‘X-W-C’–Rated – Guidelines for Turnouts in Horizontal Curves

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ABSTRACT

Turnouts in horizontal curves are usually viewed as “undesirable” to “prohibited”, and are rarely discussed in the modern publications. However, some operational and marketing circumstances or geometric situations need those configurations to provide rail service or connections. Examples are congested and built-up industrial areas, temporary connections during phased construction of realignments and improvements, and even mainline connections near a bridge or tunnel where site constraints cause a desired turnout to be located in a curve or spiral.

To provide for these needs and fill the informational void, this paper presents suggested criteria and methods to design and install turnouts in curves, based on the authors’ extensive experience and observations. Evaluation of the parent track’s curvature and selection of the optimum frog angle (‘number’) and design, switch point length, and other geometric properties for diverging tracks to either the inside or outside of the parent track’s curve, to use standard “off-the-shelf” turnout materials are considered. Geometric details through the switch and frog are discussed— including short tangents for proper fit and gage – and proportioning stock rail bends and heel joint spreads for the respective curvatures. Super-elevation of the parent track which can affect the cross-level, speed, and profile of the diverging track is addressed. Practical suggestions and methods for measuring and defining the parent track’s irregular or varying curvature by coordinate geometry and locating the new turnout’s frog angle by an iterative procedure are included. Provisions for sidetrack agreements are also suggested.
I. INTRODUCTION

A. Policies and Standards vs. Necessities, Opportunities, and Economics

Turnouts located in horizontal curves are commonly discouraged - they too “have been considered as a necessary inconvenience to an abomination”. (1) From a Class I railroad’s specifications: “No turnouts (switches) can be placed in a curve.” (2), though an Engineering Dept. handbook of a predecessor railroad stated:

“Occasionally it is necessary to construct a turnout in curved track using standard straight switch points and frog. A turnout in curved track is not desirable and it should not be installed if at all possible, because the track will not ride smoothly, and chance of derailment is increased.” (3, pg. 5-36)

Prof. William W. Hay had this sanguine advice in his treatise on RAILROAD ENGINEERING:

“Turnouts should not be placed on curves because of difficulties in maintaining adjustment and alignment. A structurally weak element would be introduced where lateral forces are usually a maximum. Further, a turnout to the outside of a curve introduces additional problems of reverse superelevation on the long turnout ties. Turnouts may be required on curves, nevertheless, especially on low-speed industrial and switching tracks without superelevation.” (4, pg. 637)

The standard location for a turnout – in tangent track – may not be feasible because of geometric obstructions, compressed space for a ladder or spur, or cost. A turnout in a curve may be operationally necessary, or to serve an important customer. In such instances, a turnout in a curve may be acceptable, and can be the best solution to the track geometry issue of the moment.

Turnouts in horizontal curves are merely conventional 'straight' turnouts, with curve geometry modified. These turnouts utilize standard 'off-the-shelf' components – no special trackwork such as curved switches or frogs or exotic Other Track Material is needed.
B. Characteristics of 2 Most Common Scenarios

For context, experience has been that the situations and locations where turnouts are installed in curves can be separated into two categories, with these typical characteristics:

- Industrial and yard or service tracks, with limited space, abundant obstacles and close clearances, sharp curvature, low speeds, little superelevation, short 'cuts' of cars, freight-only, and infrequent inspection (monthly); or,

- Main tracks – including branch or secondary lines - with few obstacles or close clearances, broad curvature, and higher speeds. However, such an alignment can be limiting and result in a curved turnout becoming the last-resort alternative. Other attributes are some superelevation (more than 1°), full train-lengths (freight and passenger), and more frequent inspections.

II. Photographs and Examples of Turnouts in Curves

A. Industrial

1. Normanskill St., Port of Albany, Glenmont, New York

No. 8 turnout without stock bends:
2. **7132 Daniels Drive, Iron Run Industrial Park, Fogelsville, PA**

   **Turnouts to Outside of Industrial Lead Track’s Existing 14° - 16° Curve:**

   Proposed No. 10 turnout for new spur to building

   Existing No. 8 turnout and spur (note kinks)

3. **Procter & Gamble Yard, Mehoopany/ Tunkhannock, PA (1978)**

   Temporary No. 10 turnout ($D_{ch} 7.35°$) to outside of $15°$ curve in existing ladder track to connect with new ladder on alignment with less curvature (approx. $D_{ch} 7.5°$) and angle, and maintain service during construction and ‘cut-over’ to relocate ladder.

4. **AREMA Committee 24’s “Track Alignment Design Seminar” Case Study (5)**

   Chapter 5 example - “Green Energy Industrial Unloading Tracks” – No. 8 turnout in $10°$ curve.

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B. Main Line

1. “Layover Track” Lead
   SEPTA Doylestown Branch, Lansdale, PA Station
2. CP 055 STREETER, Riverside, California
   Union Pacific RR, east of Magnolia Ave.

3. Allen Jct. at end of 3°-07’ curve
   (MP 1.0 of NS Cement Secondary Line [Burnside Plantation], Bethlehem, PA)

This photo by K. P. Harrier – used with permission.
4. **Lead to Quarry Yard, SEPTA West Chester Branch, Glen Mills, PA**

5. **Industrial Lead Track off Conrail’s Buffalo Line, Milton, PA (1977)**
   No. 10 turnout to inside of 0° 30’ curve in single-track main line for grocery store chain’s new warehouse.

6. **Union Pacific RR, Tehachapi Loop, Calif.**
   Set-out tracks in sidings to south (east).

