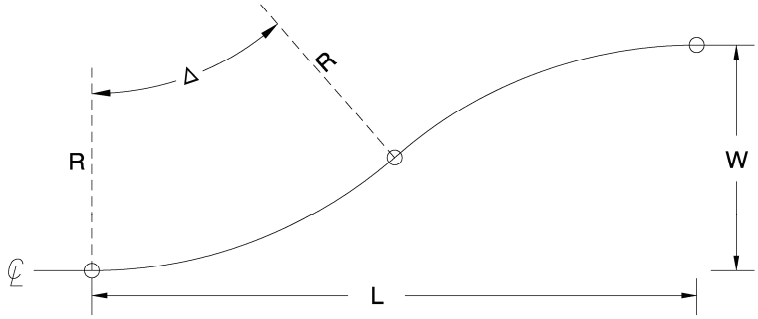
$Y = R - \sqrt{R^2 - X^2}$, $R - R \cos \Delta$

$X = \sqrt{2RY - Y^2}$, $R \sin \Delta$

$R = (X^2 + Y^2) \div 2Y$, $X \div \sin \Delta$

$\Delta = \text{Arc Sin}\,(X \div R)$, $2(\text{Arc Tan}\,(Y \div X))$

TANGENT DISTANCES OF EQUAL REVERSING CURVES



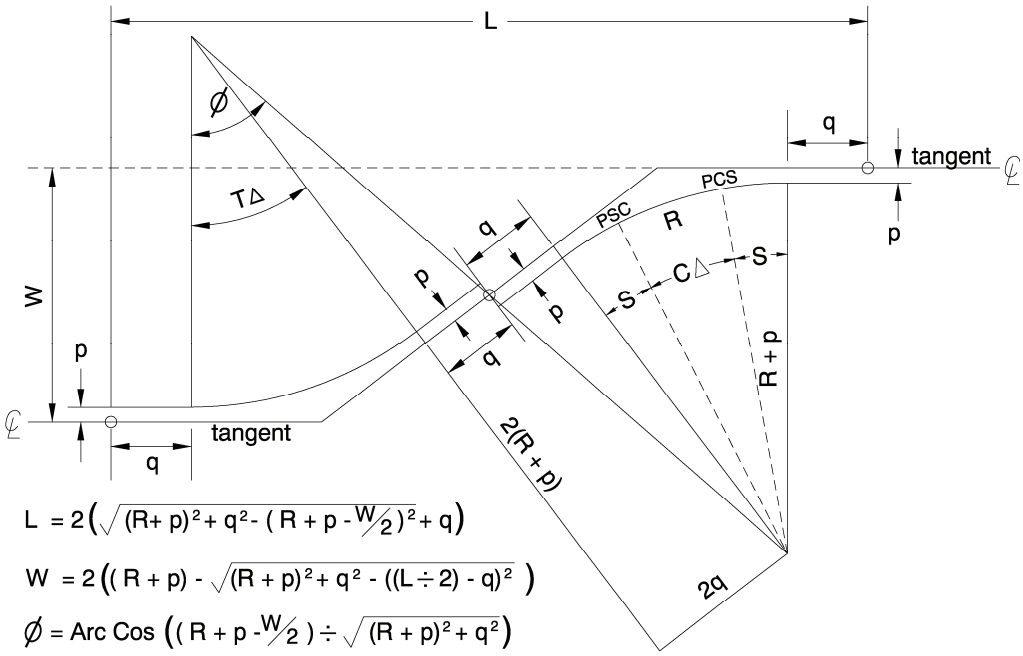
$L = 2\sqrt{R^2 - (R - \frac{W}{2})^2}$

$R = (L^2 + W^2) \div 4W$

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

$\Delta = \text{Arc Sin}\,(L \div 2R)$

TANGENT DISTANCES OF EQUAL REVERSING SYMMETRICAL SPIRALED CURVES



$L = 2\left(\sqrt{(R+p)^2 + q^2 - (R + p - W/2)^2} + q\right)$

$W = 2\left((R + p) - \sqrt{(R+p)^2 + q^2 - ((L \div 2) - q)^2}\right)$

$\varnothing = \text{Arc Cos}\left((R + p - W/2) \div \sqrt{(R+p)^2 + q^2}\right)$

$T\Delta = \varnothing - \text{Arc Tan}\,(q \div (R + p))$

$C\Delta = T\Delta - 2S$ where $S = 90\,Ls \div \pi\,Rn$

Ls = Length of spiral

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

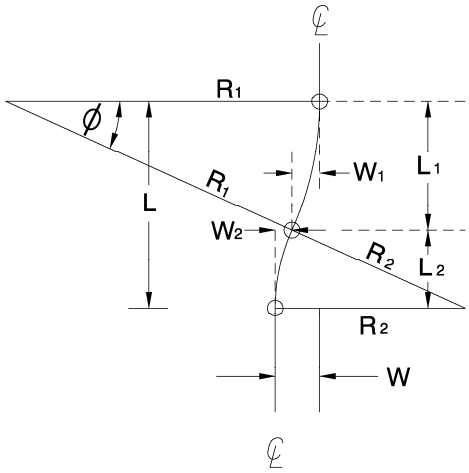
PARALLEL TANGENTS
EQUAL LENGTH
REVERSING CURVES

HIGHWAY DESIGN MANUAL

Figure J-1: Parallel Tangents – Equal Length Reversing Curve

TANGENT DISTANCES OF UNEQUAL REVERSING CURVES

$\phi = \text{SIN}^{-1}\,[L \div (R_1 + R_2)]$



$L = \sqrt{(R_1 + R_2)^2 - (R_1 + R_2 - W)^2}$

$= (R_1 + R_2)\ \text{COS}\,\phi$

$W = R_1 + R_2 - \sqrt{(R_1 + R_2)^2 - L^2}$

$= (R_1 + R_2) - (R_1 + R_2)\ \text{SIN}\,\phi$

$L_1 = R_1\,[L \div (R_1 + R_2)]$

$= R_1\ \text{SIN}\,\phi$

$L_2 = L - L_1$

$= R_2\ \text{SIN}\,\phi$

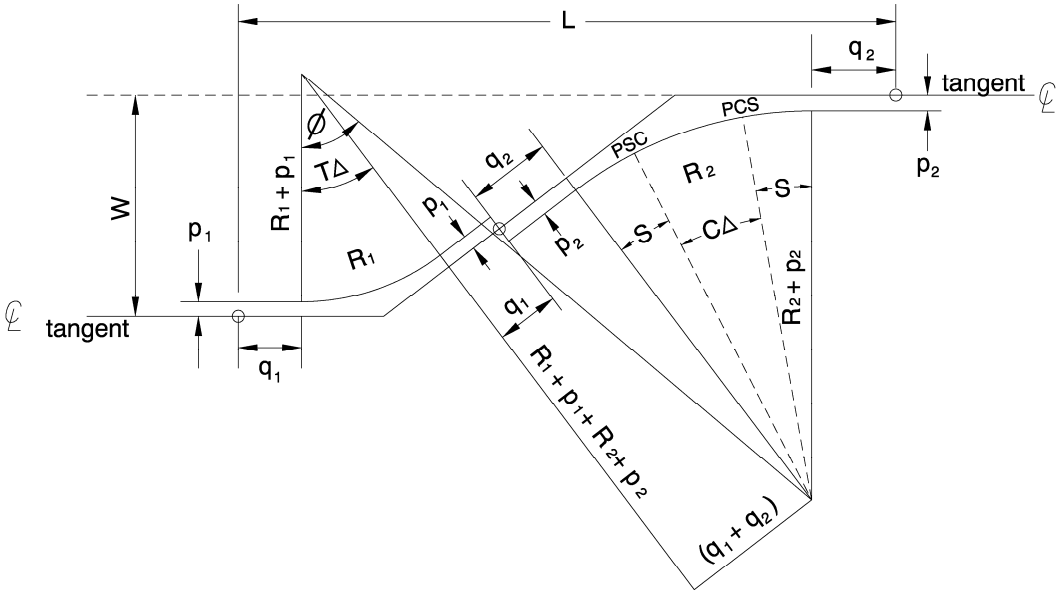
$W_1 = \sqrt{R_1^2 - L_1^2}$

$= R_1 - R_1\ \text{COS}\,\phi$

$W_2 = W - W_1$

$= R_2 - R_2\ \text{COS}\,\phi$

TANGENT DISTANCES OF UNEQUAL REVERSING SYMMETRICAL SPIRALED CURVES



$L = \sqrt{(R_1 + p_1 + R_2 + p_2)^2 + (q_1 + q_2)^2 - (R_1 + p_1 + R_2 + p_2 - W)^2} + (q_1 + q_2)$

$W = (R_1 + p_1 + R_2 + p_2) - \sqrt{(R_1 + p_1 + R_2 + p_2)^2 + (q_1 + q_2)^2 - (L - (q_1 + q_2))^2}$

$\phi = \text{Arc Cos}\left((R_1 + p_1 + R_2 + p_2 - W) \div \sqrt{(R_1 + p_1 + R_2 + p_2)^2 + (q_1 + q_2)^2}\right)$

$T\Delta = \phi - \text{Arc Tan}\left((q_1 + q_2) \div (R_1 + p_1 + R_2 + p_2)\right)$

$C\Delta = T\Delta - 2S$ where $S = 90\ Ls \div \pi\ Rn$

Ls = Length of spiral

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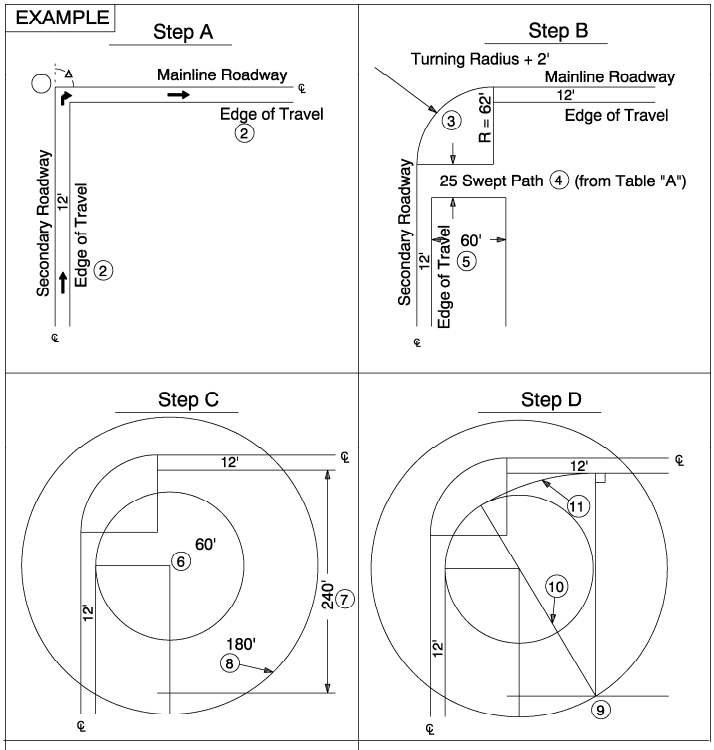
ROADWAY ENGINEERING UNIT

PARALLEL TANGENTS
UNEQUAL LENGTH
REVERSING CURVES

HIGHWAY DESIGN MANUAL

Figure J-2: Parallel Tangents – Unequal Length Reversing Curves



Note: Table "A" based on Interstate Design Vehicle 3S2, C-75, WB-67.

TABLE "A"

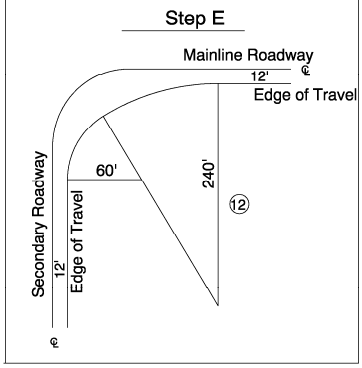
60' Turning Radius	
Delta	Swept Path Distance + 2'
60°	25.0
75°	27.3
90°	29.3
105°	31.0
120°	32.3

This will only work with a minimum 12' lane and 2' shoulder.

The 60',240' radius curve combination will work in most situtations.

If the turning area or turning radius needs to be changed, then use Autoturn turning template and lay in minimum curves.

If in a curb section, this should be checked with truck turning software to ensure that it does not encroach on the curb, walks, and ADA ramps.



This example uses a 60', 240' radius compound curvature, assuming a 60' turning radius.

Step A

① - Begin with intersection of centerlines (left edge of travel) to determine delta (Δ).

② - Copy parallel 12' lanes from each centerline to determine right edge of travel (If ramp, etc., use appropriate offset).

Step B

③ - Based upon turning radius place a 62' arc (60' turning radius + 2' overhang) at intersection of centerlines and determine radius point.

④ - Determine swept path distance for radius and delta from TABLE "A". (See also "maximum sweep for 1989 Interstate Design Vehicle" for other combinations).
Copy parallel the swept path distance (along the roadway you are turning from) from the tangent of the 62' radius curve.

⑤ - Copy parallel 60' (This distance is the radius of intial two centered curves) from the right edge of travel of the roadway you are turning from and intersect with swept path distance.

Step C

⑥ - Place a 60' radius circle at intersection of Step B No. ⑤ .

⑦ - Copy parallel a line 240' from mainline roadway edge of travel. (this distance is the radius of the 240' transition offtrack curve).

⑧ - Place a 180' circle at ⑥ (this is the difference in offtracking curves (240'-60').

Step D

⑨ - Establish point ⑨ by intersecting line ⑦ with the radius of step ⑧.

⑩ - Place line from point ⑨ passing thru point ⑥ and intersect 60' radius circle.

⑪ - Construct a 240' radius arc for transition offtrack curve.

Step E

⑫ - The two centered curves are completed.

This layout will need adjustment when spirals are used.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

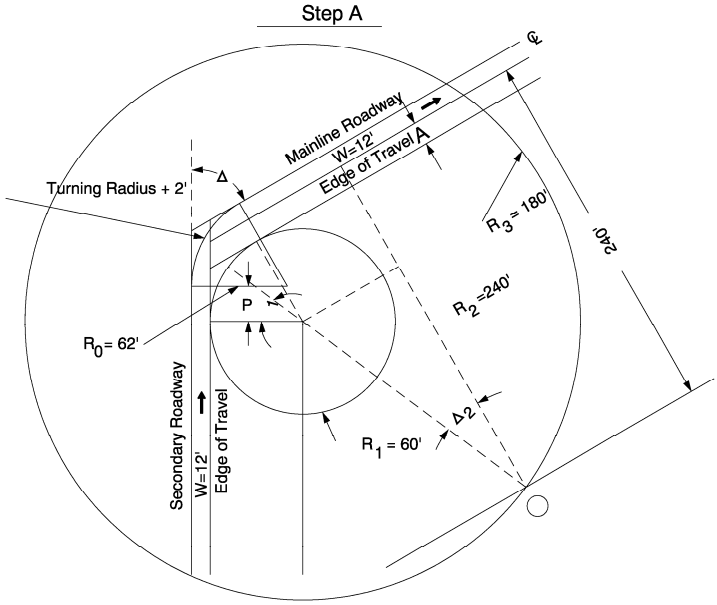
GRAPHICAL SOLUTION
TWO-CENTERED
CORNER RADII

HIGHWAY DESIGN MANUAL

Figure J-3: Two-Centered Corner Radii Graphical Solution

TWO CENTERED CURVE LAYOUT

Step A



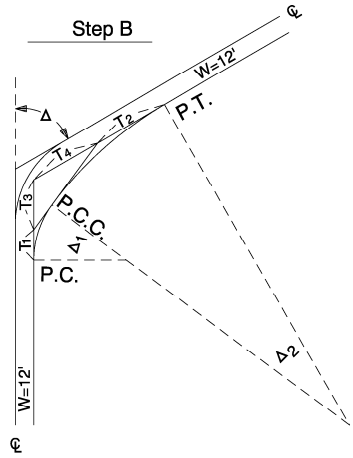
This method uses a 60', 240' radius compound curvature, assuming a 60' turning radius.

The 60', 240' radius curve combination will work in most situtations.

If the turning area or turning radius needs to be changed, then use truck turning software and lay in minimum curves.

If in a curb section, this should be checked with truck turning software to ensure that it does not encroach on the curb, walks, and ADA ramps.

Step B



Follow the illustration for the graphic method for layout of the two centered curves. Step A will be done using these equations below to calculate point ⑨.

A = distance at right angle parallel from edge of travel to 60' radius curve.

P = Swept Path + 2'

W = Lane width

R = Radius

R = R - R

Step A

1) $A = \left(P + \left[(R_0 - R_1)\ \mathrm{Tan}\ \frac{\Delta}{2}\right] - \frac{}{\mathrm{Tan}\Delta}\right) \mathrm{Sin}\ \Delta = 14.9186'$

2) $\Delta_2 = \mathrm{arc\ Cos}\ \frac{R - (R + A)}{} = 23\ \ 29'\ 30''$

$\Delta_1 = \Delta - \Delta$

Step B

1) $T_1 = R_1 \tan \frac{\Delta_1}{2}$

2) $T_2 = R_2 \tan \frac{\Delta_2}{2}$

3) $T_3 = (T_1 + T_2)\ \frac{\mathrm{Sin}\ \Delta_2}{\mathrm{Sin}\ (180 - \Delta)}$

4) $T = T_3\ \frac{\mathrm{Sin}\ \Delta_1}{\mathrm{Sin}\ \Delta_2}$

$T_1 + T_3$ = distance from intersection of edge of travel to P.C. of initial two centered curve.

$T_2 + T_4$ = distance from intersection of edge of travel to P.T. of final two centered curve.

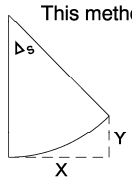
Note: Table "A" based on Interstate Design Vehicle 3S2, C-75, WB-67.

