Engineering Analysis and Geometric Design of Model Railroad Turnouts

NMRA Technical Note TN-12

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CONTENTS

FIGURES

TABLES

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EXECUTIVE SUMMARY

Background

Of the many types of turnout arrangements, straight turnouts with rigid frogs and split switches are the most common in the prototype. There are two types of split switches, one with a straight switch rail for the diverging route and the other with a curved switch rail. The switch rail for the straight route is always straight.

Curved switch straight turnouts are the subject of National Model Railroad Association (NMRA) Recommended Practices (RPs) RP-12 and RP-12.1 through RP-12.7 that tabulate turnout dimensions for O, S, HO, OO/On3, TT, HOn3 and N scales. They are the work of E.R. Frase (original calculations), Clarence H. Hill and Allen Hazen (original designers), D.B. Seville and no doubt others whose dedicated and diligent effort produced these turnout designs.

The NMRA last revised RP-12.7 for N scale turnouts in 1979 and the others in 1961, 18 years earlier. Recent examination of the turnout design dimensions tabulated in these RPs shows they are not always *consistent* (defined below). The inconsistencies are perhaps due to calculation errors made at the time of their last revision (35 and 53 years ago), and rounding errors introduced when converting decimal numbers to their nearest fractional equivalents.

While the inconsistencies are sometimes numerically excessive, they are not always visible to the naked eye. No doubt many modelers and manufacturers have used the 1961 and 1979 RPs to design, construct, and manufacture turnouts that look reasonably prototypical and operate reliably, especially when properly gauged to the appropriate NMRA Standard.

Overview

To eliminate the inconsistencies and remedy the limited coverage of the 1961 and 1979 RPs, this NMRA Technical Note (TN) constitutes an improvement and extension of the contributions of Frase et. al. It develops an engineered set of design requirements and design equations that produce curved *and* straight switch turnout design dimensions for *any* of the three general scale classes (scale fidelities) of scale model railroading identified by the NMRA. They are the Proto (and Fine), Standard, and Deep Flange (Hi-Rail) scales defined by the NMRA Standards S-1.1, S-1.2, and S-1.3, respectively.

Importantly, the revised and expanded turnout designs require *no changes* to any NMRA standard. In fact, some of the design dimensions are dependent on the NMRA standards for track gauge, frog flangeway width and switch point rail spread. With this dependency, the design requirements and design equations apply to all model scales, to standard or narrow gauge trackwork, and to any turnout numbered 4 through 20, inclusive.

The American Railway Engineering Association (AREA), and its successor the American Railway Engineering and Maintenance-of-Way Association (AREMA), publish prototype turnout designs in its annually updated portfolio of *Trackwork Plans and Specifications*. Most of the research, engineering design analysis, and equation development contained in this TN stems from careful examination and engineering evaluation of the turnout information in that portfolio.

The AREA does not specify designs for narrow gauge turnouts of either switch type. Establishing model railroad narrow gauge turnout dimensions is impractical until a narrow gauge standard of some kind surfaces from some definitive source, perhaps the NMRA. Internet searches for such a prototype standard were fruitless.

The NMRA turnout RPs do provide dimensions for On3 and HOn3 turnouts, but the origin of the lead and other dimensions (other than track gauge) is unclear. When scaled up to the prototype, their lead dimensions do not match. Nevertheless, the equations developed in this TN apply equally to narrow gauge turnout designs for any track gauge. Once an AREA-like set of narrow gauge trackwork plans become available, preparing narrow gauge turnout dimensions is straightforward.

The companion MS-Excel spreadsheet *NMRA TN-12 Generalized Model Turnout Design.xls* uses the design requirements and equations developed in this TN to generate consistent, accurate, and tabulated turnout dimensions without rounding errors. The spreadsheet output arrangement enables bulk copy-pasting into a revised and expanded set of new RPs.

The new RP set supports the premise that it is best to recommend consistent and accurate turnout dimensions. That way, any imperfections appearing in a finished turnout are the result of construction or manufacturing processes, and not of a flawed design.

This TN documents five primary research activities that culminate with updated turnout designs presented in a revised turnout RP format. In particular, this TN:

1. Documents background research regarding the geometry of prototype turnout designs, specifically those historically specified by the AREA in its 1946 portfolio of *Trackwork Plans and Specifications*.
2. Develops scale-independent equations describing turnout geometry, and shows that the calculated turnout dimensions they produce *are consistent* with the AREA tabulated dimensions, thereby demonstrating equation validity.
3. Applies those validated equations to the tabulated dimensions in NMRA RPs RP-12.1 through RP-12.7, and shows those dimensions are *not always consistent* with the calculated dimensions.
4. Develops a design approach that produces model turnout designs with consistent dimensions, and compares the effect of scale class on design results.
5. Presents a revised format for turnout RPs that contain those dimensions, and presents a few examples in the Appendices.

Turnout Engineering and Design

Turnout design stabilized once railroads began to see the economic benefit of interchange and standardization. The remainder of this **EXECUTIVE SUMMARY** highlights the key aspects of the research activities listed above and culminates with a brief description of generalized model turnout design.

Geometry

Throughout this TN, *geometry* refers to the dimensions of turnout rails and subassemblies normally built from rail stock, such as the switch and frog. These are the dimensions the 1961 and 1979 RPs and the new RP format tabulate. Geometry does not include the “nuts and bolts” of a turnout design, both literally and figuratively, as they fall in the purview of detailing. Additionally, *geometry* refers to the *gauge line* of the rails making up a turnout, and does not prescribe construction practices. Any turnout construction comments in this TN are anecdotal and do not constitute a recommendation.

Flangeway and railhead width do not directly affect gauge-line geometry of the prototype. However, flangeway width and switch point spread, critically important dimensions specified by NMRA standards, do affect the model turnout and reliable operation. In the model, they affect frog design and switch heel spread, and thus directly affect gauge-line geometry.

The AREA turnout geometry identified in the first list item above was chosen simply because it is on hand. Since then, the AREA and AREMA have no doubt changed some of the dimensional details, but those changes do not affect the validity of the equations described in the second list item. Those equations govern the geometric relationship between all essential turnout dimensions.

Dimensional Consistency and Accuracy

Here and elsewhere in this TN there is reference to dimensional *consistency*. Both the AREA and NMRA summarize turnout designs using tabulated dimensions. When enough dimensions are accepted as given, such as the frog number, frog lengths, switch length, heel or switch angle, and a few others, the design equations produce calculated values for all the remaining dimensions. For a perfectly engineered, designed, computed and tabulated turnout, there would be no difference between the tabulated and calculated values.

Non-zero differences, if large enough, indicate errors in the equations, the calculations, arithmetic rounding, or in the tabulated values themselves. Consistency then, is a measure of the cumulative effect of all these errors. This TN uses the following definition of consistency:

Turnout dimensions are *consistent* when the percent difference between a tabulated and calculated dimension is 0.5% or less.

Because of the disparate error components it includes, this is not a rigorous definition. It is simply a judgment call based on general engineering experience and examination of calculated results. Rounding decimal values to fractional feet and inches, or simply fractional inches, can sometimes cause as much as 0.25% difference.

Accuracy is a measure of how close a calculated number is to its actual value. Human beings can easily perform simple arithmetic, but when calculations require precision or become tedious, errors are prone to occur. Use of a calculator can minimize errors, but human mistakes can still occur with complicated equations and when transcribing results.

The consistency definition is reasonable given the mathematically precise equations developed in this TN and the extraordinary calculation accuracy achievable with today's personal computers. That also makes the definition reasonable for evaluating the consistency of dimensions calculated by hand or with less accurate tools.

Prior to about 1960, when mainframe computers first began to appear in engineering organizations, engineers made extensive use of slide rules that are accurate only to about three significant figures. Engineers used electromechanical calculators, widely available in the second quarter of the 20th century, to produce results of greater accuracy. Even then, the calculated results were likely recorded by manual rounding and tabulation, presenting another opportunity for human error.

It is then safe to say that the 1946 AREA tabulated dimensions evaluated in this TN were not generated by a computer. Whether or not the 1961 NMRA turnout RPs tabulate computer-generated dimensions is unknown, but unlikely. The 1979 N scale RP tabulated dimensions may have been calculated using computers, or perhaps handheld calculators, because they are of generally better consistency than those in the earlier RPs.

Engineering and Mathematical Validity

Derivation of the equations developed in this TN comes from careful review of prototype and model turnout geometry, and application of the mathematical principles of Plane Geometry, Trigonometry, Algebra and Calculus. Those equations provide a complete mathematical description of turnout geometry.

To eliminate mathematical errors, deriving and checking the equations several times, sometimes from different directions, ultimately produced the same set of equations. Only then were the equations programmed in a spreadsheet for calculation and evaluation of turnout dimensional consistency.

Consistency Evaluations

Consistency calculations, comparisons, and design calculations come from several companion MS-Excel spreadsheets, listed with other resources in **APPENDIX D: REFERENCES**. All spreadsheet calculations are accomplished using *Visual Basic for Applications* (imbedded in MS-Excel) and double precision variables to ensure maximum accuracy. Because these spreadsheets contain macros, MS-Excel will likely issue a security warning when opening them. The sole purpose of these macros is to make the necessary consistency and design calculations. They present no security threat. Although written using MS-Excel 2010, the spreadsheets are saved in MS-Excel 97-2003 form (.xls) for compatibility with earlier versions.

Applying the developed equations to the AREA tabulated dimensions shows that all AREA switch dimensions are consistent. For straight switches, the AREA dimensions match the calculated dimensions. For the AREA curved switches, the spreadsheet shows the differences between calculated values and specified values for curved switches are in the range of -0.26% to 0.17%, well within the consistency definition.

For the full AREA turnout, all dimensions, except a few curved closure rail gauge point coordinates, are consistent. Those few that are not appear to be errors in the AREA calculations and are thus ignored. Most importantly, the consistency of the AREA switch and turnout designs validates the developed equations.

Applying the validated equations to the NMRA tabulated dimensions shows that many are *not consistent*. The differences between calculated dimensions and specified dimensions for switches are in the range of -22.4% to 26.0%, and for complete turnouts in the range of -22.4% to 44.2%. These are far too large to be declared consistent. Correcting these inconsistencies is an important aspect of the effort documented in this TN.

Analysis and Design Considerations

One of the key design requirements for a prototype or model turnout is that it provide a smoothly curving set of rails along the diverging (reverse) route. This means there may be no angular discontinuities (kinks) in those rails, except for the acceptably small angle at the switch points. Further, there may be no angular discontinuities where the switch rail meets the curved closure rail and where the curved closure rail meets the frog toe. That said, if the key switch and closure rail dimensions are not consistent, those angular discontinuities will occur in either the AREA prototype tables or in the NMRA RPs.

The equations developed in this TN satisfy the smoothness requirement. Using them ensures consistent dimensional specifications for any updated or new turnout RPs.

Of course, this is a matter of degree. In some cases, the existing discontinuities in the NMRA dimensions will be unnoticeable once a turnout is constructed and properly gauged to NMRA Standards. Reliable operation will likely ensue. In other cases, rails may not line up and the discontinuities may be more obvious. Having turnout dimensional specifications that are consistent and accurate, but rounded to remain realistically achievable, is a worthy goal for any NMRA (or prototype) turnout design specification.

As noted earlier, some turnout dimensions must be accepted as given to compute the remaining dimensions. The research documented in this TN does not always discern which turnout dimensions are given, and which are derived. For each frog number, the AREA specifies frog toe and heel length dimensions that are independent of the several frog designs it catalogs. The frog angle is a direct consequence of the definition of the frog number. The frog angle is computed using its scale-independent prototype definition.

Another important turnout dimension is the switch heel spread, which the AREA standardizes at 6¼ inches for all turnout frog numbers. Similarly, the NMRA uses a fixed switch heel spread for all frog numbers, but it varies with model scale.