C. Other Situations That May Compel Installation of a Turnout in a Curve:
   - Operational needs - lengthening passing sidings, additional crossovers, reconfiguration of a junction or ladder, etc.
• Bridges or tunnels immediately adjoining a long curve
• Grade crossings nearby of roads or other tracks
• Minimum signal spacing and distances between Control Points, etc.

III. SITUATION, LOCATION, & ALIGNMENT CONSIDERATIONS

Examine the through and diverging routes for the engineering characteristics listed below to assess the situation, make a preliminary determination whether a curved turnout is likely to provide an acceptable solution, and resulting constraints or effects on operations and maintenance.

A. Type and Function of Each Route and Purpose of Turnout

*Main track, passing siding, branch/secondary line, regional/short line, industrial lead, industrial spur, yard or shop track,* ‘set-off’ track for ‘bad-order’ cars, MOW equipment storage, etc.

Most favorable are industrial or yard tracks, where geometric and functional needs are often greater, speed and traffic volume are low, and negative aspects are minimized. Most challenging and least desirable is a main track. Even there, a seldom-used trailing-point turnout to the inside may not adversely affect operations or maintenance costs.

B. Direction of Diverging Route from Curvature of Through Route

Refer to Figure 1 for depiction of the 3 possible configurations:

A. Curved in same direction, to the inside with a greater degree of curvature (least objectionable);
B. Toward the outside, but with a lesser degree of curvature, so still curved in the same direction; or,
C. Curved in opposite direction, toward the outside, with any degree of curvature. This configuration is problematic because of potential “reversed curves” at the P.S., and lack of superelevation or reverse elevation in the diverging route.

C. Trailing or Facing-Point Operation

Trailing-point arrangement is least objectionable.
Figure 1 – Turnouts in Curves – Diagrams of 3 General Configurations

A. Turnout Diverging Route to Inside of Curve - least problematic for Through Route:

- Red = Areas of concern (typ.) for wear, flattening of head, and derailments, etc.
- Superelevation favors both routes

B. Turnout Diverging Route to Outside of Through Route’s Curve, with Less Curvature in Diverging Route than in Through Route, but Diverging Route Still Curving in Same Direction as Through Route – More problematic for Through Route, which is subject to all areas of concern:

- Superelevation still favors both routes

C. Turnout Diverging Route to Outside of Curve – most problematic for both routes:

- “S-Curve” Configuration! Possible too-short tangent between curves
- Superelevation may be adverse for diverging route!
D. Superelevation

If present or necessary, superelevation is less objectionable and possibly helpful where both routes are curved in the same direction, but may be troublesome where routes are curved in opposite directions.

E. Speed Range and Other Tracking or Ride Quality Concerns for Passenger Trains

F. Other Considerations and Constraints

Vertical curves, drainage, grade crossings, obstacles, etc.

IV. LITERATURE REVIEW

A. Archival

In the published historic literature on railroad track alignment geometry, turnouts in curves are briefly discussed in Simplified Curve and Switch Work (6), a 1916 treatise by Supervisor W. F. Rench of the Pennsylvania Railroad. They are also analyzed in Railroad Curves and Earthwork (7), a 1931 textbook by M.I.T. Professor of Railroad Engineering C. Frank Allen, with specific geometric and trigonometric problems and formulas for layouts. However, both books cover only the major aspects such as selection of frog number and solving for curve radius, etc., and do not address details such as tangents at the switch and frog areas.

B. Contemporary

RAILROAD ENGINEERING by William W. Hay has a very limited mention of this subject, consisting of a single geometric problem (4, pgs. 641 – 642), and calculating the degree of curvature of routes (quoted below). The SANTA FE HANDBOOK ON TURNOOUTS by Leo Rekush (3) contains an entire sub-chapter “H. Turnouts in Curves” on pgs. 5-36 through 5-50, upon which portions of this paper are based. The Federal Railroad Administration’s Track Safety Standards (8) do not address this subject, other than mentioning reverse elevation (quoted below).
V. **Turnout Selection Guidelines**

A suggested process for design is outlined below. Careful analysis and thorough understanding of these aspects of track geometry is mandatory for safe operation and economical maintenance. Special operating instructions or restrictions may be needed to assure that will occur.

A. **Degree of Curvature and Tangents for Through Route and Diverging Route**

Evaluate both routes generally for relative degrees of curvature (including spirals, if applicable) - existing, proposed, actually needed, and acceptable. Also, operating speeds and restrictions, considering anticipated service needs and applicable regulations, standards, and railroad specification limitations. Analyze whether the alignment can accommodate tangents in the range of 25 ft. long (or more) through the switch and frog areas of each route – if not, then a curved turnout will not solve the design problem. The maximum allowable curvature for the diverging route will usually govern the selection of the turnout number “N” and frog angle “F”. For use of coupled railroad equipment listed in AAR’s UMLER (Uniform Machine Language Equipment Register), the maximum curvature suggested is 16° (radius approx. 360 ft.). However, the authors have designed and supervised construction of curved turnouts with diverging curves as sharp as 15°, 18° 30’, and even 23° (scrap yard crane).

B. **Obtain Detailed Location and Elevation Information by Survey**

Obtain survey-grade information - within 0.02 ft. (or better) accuracy horizontally and vertically - on the existing alignment, curvature, grades, and vertical curves of each track and at least 100 ft. of the approaches. Location and elevation of the tracks should be obtained at typical intervals from 20 ft. to 50 ft. (closer for sharper curvature) along the ‘line’ (outer or ‘high’) rail in curves and tangents, at the P.S., P.F., and L.L.T. of turnouts, and at other features or obstacles which may affect the alignment – grade crossings, bridges, poles, etc. Track profile, cross-level, and superelevation data may be obtained by additional ‘shots’ on the ‘gage’ (inside or ‘low’) profile rail in curves and tangents, or with a track level. The survey data should be in coordinate format (Northing / Easting) and based on a suitable datum.