TABLE "A"

60' Turning Radius	
Delta	Swept Path Distance + 2'
Δ	P
60°	25.0
75°	27.3
90°	29.3
105°	31.0
120°	32.3

TANGENT LAYOUT OF CURVE

This method will allow to layout curves, if obstructions prevent setting radius points.



$Y = R - \sqrt{R^2 - X^2}$, $R - R\ \mathrm{COS}\ \Delta_s$

$X = \sqrt{2\ R\ Y - Y^2}$, $R\ \mathrm{SIN}\ \Delta_s$

$R = (X^2 + Y^2) - 2\ Y$

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

MATHEMATICAL SOLUTION
TWO-CENTERED
CORNER RADII

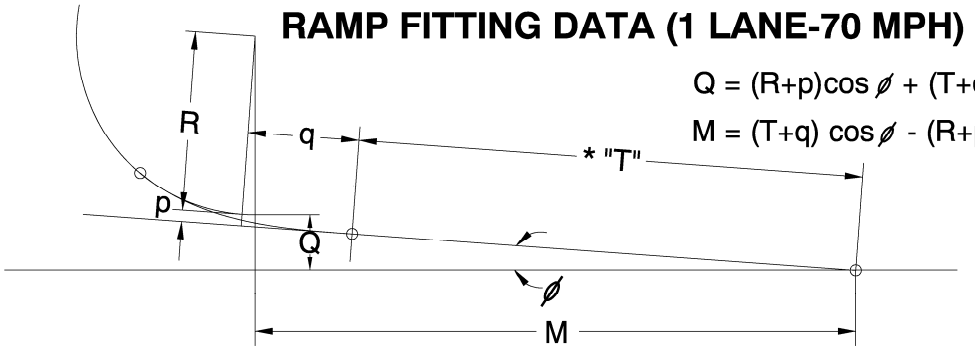
HIGHWAY DESIGN MANUAL

Figure J-4: Two-Centered Corner Radii Mathematical Solution

RAMP FITTING DATA (1 LANE-70 MPH)

$$Q = (R+p)\cos\phi + (T+q)\sin\phi - R$$

$$M = (T+q)\cos\phi - (R+p)\sin\phi$$



RAMP FITTING DATA @ HIGHWAY DESIGN SPEED 70 MPH									EXIT ø = 4° 15'			ENTRANCE ø = 2°30', T= 366.81		
mph	D	R	L	e %	a	S°	p	q	*T	Q	M	Q	M	Accel
70	1	5729.58	200	3.5	0.50	1.00	0.2909	99.9990	240	9.7316	-85.5679	15.1992	216.4307	580
70	2	2864.79	200	6.5	1.00	2.00	0.5818	99.9959	240	17.8991	126.7127	18.2163	341.3753	580
70	3	1909.86	240	8.0	1.25	3.60	1.2565	119.9842	220	21.1970	197.4194	20.6711	402.9686	580
70	3°15'	1762.95	240	8.5	1.35	3.90	1.3611	119.9815	220	21.7051	208.2964	20.9154	409.3695	580
65	3.5	1637.02	240	9.0	1.46	4.20	1.4658	119.9785	220	22.1556	217.6178	21.1397	414.8547	580
65	3.75	1527.89	240	9.0	1.56	4.50	1.5705	119.9753	220	22.5598	225.6946	21.3480	419.6074	580
65	4	1432.39	240	9.0	1.67	4.80	1.6751	119.9719	220	22.9265	232.7603	21.5433	423.7648	580
60	4.25	1348.14	250	9.5	1.70	5.31	1.9311	124.9642	215	23.4129	238.9779	22.0970	432.4164	580
60	4.5	1273.24	250	9.5	1.80	5.63	2.0446	124.9599	215	23.7317	244.5156	22.2815	435.6741	580
60	4.75	1206.23	250	9.5	1.90	5.94	2.1581	124.9553	215	24.0288	249.4689	22.4585	438.5876	580
60	5	1145.92	250	9.5	2.00	6.25	2.2716	124.9504	215	24.3075	253.9252	22.6290	441.2085	580
55	5.5	1041.74	250	10.0	2.20	6.88	2.4985	124.9400	215	24.8195	261.6182	22.9545	445.7323	580
55	6	954.93	240	10.0	2.50	7.20	2.5119	119.9369	220	25.0713	268.0476	22.8322	444.5199	580
55	6.5	881.47	240	10.0	2.71	7.80	2.7209	119.9259	220	25.4809	273.4649	23.1104	447.7040	580
50	7	818.51	240	10.5	2.92	8.40	2.9299	119.9141	220	25.8616	278.1036	23.3787	450.4294	580
50	7.5	763.94	250	10.5	3.00	9.38	3.4056	124.8885	215	26.4841	282.0868	24.1228	457.7586	580
50	8	716.20	250	10.5	3.20	10.00	3.6321	124.8732	215	26.8402	285.5931	24.3939	459.8161	580
45	8.5	674.07	250	11.0	3.40	10.63	3.8586	124.8569	265	30.8861	338.5447	24.6596	461.6275	820
45	9	636.62	250	11.0	3.60	11.25	4.0850	124.8395	265	31.2136	341.2859	24.9206	463.2338	820
45	9.5	603.11	250	11.0	3.80	11.88	4.3113	124.8212	265	31.5300	343.7340	25.1777	464.6672	820
45	10	572.96	250	11.0	4.00	12.50	4.5374	124.8019	265	31.8370	345.9328	25.4315	465.9534	820
45	10.5	545.67	250	11.0	4.20	13.13	4.7635	124.7817	265	32.1360	347.9177	25.6825	467.1134	820
40	11	520.87	250	11.5	4.40	13.75	4.9894	124.7604	315	36.1333	399.5805	25.9308	468.1642	1000
40	12	477.46	240	11.5	5.00	14.40	5.0152	119.7478	320	36.2775	402.7827	25.7793	465.0486	1000
40	13	440.74	200	11.5	6.50	13.00	3.7746	99.8286	340	35.1473	405.6771	23.7060	446.8046	1000
40	14	409.26	200	11.5	7.00	14.00	4.0638	99.8013	340	35.5202	407.9615	24.0236	448.1378	1000
35	15	381.97	200	12.0	7.50	15.00	4.3527	99.7720	390	39.5866	459.7953	24.3370	449.2860	1230
35	16	358.10	200	12.0	8.00	16.00	4.6413	99.7406	390	39.9377	461.5118	24.6466	450.2834	1230
35	17	337.03	200	12.0	8.50	17.00	4.9296	99.7073	390	40.2807	463.0183	24.9533	451.1564	1230
35	18	318.31	200	12.0	9.00	18.00	5.2176	99.6719	390	40.6168	464.3493	25.2573	451.9252	1230
35	19	301.56	200	12.0	9.50	19.00	5.5052	99.6346	390	40.9469	465.5323	25.5590	452.6061	1230
30	20	286.48	200	12.0	10.00	20.00	5.7925	99.5952	420	43.4952	496.5066	25.8586	453.2120	1350
30	22	260.44	200	12.0	11.00	22.00	6.3659	99.5106	420	44.1324	498.3098	26.4526	454.2384	1350
30	24	238.73	200	12.0	12.00	24.00	6.9377	99.4180	420	44.7555	499.7834	27.0405	455.0676	1350
30	26	220.37	200	12.0	13.00	26.00	7.5077	99.3175	420	45.3669	501.0019	27.6230	455.7434	1350
25	28	204.63	200	12.0	14.00	28.00	8.0758	99.2092	450	48.1919	531.9358	28.2007	456.2970	1420
25	30	190.99	200	12.0	15.00	30.00	8.6417	99.0931	450	48.7852	532.7891	28.7741	456.7514	1420
25	34	168.52	200	12.0	17.00	34.00	9.7667	98.8376	450	49.9500	534.1161	29.9083	457.4272	1420
25	36	159.15	200	12.0	18.00	36.00	10.3256	98.6984	450	50.5227	534.6296	30.4694	457.6721	1420

* NOTE: Where exit loop "T" distances are variable for grades in excess of 3% see HDM Figure 9-12 to calculate "T" distance.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

RAMP FITTING DATA (1 LANE - 70 MPH)

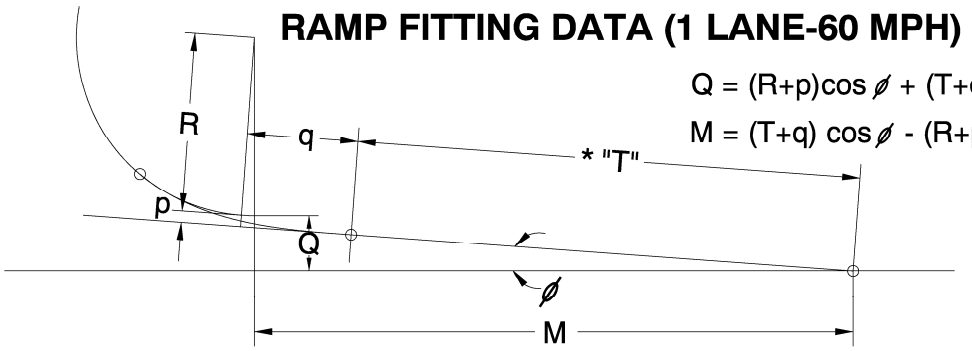
HIGHWAY DESIGN MANUAL

Figure J-5: Ramp Fitting Data - One Lane Ramps – 70 mph Highway

RAMP FITTING DATA (1 LANE-60 MPH)

$$Q = (R+p)\cos\phi + (T+q)\sin\phi - R$$

$$M = (T+q)\cos\phi - (R+p)\sin\phi$$



RAMP FITTING DATA @ HIGHWAY DESIGN SPEED 60 MPH									EXIT ø = 4° 15'			ENTRANCE ø = 2°30', T= 366.81		
Ramp Curve (mph)	D	R	L	e %	a	S°	p	q	*T	Q	M	Q	M	Min. Accel
70	1	5729.58	200	3.5	0.50	1.00	0.2909	99.9990	140	2.3208	-185.2929	15.1992	216.4307	*540
70	2	2864.79	200	6.5	1.00	2.00	0.5818	99.9959	140	10.4882	26.9877	18.2163	341.3753	*540
70	3	1909.86	240	8.0	1.25	3.60	1.2565	119.9842	120	13.7861	97.6944	20.6711	402.9686	*540
70	3°15'	1762.95	240	8.5	1.35	3.90	1.3611	119.9815	120	14.2943	108.5713	20.9154	409.3695	*540
65	3.5	1637.02	240	9.0	1.46	4.20	1.4658	119.9785	120	14.7447	117.8927	21.1397	414.8547	*540
65	3.75	1527.89	240	9.0	1.56	4.50	1.5705	119.9753	120	15.1489	125.9696	21.3480	419.6074	*540
65	4	1432.39	240	9.0	1.67	4.80	1.6751	119.9719	120	15.5156	133.0353	21.5433	423.7648	*540
60	4.25	1348.14	250	9.5	1.70	5.31	1.9311	124.9642	115	16.0020	139.2529	22.0970	432.4164	*540
60	4.5	1273.24	250	9.5	1.80	5.63	2.0446	124.9599	115	16.3209	144.7906	22.2815	435.6741	*540
60	4.75	1206.23	250	9.5	1.90	5.94	2.1581	124.9553	115	16.6180	149.7438	22.4585	438.5876	*540
60	5	1145.92	250	9.5	2.00	6.25	2.2716	124.9504	115	16.8967	154.2002	22.6290	441.2085	*540
55	5.5	1041.74	250	10.0	2.20	6.88	2.4985	124.9400	115	17.4087	161.8932	22.9545	445.7323	*540
55	6	954.93	240	10.0	2.50	7.20	2.5119	119.9369	120	17.6604	168.3225	22.8322	444.5199	*540
55	6.5	881.47	240	10.0	2.71	7.80	2.7209	119.9259	120	18.0701	173.7398	23.1104	447.7040	*540
50	7	818.51	240	10.5	2.92	8.40	2.9299	119.9141	120	18.4508	178.3786	23.3787	450.4294	*540
50	7.5	763.94	250	10.5	3.00	9.38	3.4056	124.8885	115	19.0733	182.3618	24.1228	457.7586	*540
50	8	716.20	250	10.5	3.20	10.00	3.6321	124.8732	115	19.4294	185.8681	24.3939	459.8161	*540
45	8.5	674.07	250	11.0	3.40	10.63	3.8586	124.8569	150	22.3637	223.8609	24.6596	461.6275	*540
45	9	636.62	250	11.0	3.60	11.25	4.0850	124.8395	150	22.6911	226.6021	24.9206	463.2338	*540
45	9.5	603.11	250	11.0	3.80	11.88	4.3113	124.8212	150	23.0075	229.0502	25.1777	464.6672	*540
45	10	572.96	250	11.0	4.00	12.50	4.5374	124.8019	150	23.3146	231.2490	25.4315	465.9534	*540
45	10.5	545.67	250	11.0	4.20	13.13	4.7635	124.7817	150	23.6135	233.2340	25.6825	467.1134	*540
40	11	520.87	250	11.5	4.40	13.75	4.9894	124.7604	225	29.4636	309.8279	25.9308	468.1642	*550
40	12	477.46	240	11.5	5.00	14.40	5.0152	119.7478	230	29.6078	313.0302	25.7793	465.0486	*550
40	13	440.74	200	11.5	6.50	13.00	3.7746	99.8286	250	28.4776	315.9246	23.7060	446.8046	*550
40	14	409.26	200	11.5	7.00	14.00	4.0638	99.8013	250	28.8505	318.2090	24.0236	448.1378	*550
35	15	381.97	200	12.0	7.50	15.00	4.3527	99.7720	305	33.2874	375.0290	24.3370	449.2860	*800
35	16	358.10	200	12.0	8.00	16.00	4.6413	99.7406	305	33.6385	376.7456	24.6466	450.2834	*800
35	17	337.03	200	12.0	8.50	17.00	4.9296	99.7073	305	33.9815	378.2520	24.9533	451.1564	*800
35	18	318.31	200	12.0	9.00	18.00	5.2176	99.6719	305	34.3176	379.5830	25.2573	451.9252	*800
35	19	301.56	200	12.0	9.50	19.00	5.5052	99.6346	305	34.6477	380.7660	25.5590	452.6061	*800
30	20	286.48	200	12.0	10.00	20.00	5.7925	99.5952	330	36.8255	406.7541	25.8586	453.2120	*910
30	22	260.44	200	12.0	11.00	22.00	6.3659	99.5106	330	37.4627	408.5572	26.4526	454.2384	*910
30	24	238.73	200	12.0	12.00	24.00	6.9377	99.4180	330	38.0857	410.0309	27.0405	455.0676	*910
30	26	220.37	200	12.0	13.00	26.00	7.5077	99.3175	330	38.6972	411.2494	27.6230	455.7434	*910
25	28	204.63	200	12.0	14.00	28.00	8.0758	99.2092	360	41.5222	442.1833	28.2007	456.2970	*1020
25	30	190.99	200	12.0	15.00	30.00	8.6417	99.0931	360	42.1155	443.0366	28.7741	456.7514	*1020
25	34	168.52	200	12.0	17.00	34.00	9.7667	98.8376	360	43.2803	444.3636	29.9083	457.4272	*1020
25	36	159.15	200	12.0	18.00	36.00	10.3256	98.6984	360	43.8530	444.8771	30.4694	457.6721	*1020

* These Accel Lane lengths are bare minimums. Operational analysis should be done to either validate these lengths or recommend additional distance for gap acceptance and merging needs.

NOTE: Where exit loop "T" distances are variable for grades in excess of 3% see HDM Figure 9-12 to calculate "T" distance.

NON-STANDARD -
USING 60 MPH DESIGN SPEED AS A BASIS FOR SPEED CHANGE AREAS REQUIRES AGREEMENT BETWEEN REGION AND TECH SERVICES ROADWAY MANAGERS.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

RAMP FITTING DATA (1 LANE - 60 MPH)

HIGHWAY DESIGN MANUAL

Figure J-6: Ramp Fitting Data - One Lane Ramps – 60 mph Highway

RAMP CURVE FITTING DETAIL

N = Nominal tangent length, ≥ 0

$I = q_1 + q_2 + N$

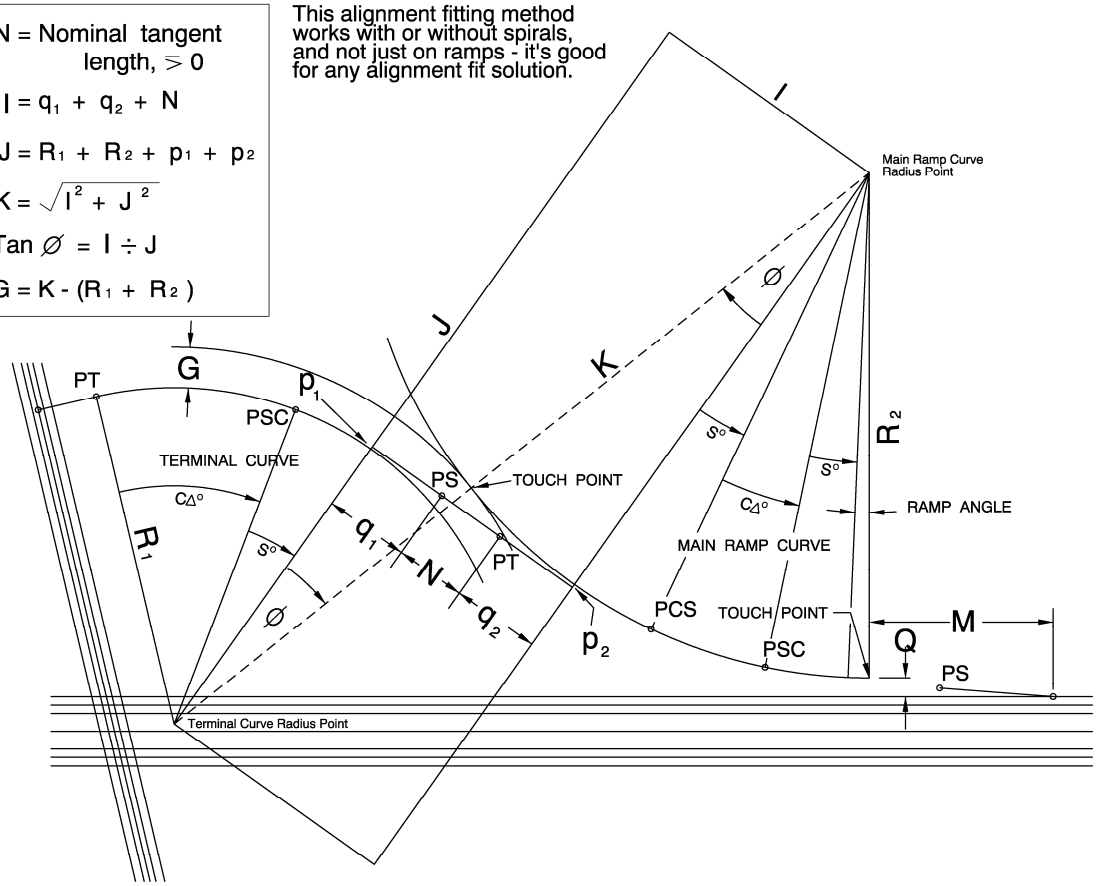
$J = R_1 + R_2 + p_1 + p_2$

$K = \sqrt{I^2 + J^2}$

$\text{Tan } \varnothing = I \div J$

$G = K - (R_1 + R_2)$

This alignment fitting method works with or without spirals, and not just on ramps - it's good for any alignment fit solution.