For an AREA turnout with a specified frog number, the most important dimension for the switch is the specified switch rail length. For a straight switch rail, the switch heel angle is a direct consequence of the switch rail length and the switch heel spread. Because the switch is straight, the point angle is the same as the heel angle. For a curved switch, the point angle depends on the curved switch rail length, a specified heel angle, and the heel spread.

Similarly, the NMRA curved switch designs specify the point and heel angles, along with the switch rail length. While the AREA chooses switch rail lengths based on commonly available rail-stock lengths, the NMRA is not similarly limited, and its specified switch rail lengths are not scaled from the AREA lengths.

Given the frog design, the developed equations show a relationship between the switch design and the reverse route curvature, and thus the other turnout dimensions, especially the lead. In fact, once the switch and frog design dimensions are set, there is only *one* lead dimension value that is consistent with the curved closure rail being a circular arc, as specified by both the AREA and the NMRA. For any other lead value, the curved closure rail cannot be circular, even though it may form a smooth curve. Conversely, for a given lead and frog design, there is only one switch length.

Thus two basic design approaches are possible. The first approach sets the switch dimensions first and then calculates the other dimensions, as apparently done in the prototype. The second approach, unlike the prototype, sets the lead dimension first and then calculates the other dimensions. For either approach, the equations ensure the designs will have *consistent dimensions*.

Setting the switch dimensions first produces lead dimensions that are excessively longer than the scaled prototype. This is due in part to larger switch heel spread dimensions necessary in the model. That leaves setting the lead dimension first as the best design approach for model turnouts.

Model Turnout Design Objective

In support of its mission to provide Standards and Recommended Practices for interoperability and interchangeability, the NMRA is essentially the scale model railroading equivalent of the AREA and its successor, AREMA, at least as it pertains to trackwork specifications.

The overall model turnout design objective is then to produce a set of turnout NMRA Recommended Practices that:

1. Cover all NMRA-recognized model scales, for Proto (and Fine), Standard and Deep Flange (Hi-Rail) scale classes.
2. Specify dimensions for both straight and curved split switch turnout designs, for frogs No. 4 through No. 20, inclusive.
3. Meet all existing NMRA Standards for turnouts.

In the same way the AREA Trackwork Plans and Specifications form a basis for prototype turnout designs, the NMRA Recommended Practices form the basis for turnout construction by modelers or commercial model trackwork manufacturers. Prototype railroads and turnout component manufacturers may deviate from the AREA designs, and similarly model builders and manufacturers may deviate from the NMRA designs. However, in doing so model turnouts must still meet applicable NMRA standards to ensure smooth and reliable operation. For turnout manufacturers, meeting the applicable NMRA standards provides a path towards receiving an NMRA Conformance Warrant.

Model Turnout Design Rationale

To achieve the model turnout design objective requires a methodical and practical design rationale. The most visual features of a turnout design are its overall length and its frog angle. Compare a No. 6 and No. 8 turnout side-by-side and the differences in those features are clearly evident. The design rationale for these and other key features follow.

Lead

The primary contributor to overall length is turnout lead. There is no apparent documentation describing how the NMRA established lead dimensions for the 1961 and 1979 turnout RPs. Some NMRA lead values are shorter than the scaled AREA lead, others are longer, but not consistently so. Using scaled AREA lead dimensions is clearly appropriate for scale model turnouts. As discussed earlier, setting the lead dimension first is the best design approach.

If scaled leads are not used, a method for selecting non-scale NMRA lead values would need to be developed, explained, quantified, and documented.

Frogs

Identifying a turnout by its frog number immediately implies its calculable frog angle. The frog angle and the other frog dimensions are equally important. The NMRA flangeway widths are roughly twice the prototype flangeway width (Proto scales excepted), making the flangeway gap between the frog throat and the frog point roughly twice as long. This has no effect on the frog heel length, but reduces the available toe length necessary for the mechanical features that attach the frog toe to the closure rails.

The NMRA frog dimensions are about 30% longer than the prototype, perhaps to accommodate the longer flangeway gap, but for otherwise undocumented reasons. Further, the NMRA RPs show toe and heel lengths that are *both* longer than the prototype. However, only the toe length needs adjustment for the longer flangeway gap of the model. Using the scaled prototype heel length and the scaled prototype toe length adjusted for the longer flangeway gap in the model is a refinement to the current NMRA design. This also makes frog dimensions closer to the scaled prototype. For Proto scales, they will be nearly the same as the scaled prototype.

Flare dimensions for the frog wing rail and a guard rail (discussed below) are different. They are dependent on frog number, and are now included in the new RP format.

Switch Heel Spread

Although not as visually obvious as lead and frog angle, the switch heel spread has a significant effect on turnout dimensions. The AREA sets heel spread to 6.25 inches for turnouts of any frog number, either switch type (curved or straight), and for any switch rail length. The NMRA RPs set switch heel spread as well, but to values that are more than half again as large as the scaled prototype.

The NMRA heel spread was perhaps set to accommodate early, thicker wheel flanges that perhaps preceded the development of NMRA RP-25 Wheel Contour. A reasonable assumption is that the AREA considered wheel flange thickness and some adequate clearance between the back of the wheel and the adjacent switch rail when setting its heel spread.

Using the AREA approach, with an NMRA standard flangeway width that accommodates the appropriate RP-25 (or Proto scale) wheel flange thickness, is then a reasonable design approach for setting model switch heel spread. This TN prescribes two methods for doing this. One produces switch heel spreads similar to those in the current RPs, and the other produces narrower, and thus more prototypical, switch heel spreads.

In either method, the switch heel spread must still meet the NMRA standards for switch point spread. Switch point spread applies over the full length of the switch rail, including the heel end where the heel spread dimension occurs. Because of this, the switch point spread standard (mechanical) sets the switch heel spread for Proto scale. For the other scales, with their wider flangeways, the point rail spread is satisfied, but is not limiting.

Turnout Number Range

The AREA does not specify dimensions for No. 4, No. 13, No. 17 and No. 19 turnouts. Skipping No. 17 and No. 19 is not surprising, especially because these are generally high-speed mainline turnouts where any length is readily accommodated and intermediate lengths are likely not needed. Some sources say skipping No. 13 is rooted in superstition, much like many buildings in New York City that have no *numbered* 13th floor. No. 4 turnouts have limited application in the prototype, except for industrial applications where space limitations may require them, and short wheelbase switchers are more the norm. Still, skipping the No. 4 turnout is somewhat surprising because the AREA *does* specify dimensions for a No. 4 frog.

Nevertheless, it is possible to infer dimensions for the missing-number turnouts by examining the frog dimensions and switch rail lengths of adjacent-numbered turnouts. The AREA No. 5 and No. 6 turnouts use the same switch design for a given type (curved or straight). Thus it is reasonable to expect that the AREA would use that same switch design for the more compact No. 4 turnout, including the associated switch or heel angle. For the other missing turnout numbers, the AREA tables imply they would have the same switch dimensions as the adjacent-numbered designs. Frog dimensions appear to vary linearly with frog number, so it is reasonable to linearly interpolated them for No. 13, 17 and 19 frogs. The validated equations then produce the remaining dimensions. This enables calculation of turnout dimensions for the full range of No. 4 to No. 20 turnouts, inclusive.

Curved Closure Rail Gauge Points

The AREA specifies three gauge points along the curved closure rail at roughly even spacing. These gauge points aide in forming the closure rail radius during construction in the field. The NMRA uses one, two, or three gauge points, depending on model scale and frog number, for the same purpose. The number of NMRA gauge points seems to be based on the length of the closure rails, but the choice is not always consistent across different model scales. Always using three gauge points, as the AREA does, is a better choice for NMRA turnout gauge points.

Guard Rails and Setting

Guard rails and their proper setting in relation to the frog flangeway gap are also important to reliable operation. The AREA specifies only two guard rail designs, one constructed from rail stock and the other made as a single casting. The rail stock design adapts well to the model turnout, but the cast design is too restrictive because it requires specific tie spacing under the frog.

The AREA also specifies two lengths for the rail stock design used with rigid frogs. This is adequate for Proto scale guard rails, but the other scales, with wider flangeway gaps needing protection, require a set of longer guard rails. The lengths of these longer guard rails come from the prototype practice of making them from standard-length rail stock. For this reason the new RP format includes guard rail length, flare and parallel-section setback dimensions that are dependent on frog number.

Generalized Model Turnout Design

The design rationale discussed above makes it possible to use the validated equations to produce turnout dimensions in any prototype gauge or model scale, standard or narrow gauge, and for any frog number 4 to 20 inclusive. The AREA designs are the logical starting point for standard gauge turnouts. A narrow gauge equivalent to the AREA designs is not currently on hand and requires further effort to uncover or otherwise establish.

For standard gauge turnouts, the design rationale summary is:

1. Use AREA straight switch and curved switch lead dimensions.
2. Set frog designs by frog number and flangeway standards.
3. Set switch heel spread by NMRA flangeway standards (this also accommodates appropriate wheel flange thickness), adjusted as necessary for NMRA switch point spread standards.
4. Specify guard rail dimensions and setback that fully protect the wider flangeway gaps of the model frog.

The companion spreadsheet *NMRA TN-12 Generalized Model Turnout Design.xls* makes all design calculations for any specified scale class and presents results in the new RP format.

DOCUMENT ORGANIZATION

In addition to the **EXECUTIVE SUMMARY**, this TN is organized into five main parts and four appendices:

PART I: PROTOTYPE TURNOUTS

This part describes the geometric details of prototype turnouts specified by the AREA. It presents a discussion of each pertinent turnout feature and develops equations describing its relevant geometry. Except for an occasional comment in this part, a more complete discussion of model railroad turnouts occurs in **PART II**.

PART II: MODEL RAILROAD TURNOUTS

Similar to **PART I**, this part describes the details of model railroad turnout geometry, and explains any adjustments to prototype equations needed for model turnout considerations.

PART III: MODEL TURNOUT DESIGN ISSUES AND REQUIREMENTS

This part discusses issues for model turnout design, addresses and establishes basic design requirements that cover both curved switch and straight switch turnouts.

PART IV: DESIGN CALCULATIONS FOR MODEL RAILROAD TURNOUTS

This part develops design calculation algorithms for straight and curved switch turnouts, based on the equations developed in **PART I** and **PART II**, that meet the design requirements set in **PART III**.

PART V: CHECKING FINAL DESIGN CONSISTENCY WITH CAD DRAWINGS

This part discusses the consistency evaluation of the design examples presented in **APPENDIX A**. Additionally, it includes CAD drawings that compare the prototype and model turnouts for several model scales and frog numbers.

APPENDIX A: REVISED TURNOUT RP FORMAT AND EXAMPLES

This appendix contains examples of recommended revisions to the turnout RPs. At best, modelers can only measure things to about a hundredth of an inch (two decimal places), or 1/64 of an inch using readily available engineer's and machinist scales. More accurate measurement tools, such as micrometers, Vernier calipers, dial indicators, feeler gages, and for trackwork, the NMRA Standards Gauge, are typically accurate to the nearest thousandth of an inch. Turnout manufacturers would presumably prefer dimensions to the nearest thousandth of an inch for manufacturing purposes. For these reasons, the new turnout RPs show all dimensions rounded to the nearest thousandth of an inch, or for angles, the nearest thousandth of a degree.

APPENDIX B: ALTERNATE CLOSURE RAIL CURVE AND LEAD LIMITS

This appendix describes an alternate, non-circular shape for the curved closure rail. It also describes how a reasonable *range* of lead values can still describe a turnout with a smooth reverse route curve. The developed equations apply to both the prototype and model turnout.

APPENDIX C: VARIABLE DEFINITIONS

This appendix defines all variables used in all equations appearing in the **PART I** though **PART IV** and **APPENDIX B**.

APPENDIX D: REFERENCES

This appendix contains a numbered list of all references and companion MS-Excel spreadsheets.