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C. Irregular Existing Curves

Existing curves are usually irregular - the degree of curvature varies significantly along their length. Resist the temptation to immediately realign them uniformly. A more efficient design process is to first establish the geometry of the curved turnout (as detailed below). Next, insert that curved turnout’s assemblage of essentially fixed curves and tangents into the existing alignment. Finally, design revised geometry for smooth connections.

D. Select a Tentative Turnout/ Frog Number/ Angle

The critical frog number interacts with the curvatures of the ‘lead’ or closure rails for each route, and the resulting angle for the diverging route. The basic principles:

“Degree of Turnout Curve leading From Curved Track.— To determine the degree of curve of a turnout from curved track, it is only necessary to add the degree of the main track curve to the normal degree of the turnout when the connection is from the inside and to subtract it from the normal degree when the connection is from the outside. In the latter case, if the subtrahend should be the greater, the result would be a minus quantity, and this would indicate that the connection, instead of turning away from the main track, curved in the same direction.” (6, pg. 121; emphasis added)

“The effect on lead curvatures should be carefully noted. If the diversion is to the inside of the curve, the effective lead curve is the sum of the turnout and track curvatures. If the track curve were 3° and the turnout lead curve were 11° 46’, the effective lead curve would be 14° 46’. For a diversion to the outside of a curve the reverse occurs; that is, the effective lead curve is the difference of the two curvatures or, in the example, 8° 46’.” (4, pg. 637)

In equation form, these principles may be stated as follows (where the sign for \( D_{TR} \) is positive when the through route is curved in the same direction as the turnout’s diverging route curve, and negative when in the opposite direction):

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Figure 2 - Degree of Curvature for Diverging Route to Inside of Through Track’s Curve - Industrial Tracks / Sharp Curves

No. 8 Turnout
(Dch of Lead = 11.8° +/-)

No. 10
(7.3° +/-)

No. 15
(3.3° +/-)

No. 20
(1.7° +/-)

Diverging Route’s Curvature, in Degrees

Through Route’s Curvature, in Degrees

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Figure 3 - Degree of Curvature for Diverging Route to **Inside** of Through Track's Curve - Main Track

- No. 8 Turnout
  \( D_{ch} \) of Lead = 11.8° +/-

- No. 10
  7.3° +/-

- No. 15
  3.3° +/-

- No. 20
  1.7° +/-
Figure 4 - Direction and Degree of Curvature for Diverging Route to Outside of Through Track's Curve

D\textsubscript{ch} Diverging Route = D\textsubscript{ch} Through Route - D\textsubscript{ch} Turnout

- Diverging Route Curves in Same Direction as Through Track's Curve
- Diverging Route Curves in Opposite Direction from Through Track's Curve
- "S-Curve" Risk if Through Track is Curved up to P.S.

No. 20 Turnout (D\textsubscript{ch} of Lead = 1.7° +/-)
No. 15 (3.3° +/-)
No. 10 (7.3° +/-)
No. 8 (11.8° +/-)
No. 6 Turnout (22.3° +/-)

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\[ D_{DR} = D_{TO \ Lead \ Curve} \pm D_{TR} \] (Eq. 1)

A standard 'straight' turnout may be viewed as a special and simple case where \( D_{TR} \) is 0°. A curved turnout may be viewed as a straight turnout that has been 'bent' by the amount of \( D_{TR} \) (7, pgs. 96 - 97).

The diverging route’s curvature will often approach maximum allowable values, so by subtracting the through route’s curvature, the remaining curvature is the maximum acceptable curvature for the lead or closure curve of the turnout itself. Comparing that value with the published lead curvatures for standard turnouts will quickly find one with curvature in the acceptable range for the first design iteration. To assist that determination for turnouts in the same direction as the through route’s curve, refer to Figure 2 for industrial tracks, yards, and sharper curves, and / or Figure 3 for main tracks and shallower curves. For turnouts in the opposite direction from the through route’s curve, refer to Figure 4.

For the unusual situation of a crossover between concentric curved tracks, apply the same principles of curvature superposition. The crossover track between the two frogs will have curvature similar to the through routes, and the longitudinal distances will be nearly the same as for a crossover between parallel straight tracks at the same track center spacing. (6, pg. 125; 7, pg. 101)

E. Details for the Center-Line Geometry of the Selected Turnout

The curved turnout’s geometric details should conform to the following recommendations.

Note that a curved turnout does not have either a useful 'Lead' distance from the P.S. to the actual \( \frac{1}{2} \) P.F., or a meaningful “Point of Intersection of the Turn-Out” (“P.I.T.O.”). The curvature in both routes rotates the frog to point towards the outside of the turnout, unlike a standard straight turnout or an equilateral (“wye” or “Y”) type turnout; contrast Figure 5-A with Figure 5-C; compare with Figure 5-B.
1. **Tangents Through Both Routes at the Switch, and at the Frog and Guardrail Areas.**

These tangents – same as for a "straight split switch" in a standard straight turnout - are required for proper fit and support of the switch points against both stock rails, and good alignment from the switch’s heel joint blocks at the proper spread. Similarly, at the frog the tangents should encompass the entire length of the frog (toe to heel). Since standard straight-angle frogs are comparatively short and rigid, designing or constructing a uniform curve that includes a frog, or to bend a frog to conform to such a curve, is impractical. Where guardrails are used (see below regarding self-guarded frogs), these tangents should include the guardrails, to help maintain correct guardrail gage dimensions through this critical area.