A.) Establish the location of the ramp terminal intersection with the crossroad. Refer to HDM Figure 9-17 (Diamond Interchange - Terminal Ramp Spread) and HDM Figure 9-18 (Detail at Ramp & Crossroad Intersection). When Loop Ramps are present refer to Appendix J - Figure J-8 (Loop Fitting Data), HDM Figure 9-24 (Partial Cloverleaft Intersection Detail) and Figure 9-25 ((Folded Diamond Terminal Detail) to fix terminal location.

B.) Choose curves and tangency between them appropriate for the individual situation. Normally the Terminal Curve is designed to between 50 and 75% of the Main Curve design speed. The Main Curve design speed should be between 75 and 85% of the Thru Roadway design speed. The tangent length between curves is variable - strive for 100'.

C.) Having established the ramp terminal, and appropriate ramp curves, the next steps are:

1.) Establish radius point of terminal curve.

2.) Look up values for p_1 & q_1 from HDM Fig. 9-19 (for the Terminal Curve) and p_2 & q_2 from Appendix J - Figure J-5 (For the Main Ramp Curve). Q & M are also found in Figure J-5.

3.) Compute value of "K".

4a.) Establish touch points for main ramp curve from the formula "K - R_2 = distance from radius point of terminal curve" and "Q = distance from edge of travel lane".

4b.) Establish radius point of main ramp curve "K" distance from radius point of terminal curve and "Q + R_2" from edge of travel lane.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

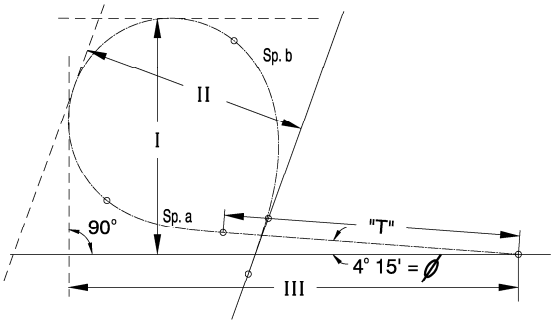
RAMP CURVE FITTING DETAIL

HIGHWAY DESIGN MANUAL

Figure J-7: Ramp Curve Fitting Details

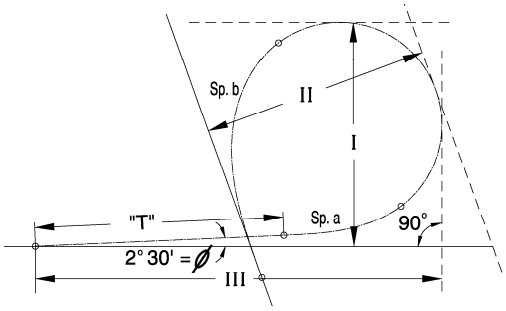
LOOP FITTING DATA (1 LANE)

EXIT LOOP



$I = (R+p)\cos\phi + (T+q)\sin\phi + R$ $II = 2R + p_b$

ENTRANCE LOOP



$III = (T+q)\cos\phi - (R+p)\sin\phi + R$

Highway Design Speed=70 mph															
SPEED MPH	CURVE RADIUS	Sp. a LENGTH	p_a	q_a	Sp. b LENGTH	p_b	q_b	EXIT * "T"	I	II	III	ENTRANCE "T"	I	II	III
30	238.73	200	6.9377	99.4180	400	27.2356	195.4112	420	522.2203	504.7005	738.5158	366.81	504.5053	504.7005	693.8000
25	220.37	200	7.5077	99.3175	400	29.3778	194.6327	450	488.3270	470.1146	751.2878	366.81	468.3598	470.1146	676.1118
25	204.63	200	8.0758	99.2092	400	31.4902	193.7978	450	457.4475	440.7458	736.5636	366.81	437.4563	440.7458	660.9248
25	190.99	200	8.6417	99.0931	400	33.5708	192.9079	450	430.7571	415.5427	723.7750	366.81	410.7459	415.5427	647.7373
25	179.05	200	9.2054	98.9692	400	35.6177	191.9644	450	407.4696	393.7163	712.5577	366.81	387.4418	393.7163	636.1730
25	168.52	200	9.7667	98.8376	400	37.6291	190.9687	450	386.9840	374.6631	702.6331	366.81	366.9423	374.6631	625.9442
25	159.15	200	10.3256	98.6984	400	39.6030	189.9224	450	368.8326	357.9129	693.7846	366.81	348.7793	357.9129	616.8270

** Minimum deceleration lengths for exit ramps with heavy truck volumes								
SPEED MPH	CURVE RADIUS	Sp. a LENGTH	p_a	q_a	EXIT * "T"	I	II	III
30	238.73	200	6.9377	99.4180	700	542.9707	504.7005	1017.7459
25	220.37	200	7.5077	99.3175	745	510.1890	470.1146	1045.4766
25	204.63	200	8.0758	99.2092	745	479.3095	440.7458	1030.7524
25	190.99	200	8.6417	99.0931	745	452.6191	415.5427	1017.9638
25	179.05	200	9.2054	98.9692	745	429.3316	393.7163	1006.7465
25	168.52	200	9.7667	98.8376	745	408.8460	374.6631	996.8219
25	159.15	200	10.3256	98.6984	745	390.6946	357.9129	987.9734

NOTES:

* Exit Loop "T" Distances variable for grades in excess of 3%.

** Consideration for use should be given whenever truck volumes reach or exceed 6 trucks per hour.

A 36° exit loop is considered very minimal for design; using 30° or flatter is highly desirable.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

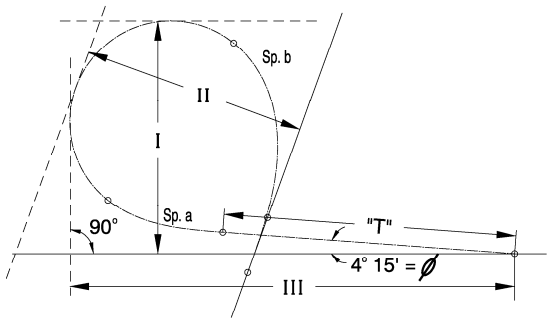
LOOP FITTING DATA (1 LANE)

HIGHWAY DESIGN MANUAL

Figure J-8: Loop Ramp Fitting Details - Single Lane Loops

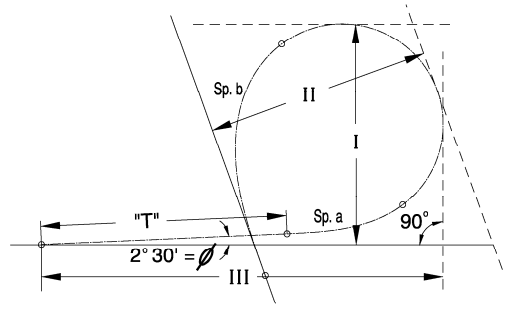
LOOP FITTING DATA (2 LANE)

EXIT LOOP



$I = (R+p)\cos\phi + (T+q)\sin\phi + R$ $\quad II = 2R + p_b$

ENTRANCE LOOP



$III = (T+q)\cos\phi - (R+p)\sin\phi + R$

Highway Design Speed=70 mph																
SPEED MPH	CURVE RADIUS	Sp. a LENGTH	p_a	q_a	Sp. b LENGTH	p_b	q_b	EXIT * "T"	EXIT I	EXIT II	EXIT III	ENTRANCE "T"	ENTRANCE I	ENTRANCE II	ENTRANCE III
30	238.73	240	9.9629	118.9964	400	27.2356	195.4112	510	533.3578	504.7005	847.5688	550.2141	516.3816	504.7005	896.4580
25	220.37	240	10.7762	118.8236	400	29.3778	194.6327	540	499.7018	470.1146	860.2506	550.2141	480.4760	470.1146	878.6869
25	204.63	240	11.5856	118.6375	400	31.4902	193.7978	540	469.0573	440.7458	845.4309	550.2141	449.8103	440.7458	863.4117
25	190.99	240	12.3907	118.4381	400	33.5708	192.9079	540	442.5992	415.5427	832.5415	550.2141	423.3352	415.5427	850.1306
25	179.05	240	13.1911	118.2255	400	35.6177	191.9644	540	419.5412	393.7163	821.2182	550.2141	400.2637	393.7163	838.4673
25	168.52	240	13.9867	118.0000	400	37.6291	190.9687	540	399.2822	374.6631	811.1825	550.2141	379.9941	374.6631	828.1344
25	159.15	240	14.7771	117.7616	400	39.6030	189.9224	540	381.3544	357.9129	802.2180	550.2141	362.0581	357.9129	818.9081

** Minimum deceleration lengths for exit ramps with heavy truck volumes								
SPEED MPH	CURVE RADIUS	Sp. a LENGTH	p_a	q_a	EXIT * "T"	EXIT I	EXIT II	EXIT III
30	238.73	240	9.9629	118.9964	790	554.1082	504.7005	1126.7988
25	220.37	240	10.7762	118.8236	835	521.5638	470.1146	1154.4394
25	204.63	240	11.5856	118.6375	835	490.9193	440.7458	1139.6197
25	190.99	240	12.3907	118.4381	835	464.4612	415.5427	1126.7303
25	179.05	240	13.1911	118.2255	835	441.4032	393.7163	1115.4070
25	168.52	240	13.9867	118.0000	835	421.1442	374.6631	1105.3714
25	159.15	240	14.7771	117.7616	835	403.2164	357.9129	1096.4068

NOTES:

* Exit Loop "T" Distances variable for grades in excess of 3%.

** Consideration for use should be given whenever truck volumes reach or exceed 6 trucks per hour.

A 36 (R-159.15') exit loop is considered very minimal for design; using 30° (R-190.99') or flatter is highly desirable.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

LOOP FITTING DATA (2 LANE)

HIGHWAY DESIGN MANUAL

Figure J-9: Loop Ramp Fitting Details - Two Lane Loops

Table 10-3 from AASHTO, 2011, page 10-110. Minimum Acceleration Lengths for Entrance Terminals with Flat Grades of 2 percent or Less.
Acceleration Length, L (ft)
for Entrance Curve Design Speed (mph)

Highway Design Speed, V (mph)	Speed Reached, V (mph)	Stop Condition	15	20	25	30	35	40	45	50
		0	14	18	22	26	30	36	40	44
30	23	180	140	-	-	-	-	-	-	-
35	27	280	220	160	-	-	-	-	-	-
40	31	360	300	270	210	120	-	-	-	-
45	35	560	490	440	380	280	160	-	-	-
50	39	720	660	610	550	450	350	130	-	-
55	43	960	900	810	780	670	550	320	150	-
60	47	1200	1140	1100	1020	910	800	550	420	180
65	50	1410	1350	1310	1220	1120	1000	770	600	370
70	53	1620	1560	1520	1420	1350	1230	1000	820	580
75	55	1790	1730	1630	1580	1510	1420	1160	1040	780

TAPER TYPE
(Not recommended by ODOT)

Table 10-5 from AASHTO, 2011, page 10-115 Minimum Deceleration Lengths for Exit Terminals With Flat Grades of 2 Percent or Less.
Deceleration Length, L (ft)
for Design Speed of Exit Curve V' (mph)

Highway Design Speed, V (mph)	Speed Reached, V (mph)	Stop Condition	15	20	25	30	35	40	45	50
		0	14	18	22	26	30	36	40	44
30	28	235	200	170	140	-	-	-	-	-
35	32	280	250	210	185	150	-	-	-	-
40	36	320	295	265	235	185	155	-	-	-
45	40	385	350	325	295	250	220	-	-	-
50	44	435	405	385	355	315	285	225	175	-
55	48	480	455	440	410	380	350	285	235	-
60	52	530	500	480	460	430	405	350	300	240
65	55	570	540	520	500	470	440	390	340	280
70	58	615	590	570	550	520	490	440	390	340
75	61	660	635	620	600	575	535	490	440	390

PARALLEL TYPE
(Not recommended by ODOT)

V = Design speed of highway
V = Average running speed on highway
V' = Design speed of exit curve
V' = Average running speed on exit curve

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DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

MINIMUM DECELERATION AND ACCELERATION LENGTHS FOR RAMPS

HIGHWAY DESIGN MANUAL

Figure J-10: Minimum AASHTO Acceleration & Deceleration Lengths for Ramps

Truck Deceleration Length "L" (in feet) For Design Speed of Exit Curve, V' (mph)

Highway Design Speed, **V** (mph)	Average Running Speed **Va** (mph)	Stop Condition	15	20	25	30	35	40	45	50	55
		For Average Running Speed on Exit Curve, V'a (mph)									
		0	14	18	22	26	30	36	40	44	48
30	28	270	230	200	165	-	-	-	-	-	-
35	32	340	295	270	230	-	-	-	-	-	-
40	36	415	370	340	305	265	215	-	-	-	-
45	40	495	455	425	390	345	295	-	-	-	-
50	44	585	540	515	480	435	385	295	-	-	-
55	48	680	640	610	575	530	480	395	325	-	-
60	52	785	470	715	675	635	585	495	430	355	-
65	55	865	825	795	760	715	665	580	510	435	355
70	58	955	910	880	845	800	750	665	595	520	440
75	61	1045	1000	970	935	890	845	755	685	610	530

V = Design Speed of Highway

Va = Average Running Speed on Highway

V' = Design Speed of Exit Curve

V'a = Average Running Speed on Exit Curve

Note:

Consider using these lengths whenever truck volumes are 6 or more per hour.
See HDM Figure 9-12 "EXIT RAMP DETAILS" for geometry details at ramps. This information has been incorporated into that Figure.
Recommendation based on anticipated operational effects of trucks.
DATA Source: "Improving truck Safety at Interchanges" US DOT Publication #FHWA-ip-89-024 - Pg. 20, September 1989

Figure J-11: Truck Deceleration

PREFERRED DESIGN VALUES FOR SINGLE POINT INTERSECTION

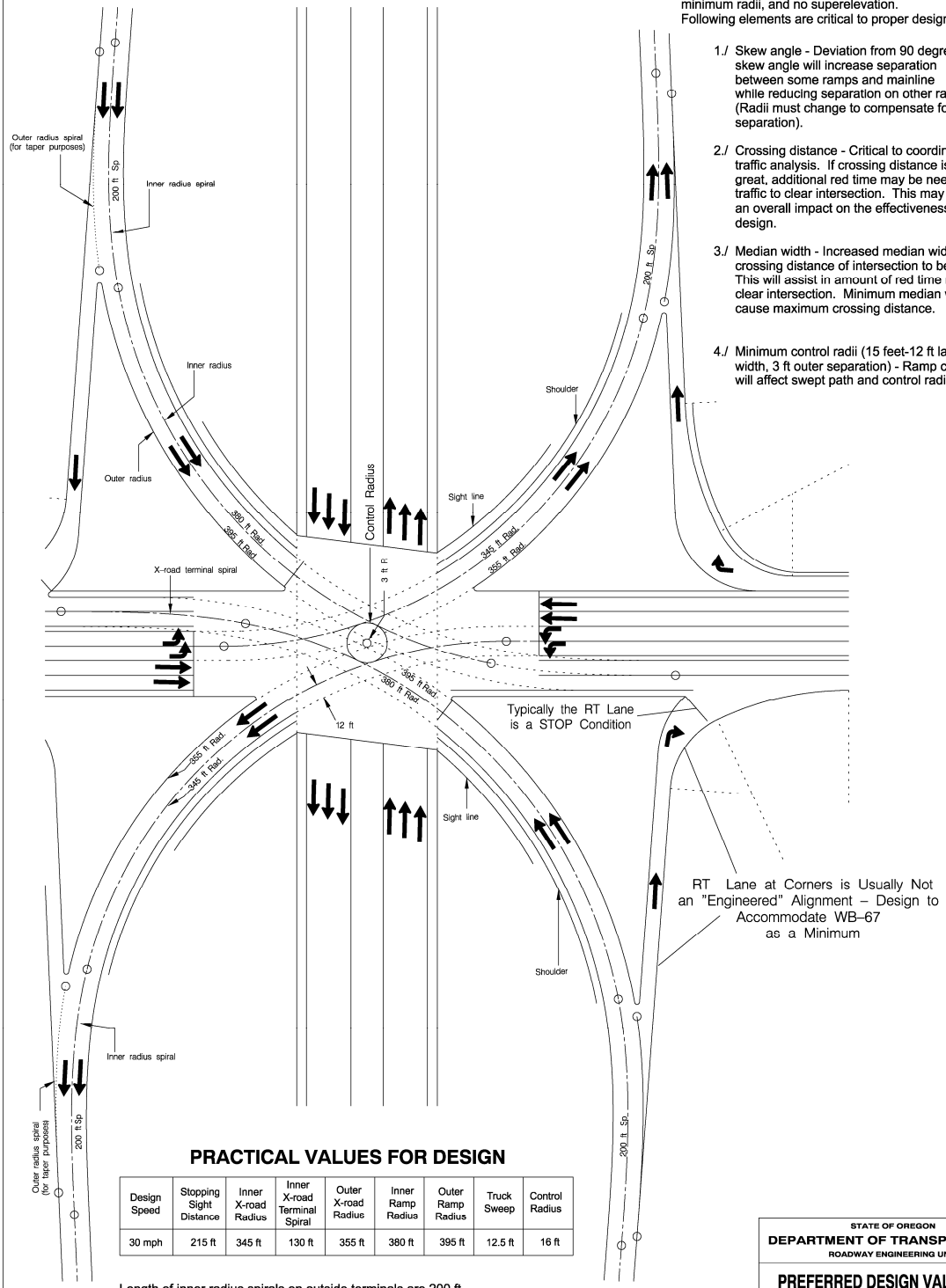
NOTES: Single Point Layout based on 90 degree intersection angle, minimum radii, and no superelevation.
Following elements are critical to proper design:

1./ Skew angle - Deviation from 90 degree skew angle will increase separation between some ramps and mainline while reducing separation on other ramps (Radii must change to compensate for separation).