PART I through **PART IV** and **APPENDIX B** develop equations that define a turnout's geometric features diagrammed in associated figures. The initial set up of most equations, using the principles of Plane Geometry and Trigonometry, is straightforward. Any algebraic manipulations needed to put the equations in final form are not detailed, with a few exceptions where some intermediate steps clarify the logic.

In **APPENDIX B**, derivation of some important equations involving turnout closure rail curvature and lead additionally require application of basic Calculus, notably the use of derivatives and the principles of maxima and minima.

Finally, all equations in this TN have a unique identifier contained in parentheses and following on the same line. The identifier consists of the **PART** roman numeral or **APPENDIX** letter followed by a dash and a sequential number staring with 1, for example: (IV-7).

PART I: PROTOTYPE TURNOUTS

Many good sources of information about prototype turnouts are available. Books on railroad engineering abound, historically and in the present. E.E. Russell Tratman's book *Railway Track and Maintenance, A Manual of Maintenance-of-way and Structures* [1][1] provides early 20th century insights into railway engineering, including that of turnouts. William W. Hay's highly regarded and definitive book, *Railroad Engineering* [2] dating from 1982, enlightens further. John A. Droege's book, *Freight Terminals and Trains* [3], reprinted in 2012 by the NMRA briefly discusses turnouts. There are no doubt others.

A significant source of prototype mechanical engineering information regarding turnouts is the American Railway Engineering and Maintenance Association (AREMA) and its predecessor, the American Railway Engineering Association (AREA). They annually publish a *Portfolio of Trackwork Plans and Specifications* that contains a wealth of mechanical design information about turnouts, crossovers, crossings and the detail parts in their assemblies. AREMA offers the 2014 printed version of this portfolio for sale at a cost of $1465.00 plus $45.00 for shipping and handling, but this is cost-prohibitive for a single researcher. The CD version at $965.00 is still cost-prohibitive.

One historical version of this portfolio, obtained from the internet[2], is the AREA *Trackwork Plans and Specifications* dating from 1946 [4]. Much of the engineering information discussed or referenced in this TN comes from it. There is no doubt that changes to these plans have occurred since then. However, the basic mechanical and geometric characteristics of turnouts remain the same, so the engineering principles developed from that information are equally valid today. There is no requirement that prototype railroads use the AREA or AREMA designs exclusively, but many do, or use them as a basis for their own turnout design specifications.

After defining pertinent turnout nomenclature in the first section below, a following section for each major turnout feature develops equations that describe feature geometry in terms of dimensions labeled in an associated figure. Collectively, the equations from each section define the geometry of a turnout.

Turnout Nomenclature

A straight turnout, as the name suggests, consists of a straight path normally aligned on a tangent (straight) track, with a second path diverging to the right or left of the straight path. A turnout whose diverging path departs to the left is a *left-hand* turnout and one diverging to the right is a *right-hand* turnout. The railroad name for the straight path is the *normal* route and for the diverging path the *reverse* route. Figure 1 shows a left-hand turnout and identifies its main features. It shows only the railheads and, for clarity, excludes the ties and mechanical assembly details.

The primary features of a turnout are the *frog* and the *switch*, circled in the figure. The *straight* and *curved closure rails* connect them. Opposite these rails, at the track gauge distance, are the corresponding *stock rails*.

The frog is a mechanical assembly that provides a gap where the closure rails would otherwise intersect, allowing passage of wheel flanges. Opposite the frog are the *guard rails* that ensure wheels passing through the frog proceed along the correct route.

The switch is the only moving part of the turnout[3]. Its purpose is to direct an approaching train to the normal route or to the reverse route. The two vertical lines between the two *switch rails* represent the *switch rods*, which are the mechanical devices that cause the two switch rails to move together. The switch rails pivot at their heels, located at the heel of switch.

An important turnout dimension is the *lead*, the distance between the point of switch and the point of frog measured parallel to the normal route. Later sections fully describe the lead and its relationship to the frog and switch designs.

[1] Numbers in square brackets identify sources listed by the same number in **APPENDIX D: References** of this TN.

[2] Unfortunately, as of this writing, the link to this PDF document is broken.

[3] Spring rail frogs also move, but they are beyond the scope of this TN.

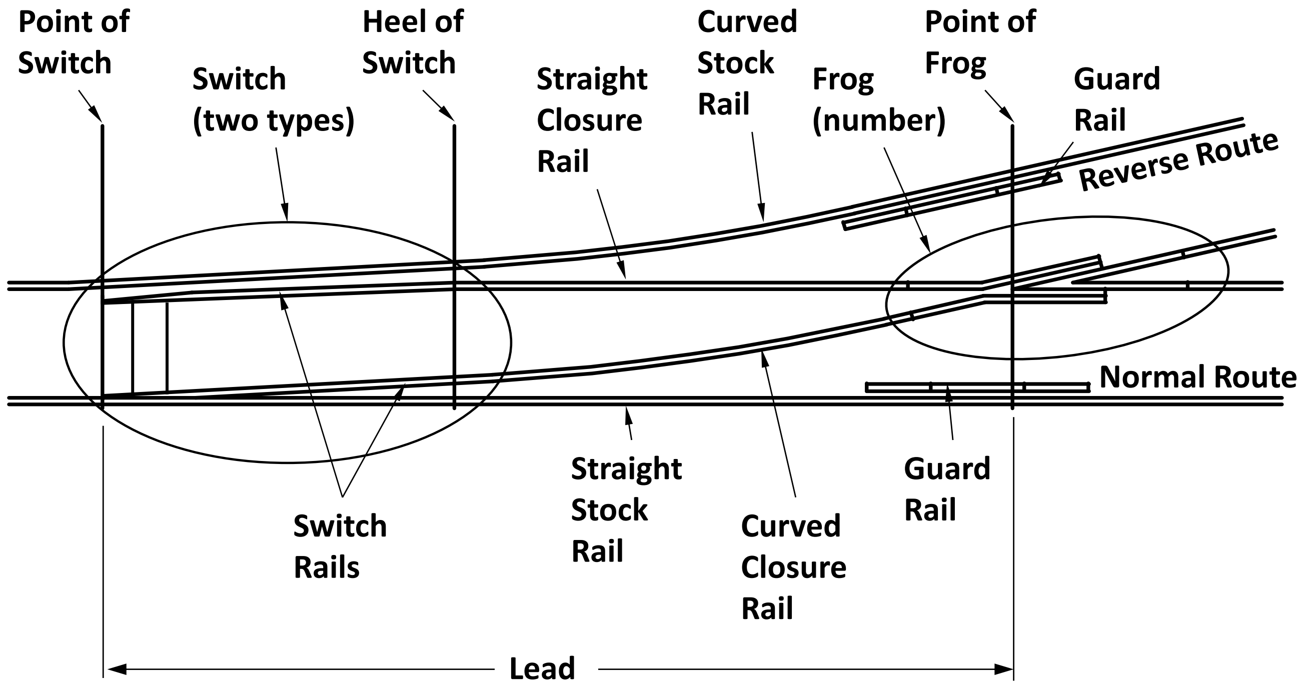


Figure 1: Turnout Nomenclature

Frogs

Railroad design engineers identify turnouts by their *frog number*. For example a "No. 8" turnout is one constructed using a No. 8 frog. Figure 2 illustrates the pertinent features of a frog, including the frog number and angle, but shows only the rail heads for simplicity.

The AREA presents several types of frog designs in its Trackwork Plans & Specifications. The types are named for their major components and construction:

Bolted Rigid Frog
Rail-Bound Manganese Steel Frog
Spring Rail Frog
Solid Manganese Steel Frog
Self-guarding Solid Manganese Steel Frog

The first two frog types, the Bolted Rigid Frog and the Rail-Bound Manganese Steel Frog, have the same toe length, heel length, toe spread and heel spread for a given frog number.

The last three types, whose designs vary even for the same frog number and sometimes specify different rail weights, have dimensions that are different from the first two types. This TN covers only the first two types of frogs, perhaps the most common.

A frog assembly is symmetric about its own centerline. That way the same frog can serve either a right- or left-hand turnout. The rails connecting to the closure rails are the *frog wing rails*. The rails converging at the frog point are the *frog point rails*. The angle between the frog point rails, and the normal and diverging routes, is the *frog angle*.

Notice the point where the gauge sides of the frog point rails intersect. Because it is mathematically sharp, turnout design engineers call this point the *theoretical point of frog*, in part because it is not actually fabricated. In practice, the actual frog point is cutback to the *½-inch point* where the frog point rails diverge to one-half inch.

Frog Number and Angle

The frog number is the distance *n* units, measured along the bisector of the frog point rails (the frog's centerline), from the theoretical point of frog to the location where the gauge side of the frog point rails separate by one unit. For example, if $n = 8$ feet, measured to a point where the separation is 1 foot, the frog is a No. 8. The separation does not have to be one unit. For example, if the separation is 6 inches at a distance of 48 inches the frog number is $48/6 = 8$. The frog number is usually a whole number, but that is not a requirement. The Pennsylvania Railroad (PRR) used a No. 5.289 frog some special

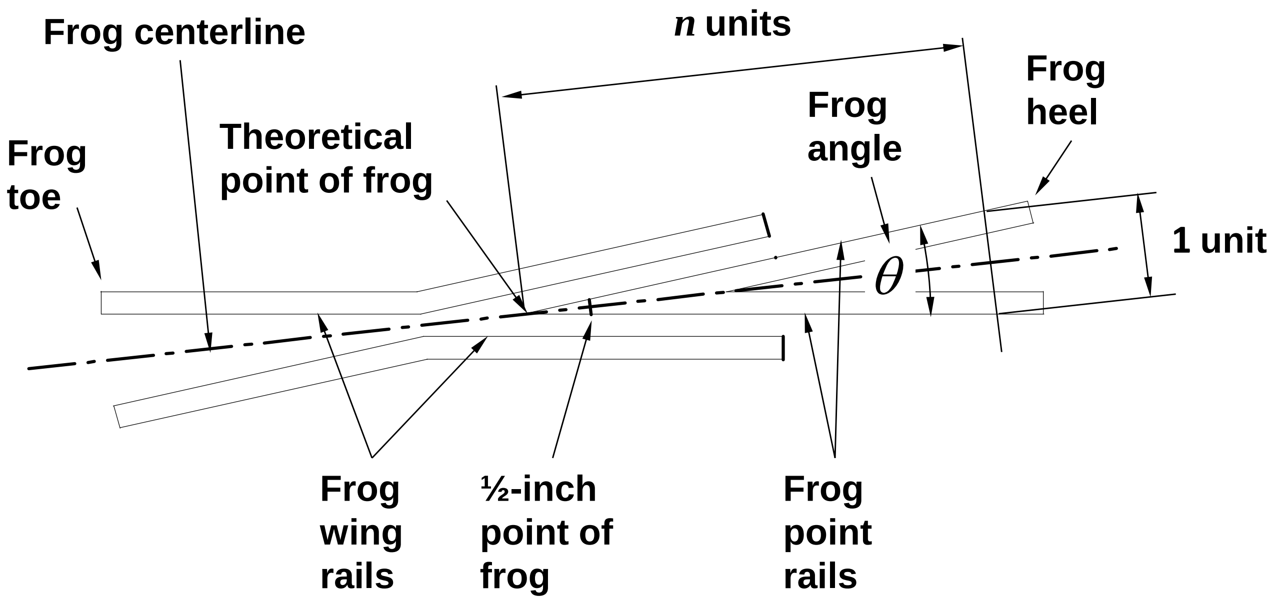


Figure 2: Frog nomenclature, frog number *n*, and frog angle

circumstance. The Denver & Rio Grande Western employed No 4½ and 8½ frogs in addition to No. 4 and No. 8 frogs. AREA frog numbers fall in the whole number range from 4 to 20, skipping 13, 17 and 19, although some high-speed turnouts can have higher frog numbers. No. 4 turnouts occasionally occur in tight, mostly industrial, locations. Discussed later, the AREA does not specify a No. 4 turnout.