2. **Extend Tangents 6 Ft. Ahead of P.S. and 3 Ft. Beyond Other Tangents**

Include 3 ft. long tangents in both routes after the heel joints of the switch points, and also before and after the frog (toe and heel joints) and guardrail areas. Typical lengths of these tangents are then about 25 ft. for a 16'-6" switch, and about 22 – 23 ft. for a 16'-6" long frog.
Figure 5 - Schematic Diagram of Center-Line ("C-L") and P.I. Geometry of Turnouts:

A. Standard Turnout – 1 Through Route, 1 Diverging Route

B. Equilateral ("Wye" or "Y") Turnout – 2 Diverging Routes

C. Curved Turnout – 2 Curved Routes, 1 Through, 1 Diverging

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These tangents are based on pragmatism – the rail ends with the stiffening effect of the bolted joint bar pairs at these locations are difficult to bend into smooth curves, and prone to developing kinks in their 'line'. The paired nearly opposite joints just ahead of the P.S. are a similar potential 'weak spot'. Even a theoretically uniform curve in such high-stress areas will degenerate slightly during construction, and with loads and impacts under service, into a shorter tangent and a slight spiral. Providing these short tangents by design reduces the risk of sharper curves or kinks forming in the alignment at these critical points.

3. **Connect Interior Tangents with Lead Curves**

   For each route, connect the short tangent behind the switch’s heel to the similar tangent at the frog’s toe, with a curve having as large a radius as possible; the usual ‘shorter tangent governs’ method is appropriate.

4. **Connect to Approaches with Smooth Curves**

   Design the 3 approaches to the turnout from the connecting tracks, using as large radii as possible. Explicitly designing the connecting geometry may prevent a sharper curve or kink from appearing when the turnout and its associated tangent segments are inserted into the previous alignment.

   These curves will often begin on the long switch timbers behind the heel of the frog; although sometimes prohibited by specifications, waivers may be justified in the situation.

   Review each route's alignment to check against reverse curve configurations. If found, either provide the prescribed tangent distance (e.g., 100 ft), and/ or revise the alignment to reduce or remove the offending curves.

   **F. Refer to Figure 6 for Example – Recent PVRR Turnout**
Tabulation of Angles Through Turnout Routes

<table>
<thead>
<tr>
<th>Type of Route</th>
<th>Standard No. 10 Turnout</th>
<th>Through Route</th>
<th>Diverging Route</th>
</tr>
</thead>
<tbody>
<tr>
<td>Curve in Lead</td>
<td>3°-59'-17&quot;</td>
<td>0°-00'-00&quot;</td>
<td>3°-59'-17&quot;</td>
</tr>
<tr>
<td>+ Curve of Turnout</td>
<td>+ 0°-00'-00&quot;</td>
<td>+ 3°-00'-00&quot;</td>
<td>+ 3°-00'-00&quot;</td>
</tr>
<tr>
<td>Subtotals</td>
<td>3°-59'-17&quot;</td>
<td>3°-00'-00&quot;</td>
<td>6°-59'-17&quot;</td>
</tr>
<tr>
<td>+ Switch</td>
<td>+ 1°-44'-12&quot;</td>
<td>+ 0°-00'-00&quot;</td>
<td>+ 1°-44'-12&quot;</td>
</tr>
<tr>
<td>TOTALS</td>
<td>5°-43'-29&quot;</td>
<td>3°-00'-00&quot;</td>
<td>8°-43'-29&quot;</td>
</tr>
<tr>
<td>Cf. Frog</td>
<td>5°-43'-29&quot;</td>
<td>0°-00'-00&quot;</td>
<td>5°-43'-29&quot;</td>
</tr>
</tbody>
</table>

Figure 6 – Example of Typical Geometry for a Turnout in a Curve (not to exact scale)

“Hill to Horn” Switch - Pioneer Valley RR, Holyoke, Massachusetts – October 2009
1 Through Route, 1 Diverging Route, in Same Direction but with Different Curvatures
This diagram and the photo below depict the application of these details in an actual turnout recently designed by one of the authors and constructed under his supervision in a main track for the Pioneer Valley Railroad in Holyoke, MA.

G. Create CAD Block or Object to Simplify
Assembling and merging these geometric details into a single integrated ‘block’ or ‘object’ - comprised of the curved turnout and short distances of each approach – is recommended. Such a unit is easier to manipulate with most Computer-Assisted Drafting systems (instead of several separated or “exploded” elements). This usually simplifies and facilitates the design process, which is commonly iterative (‘trial and error’) to obtain a geometric alignment solution fitting the situation.

H. Superelevation Considerations
Most curved turnouts are in yard and industrial settings where speeds are low, and neither superelevation nor spirals are needed. Such trackage can be traversed at speeds under 25 MPH without superelevation.
or exceeding the 3” maximum unbalance limit. Confirm that either operating speeds will be permissible for these curvatures without superelevation, or the amount of superelevation needed. Note that alternating curves and tangents through the turnout may have very inconsistent amounts of unbalance, but superelevation should not be changed – “run-off” – within the turnout, so its selection should be made with care and consideration of all requirements.