2./ Crossing distance - Critical to coordinate with traffic analysis. If crossing distance is too great, additional red time may be needed for traffic to clear intersection. This may have an overall impact on the effectiveness of the design.

3./ Median width - Increased median width will allow crossing distance of intersection to be reduced. This will assist in amount of red time needed to clear intersection. Minimum median width will cause maximum crossing distance.

4./ Minimum control radii (15 feet-12 ft lane width, 3 ft outer separation) - Ramp curvature will affect swept path and control radii.



PRACTICAL VALUES FOR DESIGN

Design Speed	Stopping Sight Distance	Inner X-road Radius	Inner X-road Terminal Spiral	Outer X-road Radius	Inner Ramp Radius	Outer Ramp Radius	Truck Sweep	Control Radius
30 mph	215 ft	345 ft	130 ft	355 ft	380 ft	395 ft	12.5 ft	16 ft

Length of inner radius spirals on outside terminals are 200 ft.
Length of outer radius spirals on outside terminals are determined by measured "p" distance.
Inside lanes are all 12 ft.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

PREFERRED DESIGN VALUES FOR SINGLE POINT INTERSECTION

HIGHWAY DESIGN MANUAL

Figure J-12: Preferred Design Values For Single Point Interchanges

MINIMUM DESIGN VALUES FOR SINGLE POINT INTERSECTION

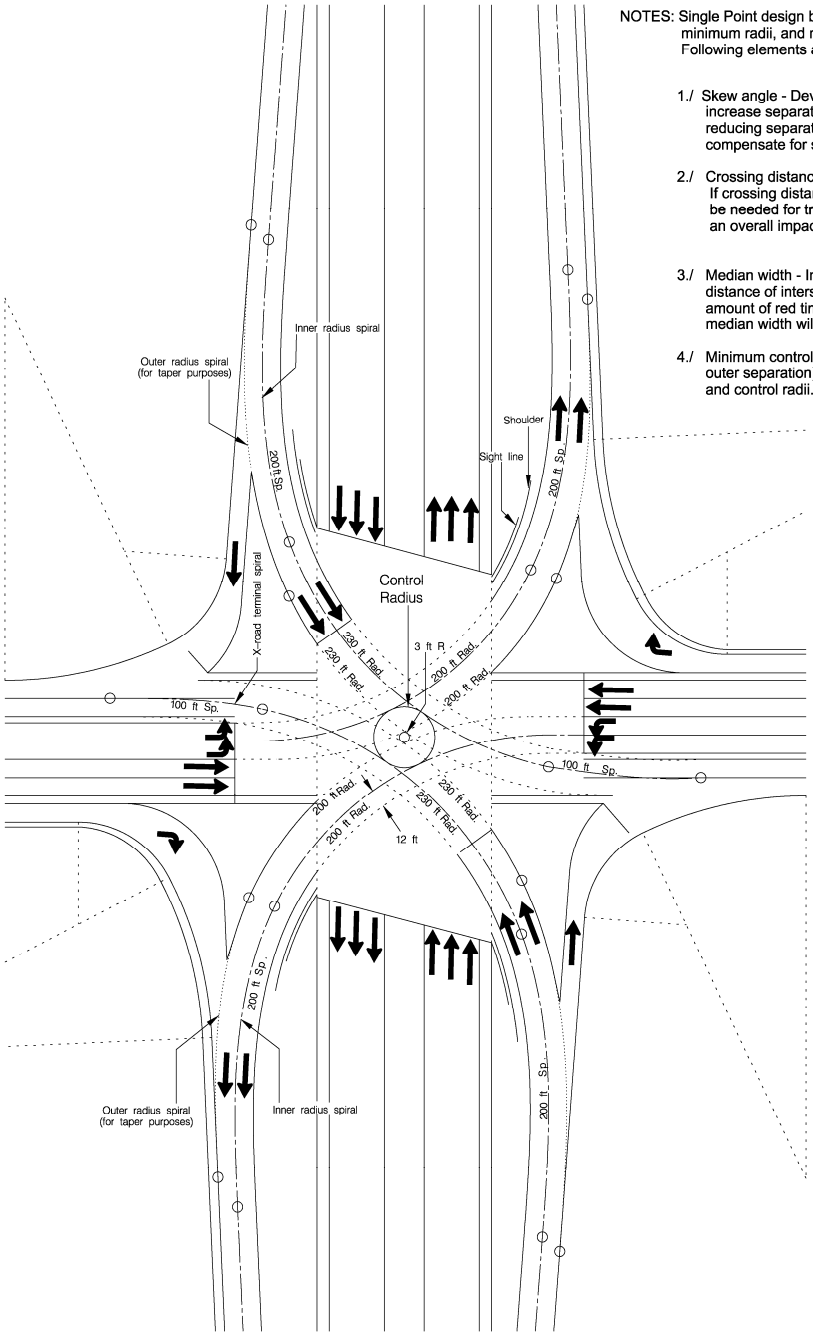
NOTES: Single Point design based on 90 degree intersection angle, minimum radii, and no superelevation.
Following elements are critical to proper design:

1./ Skew angle - Deviation from 90 degree skew angle will increase separation between some ramps and mainline while reducing separation on other ramps(Radii must change to compensate for separation).

2./ Crossing distance - Critical to coordinate with traffic analysis. If crossing distance is too great, additional red time may be needed for traffic to clear intersection. This may have an overall impact on the effectiveness of the design.

3./ Median width - Increased median width will allow crossing distance of intersection to be reduced. This will assist in amount of red time needed to clear intersection. Minimum median width will cause maximum crossing distance.

4./ Minimum control radii (15 ft -12 ft lane width, 3 ft outer separation) - Ramp curvature will affect swept path and control radii.



MINIMUM VALUES FOR DESIGN

Design Speed	Stopping Sight Distance	Inner X-road Radius	Inner X-road Terminal Spiral	Outer X-road Radius	Inner Ramp Radius	Outer Ramp Radius	Truck Sweep	Control Radius
25 mph	150 ft	200 ft	100 ft	200 ft	230 ft	230 ft	15.5 ft	20 ft

Length of inner radius spirals on outside terminals are 200 ft.
Length of outer radius spirals on outside terminals are determined by measured "p" distance.
Inside lanes are all 12 ft.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

MINIMUM DESIGN VALUES FOR SINGLE POINT INTERSECTION

HIGHWAY DESIGN MANUAL

Figure J-13: Minimum Design Value For Single Point Intersection Design

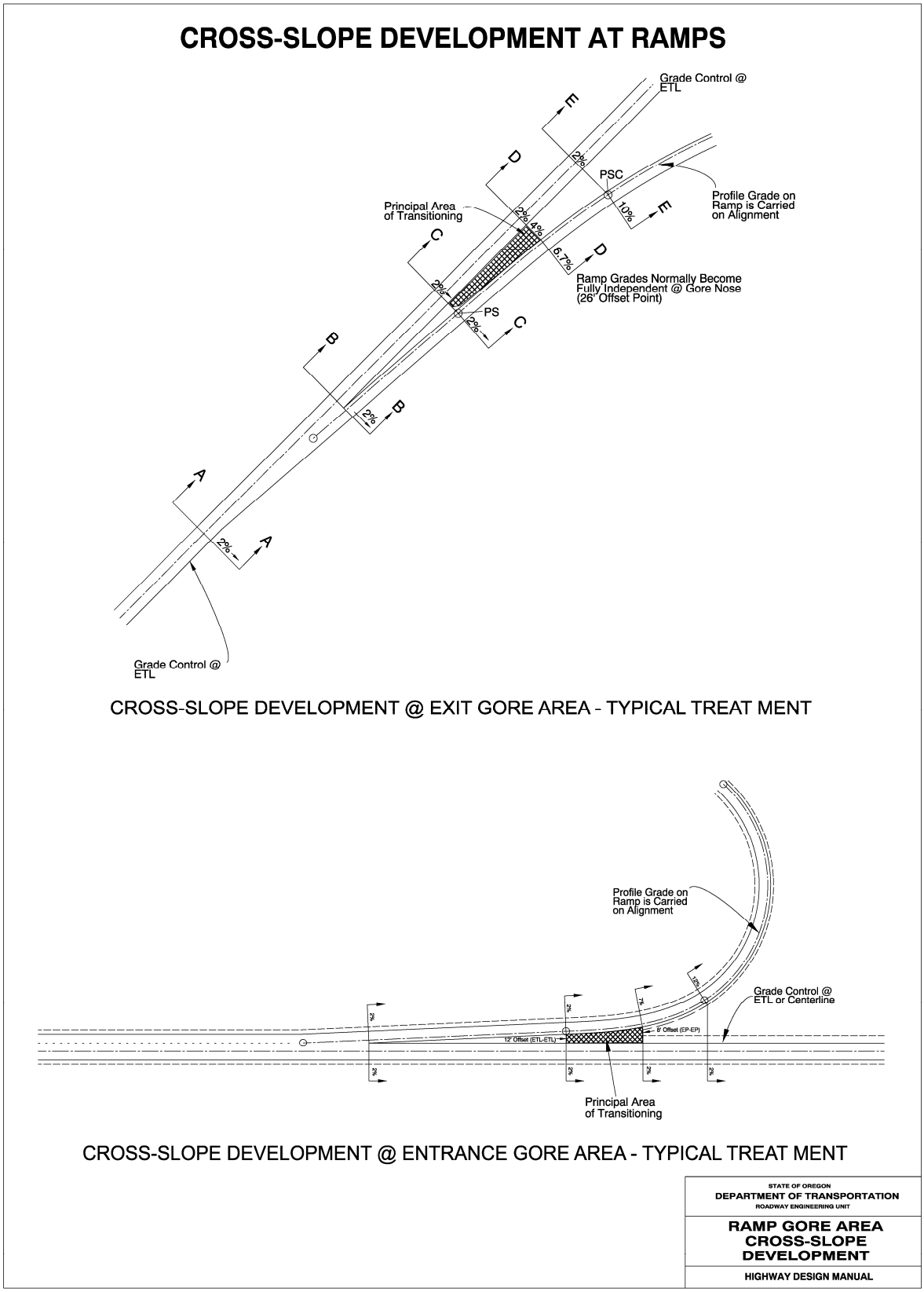
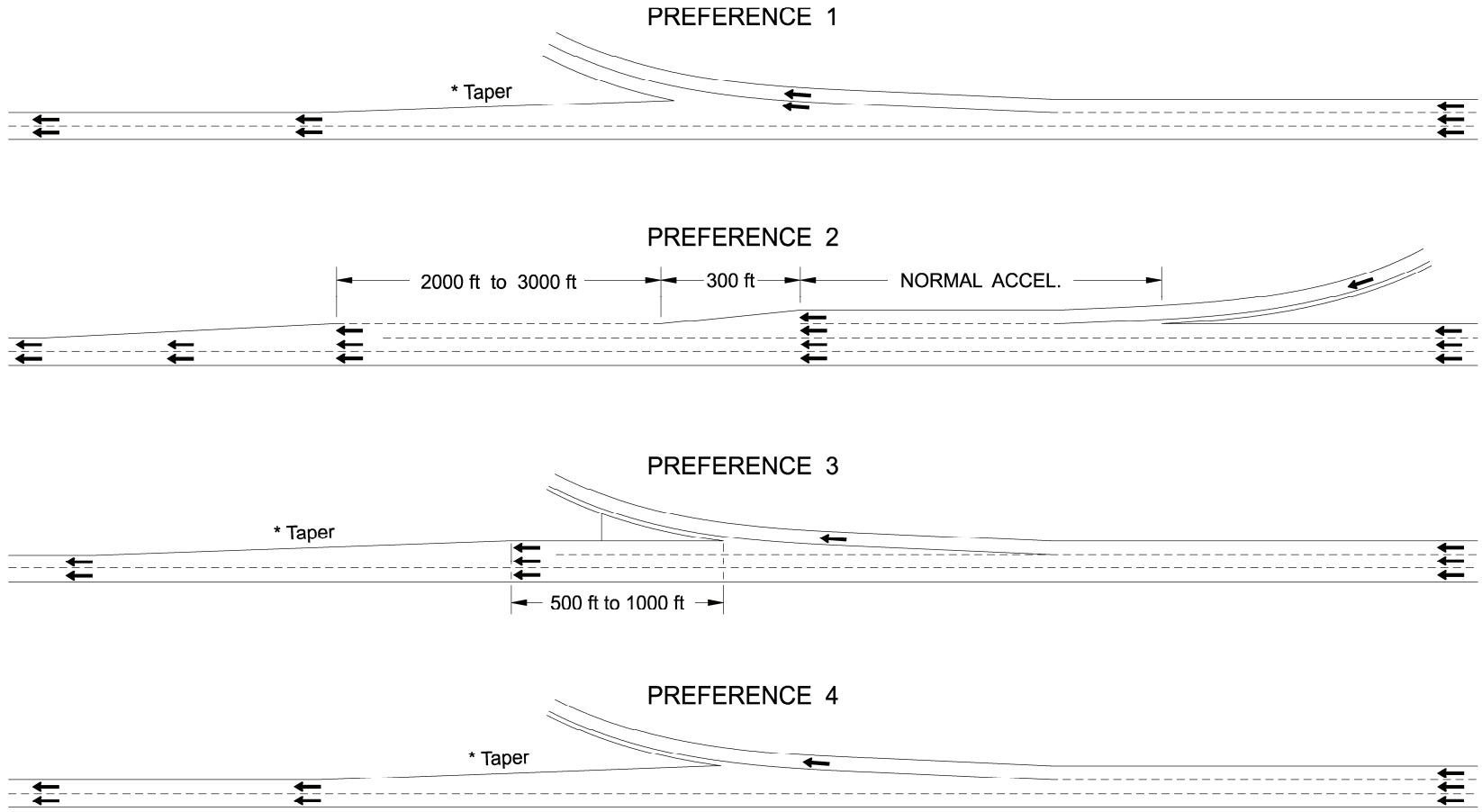


Figure J-14: Cross Slope Development at Gores - (Exit and Entrance)

AASHTO BASIC LANE DROP HIERARCHY



First preference is to drop the lane at a two lane exit, within the interchange.
Second is to drop the 2000 to 3000 ft beyond interchange allowing for adequate signing.
Third is to drop the lane at a single lane exit with an adequate recovery lane.
Fourth is to drop the lane at a single lane exit without a striped recovery lane (lane drop for auxillary lanes).

* - Use Speed Ratio Taper (between 70:1 & 50:1)
Pavement Marking shown is for illustrative purposes. Refer to ODOT Traffic Line Manual for appropriate markings.