The frog angle θ is a consequence of the frog number *n*. The frog angle is also the angle the reverse route makes with the normal route. From trigonometry and the geometry in Figure 2:

$$\tan\left(\frac{\theta}{2}\right) = \frac{1}{2n} \quad \text{(I-1)}$$

The definition of the frog angle is then:

$$\theta = 2\arctan\left(\frac{1}{2n}\right) \quad \text{(I-2)}$$

Frog Point Cutback

Again, consider the theoretical point of frog in Figure 2. A real frog point can be extremely sharp, but not perfectly so, making a sharp frog point impractical and unnecessary. Turnout design engineers deliberately cut the frog point back towards the heel of the frog until the separation of the gauge side of the frog point rails reaches ½ inch. This cutback distance *d*, as Figure 3 illustrates, locates the *half-inch* point of frog. Other names for the ½-inch point of frog are the *actual* or *practical* point of frog. From similar triangles:

$$\frac{1}{4d} = \frac{1}{2n} \quad \text{(I-3)}$$

Thus, the cutback distance, in inches, is simply one-half the frog number:

$$d = \frac{1}{2}n \quad \text{(I-4)}$$

For example, a No. 6 frog has a 3-inch cutback to the ½-inch point. Measured along a gauge line, the cutback distance d_{GL}, again in inches, is slightly longer:

$$d_{GL} = \frac{d}{\cos(\theta/2)} \quad \text{(I-5)}$$

Equation (I-5) will be useful later. Using the half-angle formula (from trigonometry) for the tangent, and equation (I-1), leads to other relationships between the frog angle and frog number, useful for engineering analysis:

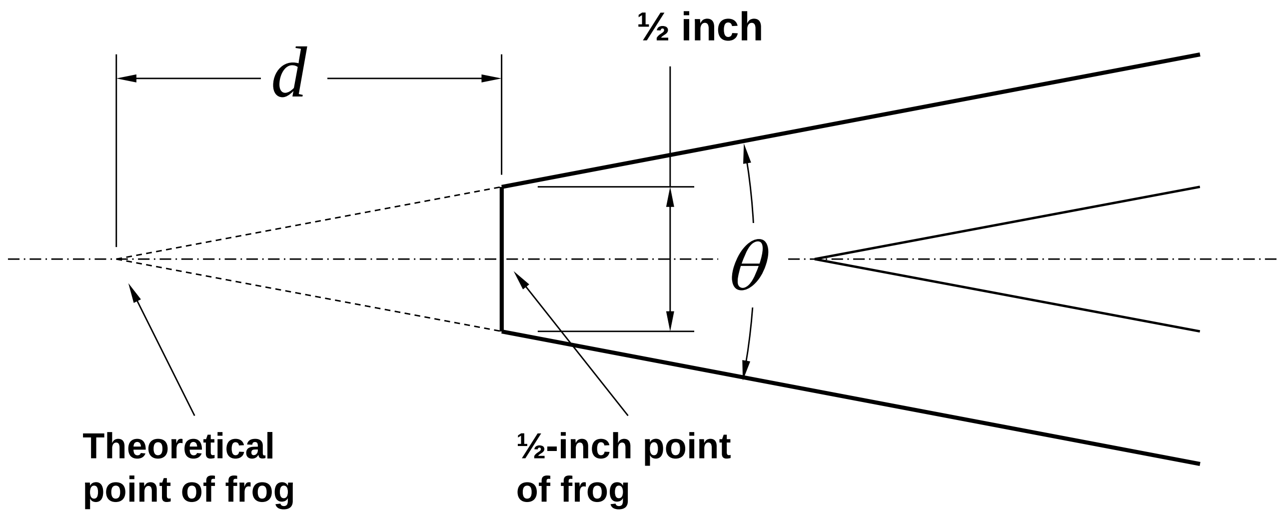


Figure 3: 1/2-inch point of frog

$$\tan\theta = \frac{4n}{4n^2 - 1} \qquad \text{(I-6)}$$

$$\sin\theta = \frac{4n}{4n^2 + 1} \qquad \text{(I-7)}$$

$$\cos\theta = \frac{4n^2 - 1}{4n^2 + 1} \qquad \text{(I-8)}$$

$$\cos\left(\frac{\theta}{2}\right) = \frac{2n}{\sqrt{4n^2 + 1}} \qquad \text{(I-9)}$$

Frog and Toe Length

Other features Figure 2 illustrates include the toe of the frog, which is the end closest to the switch. The other end is the heel of the frog. Figure 4 shows the important frog dimensions. The toe length L_{Toe} is the distance from the frog toe to the ½-inch point of frog. The heel length L_{Heel} is the distance from the ½-inch point of frog to the frog heel. Prototype drawings normally indicate these ½-inch point lengths, measured along a guage line, *not* the frog centerline.

What rationale the AREA uses to define frog toe and heel length is not evident from [4]. Because frogs are bolted assemblies of rails, various filler blocks, risers, or manganese steel castings, the toe and heel lengths must be long enough to accommodate these mechanical features. Further, there must be enough toe and heel spread distance to allow insertion of the joint bar bolts and nuts, and clearance for the wrenches required to tighten them. Because the toe and heel spreads are rounded to the nearest 1/16th inch, they are likely calculated after the toe and heel lengths are established for various mechanical reasons.

Nevertheless, the fact that the toe and heel spreads are nearly the same for all frog numbers suggests they may be set on the basis of some mechanical feature.

The toe and heel lengths can also be measured from the theoretical frog point. The variable L_{FT} represents the toe length to the theoretical frog point, and L_{FH} the like-measured heel length. The total frog length is always the sum of these two lengths, regardless of the point from which they are measured. Another important characteristic to note is that the gauge lines along the frog length are *straight*. That frogs are straight is an important factor in establishing the curvature of the reverse route centerline between the switch and the frog.

Substituting equation (I-4) into (I-5) gives:

$$d_{GL} = \frac{n}{2\cos(\theta/2)} \qquad \text{(I-10)}$$

Then, expressing the practical toe length in inches, the frog toe length to the theoretical point is:

$$L_{FT} = L_{Toe} - d_{GL} \qquad \text{(I-11)}$$

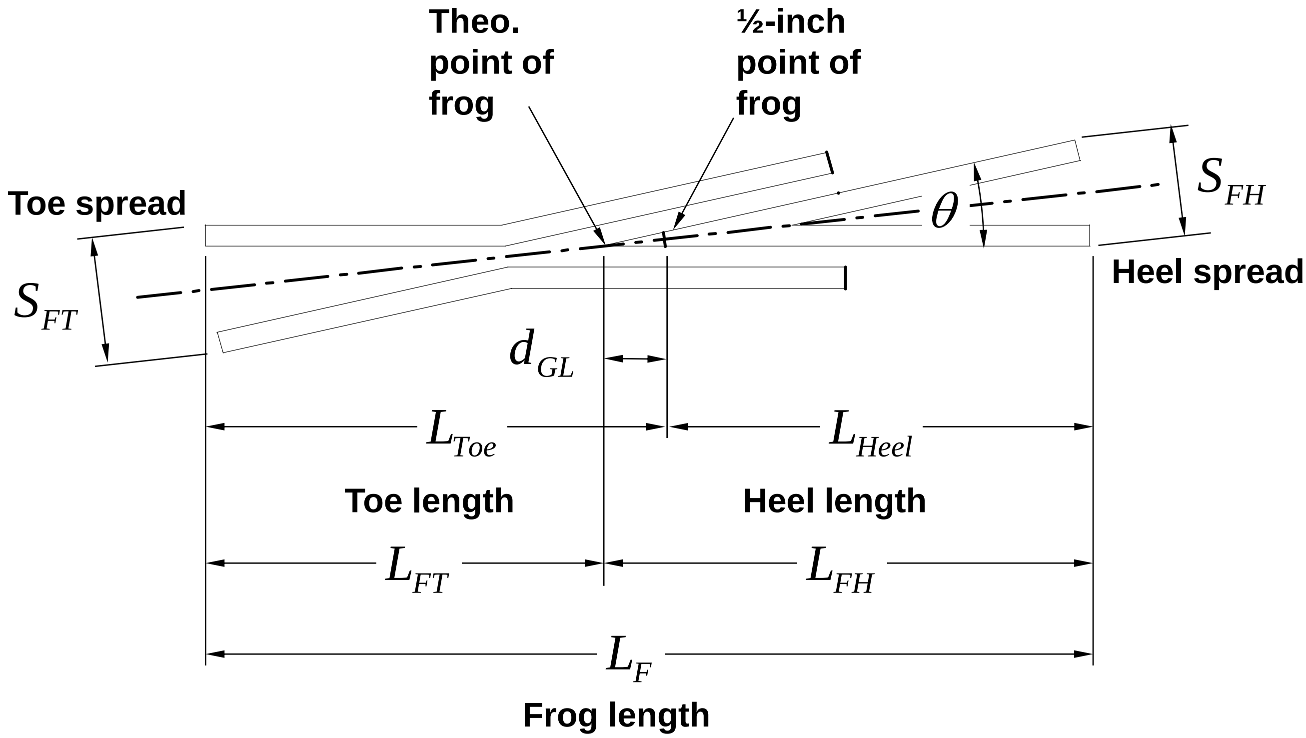


Figure 4: Frog dimensions

Similarly, the frog heel length to the theoretical point is:

$$L_{FH} = L_{Heel} + d_{GL} \tag{I-12}$$

Frog Flangeway Gap

The frog flangeway gap, for any frog type, is the distance from the throat to the ½-inch point measured along a gauge rail, as Figure 5 illustrates. Flangeway gap should not be confused with flangeway width measured perpendicular to the point and wing rails.

For a flangeway width w_F, expressed in inches, the frog flangeway gap g_T measured along a gauge line in inches to the theoretical point is:

$$g_T = \frac{w_F}{\sin\theta} \tag{I-13}$$

The total frog flangeway gap g_F, in inches, is then:

$$g_F = g_T + d_{GL} \tag{I-14}$$

Substituting (I-13) and (I-10) into (I-14) gives:

$$g_F = \frac{w_F}{\sin\theta} + \frac{n}{2\cos(\theta/2)} \tag{I-15}$$

Because equation (I-2) readily quantifies the frog angle, there is no need to simplify equation (I-15) further for computational purposes. Note that the flangeway width must have units of inches for equation (I-15) to be correct.

By design intent, toe lengths are always long enough to span the frog flangeway gap given by (I-15). For a prototype flangeway width of 1.875 inches [4], Table 1 shows how the flangeway gap increases dramatically with increasing frog number. The frog flangeway gap is almost one foot wide for a No. 5 frog, almost two feet wide for a No. 10, and almost four feet wide for a No. 20 frog. While a wheel flange is in this gap, the wheel on the opposite side of the wheel set must be held against its running rail to ensure that the wheel flange in the frog flangeway gap stays in the proper flangeway. The guard rails make sure that happens. The later discussion of guard rails will make use of equation (I-15).