1. **1/2” to 1” Minimum Superelevation in Through Route Recommended**

   This nominal or minimal superelevation should reduce the lateral loads on and wear of the outer rail and switch point which closes against it (and provide a tolerance against possible settlement of the outer or ‘high’ rail of a curve from creating reverse elevation). A diverging route in the same direction will also benefit; but a diverging route in the opposite direction will then suffer from reverse elevation (see below).

2. **Superelevation in and Speeds of the Main Track/ Through Route**

   Superelevation may need to be considered in design selection to attain an operating speed, or an existing geometric constraint that cannot be changed. Turnouts in main track curves should conform to the existing superelevation and speed limit, which may limit the turnout number and diverging route’s curvature. Alternatively, the superelevation may be adjusted to accommodate the turnout, and the speed limit reduced accordingly.

3. **Superelevation in and Speeds of the Diverging Route**

   For a turnout to the inside of a curve, the diverging route’s curvature will be greater than the through route’s, but its superelevation will be the same, likely resulting in a lower speed limit. In contrast, for a turnout to the outside of a curve, the diverging route’s curvature may be less than the through route’s, which could permit a higher speed limit. But for a diverging route in the opposite direction, any through route superelevation will impose reverse elevation which adversely impacts the diverging route’s outside (and now lower) switch point and rails, and a lower speed limit (below). Each situation must be carefully analyzed and the limiting effect on allowable speeds of regulations and safety standards as applied to the geometric parameters fully understood.
4. **Speed Restrictions from Possible Reverse Elevation in Diverging Route**

Reverse elevation in the diverging route may limit allowable speeds, per FRA’s Track Safety Standards Compliance Manual for **Sec. 213.57 Curves; Elevation and Speed Limitations** on the application and use of the $V_{\text{max}}$ formula in situations of “reverse elevation” as follows:

Reverse elevation occurs when the inside rail is higher than the outside rail; . . . The condition can also occur where a turnout has been installed in a main track (e.g., an equilateral turnout constructed in a left-hand curve).” (8)

See Figure 7 for a graph of allowable speeds as a function of the diverging route’s curvature and amount of reverse elevation. Note that for reverse elevations approaching 3”, the diverging route may not be operable under the Track Safety Standards.

5. **Superelevation May Cause Vertical Curve, Grade, and Height Difference in the Diverging Route**

Significant superelevation may cause an unusual result in the diverging route - a moderate vertical curve and grade (usually descending) can be induced as its angled alignment crosses the tilted plane of the switch timbers, necessitating close examination of the vertical dimension’s geometry to avoid unintended consequences. This cause-and-effect relationship is depicted and quantified in Figure 8. Specifically, the vertical differential in height between the routes at the Last Long Timber will be about 1.7 times the through route’s superelevation. The vertical curve – entirely within the turnout !- commences at the PS and ends at the PF, and is approximately as long as the lead. The resulting grade in the diverging route at the frog can be found mathematically as shown. That grade can then cause a significant differential in the height of parallel tracks – for example, about 3 times the superelevation for tracks at 15 ft. centers – which may be inconsistent with the cross-slope of the top-of-rails plane and subgrade. These effects may preclude crossovers or close connections between curves with significant superelevation.

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Figure 7 - Maximum Allowable Operating Speeds on Diverging Routes of Turnouts with Reverse* Super-Elevation per Formula in FRA Track Safety Standards Sec. 213.57(b)(1) for Actual Elevation with 3" of Unbalance (*Adverse or Negative Cross-Level or Elevation, etc.)
Figure 8 - Diagram of Effect of Superelevation in Curved Turnout on an Inside Diverging Route's Grade, Vertical Curve, and Elevation

-not to scale-

**Superelevation SE (In.)**

**Vertical Curve**

**Vertical Tangent**

**Profile Grade Rail =**

"Low Rail"

**Slope S (%) =** $100 \times \frac{\text{SE [In.]} / 12 \text{ in. per Ft.}}{\text{Rail-to-Rail Distance}^* \text{(Ft.)}}$

*Track gauge = 4'-8 1/2" +/-%
C/L head of rail to C/L head of rail = 4'-11 1/2" +/-% or 5.0 Ft., etc.

**Superelevation SE (In.)**

**Cross-Section**

**Single Track Ahead**

**At Last Long Switch Timber**

**Profile Grade Rail =**

"Low Rail"

**Profile Grade Rail =**

"Low Rail"

**H (Ft.) = 1.7 \times \text{SE (In.)} / 12$

**Examples:**

For SE = 3" then S = 3" = 0.25'/5.0 Ft. = 0.05 = 5.0 %.

For standard timbers, then H = (5.0' / 8.5' = 1.7) \times (3" / 12) = 0.425' = 5.1".

For N = No. 15, then G = 5.0% / 15 = 0.333 %.

For No. 15 Lead = LVC = 111.23' then Rate = 0.333 % / 111.23' = 0.300 % / 100 ft. Station

**Profile**

**Note:** For a turnout diverging to the outside of a superelevated curve, the vertical directions will be in the opposite direction (above) from those shown.

**Through Route**

**Diverging Route**

**Frog Number (Angle), N**

**Plan**

**Turnout in Curve**

**Long Switch Timbers**

**Grade G (%) = S (%) / N**

**L.L.T.**

**P.S.**

**P.F.**

Bold text represents key equations and calculations, while regular text provides additional explanatory details. The diagram illustrates the effect of superelevation on the grade, vertical curve, and elevation at various points in the turnout. The text below the diagram includes examples and notes to aid in understanding the principles involved.