Based upon information from AASHTO 2011, pg. 10-76 to 10-80

STATE OF OREGON
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ROADWAY ENGINEERING UNIT

FREEWAY LANE DROPS

HIGHWAY DESIGN MANUAL

Figure J-15: AASHTO Basic Freeway Lane Drop Hierarchy

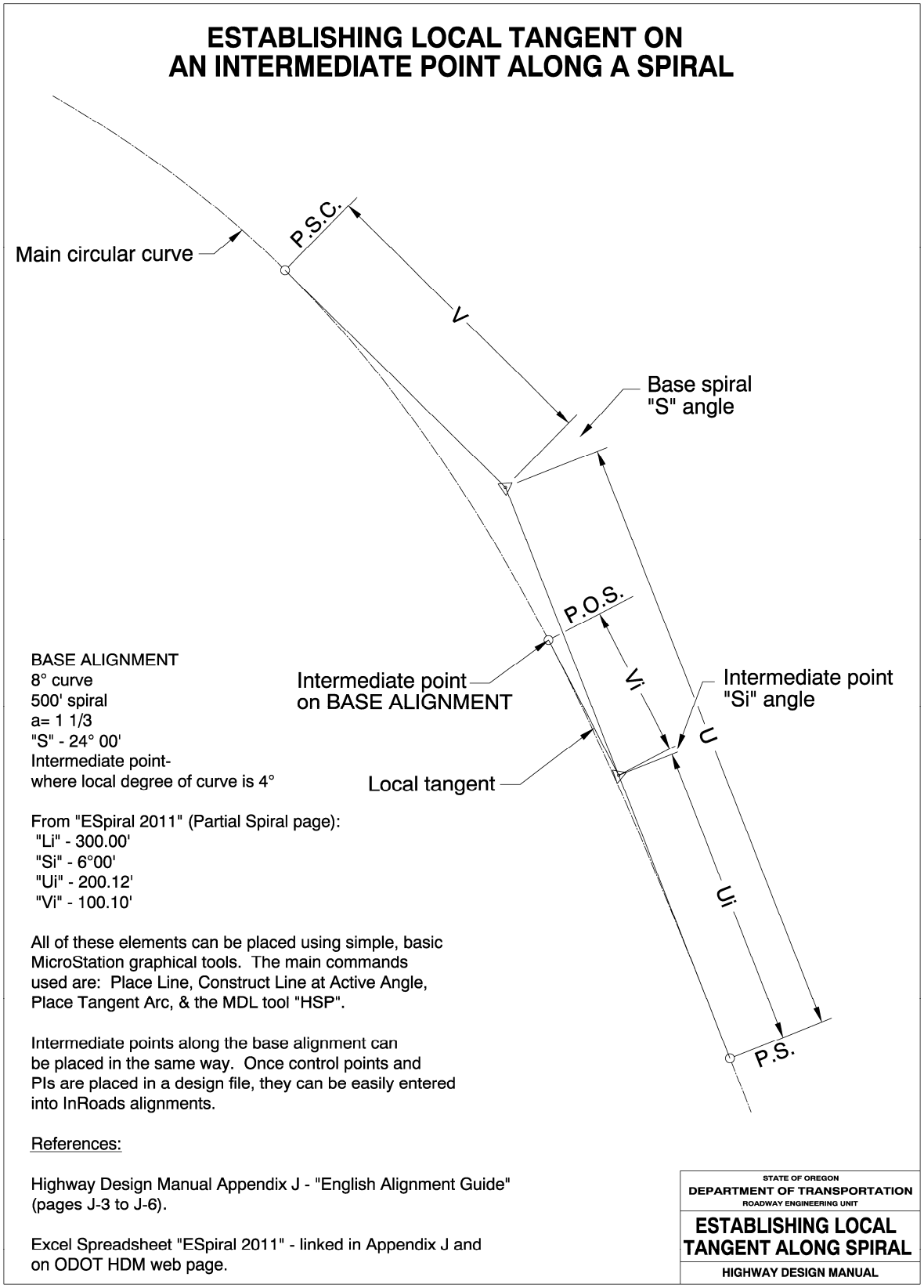


Figure J-16: Establishing Local Tangent on Horizontal Curves

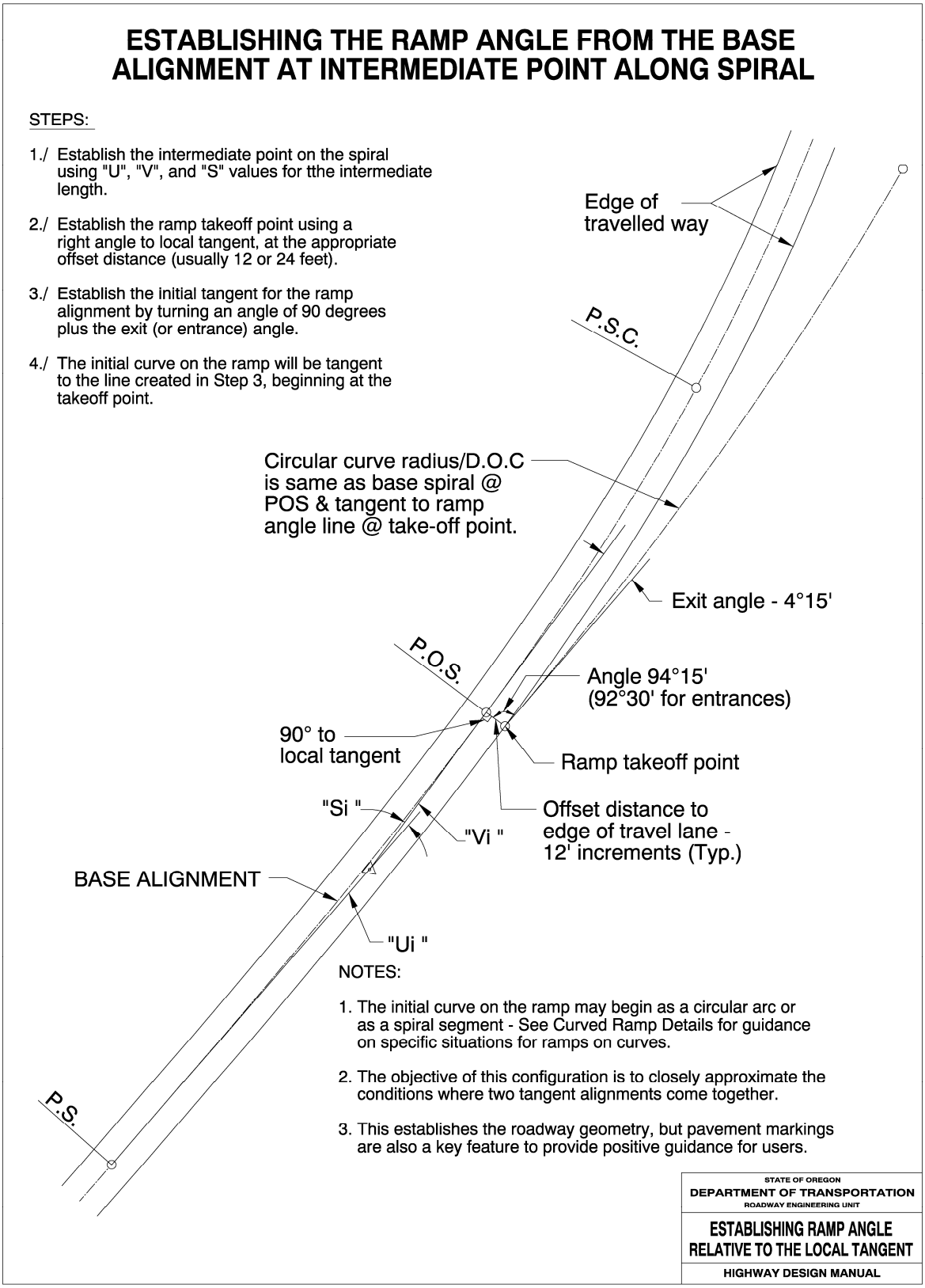


Figure J-17: Establishing Ramp Takeoff/Touchdown Points And Ramp Angles From Local Tangent

COMPOUND CURVE TREATMENT USING SPIRAL SEGMENT

NOTES:

1./ The compound situation is most common on ramp alignments, particularly where the mainline is a curve, or in mountainous areas.

2./ It's less common on mainline alignment and rare on freeways; although alignments in mountainous areas may employ compound curves in particularly difficult terrain.

3./ ODOT practice is to use spiral segments in situations where compounding is truly necessary - some older alignments and mountain passes still have compound curves with no segment transition.

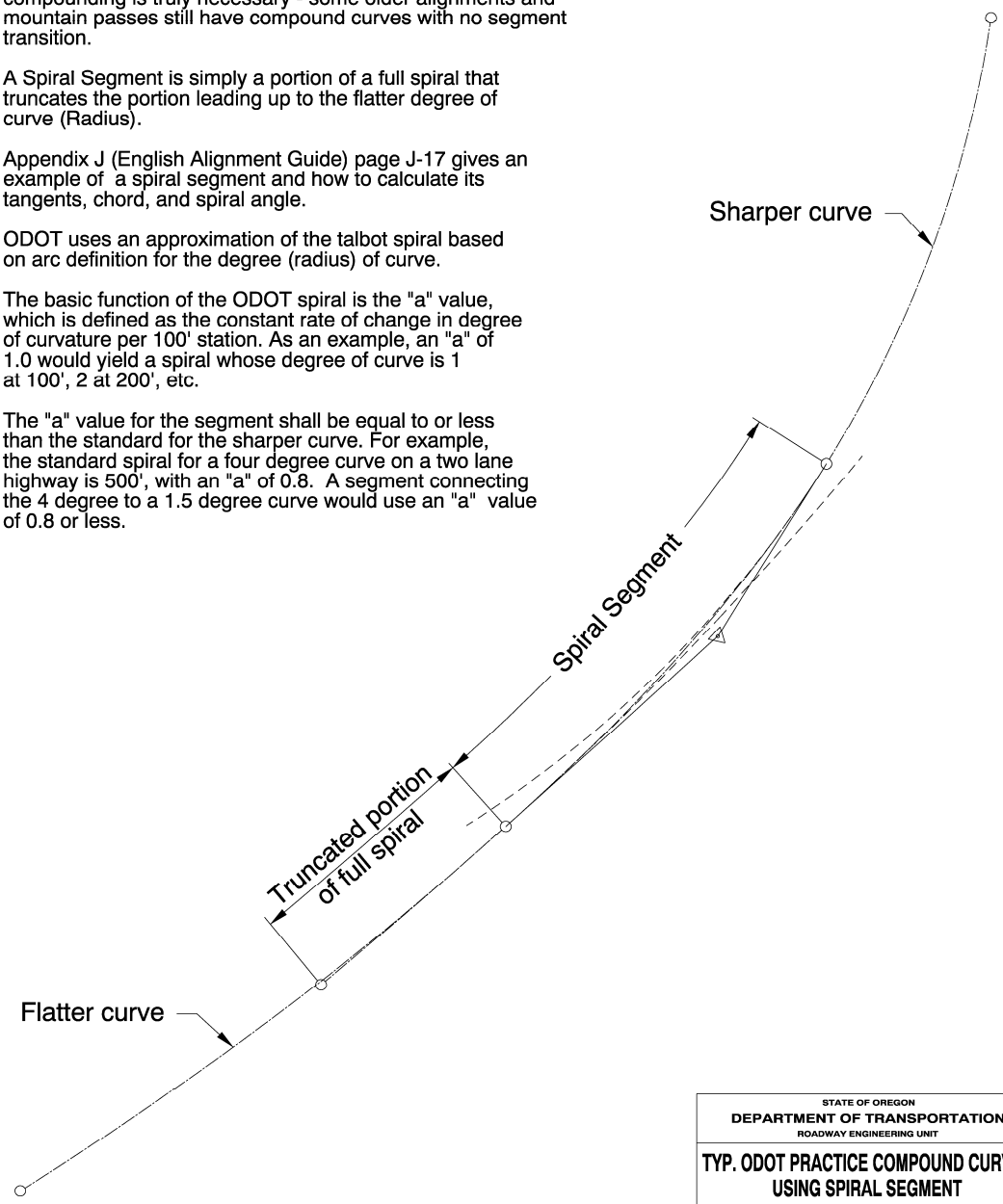
4./ A Spiral Segment is simply a portion of a full spiral that truncates the portion leading up to the flatter degree of curve (Radius).

5./ Appendix J (English Alignment Guide) page J-17 gives an example of a spiral segment and how to calculate its tangents, chord, and spiral angle.

6./ ODOT uses an approximation of the talbot spiral based on arc definition for the degree (radius) of curve.

7./ The basic function of the ODOT spiral is the "a" value, which is defined as the constant rate of change in degree of curvature per 100' station. As an example, an "a" of 1.0 would yield a spiral whose degree of curve is 1 at 100', 2 at 200', etc.

8./ The "a" value for the segment shall be equal to or less than the standard for the sharper curve. For example, the standard spiral for a four degree curve on a two lane highway is 500', with an "a" of 0.8. A segment connecting the 4 degree to a 1.5 degree curve would use an "a" value of 0.8 or less.



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ROADWAY ENGINEERING UNIT

TYP. ODOT PRACTICE COMPOUND CURVES USING SPIRAL SEGMENT

HIGHWAY DESIGN MANUAL

Figure J-18: Using Spiral Segment in Compound Horizontal Curve Situations

ESTABLISHING SEGMENT CONTROL POINTS IN COMPOUND CURVE SITUATIONS

NOTES:

1./ The "p3" offset distance is the key to determining the location of the segment control points. At this offset, local tangents to each curve are parallel and the curves are at their closest approach to one another.

2./ For any given "a" value Spiral, the "p3" offset is the same as the "p" for a Spiral whose degree of curve is equal to D2-D1.

Example:

"a" = 1.25
D1 - 1°, D2 - 6°, segment length - 400'
D2-D1 = 5°
"p" for spiral, "a" of 1.25, 5° curve, 400' long =5.81'

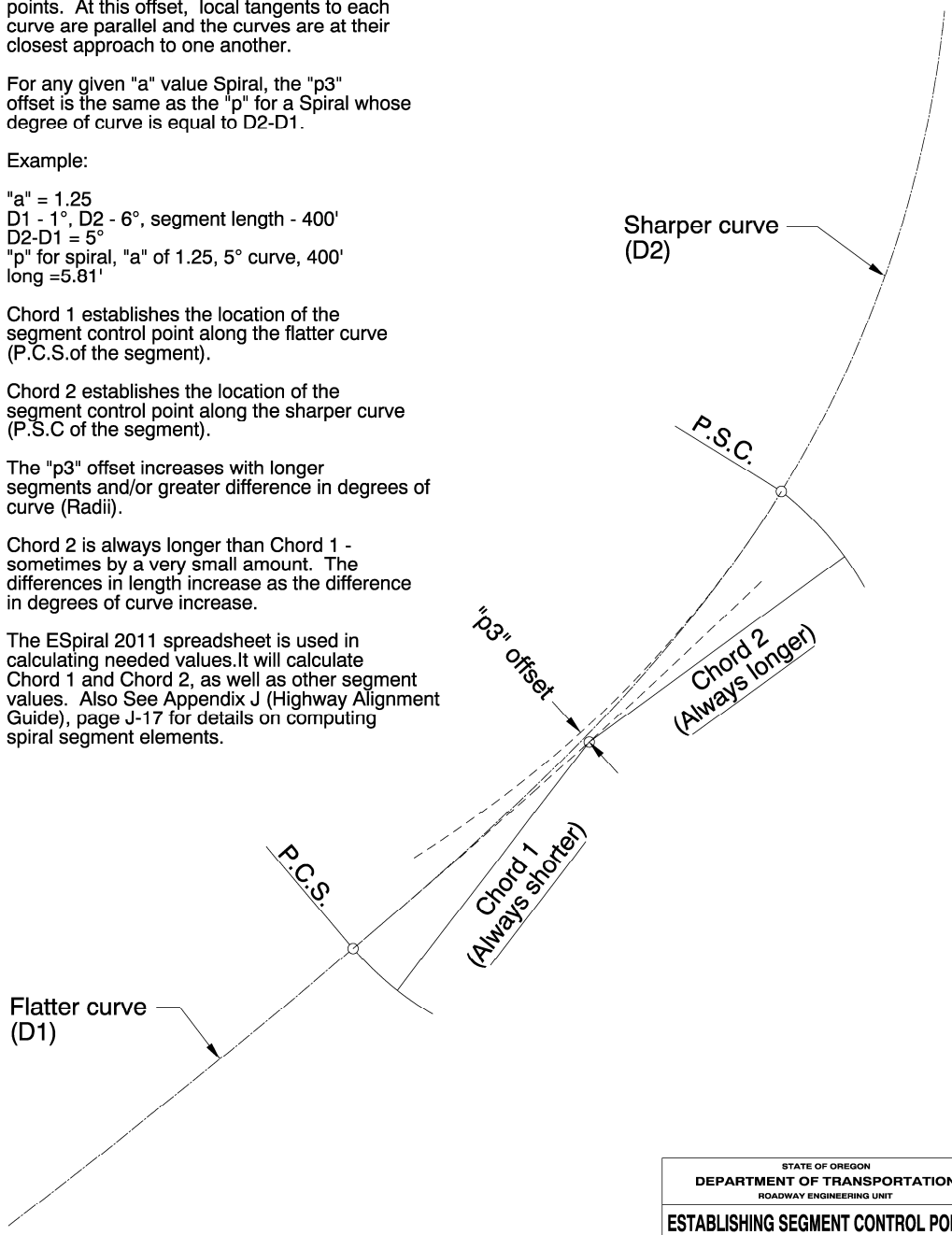
3./ Chord 1 establishes the location of the segment control point along the flatter curve (P.C.S.of the segment).

4./ Chord 2 establishes the location of the segment control point along the sharper curve (P.S.C of the segment).

5./ The "p3" offset increases with longer segments and/or greater difference in degrees of curve (Radii).

6./ Chord 2 is always longer than Chord 1 - sometimes by a very small amount. The differences in length increase as the difference in degrees of curve increase.

7./ The ESpiral 2011 spreadsheet is used in calculating needed values.It will calculate Chord 1 and Chord 2, as well as other segment values. Also See Appendix J (Highway Alignment Guide), page J-17 for details on computing spiral segment elements.



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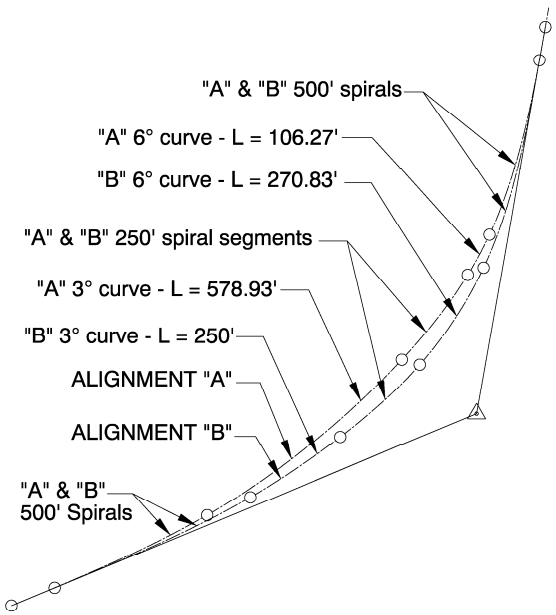
ROADWAY ENGINEERING UNIT

ESTABLISHING SEGMENT CONTROL POINTS IN COMPOUND CURVE SITUATIONS

HIGHWAY DESIGN MANUAL

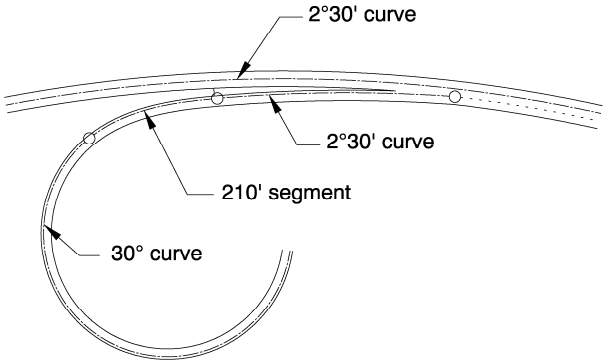
Figure J-19: Establishing Spiral Segment Control Points (in conjunction with ESpiral 2011 spreadsheet)

DETERMINING MINIMUM AND MAXIMUM SEGMENT LENGTHS



DETAIL "A"

This example illustrates identical combinations of curve radii, spirals, segment & total delta; alignment "B" elements have balanced lengths.