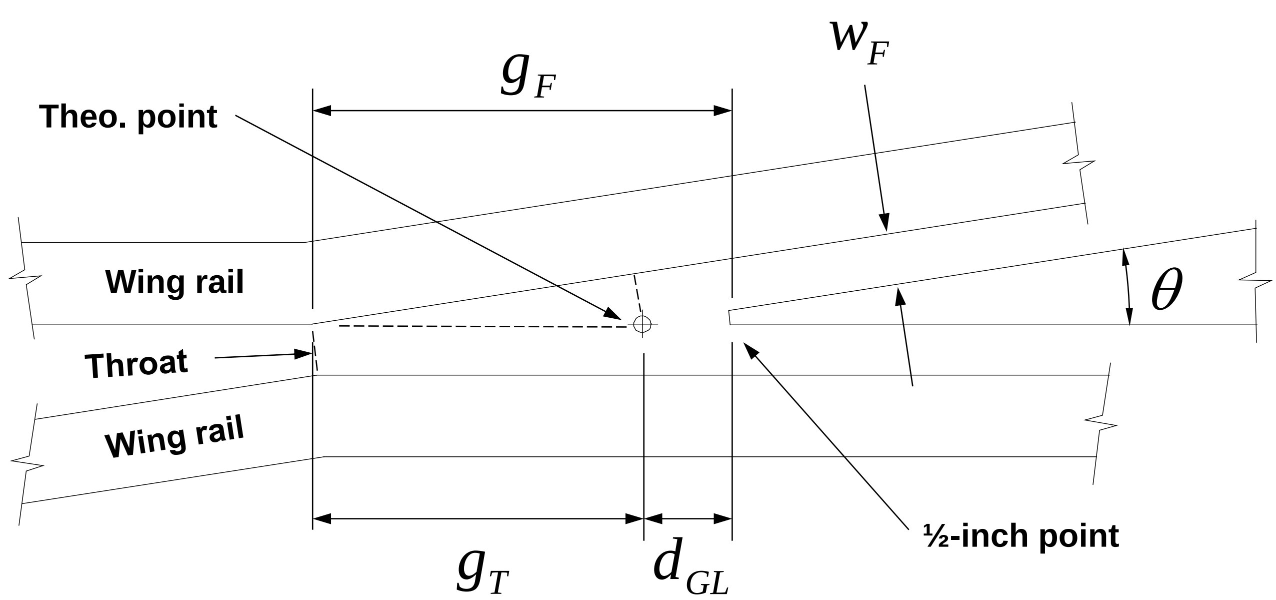


Figure 5: Frog flangeway gap (No. 6 shown)

The first term in equation (I-15) is the distance from the frog throat to the theoretical point, measured along a gauge line. The second term is the cutback distance to the ½-inch point, also along a gauge line, given by equation (I-10). The additional distance making up the toe length is that required by the mechanical features discussed earlier.

Using only the first term from equation (I-15), the part of the *given* theoretical toe length required for the mechanical features described above is:

$$L_{TM} = L_{FT} - \frac{w_F}{\sin\theta} \quad \text{(I-16)}$$

Looking ahead, solving equation (I-16) for the theoretical toe length is useful for model frogs having specified flangeway widths that are wider than the scaled prototype:

$$L_{FT} = L_{TM} + \frac{w_F}{\sin\theta} \quad \text{(I-17)}$$

Similarly, the theoretical heel length must be long enough to accommodate its required mechanical features, but not the flangeway gap already included in the toe length.

Toe and Heel Spread

The AREA also provides values for two other frog parameters, the Toe Spread S_{FT} and the Heel Spread S_{FH}, both measured from the theoretical point of frog (see Figure 2).

The Toe Spread is then:

$$S_{FT} = 2L_{FT}\sin(\theta/2) \quad \text{(I-18)}$$

Similarly, the Heel Spread is:

$$S_{FH} = 2L_{FH}\sin(\theta/2) \quad \text{(I-19)}$$

In (I-18) and (I-19) the toe and heel lengths must be in inches to properly express the spread in inches.

Table 1: Frog Flangeway Gap

Frog No.	Flangeway Gap (in.)	Frog No.	Flangeway Gap (in.)	Frog No.	Flangeway Gap (in.)	Frog No.	Flangeway Gap (in)
5	11.98	9	21.43	13	30.92	17	40.41
6	14.34	10	23.80	14	33.29	18	42.78
7	16.70	11	26.17	15	35.66	19	45.15
8	19.07	12	28.54	16	38.03	20	47.53

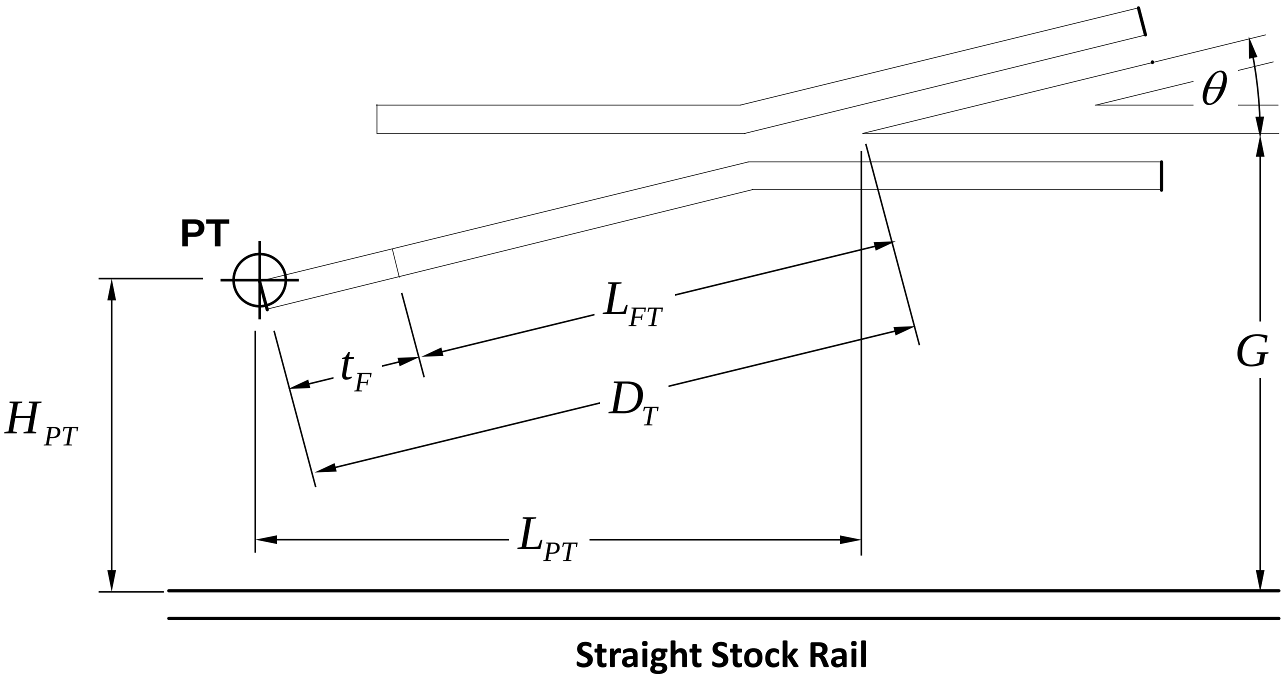


Figure 6: Location of point PT

Point of Tangent (PT) Location

Sometimes the AREA specifies a short tangent extension t_F in front of the frog toe, as in Figure 6. The reasons for using this extension are not clear. In some cases, again for unknown reasons, the extension has a *negative* value.

At the end of this tangent is the point **PT** representing the location where the curved closure rail meets that tangent. If the tangent length is zero, **PT** is at the frog toe. The location of point **PT** relative to the theoretical frog point and the straight stock rail is then:

$$L_{PT} = (L_{FT} + t_F)\cos\theta \qquad \text{(I-20)}$$

And

$$H_{PT} = G - (L_{FT} + t_F)\sin\theta \qquad \text{(I-21)}$$

Equations (I-20) and (I-21) are correct regardless of the algebraic sign of t_F .

Wing Rails

The AREA Plans show frog construction details for bolted rigid frogs, spring rail frogs, rail-bound manganese steel frogs and solid (self-guarding) manganese steel frogs. While the AREA plans specify toe length and heel length for all types, they do not specify the distance from either the ½-inch point or the theoretical point to the heel-end of the wing rails, except for rail-bound manganese steel frogs.

Plan drawings for rail-bound manganese steel frogs do not specifically dimension the wing rail extension length, but imply it as the sum of two other given dimensions, the first from the ½-inch point. Some frog drawings from the PRR show this dimension. By inference, other railroads may as well. Meaningful explanations of how wing rail extension lengths are set have been elusive.

AREA Plans 611-41 through 615-41 show details of rail-bound manganese steel frogs for numbers 4 through 12, 14 through 16, 18 and 20 (the dash number after the AREA Plan number is the adoption or revision year, 1941 in this case). Table 2 compares the computed wing rail length (sum of two dimensions) with other frog dimensions. The fact that the computed values have decimal values to the nearest ¼ inch suggests they are less important and perhaps somewhat arbitrary.

Table 2 shows the AREA wing rail extension lengths in the fifth column as the sum of the two dimensions on the frog drawings. The last column shows the ratio of the extension length to the heel

Table 2: Wing Rail Extension Lengths (in inches, for rail-bound manganese steel frogs)

Frog No.	Toe Length	Heel Length	Total Length	Extension Length	Extension Length / Heel Length
4	40.00	56.00	96.00	35.50	0.598
5	42.50	65.50	108.00	37.75	0.576
6	45.00	75.00	120.00	42.00	0.560
7	56.50	87.50	144.00	46.25	0.529
8	61.00	95.00	156.00	50.50	0.532
9	76.50	115.50	192.00	54.75	0.474
10	77.00	121.00	198.00	59.00	0.488
11	84.00	140.50	224.50	63.25	0.450
12	93.50	150.50	244.00	67.50	0.449
14	103.50	179.50	283.00	82.50	0.460
15	113.00	179.50	292.50	86.75	0.483
16	113.00	199.00	312.00	96.00	0.482
18	132.50	218.50	351.00	104.50	0.478
20	132.50	238.00	370.50	119.50	0.502

length, varying from 0.449 to 0.598, and averaging 0.504.

Wing Rail Flares

Figure 7 shows a flare diagram of a Bolted Rigid Frog, and Figure 8 shows one for a Rail-Bound Manganese Steel Frog. Neither is drawn to scale, but both are exaggerated to show the important details. At the end of the flare is a 3.5-inch by 45-degree vertical bevel, called the *end bevel*, or sometimes the *end chamfer*. The total flare opening, sometimes called the *gather*, is a standard 3.5 inches for all bolted rigid and rail bound manganese steel frogs, measured between the point rail and the wing rail where the flare bevel intersects the end bevel.

Wing Rail Flare – Bolted Rigid Frog

A bolted rigid frog wing rail has a beveled flare in the otherwise straight wing rail extension accomplished by planing the railhead. The bevel length is the same as the flare length, measured from the heel end of the rail. The AREA drawings indicate the flare opening dimension as 3½"+ where the "+" may mean it can be larger, making the 3.5 inch value a minimum.

The flare opening is measured at a depth of 5/8 inches from the top of the railhead, the same depth where track gauge and flangeway width measurements are taken. Measurements at this depth avoid the railhead filet radius, which varies with rail section design. This makes the flare opening at the top of the railhead slightly wider. The flare opening is the sum of the flangeway width w_F and the flare width w_{FL}.

The rail flare is most useful, especially when looking forward to the model, for defining the flare geometry. In the model, the most likely construction method would be to cut the wing rail length first, then introduce the flare bevel (if used), and finally cut the 45-degree end bevel. This appears to be the opposite of prototype construction that likely cuts the end bevel before the flare bevel, then achieving the 3.5-inch flare opening with further planing.

Consider Figure 7. The AREA plans specify the bevel length L_{BV}, which is the same as the flare length L_{FL}. Thus, from similar triangles, the flare width is:

$$w_{FL} = \frac{1.9375\,L_{FL}}{L_{FL} - 3.5} \qquad \text{(I-22)}$$

The 1.9375 constant in equation (I-22) comes from examination of AREA Plan 320. The wing rail end view geometry detail sets the flare width at $0.625\tan 25^o + 3.5 - 1.875 = 1.916442$ inches.

Rounding the first term in that calculation (0.291 inches) to the nearest 1/16th inch, as the AREA does on Plan 600, gives 5/16 or 0.3125 inches. Thus the flare width at the top of the wing rail end bevel is $0.3125 + 3.5 - 1.875 = 1.9375$ inches.