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I. Other Design and Material Selection Detail Considerations

1. Self-Guarded Frogs

Self-guarded frogs are preferable where allowed – typically low-speed industrial and yard tracks. Their shorter length and lack of a guardrail inflicts less tangent in that area, which reduces the ‘flat spot’ in the curves. A self-guarded frog eliminates maintaining guardrail gage, although guardrails are sometimes installed for extra protection at the critical P.F.

2. Switch Length

Where a choice is feasible, shorter is preferable for the same reason.

3. Heel Blocks

Heel blocks bolted through the stock rails are recommended to maintain proper geometry of the switch. Heel joints consisting of only a pair of joint bars are sometimes seen - perhaps to start the lead curve sooner - but that risks an improper switch point angle.

4. Switch Point Guard Rails or Point Protectors

Switch point guard rails or point protectors on the outer rail of a curved turnout are a worthwhile accessory where permitted - usually yard and industrial tracks – to reduce wear of that switch point.

5. Bill of Switch Timbers

The additional curvature within the turnout may change the lengths of some timbers. Computing and confirming the length of each timber to provide the specified support distance, and the requisite number of each length, is recommended.

6. Stock Rail Bends

Where both routes in the turnout curve in the same direction, the stock rail bend per standard plan is made on the side of the switch with the most curvature. But where the turnout’s routes curve in opposite
directions, both stock rails should share the stock bend between them, in proportion to their respective curvatures. For example, if one route is a 4° curve and the other route is a 2° curve in the opposite direction, the former should have 2/3 of the stock bend, and the latter 1/3 of the stock bend. (3, pg. 5-40)

7. Offset Diagram and Measurements

Conceptually, a turnout in a curve is a standard straight turnout, but one that has been bent horizontally, with a curve superimposed or inserted into its middle portion. Accordingly, the same distances and offsets on the standard plan can be used. For a turnout to the inside of a curve, those offsets are measured from the gage line of the outside curved ('line' or 'high') rail. (3, pg. 5-37, Fig. 5.11) For a turnout to the outside of a curve, those offsets are measured from the gage line of the inside curved ('low') rail. (3, pg. 5-39, Fig. 5.12)

The designer or installer of a curved turnout may generate a custom table of offsets, reflecting its unique geometry, to facilitate the layout measurements. Any convenient baseline along the axis of the turnout may be selected for those dimensions, which can then be calculated, and plotted or printed. One author used a straight line from the centerline at the P.S. to the actual ½" P.F., even though it cut across both curves (Figure 6).

8. Closure Rail Lengths and Geometry

Closure rail geometry will vary slightly from standard plans due to the additional curvature. Their lengths will have to be calculated using drafting or surveying software, and individually measured and cut for each route.

9. Panelized Turnouts

Curved turnouts can be panelized, though the overall width (height during transport) will be greater from the added curvature. Using a standard panel turnout plan or an assembled one is not practical, since each curved turnout is unique and must be custom-built to the design curvature, as it cannot be curved later. Rail anchors should be used extensively – even applying them from the other side where

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interference occurs - to hold the turnout into the design geometry, and help prevent the switch timbers from skewing and narrowing the track gage.

VI. COGO METHOD TO DEFINE EXISTING IRREGULAR CURVES AND SELECT A TURNOUT/ FROG LOCATION

A. Defining Existing Irregular Curves

Refer to Figure 9 for a depiction of this procedure; the ‘step’ numbers correspond.

1. Obtain coordinates (“North/ East”) of points on either Center-Line or gage line of ‘line’ (outer or ‘high’) rail on curves and tangents, at intervals of not more than about 5 % of the nominal radius or about 3° of central angle, or 50 ft. maximum. Labeling or designating those points with their nominal or approximate ‘stationing’ (based on either engineering records or an assumed local origin) is useful for reference.

2. Inverse between those coordinate values for successive points to obtain the bearing and length of each of the local chords between those points.

3. At each interior point, from the data for the adjoining chords on each side, calculate the difference between the bearings (deflection angle), half the length of each chord, and the sum of those half-lengths to obtain the average chord length at that point.

4. Find the approximate local degree of curvature at that point by dividing its difference in bearings by its average chord length. Then use that local value for degree of curvature to calculate the approximate local radius at the same point by the standard equation for the arc definition of a curve.

5. Next calculate the deflection angle from the each of the 2 adjoining chords to the local tangent at that same point. That deflection is weighted, adjusted, or pro-rated from the difference in bearings at that point on the basis of each chord’s half-length by multiplying it by the local degree of curvature. Note that these deflections normally will not be equal; and, that they can be checked by comparing their sum with the difference in bearings at the point.

6. Calculate the local tangent at that point by adding (or subtracting) the deflection angle as just calculated to the bearing of the respective adjoining chord – but, as a check, those results should be equal. Next, calculate the bearing to the local center of the curve by adding (or subtracting) 90° to the local tangent’s bearing as just calculated.
Figure 9 - Diagram of Curve Geometry-Finding Procedure and Sequence
(not to scale)

1. Point No. (typ.)
2. Brg.
3. Dist.
4. D
5. ∆ Brg.
6. Brg. To Center
7. Center
8. Brg. To Midpoint Curve
9. Midpoint Curve
10. Check:

Note: Do NOT assume any values are equal – e.g., ∆ Brg.1-2 ≠ ∆ Brg.2-3 at Point 2 – unless specifically stated.

Valid for ½ chord each side of Point 2

Valid for ½ chord each side of Point 3

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7. Calculate the coordinates of the local center of the curve by starting from the point's coordinates, and then going towards the inside of the curve on the bearing just calculated for a distance that is the approximate local radius as calculated in 4. above.