DETAIL "B"

NOTES:

1./ Spiral Segments have practical minimum and maximum lengths. The absolute minimum is the length needed to provide for super runoff. As a rule, the length of the segment needs to provide at least 2 seconds of transition time at the design speed of the flatter curve.

Example:

Find segment needed to transition from a 2 degree curve to a 5 degree curve on a ramp, based on transition time.
2 deg. curve - 70 mph (103 fps)
(103 fps)(2 Sec)=206' ("a" - 1.4563; should be 2.0 or less)
Check against HDM Table 3-2 alternate formulas.
2 Deg Curve - 6.5% super, 5 Deg. - 9.5% super
Ls = (24)(3)/(2)(0.40) = 90 feet - Runoff Control
Ls = (2)(343000/3638) = 189 feet - Centrifugal Control
L2 = (2.9)(70) = 203 feet - Aesthetic Control
2 Seconds @ Design Speed (fps)
Meets/exceeds all alternate formula criteria.

2./ Maximum segment lengths are usually not exact values. Providing longer segment transitions uses up delta angle fairly rapidly. It's equally important to provide circular curves of adequate length within the curve set, otherwise users are continually driving a transition rather than the actual curves. The maximum segment length is often a function of the delta angle available, and the relative sharpness of the two circular curves. See Detail "A".

3. / Using appropriate Spiral Segments makes it possible to use radius combinations outside the "usual" ratio of 2:1. For example, a 30° loop entrance ramp can be connected to a curved mainline with a 2.5° curve using a 210' segment. See Detail "B".

4./ Both alignments "A" & "B" meet the "Letter of the Law", but balanced lengths of individual elements provide a smoother transition. If necessary, degree of curve (Radii) can be adjusted to fit required exact location of alignment.

STATE OF OREGON
DEPARTMENT OF TRANSPORTATION
ROADWAY ENGINEERING UNIT

DETERMINING MINIMUM AND MAXIMUM SEGMENT LENGTHS

HIGHWAY DESIGN MANUAL

Figure J-20: Example of Spiral Segment in a Mainline Alignment Situation

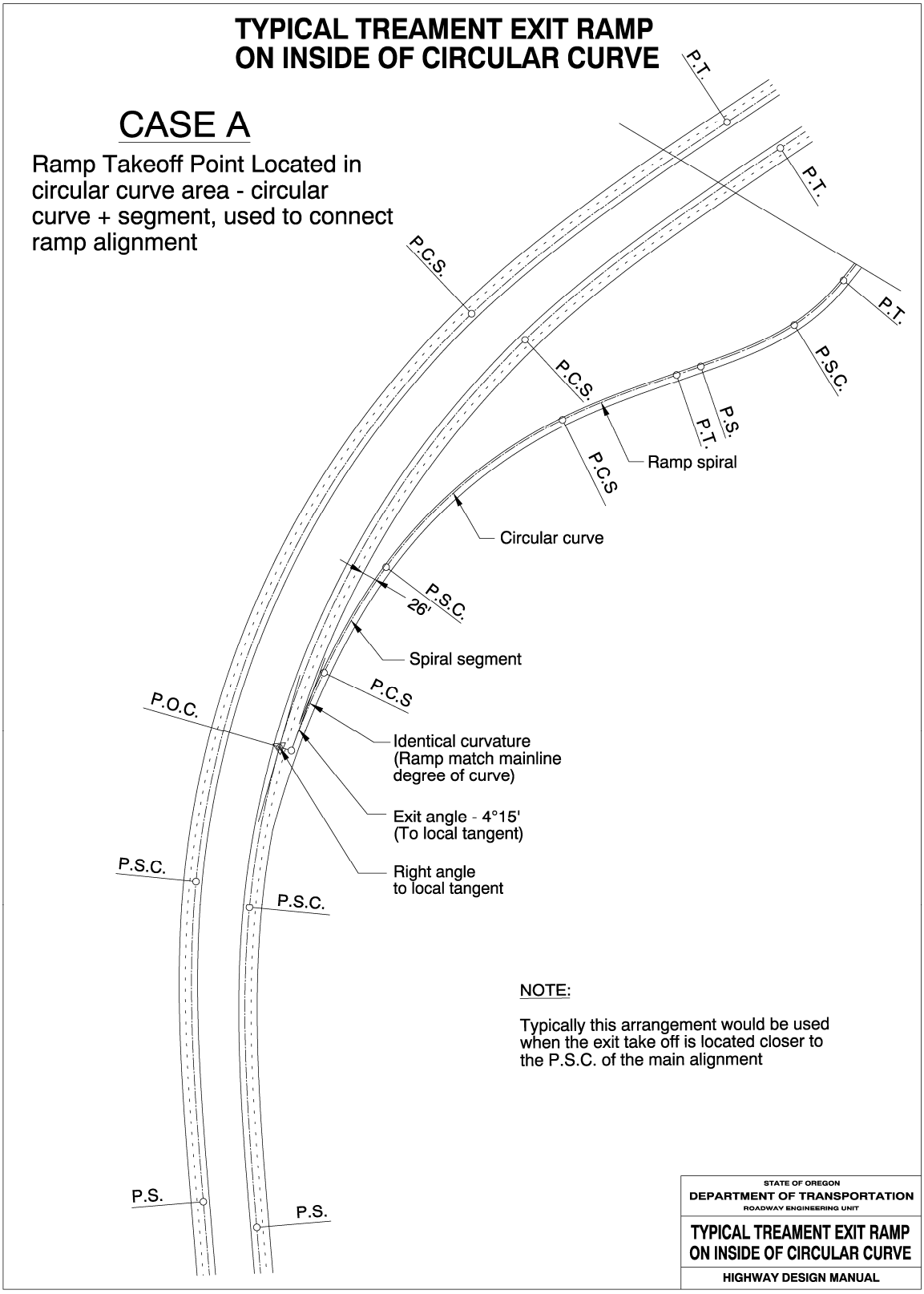


Figure J-21: Typical Treatment For Exit Ramp on the Inside of Circular Curve

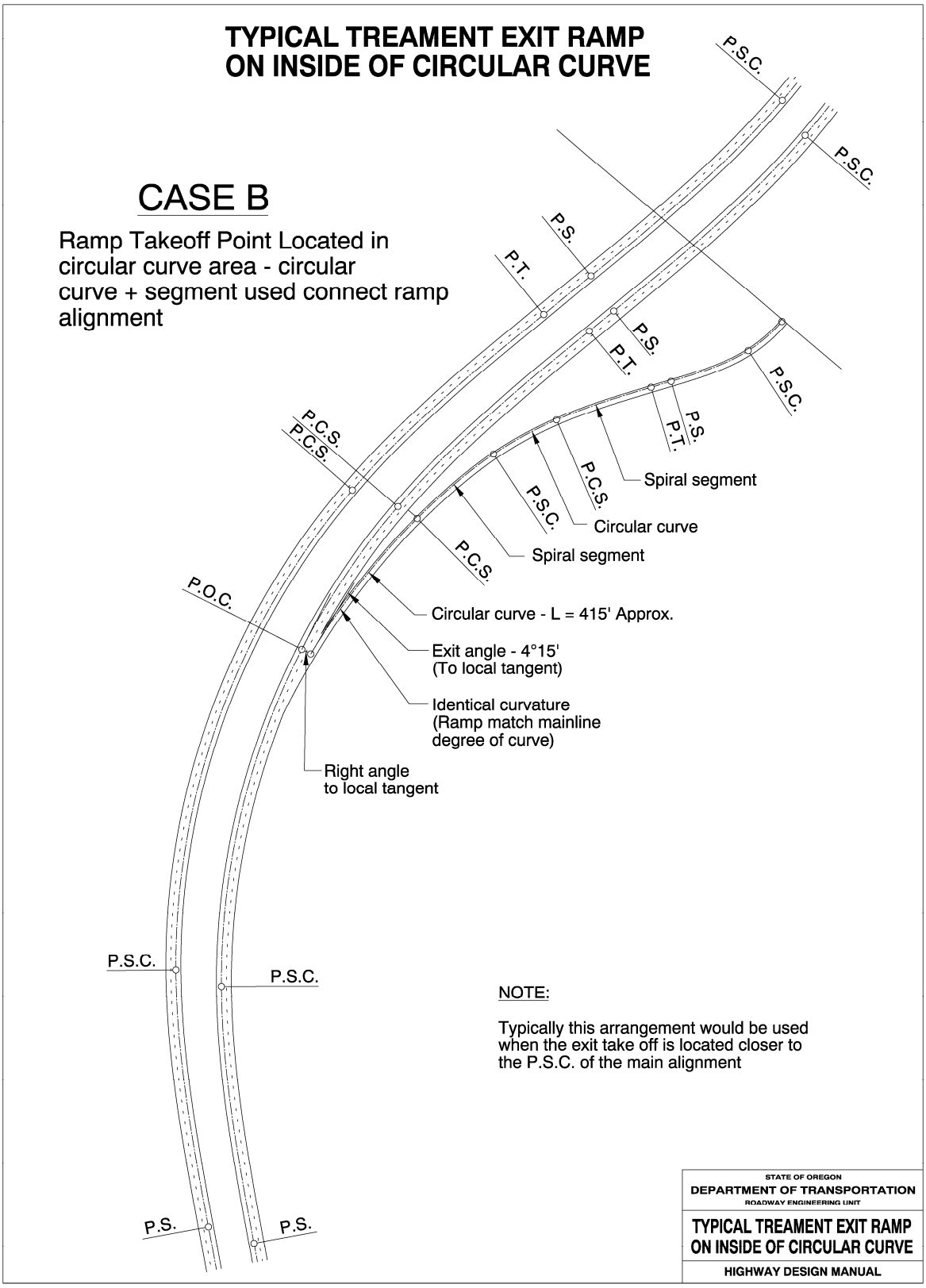


Figure J-22: Typical Treatment For Exit Ramp on the Inside of Circular Curve Takeoff Point located along Circular Curve when 415' or less from PCS of Highway alignment

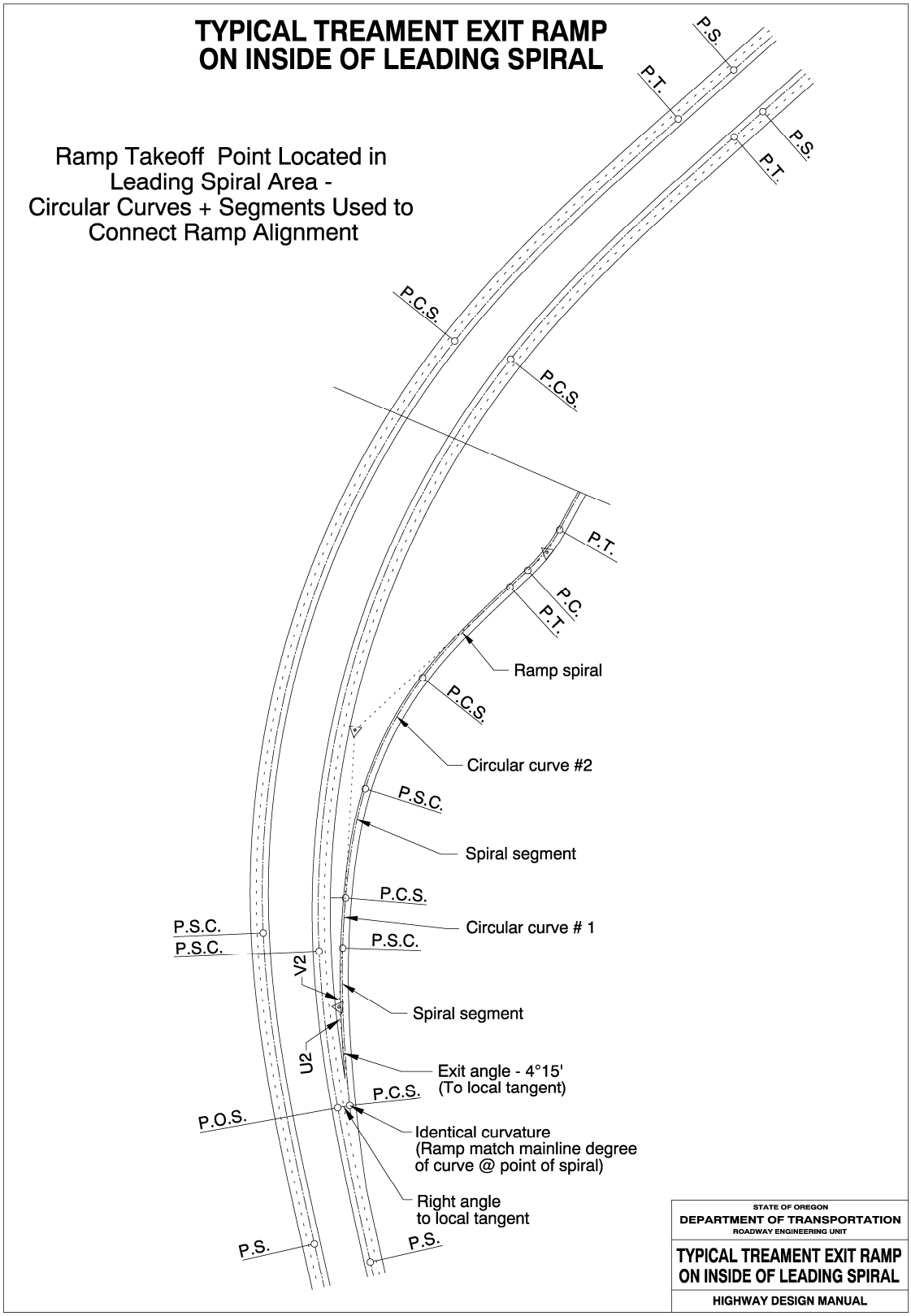


Figure J-23: Typical Treatment for Exit Ramp on the Inside of Curve Takeoff Point located along leading Spiral

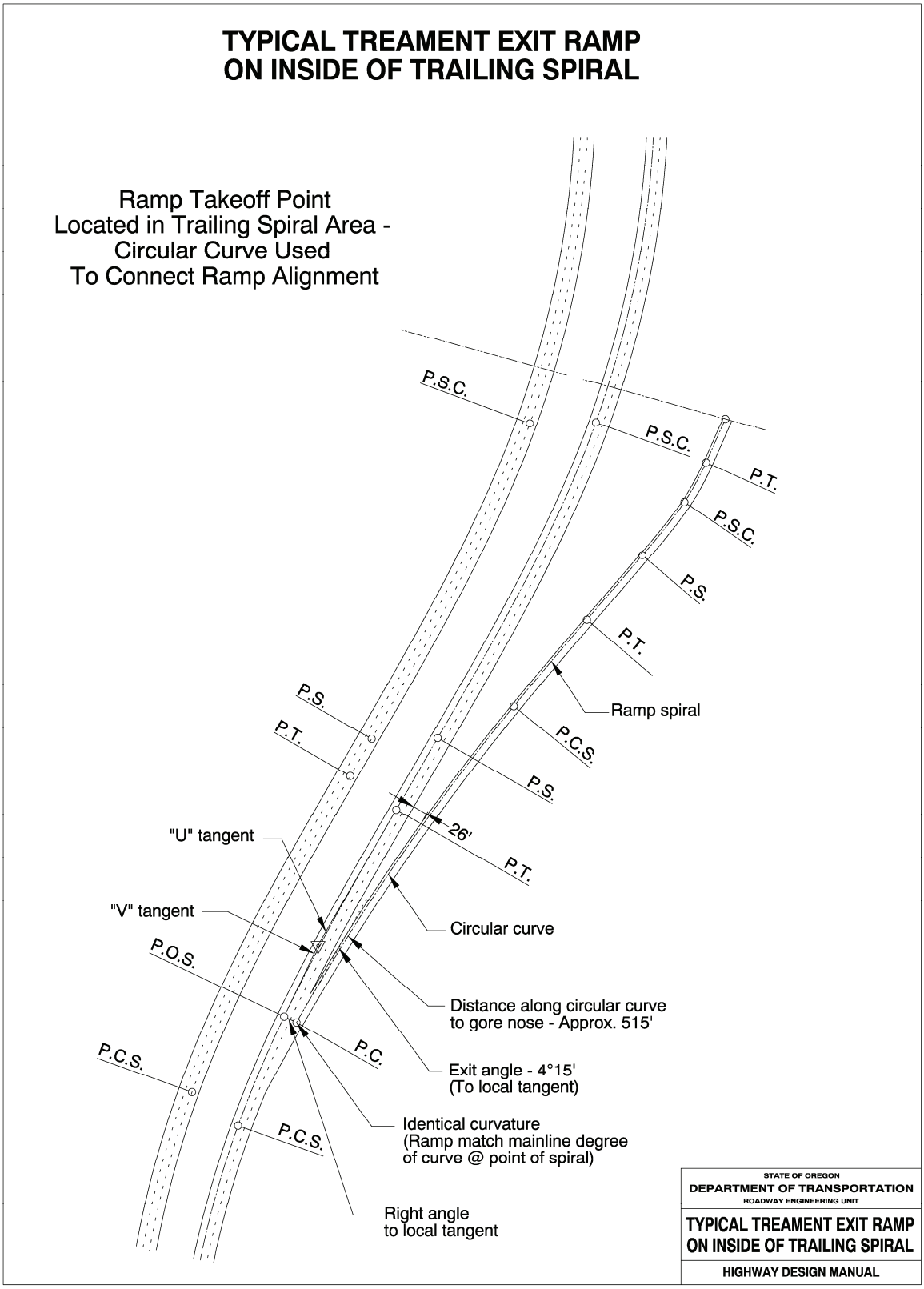


Figure J-24: Typical Treatment for Exit Ramp on the Inside of Curve Takeoff Point located along Trailing Spiral