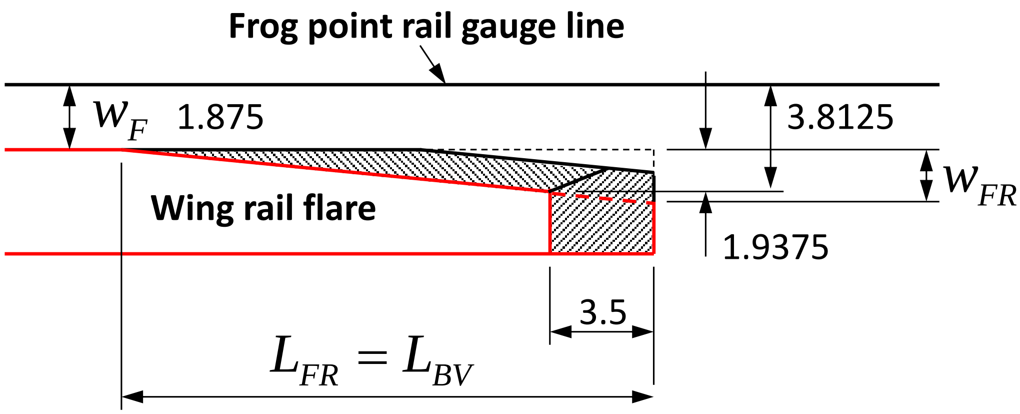


Figure 7: Bolted Rigid Frog End Flare (not to scale)

Wing Rail Flare - Rail Bound Manganese Steel

A wing rail for a rail-bound manganese steel frog has a double bend in the wing rail extension and is planed into a bevel to form the full flare when combined with the cast manganese steel insert. This complicates the flare geometry, as Figure 8 shows. Again, the AREA plans specify the bevel length, L_{BV}. The remainder of the flare, part of the full flare length L_{FL}, is cast into the manganese insert.

Thus, from similar triangles:

$$\frac{w_{FL} - 0.375}{L_{BV}} = \frac{1.9375 - 0.375}{L_{BV} - 3.5} \tag{I-23}$$

Solving for the flare width:

$$w_{FL} = \frac{1.5625 L_{BV}}{L_{BV} - 3.5} + 0.375 \tag{I-24}$$

Then, again by similar triangles:

$$\frac{w_{FL}}{L_{FL}} = \frac{1.9375 - 0.375}{L_{BV} - 3.5} \tag{I-25}$$

Substituting equation (I-24) into (I-25) and solving for the total flare length:

$$L_{FL} = 1.24 L_{BV} - 0.84 \tag{I-26}$$

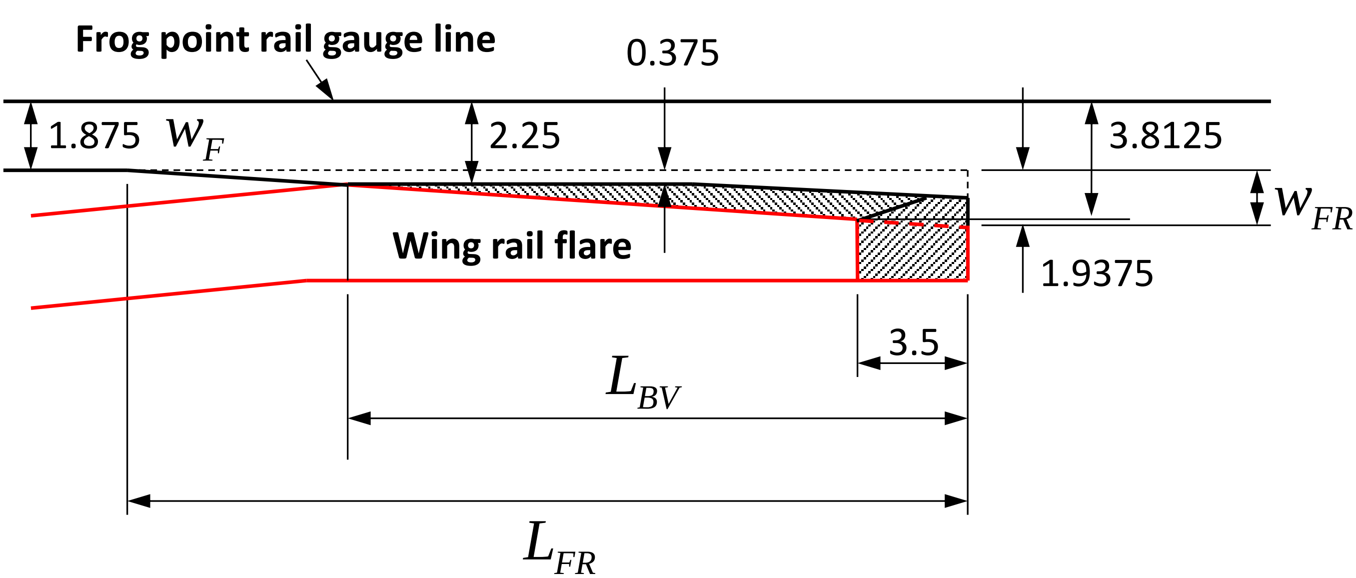


Figure 8: Rail Bound Manganese Steel Frog End Flare (not to scale)

By similar triangles the plane width at the end of the wing rail is:

$$w_{BP} = \frac{0.375 L_{FL}}{L_{FL} - L_{BV}} \quad \text{(I-27)}$$

Solid manganese steel frogs (self-guarding or not) have a cast-in flare with a single planed bevel. Dimensions vary widely with frog number and rail weight. Their details are beyond the scope of this TN.

Frog Dimension Summary

The AREA specifies dimensions for Bolted Rigid Frogs for No. 4 through No. 12. Rail-Bound Manganese Steel frogs have the same basic dimensions, but with frog numbers that extend to No. 20.

When used in a turnout assembly, the AREA sometimes specifies a tangent extension at the frog toe that depends on the frog number and the type of switch (discussed in the next section). The reasons for using this extension are not clear. More surprisingly, some values are negative, effectively decreasing the toe length.

Table 3 gives the principle frog dimensions, dependent on the frog number (columns 1), as specified by the AREA plans. The AREA specifies dimensions in feet and fractional inches. Table 3 converts them to decimal inches. Measurements of the toe and heel lengths (col. 2 and 3) are from the frog ½-inch point. Total frog length (col. 4) is always the sum of the toe and heel lengths, regardless the frog point from which they are measured. The AREA plans specify the extra tangent lengths in decimal feet. Table 3 lists them in decimal inches.

The AREA plans specify toe and heel lengths (col. 2 and 3 in Table 3) to the nearest ½ inch. This suggests that they are not rigorously calculated values, and must be at least somewhat arbitrary. For that reason, estimates of frog dimensions for the missing frog numbers are simply averages of the adjacent frog number values. The extra tangents are similarly averaged, while the No. 4 extra tangents are values extrapolated using the No. 5 and No. 6 values. Table 4 shows an expanded set of frog dimensions with the estimated values in the cells highlighted in yellow.

Table 3: AREA Frog Dimensions

Frog No.	Toe Length (in)	Heel Length (in)	Total Length (in)	Straight Switch Extra Tangent (in)	Curved Switch Extra Tangent (in)
4	40.0000	56.0000	96.0000	Not specified	Not specified
5	42.5000	65.5000	108.0000	9.3600	0.0000
6	45.0000	75.0000	120.0000	21.0000	0.0000
7	56.5000	87.5000	144.0000	0.0000	6.2400
8	61.0000	95.0000	156.0000	0.0000	0.0000
9	76.5000	115.5000	192.0000	2.0400	-8.0400
10	77.0000	121.0000	198.0000	0.0000	0.0000
11	84.0000	140.5000	224.5000	1.5600	-3.8400
12	93.5000	150.5000	244.0000	6.0000	7.3200
14	103.5000	179.5000	283.0000	0.0000	7.9200
15	113.0000	179.5000	292.5000	0.0000	-0.7200
16	113.0000	199.0000	312.0000	0.0000	-9.3600
18	132.5000	218.5000	351.0000	0.0000	11.0400
20	132.5000	238.0000	370.5000	0.0000	-3.2400

Switches

There are three basic types of switches, two of which the AREA specifies. The first, and most common, is the *split switch*. The second type is the occasionally used *spring switch*, and the third is the essentially obsolete *stub switch*. This TN addresses only the split switch.

A split switch consists of a pair of tapered switch rails, pivoting at their heels, connected by one or more switch rods near the point of the switch. This connection allows the switch rails to operate together. When one switch rail closes against the adjacent stock rail, the other opens, diverting the train to the desired route. The headblocks (long ties), straddling the first switch rod, support a manually operated

Table 4: Expanded AREA Frog Dimensions

Frog No.	Toe Length (in)	Heel Length (in)	Total Length (in)	Straight Switch Extra Tangent (in)	Curved Switch Extra Tangent (in)
4	40.0000	56.0000	96.0000	-2.2800	0.0000
5	42.5000	65.5000	108.0000	9.3600	0.0000
6	45.0000	75.0000	120.0000	21.0000	0.0000
7	56.5000	87.5000	144.0000	0.0000	6.2400
8	61.0000	95.0000	156.0000	0.0000	0.0000
9	76.5000	115.5000	192.0000	2.0400	-8.0400
10	77.0000	121.0000	198.0000	0.0000	0.0000
11	84.0000	140.5000	224.5000	1.5600	-3.8400
12	93.5000	150.5000	244.0000	6.0000	7.3200
13	98.5000	165.0000	263.5000	3.0000	7.6200
14	103.5000	179.5000	283.0000	0.0000	7.9200
15	113.0000	179.5000	292.5000	0.0000	-0.7200
16	113.0000	199.0000	312.0000	0.0000	-9.3600
17	122.7500	208.7500	331.5000	0.0000	0.8400
18	132.5000	218.5000	351.0000	0.0000	11.0400
19	132.5000	228.2500	360.7500	0.0000	3.9000
20	132.5000	238.0000	370.5000	0.0000	-3.2400

switch stand or a remotely operated actuator (mechanical, pneumatic or motorized). The actuator, attached to the first switch rod, moves the switch aligning it with either the normal or the reverse route.

Turnout fabricators cut switch rails from standard length rail stock, historically 33 or 39 feet. To minimize scrap, switch rails are typically ¼, ⅓ or ½ these lengths, or the full length. The AREA Plans specify common lengths of 11'-0", 16'-6", 22'-0", 19'-6", and 39'-0". They also specify 30'-0" switch rails, but not 33'-0" switch rails. An early switch diagram for the PRR shows an 8'-3" switch rail (¼ of 33 feet).

The AREA describes split switches as one of two types, the *straight rail* and *curved rail* type, named for the type of switch rail that diverts the train to the reverse route. Regardless of switch type, the switch rail that directs a train to the normal route is always straight. AREA Plan 221-40 shows three details for the point ends of switch and stock rails. It identifies which detail applies to the construction of which variety of switch as indicated in Table 5.

Although not explicitly stated on the AREA plans, a switch point rail has a slight bend located about ⅓ to ½ of its length from the switch point, depending on the switch point length (Figure 9). When the railhead is planed to match the gauge lines, the bend ensures adequate rail web thickness remains for strength. The reinforcing bars mounted on each side of the planed switch point rail provide additional strength and restore much of the stiffness lost by railhead planing.