8. The bearing to/ from the local center of a curve to the midpoint of a chord is calculated at 90° from the bearing of that chord.

9. Calculate the coordinates of the midpoint of the curve between any 2 points by starting at the respective local curve center's coordinates for either point, and then going back towards the midpoint on the curve at the bearing to it as just calculated, again for a distance that is the approximate local radius from that point as calculated in 4 above.

10. Check for precision and consistency by comparing the 2 sets of calculated values for the coordinates of the midpoint of the curve – one set based on each adjoining point - they should be nearly identical. Note that the values for degree of curvature, radius, and curve center - as calculated for each point - are presumptively valid between the midpoints of the adjoining chords on each side. Despite considerable variations in these values from point to point, they do converge to common coordinate values for points on the curve quite well, and seem to be stable and reliable for that purpose, certainly good enough for use as representing the existing conditions in most track geometry calculations. For example, differences at the curve midpoints of as little as 0.02 to 0.04 ft. (1/4 to 1/2") and precision or ‘closure’ on the order of 1 in 20,000 and better are typical.

With this geometric data - the center of curve coordinates, degree of curvature, and radius at or for each local point – solidly established, the designer can use it as the basis or ‘background’ existing conditions, from which to confidently extend a design.

B. Iterative Method to Solve for Frog/ Turnout Location

Often finding the optimum geometric location for a turnout in a curve is not susceptible or intractable to solution by analytical or formulaic means, usually due to the collection of curves and tangents with different dimensions and their potential range of variability, etc. Instead, a simple numerical methods
iterative procedure - based on successive approximations being essentially linear for small changes - which should be in the repertoire of most practicing engineers, is outlined below. Note that distances should be computed to 0.001 ft. and angles to at least 5" of arc. Although figures that detailed may seem to be ‘false precision’ and too refined for actual construction, they are useful primarily for computational purposes by closely tracking the results which depend on small differences, and thereby facilitating and expediting convergence to a solution with this method.

1. Select (assume) a ‘1st trial’ location for the turnout – “Location 1” - i.e., the Center-Line ("C-L") opposite the ½” P.F. for the proposed route.
2. Calculate the C-L geometry to the Point Of Interest ("POI") – e.g., a close clearance or a connection point. Calculate the distance or angle by which this 1st trial misses the POI.
3. Select another location for a 2nd trial – “Location 2” - using good engineering judgment as to the direction and magnitude of the change - and repeat steps 1 and 2 above.
4. Establish a ratio to compare the resulting change in the desired result at the POI – the “output” – to the change in the selected location – the “input” – as follows:

   \[
   \text{Ratio}_2 = \frac{\text{POI Result}_2 - \text{POI Result}_1}{\text{Location}_2 - \text{Location}_1}
   \]  

   (Eq. 2)

   Note that the units for this ratio are ad hoc depending on the needs of each situation, and can be different as needed. For example, in one situation the ratio may be in units of “Increase in Clearance, Ft. per Ft. of Change in Frog Location”, and in another the ratio may be in terms of “Change in Alignment at Connecting Point, in Ft. per Ft. of Change in Frog Location”, or “Change in Alignment at Connecting Point, in Minutes of Arc. per Ft. of Change in Frog Location”, etc.

5. Predict a new location for the next trial –“Location 3” – using the amount by which the 2nd trial missed the POI to adjust from Location2, with this principle:

   \[
   \text{Location}_3 = \text{Location}_2 \pm \frac{\text{POI Result}_2}{\text{Ratio}_2}
   \]  

   (Eq. 3)

6. Repeat steps. 2 – 5 for location 3 and any subsequent trials. The ratio per Eq. 2 and the next location trial per Eq. 3 should be revised using the results from the immediately preceding trial’s results to refine the predicted new location for each subsequent trial.
Experience with this method has been that the geometry usually converges to a stable result within 5 trials or so.

VII. COST ALLOCATION CONSIDERATIONS

A. Overview of Concerns

One reason suggested for the reluctance of railroads to approve turnouts in curves is this: Logic and track maintenance experience indicate that a turnout in a curve incurs higher maintenance costs and presents a greater risk of derailment. Further, they are often proposed to save costs – but for an entity other than the railroad, such as an industry, development agency, DOT, etc. The railroad may justifiably view that cost-shifting scheme as to the railroad’s disadvantage - the other entity benefits from the savings, while the railroad is burdened with increased maintenance costs.

As a result, all turnouts in curves are prohibited. But that potential disparity in cost responsibility for a curved turnout which the railroad maintains can – in theory - be redressed through adjustment in the rates charged. (For the other common case of a curved turnout which the industry maintains, suggested below are special provisions for the sidetrack agreement which clearly place that responsibility and cost on the industry.) Accordingly, a brief exploration of those typical additional cost elements may be informative to those involved with such matters, which follows.