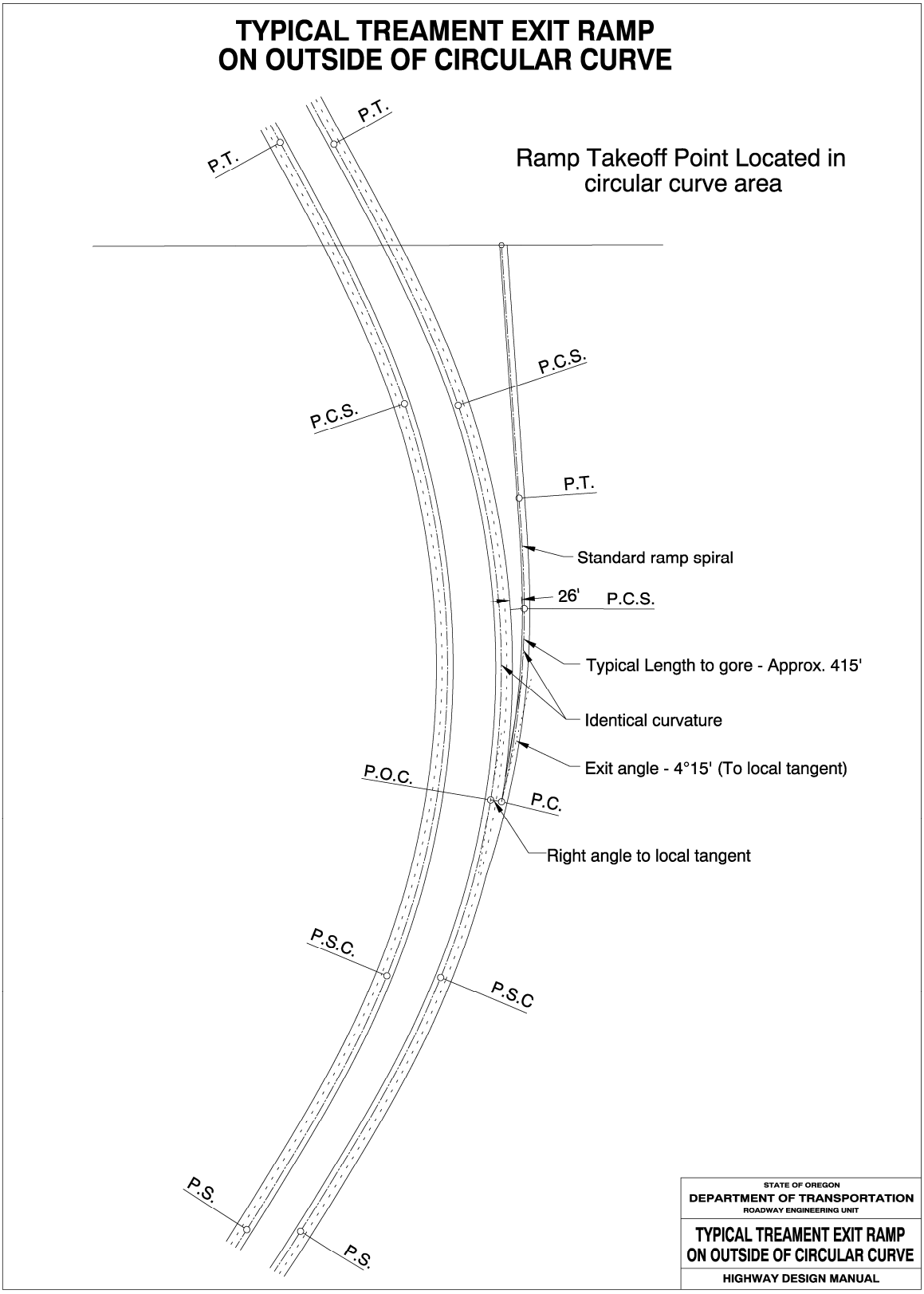


Figure J-25: Typical Treatment for Exit Ramp on the Outside of Curve
Takeoff Point located along Circular Curve

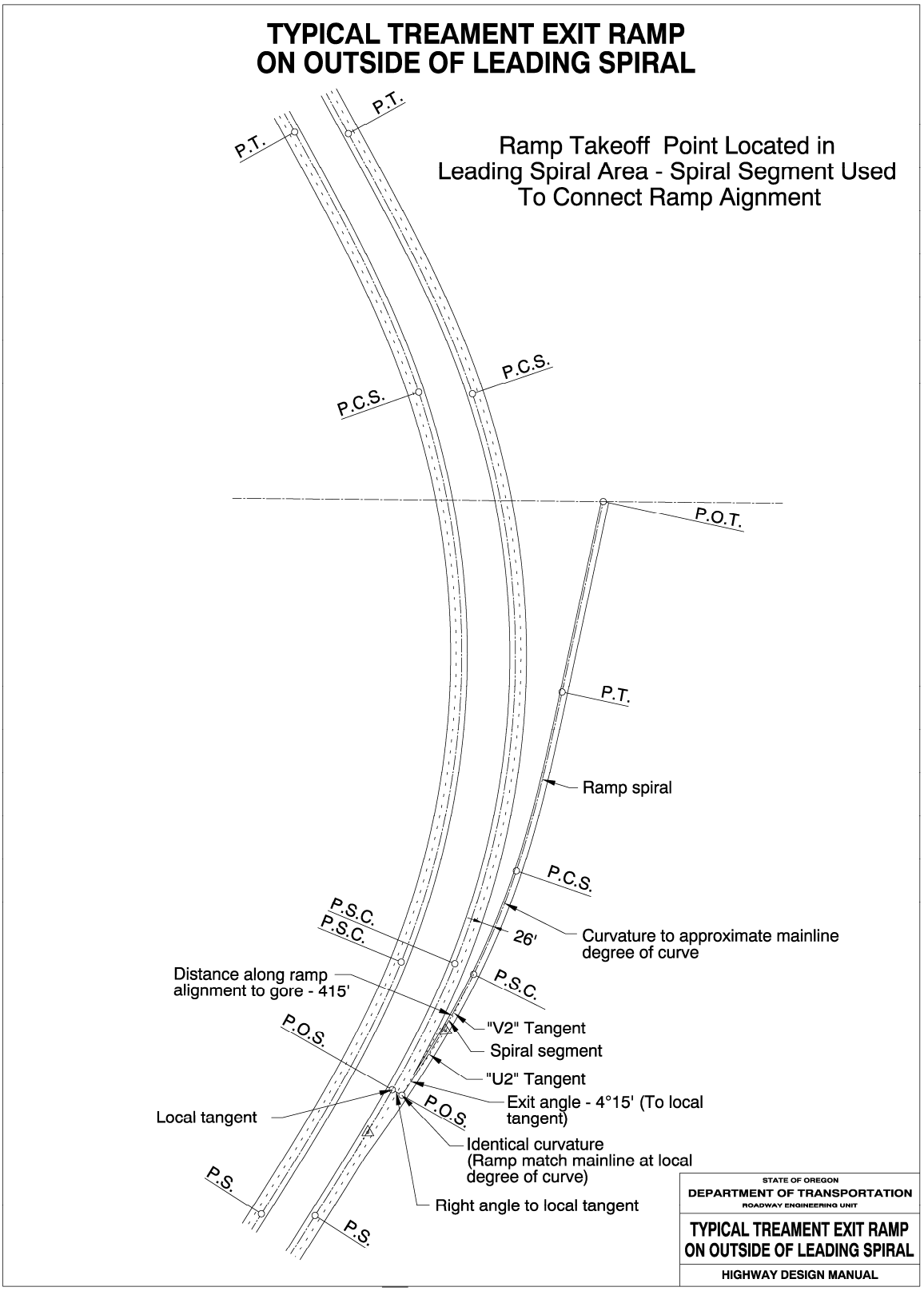


Figure J-26: Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along leading Spiral

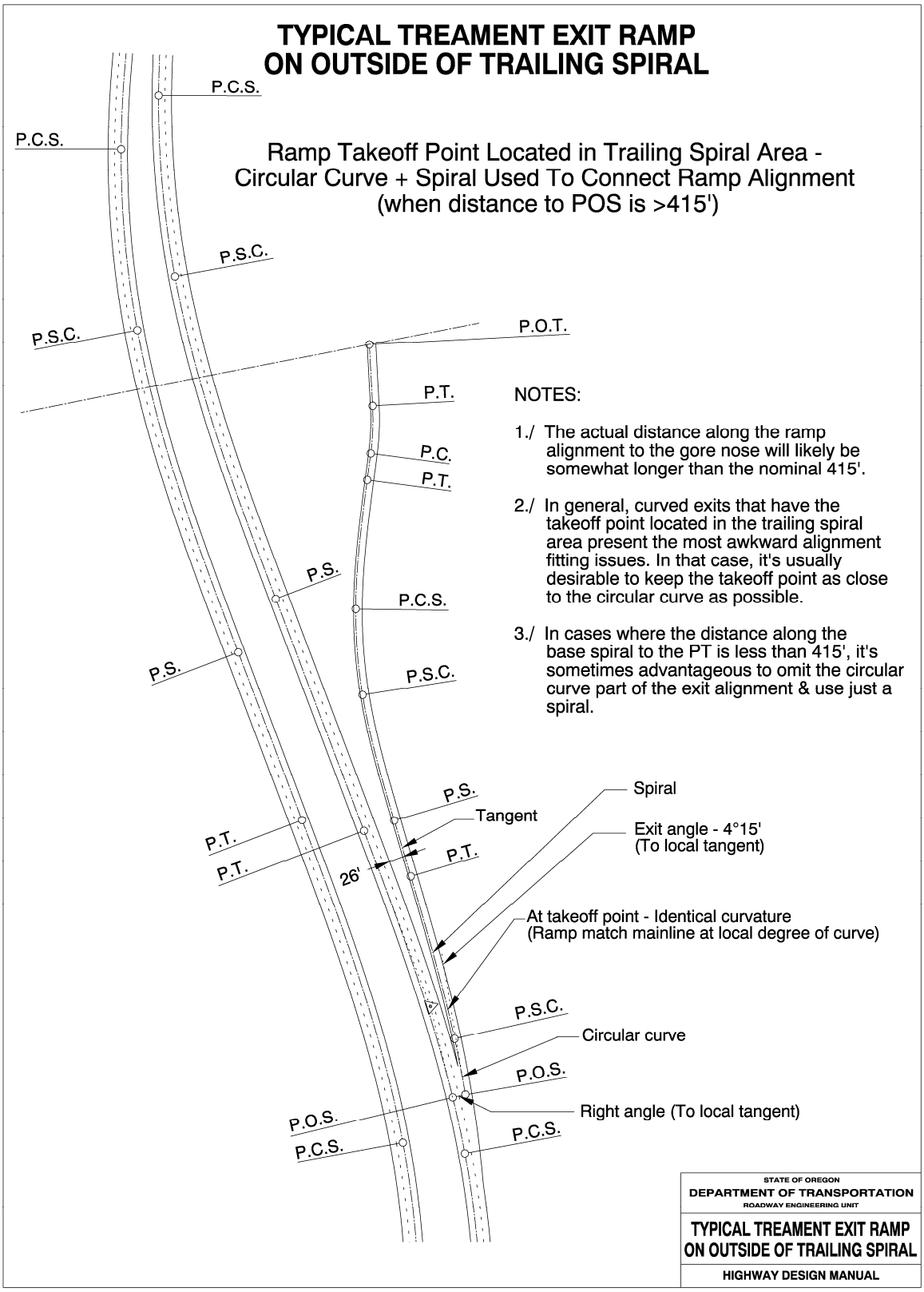


Figure J-27: Typical Treatment for Exit Ramp on the Outside of Curve Takeoff Point located along Trailing Spiral

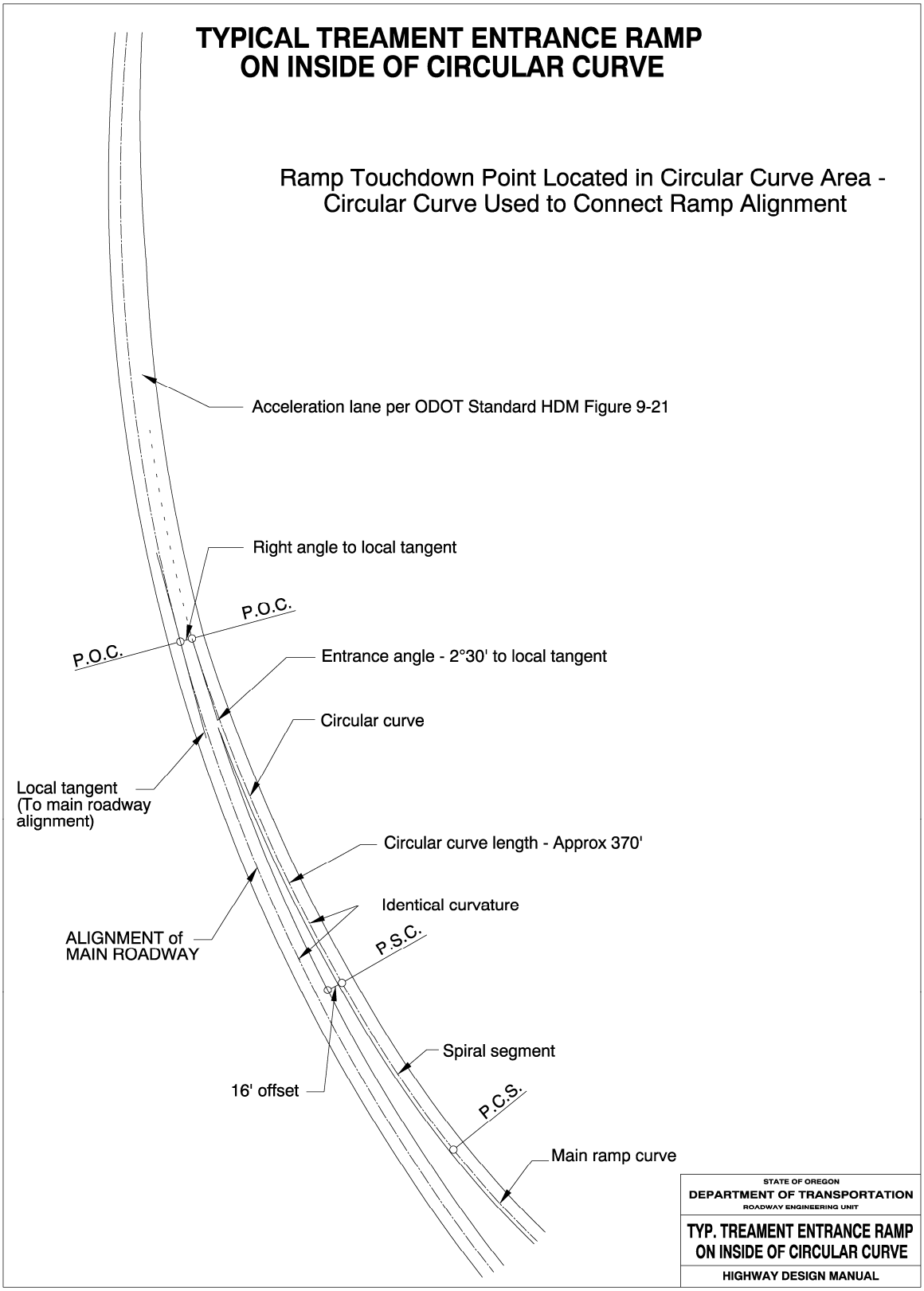


Figure J-28: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Circular Curve

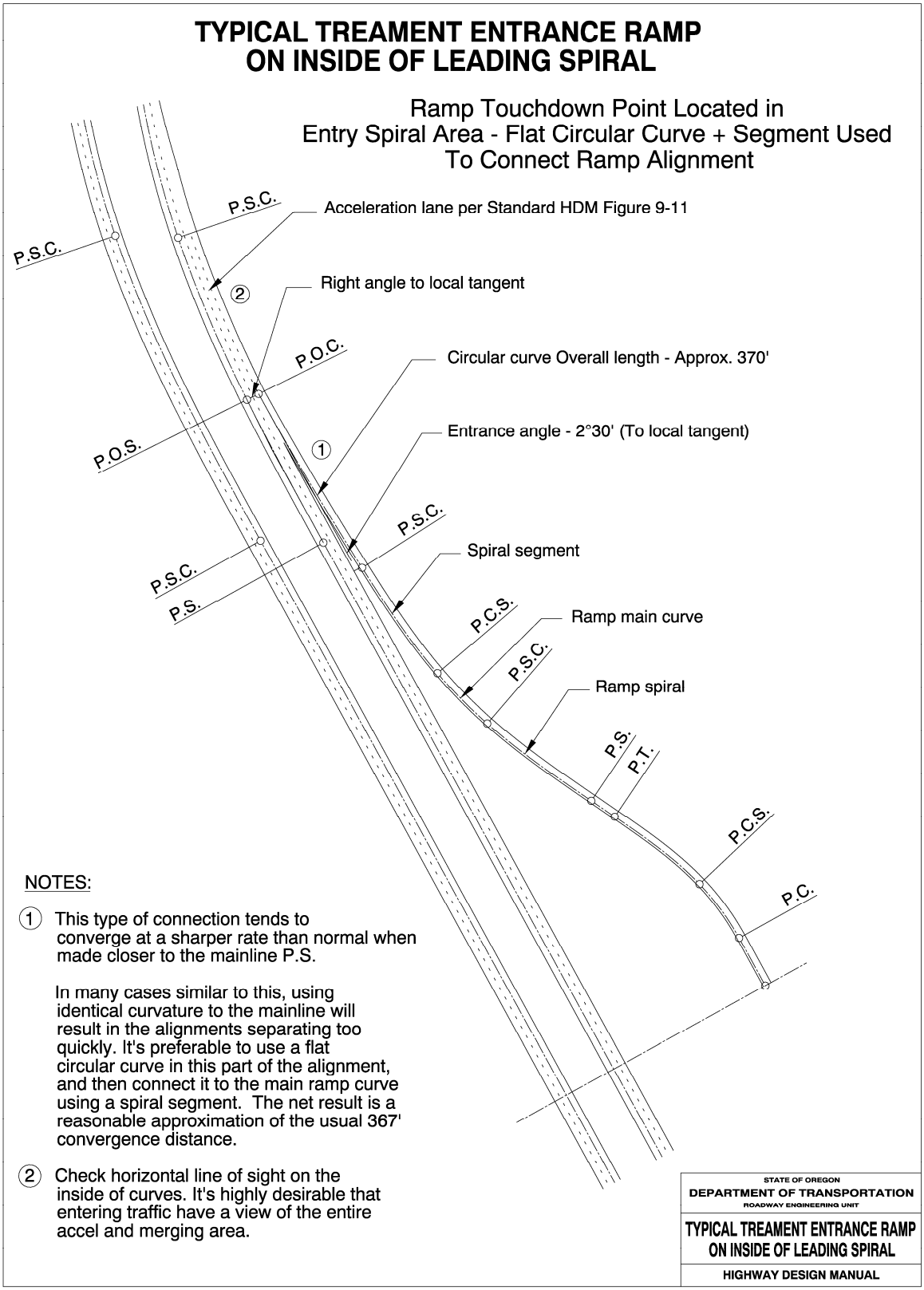


Figure J-29: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along leading Spiral