Straight Switches

Because of their taper, the switch rails also form an infinitely sharp point. Again, engineers cut the switch rails back from the theoretical point, this time to where the thickness of the switch point, t_P, is ⅛-inch. The switch rail length L_S is the distance from the ⅛-inch point to the switch heel. Switch point thickness is the same for all straight switch lengths. For some straight switch turnout numbers the AREA includes a short tangent beyond the switch heel. At

Table 5: Switch Point Construction Details (AREA Plan 221-40)

Detail No:	Straight Switch	Curved Switch
4000	Alternate	Alternate
5000	Alternate	**Preferred**
6100	**Preferred**	Alternate

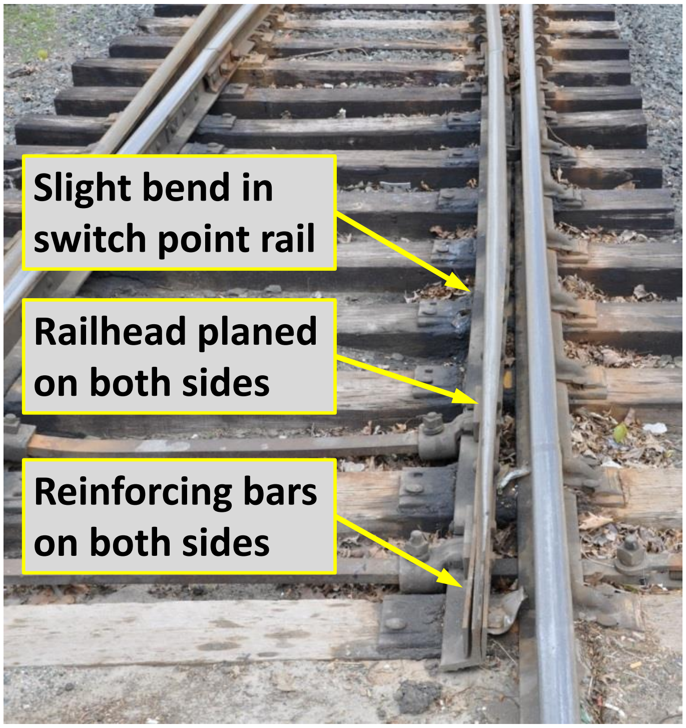


Figure 9: Switch Point Rail Bend ***Van S. Fehr photo***

the end of this tangent (which can be zero length) is the point **PC** indicating the location where the curved closure rail begins.

Straight Switch Geometry

Straight switches are geometrically simple. Figure 10 illustrates the geometry of a straight switch rail, exaggerated to show the switch angle ϕ more clearly. A fundamental question about switch geometry is "Which parameters are specified (given), and which are derived from the given parameters?" The AREA specifies switch length because specific lengths are readily cut from standard-length rail stock. It also specifies the heel spread, S_{SH}, (switch heel gauge- line separation from adjacent straight stock rail gauge line), standardized at 6¼ inches for all AREA switches (the AREA also standardizes switch throw at 4¾ inches).

The distance from the switch point to the switch heel, aligned with the normal route, is always equal to the switch length L_S. Thus, derived from the geometry in Figure 10:

$$\phi_S = \arcsin\left(\frac{S_{SH} - t_P}{L_S}\right) \qquad \text{(I-28)}$$

For example, if the switch rail length L_S is 16'-6" (198 inches), then:

$$\phi_S = \arcsin\left(\frac{6.25 - 0.125}{198}\right) = 1.772690122 \ \text{deg.}$$

Expressed in degrees-minutes-seconds:

$$\phi_S = 1^0\ 46'\ 21.684''$$

Point of Curve **(PC)** ***Location***

Sometimes the AREA specifies a short tangent extension t_S after the switch heel. The reasons for using this extension are not clear. At the end of this tangent is the point **PC** representing the location where the tangent meets the curved closure rail. If the tangent length is zero, **PC** is at the switch heel. The location of point **PC** relative to the switch point and the straight stock rail is then:

$$L_{PC} = L_S + t_S \cos\phi_S \qquad \text{(I-29)}$$

$$H_{PC} = S_{SH} + t_S \sin\phi_S \qquad \text{(I-30)}$$

AREA Straight Switch Consistency Evaluation

When rounded to the nearest second of arc, the result above agrees with the switch angle annotated 1-46-22 on AREA Plan 111-41 [4]. The same calculation agrees with switch angles for all the switch lengths tabulated on Plan 910-41 [4], as Table 6 quantifies. Because the switch rail is straight, the point angle γ is the same as the switch angle.

For either type of switch rail, the switch angle (straight switches) or heel angle (curved switches) is a key switch parameter affecting the geometry of the curved closure rail (See ***Turnout Lead*** below). While there is a shallow angular kink at the switch point, turnout designers allow no kink where the switch rail meets the curved closure rail.

Hay [2] states the practical switch angle is often one-fourth (0.25) of the frog angle, or in some cases 2/7 (0.2857) of the frog angle. These ratios limit the abrupt transition of rolling stock entering the reverse route of the turnout. Detailed examination of the AREA dimensions for straight switches shows this ratio actually varies between 0.217 and 0.340, so these ratios must only be guidelines. Given a standardized heel spread of 6.25 inches [4], AREA switch

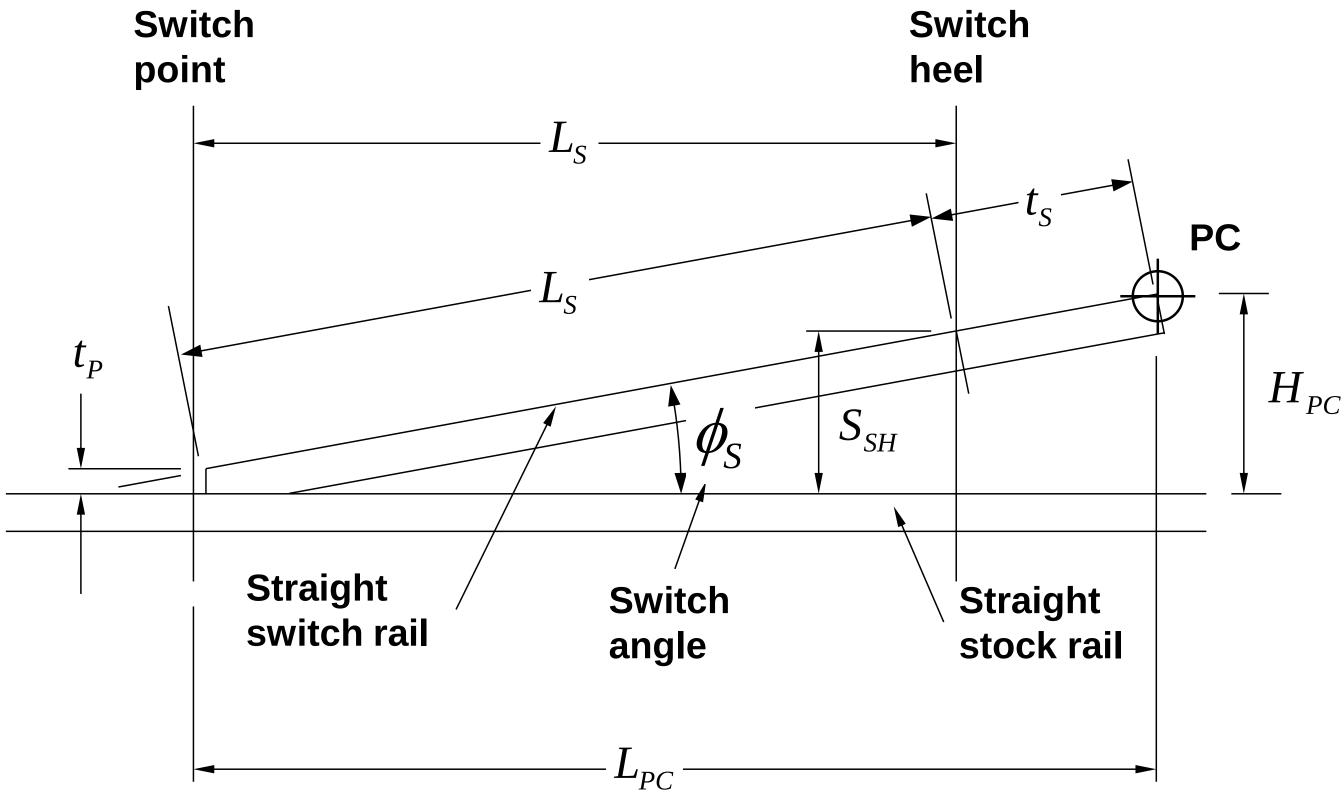


Figure 10: Straight switch rail geometry and location of point PC (no scale)

angles are a direct consequence of switch rail length and point thickness given by (I-28).

Curved Switches

The AREA plans define the distance between the switch point and switch heel the same way for curved switches. Additionally, the plans present three different curved switch rail designs (A, B and Alternate) tabulated on AREA Plan 920-41. Details for Design A and Design B appear on the switch rail plans, but not for the Alternate Design. The primary differences seem to be in the planing of the stock rail, the switch rail radius and the details of the taper. However, all three design types, for a specified switch rail length and frog number, share the same switch heel angle. The mathematical tangent to the switch rail radius at the switch heel equals the tangent of the switch angle. Neither Hay [2] nor Droege [3] discuss how the switch heel and point angles are set for curved switches.

The presentation of curved switch designs in [4] requires some interpretation. There is a set of two plans for each switch length in the AREA Plans, one for graduated risers[4] and one for uniform risers. There are five switch lengths, 11’-0”, 16’-6”, 19’-6”, 30’-0” and 39’-0”. There are notes on each plan that include the following statement: *For right-hand turnouts the right-hand switch point and left-hand stock rail are straight, and the left-hand switch point and right-hand stock rail are curved.* They also include the logical opposite statement: *For left-hand turnouts the left-hand switch point and right-hand stock rail are straight, and the right-hand switch point and left-hand stock rail are curved.* While

Table 6: Straight Switch – Calculated Switch Angle vs. AREA Switch Angle (Plan 910-41)

Length (ft)	Exact angle (deg.)	Deg.-Min.-Sec.	Rounded	AREA
11.0	2.659565950	2-39-34.437	2-39-34	2-39-34
16.5	1.772690122	1-46-21.684	1-46-22	1-46-22
22.0	1.329424775	1-19-45.929	1-19-46	1-19-46
30.0	0.974871063	0-58-29.536	0-58-30	0-58-30

wordy, both of these statements are logical and make physical sense.

Another note for curved switches on each plan states: *Point planing per Detail 6100, and point and stock rail alinement* [older spelling of “alignment”] *per Design B shown on this plan*. One more note states: *Point planing per Detail 4000.* Plan 221-40 shows details 6100, 5000, and 4000. The switch plans themselves show drawings of Design A (detail 5000) and Design B (detail 6100), but not the Alternate design (detail 4000). The primary visual difference between Designs A and B is that Design A shows a narrowing of the stock rail railhead over the switch planing distance while Design B does not. The Alternate design appears to call for a point cutback of ¼ inch, followed by an additional chamfer cut to 1/16 inch.

The Design A and Design B diagrams for the 11’-0” switch length are different than the same design diagrams for the longer length switches. For the 11’-0” length the design diagrams show the curved switch rail and its radius, and the adjacent straight stock rail. For the longer switch rail lengths, the design diagrams show the straight switch rail, and the adjacent curved stock rail and its radius. For the longer length switches that means the radius of the curved switch rail R_S must be the radius of the curved stock rail R_{STK} plus the track gauge distance G:

$$R_S = R_{STK} + G \qquad \text{(I-31)}$$

For the 11’-0” switches the radius of the curved stock rail must be the radius of the curved switch rail minus the gauge distance:

$$R_{STK} = R_S - G \qquad \text{(I-32)}$$

Then, for all switch lengths the switch centerline radius R_{SCL} is:

$$R_{SCL} = R_S - \frac{G}{2} \qquad \text{(I-33)}$$

Table 7 compares the switch rail radii from the AREA switch design diagrams with those specified on AREA Plan 920-41. The boldface values in the second and third columns are from the AREA design diagrams on the curved switch plans for the specified switch lengths. The other values are calculated results from the appropriate choice of equation (I-31) or (I-32) using G = 4.70833 feet (56.5 inches).

All of the switch radius values given in AREA Plan 920-41 match the values given in column three, except for that of the 30’0” switch Design A, highlighted in yellow. Without a documented reason for this difference, the value in Plan 920-41 must be in error because all the other values are consistent with the calculations. In the 1940’s, when draftsmen lettered engineering drawings by hand, a scribbled “8” could be easily misread as a “3.” Whether this has been corrected in later revisions of Plan 920 is not known. There are no diagrams for the Alternate Design.