B. Estimate of Added Costs to Maintain a Turnout in a Curve over 10 Years

This estimate is necessarily general, based on assumptions, and actual costs will vary depending on the volume of traffic, degree of curvature, type of rail and turnout materials used, maintenance intervals and practices, and other similar factors. Nevertheless, based on reasonable understandings and common practices and rates, an estimate can be made of the increase in typical annualized costs for a turnout in a curve of an industrial lead or siding, compared to a similar turnout in tangent track. Since the frequency of these cost events varies, they are aggregated over an evaluation period of 10 years, selected for simplicity and convenience.
TABLE 1 Estimated Typical Additional Costs for Turnout in Industrial Track Curve – 10-Year Totals

<table>
<thead>
<tr>
<th>Maintenance Or Repair Item</th>
<th>Scope / Quantity/ Description (allowance)</th>
<th>Frequency (estimated)</th>
<th>Added Cost per Event (estimated)</th>
<th>Added Cost for 10 years (estimated)</th>
</tr>
</thead>
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<tr>
<td>1. Inspections</td>
<td>Routine</td>
<td>1 Month</td>
<td>None</td>
<td>$0</td>
</tr>
<tr>
<td>2. Welding &amp; Grinding</td>
<td>Switch points, stock rails &amp; frog</td>
<td>3 Months</td>
<td>$700</td>
<td>$30,000</td>
</tr>
<tr>
<td>3. Replace Curve-Worn Rail, Switch Points, &amp; Guard Rails</td>
<td>100 Lin. Ft. (2 – 3 pcs. @ 39 ft.)</td>
<td>5 Years</td>
<td>$10,000</td>
<td>$20,000</td>
</tr>
<tr>
<td>4. Replace Switch Timbers, Misc. Re-Gaging &amp; Tamping/ Surfacing</td>
<td>50 LF = 250 Bd. Ft. (4 pcs. @ 10 – 14 ft.)</td>
<td>3 Years</td>
<td>$3,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>5. Derailments (minor)</td>
<td>Track &amp; Equipment</td>
<td>10 Years</td>
<td>$20,000</td>
<td>$20,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$80,000</strong></td>
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The total estimated additional costs for a turnout in curved track over a 10-year period is approximately $80,000. Breaking that figure down for comprehension and comparison, averages are approximately $8,000 per year, $670 per month, $155 per week, or $22 per day.

**C. Conclusion**

This total estimated additional cost is roughly comparable to the turnout’s initial construction cost. It is considerably less than the likely cost of modifications to an obstacle such as a bridge, building, etc. for use of a standard turnout, but considerably more than the typical cost for relocating a utility pole, or modifying a loading rack, etc. Accordingly, if the obstacle could be removed or negated for a lesser amount, that would be the indicated economic resolution. But if removal or modification of the interference would cost more than this estimate, then utilizing the turnout in a curve would be economically justified – as would attempting to recoup that increase in costs from the entity which benefits from that configuration.
VII. SIDETRACK AGREEMENTS – SUGGESTED PROVISIONS

A. Monthly Inspection and Report Requirement

The turnout installed in a curve shall be inspected by a qualified person (per FRA Track Safety Standards) on a monthly frequency. A written report of the inspection including all significant observations, exceptions, recommendations, defects per the FRA Track Safety Standards, and non-compliance with the Railroad’s applicable specifications, shall be submitted to the Railroad within 1 week after the inspection, either on paper or by electronic mail, to: (address of local official).

B. Corrective Work or Change in Class of Track and Maintenance Required

For any exceptions noted during the above inspection which are either defects per the FRA Track Safety Standards for the Class of the track, or do not comply to the Railroad’s applicable specifications, one of the following shall occur immediately (regardless of the pending written report): Either the defect or non-compliance shall be corrected; or else the Class of the track shall be reduced, the track placed into “Excepted” status, or the track taken out of service, as necessary to eliminate the defect violation or non-compliance. All other corrective repair or maintenance work in the written report shall be performed and completed within 2 weeks after submission, unless waived in writing by an authorized Railroad official.

C. Spare Turnout Components Requirement

All of the following spare parts and components for the turnout shall be obtained and stored on site in a secure and accessible location within 100 yards of the turnout, as follows:

Spare turnout, complete (but not switch timbers or ballast stone), of the same rail section, including:

- Both switch points, all switch plates and braces, heel blocks, rods (switch, operating, and connecting), switch stand, etc.;
- Frog, with all hook plates;
- Guard rails, with all plates, bolts, blocks, etc.; and,
- Rail and Other Track Materials (joint bars, bolts, tie plates, spikes or clips, rail anchors, gage rods, etc.) for the entire turnout.
Materials which are withdrawn from this stockpile shall be replaced within 1 week.

**D. Suspension of Service for Failure to Comply**

Failure to timely comply with the above requirements is agreed and shall be deemed to be sufficient reason and good cause for the Railroad to suspend service over the turnout - without any prior notice - until corrected or cured and approved by the Railroad.

**XI. Conclusion**

Turnouts in horizontal curves need not be pariahs in railroad track design, construction, and maintenance practice. Where a compelling need can be fulfilled, their capabilities should be given due consideration – along with the respect demanded by their inherent characteristics, challenges, and limitations. From a design and construction perspective, the primary rule is to provide tangents on both routes through the switch and frog and guardrail areas, and for several feet beyond each. The resulting curvature in the diverging route to achieve the alignment goal must be confirmed to be within an acceptable range. Where superelevation is involved, the unusual effects on the diverging route should be evaluated. Selection of materials and accessories – particularly the frog design and switch point length – and careful planning can facilitate the design, construction, and maintenance of turnouts in curves. While curved turnouts are somewhat more maintenance-intensive and expensive than standard turnouts, experience has been that the increase in cost is usually modest when compared to the alternatives and benefits, and may be recovered through rates or otherwise. For curved turnouts in industry tracks, special agreement provisions to require their frequent inspection, maintenance, and spare track materials are suggested. The ultimate decision regarding the use of a turnout in a horizontal curve depends on the fully informed application of “Good Engineering Judgment” to the specific situation, based on the guidelines set forth in this paper.
ACKNOWLEDGMENTS

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