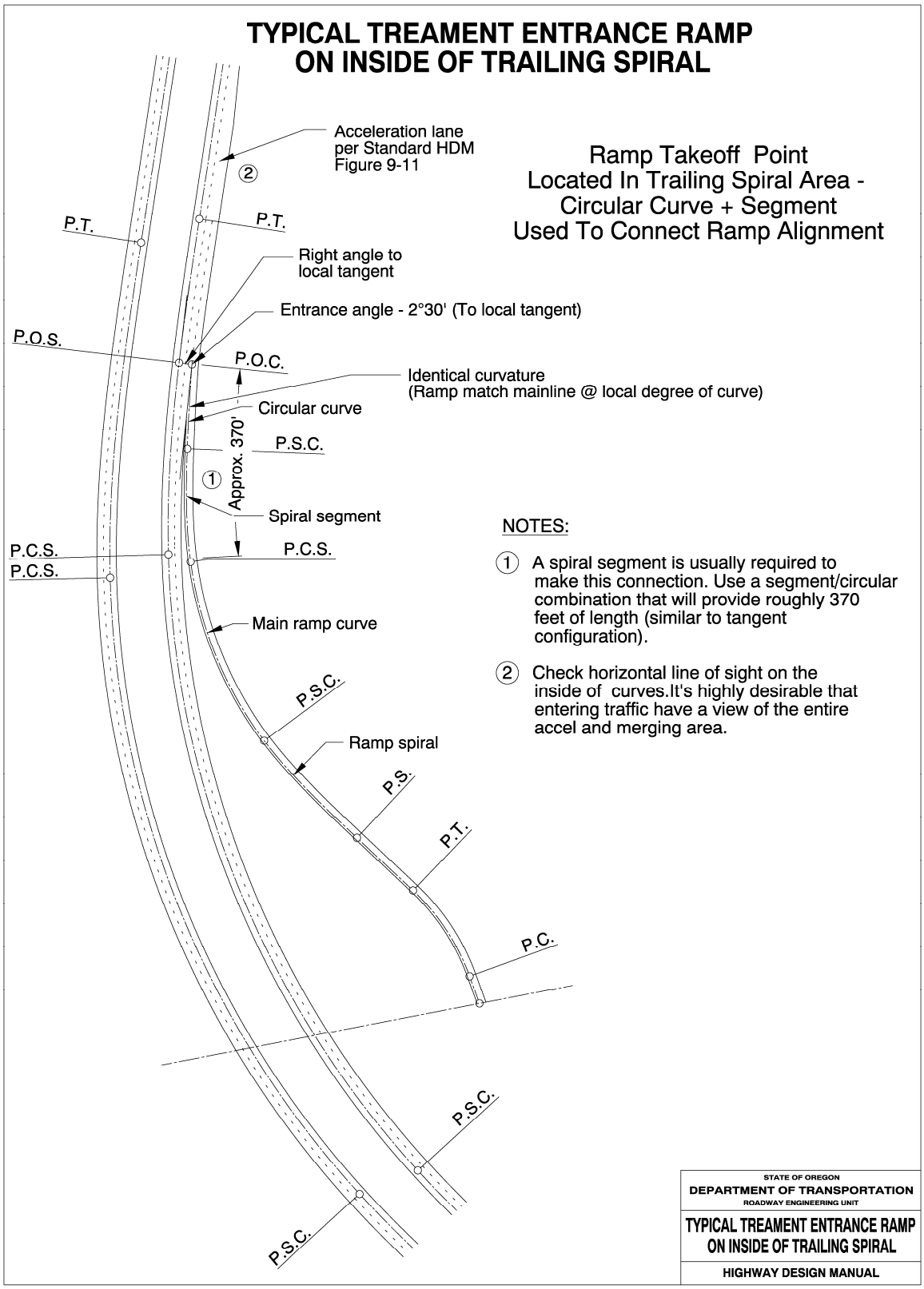


Figure J-30: Typical Treatment for Entrance Ramp on the Inside of Curve Touchdown Point located along Trailing Spiral

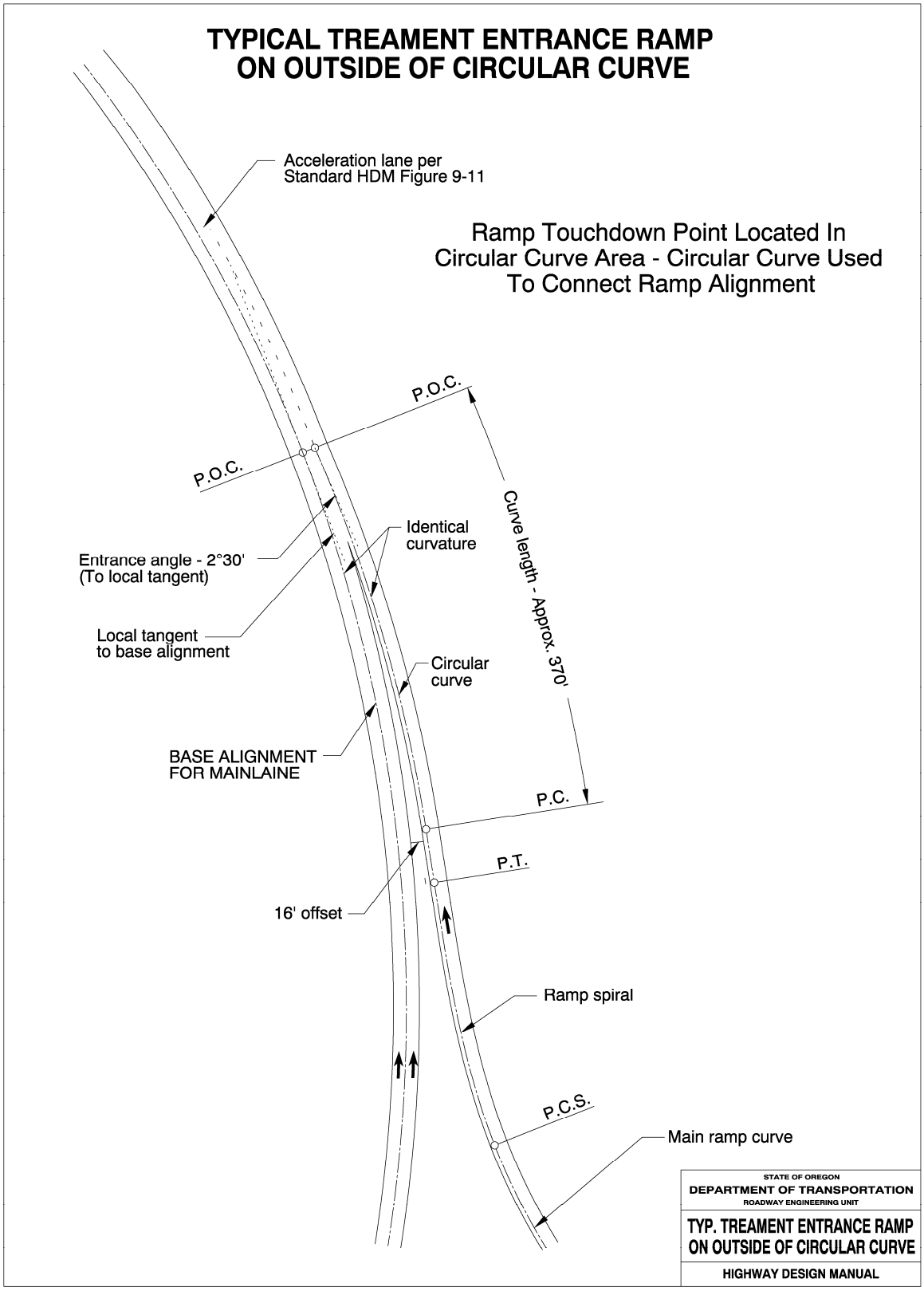


Figure J-31: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Circular Curve

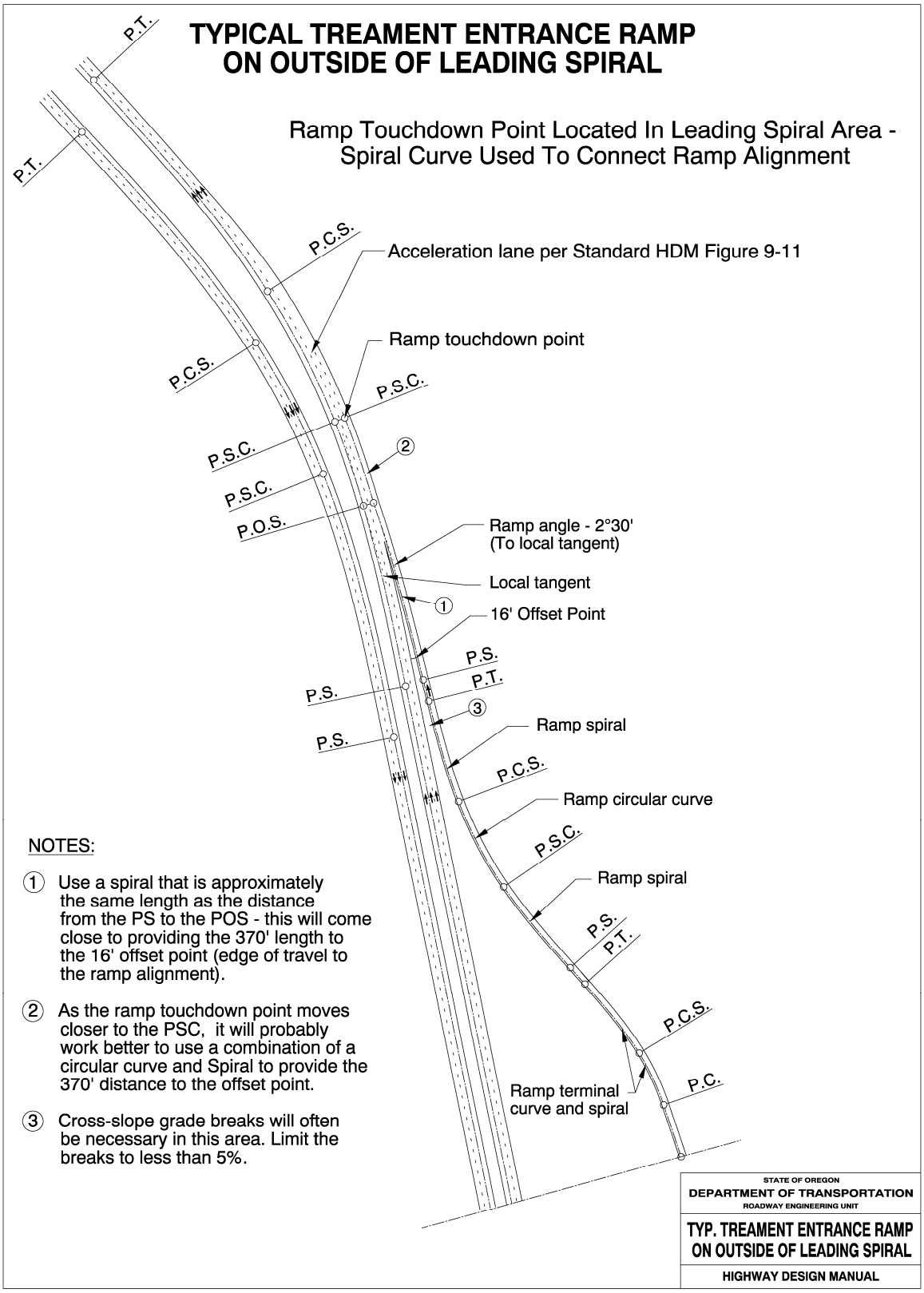


Figure J-32: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along leading Spiral

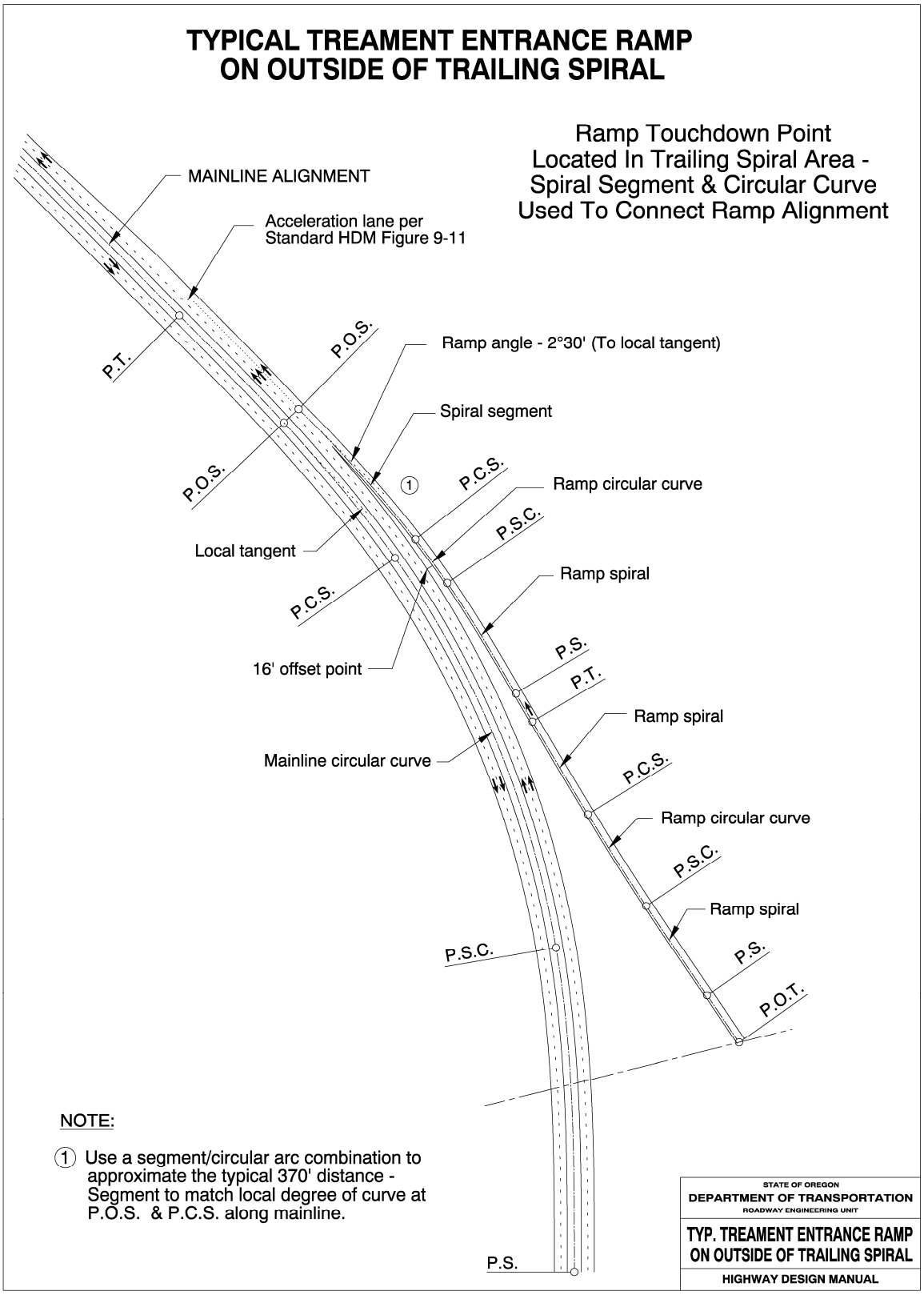


Figure J-33: Typical Treatment for Entrance Ramp on the Outside of Curve Touchdown Point located along Trailing Spiral