Curved Switch Geometry

Curved switches, while visually simple, are geometrically more complicated than straight switches. They require more parameters for a complete description. Figure 11 illustrates a geometric diagram of the curved switch rail exaggerated to show the details and its parameters. It shows only the gauge lines of the curved switch rail and the straight stock rail (blue lines).

Unlike the straight switch, the AREA does not

Table 7: Curved Switch Rail Radius (feet) Comparisons

Switch Length	Stock rail radius	Switch rail radius	Plan 920-41
11’-0” Design A	255.30	**260.01**	260.01
11’-0” Design B	244.50	**249.21**	249.21
19’-6” Design A	**796.98**	801.69	801.69
19’-6” Design B	**763.61**	768.32	768.32
30’-0” Design A	**2084.63**	2089.34	2039.34
30’-0” Design B	**1988.48**	1993.19	1993.19
39’-0” Design A	**3201.43**	3206.14	3206.14
39’-0” Design B	**3066.85**	3071.56	3071.56

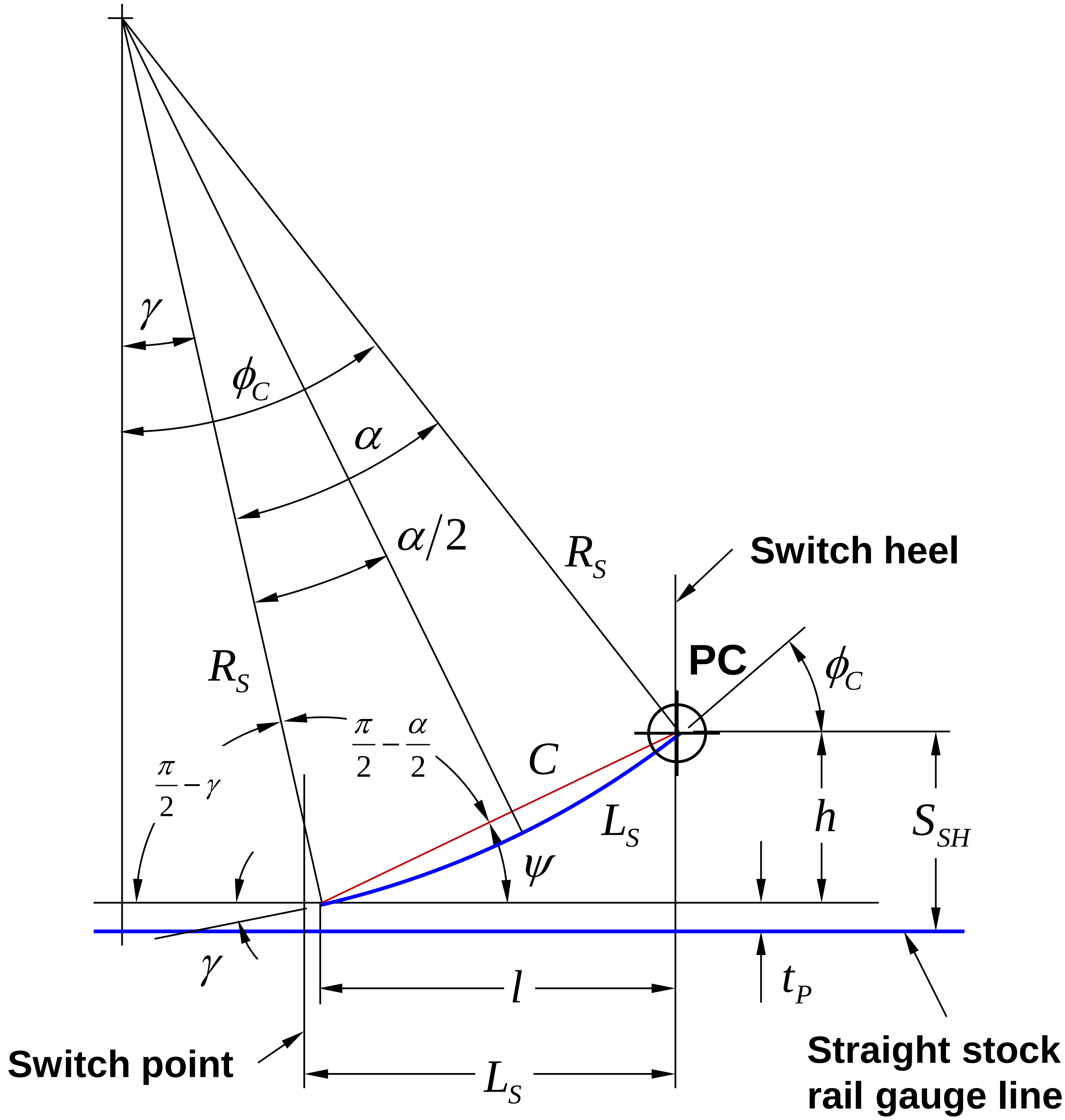


Figure 11: Curved switch rail geometry and location of point PC (no scale)

specify a short tangent after the switch heel for a curved switch. Thus, the curved switch location of point **PC** is simply:

$$L_{PC} = L_S \quad \text{(I-34)}$$

And

$$H_{PC} = S_{SH} \quad \text{(I-35)}$$

These are the same equations as the straight switch **PC** location with t_S set to zero.

For each curved switch rail design, the AREA drawing dimensions indicate the switch rail gauge line is a circular arc of radius R_S and arc length L_S, indicated by the curved blue line in Figure 11.

Some basic geometric equations derive from the geometry in Figure 11. The angle α (in radians) subtended by the circular arc of the switch rail is:

$$\alpha = \frac{L_S}{R_S} \quad \text{(I-36)}$$

The subtended angle is also expressed:

$$\alpha = \phi_C - \gamma \qquad \text{(I-37)}$$

In equation (I-37) γ is the point angle. Unlike straight switches, the point angle for curved switches is not the same as the switch angle ϕ_S (here called the heel angle). The red line Figure 11 indicates the chord C connecting the end points of the switch rail. Its length is:

$$C = 2R_S \sin\left(\frac{\alpha}{2}\right) \qquad \text{(I-38)}$$

The perpendicular distance S_{SH} from the stock rail locates the heel spread of the curved switch rail. The other end is the distance of the switch point thickness t_P from the stock rail. The distance h of the switch heel above the switch point is then:

$$h = S_{SH} - t_P \qquad \text{(I-39)}$$

The projection l of the switch rail chord length along the straight stock rail is then:

$$l = \sqrt{C^2 - h^2} \qquad \text{(I-40)}$$

The angle ψ the chord makes with the stock rail is:

$$\psi = \arctan\left(\frac{h}{l}\right) \qquad \text{(I-41)}$$

From plane geometry, the chord angle is also:

$$\psi = \frac{1}{2}(\phi_C + \gamma) \qquad \text{(I-42)}$$

Like the straight switch rail, a fundamental question about curved switch rails is which parameters are specified (given), and which are derived from the given parameters.

For the curved switch the AREA also specifies the switch rail length and a standardized heel spread (6¼ inches), so these are known quantities. The AREA specifies the same switch heel angle for each curved switch rail design (A, B and Alternate). This implies, but in no way proves, that the curved switch heel angle may be set for reasons not determined here. Each design also specifies an associated switch rail radius and switch rail point thickness.

The minimum information required to uniquely define the curved switch rail geometry are its length L_S, the point angle γ, and the heel angle ϕ_C (the specified heel spread is the same for all turnouts). Specified values for these three dimensions lead to a simple expression for the curved switch rail radius:

$$R_S = \frac{L_S}{(\phi_C - \gamma)} \qquad \text{(I-43)}$$

However, when only the curved switch rail length and one of the two angles are given, the mathematics for finding the unknown angle is more complicated. Substituting (I-36) and (I-37) into (I-38) gives:

$$C = \frac{2L_S}{(\phi_C - \gamma)} \sin\left(\frac{\phi_C - \gamma}{2}\right) \qquad \text{(I-44)}$$

From Figure 11 C is also:

$$C = \frac{h}{\sin\left(\frac{\phi_C + \gamma}{2}\right)} \qquad \text{(I-45)}$$

Equating (I-44) and (I-45), then solving for L_S:

$$L_S = \frac{h(\phi_C - \gamma)}{2\sin\left(\frac{\phi_C + \gamma}{2}\right)\sin\left(\frac{\phi_C - \gamma}{2}\right)} \qquad \text{(I-46)}$$

Noting the trigonometric identity:

$$\cos\gamma - \cos\phi_C = 2\sin\left(\frac{\phi_C + \gamma}{2}\right)\sin\left(\frac{\phi_C - \gamma}{2}\right) \qquad \text{(I-47)}$$

Substituting (I-47) into (I-46) gives:

$$L_S = \frac{h(\phi_C - \gamma)}{(\cos\gamma - \cos\phi_C)} \qquad \text{(I-48)}$$

Equation (I-48) requires angles expressed in radians. When the point and heel angles are given, the switch rail length comes directly from (I-48).

Although valid, equation (I-48) is a transcendental equation that cannot be solved algebraically for one of the angles when given the other and the switch rail length. In this case the solution is found using a numerical iteration procedure, finding the roots of (I-48) rewritten as:

$$L_S(\cos\gamma - \cos\phi_C) - h(\phi_C - \gamma) = 0 \qquad \text{(I-49)}$$

Using (I-49) instead of (I-48) avoids the possibility of division by zero while searching for the roots.

AREA Curved Switch Consistency Evaluation

The equations above allow evaluation of the consistency of the specified switch dimension. The dimensions are *consistent* when their specified and computed values differ by 0.5% (See **EXECUTIVE SUMMARY** for definition). In addition to the heel spread S_{SH}, and point thickness t_P, which are always given, taking two additional specified dimensions as input, the equations above produce computed values for the others. To determine consistency, examination of three useful options is appropriate:

1. Given ϕ_C and γ, find L_S
2. Given L_S and ϕ_C, find γ
3. Given L_S and γ, find ϕ_C

For the first option, equation (I-48) produces a value for L_S. The second and third options require a numerical solution of equation (I-49). For each option, after determining the unknown value, finding the corresponding switch rail radius using equations (I-43) is straightforward.

The companion MS-Excel spreadsheet *NMRA TN-12 AREA Curved Switch Consistency Evaluation.xls* [28] makes the calculations for each of the three options for the AREA curved switch plans. It has two computational approaches, one that calculates exact values and another that rounds the exact values in the same manner as the AREA, specifically:

Angles:	1 arc-sec.
Radii and extra tangents:	0.01 ft.

All Others: nearest feet-inches:

Lead & closure distances:	¼ in.
Gage line point (location):	¼ in.
Gage line offsets (lateral):	1/16 in.
Frog lengths:	½ in.
Frog spreads:	1/16 in.
Crossover dimensions:	1/16 in.

To be fair, the evaluation compares the rounded exact values to the AREA tabulated values. The spreadsheet shows the differences between the rounded exact values and tabulated values for all three possibilities are in the range of -0.2586% to 0.1734%. Because these percentages are so small, of absolute value 0.5% or less, the AREA tabulated dimensions are consistent. Their consistency also validates the equations used to compute the exact (and rounded) values. Note that the spreadsheet calculations use the corrected value of 2089.34 feet for the Design A 30-foot switch rail radius reported in Table 7.

Switch Heel Spread

Switch heel spread is an important turnout parameter that significantly affects the calculation of other turnout dimensions. It directly affects the switch angle or switch heel angle, which in turn affects the radius of the curved closure rail and finally the turnout lead.

Figure 12 shows a schematic (no scale) cross-section of the switch through the switch heel, with a wheel located on the stock rail (various fillet radii are not shown). Regardless of the frog number or switch type, the AREA specifies the switch heel spread as $S_{SH} = 6.25$ inches.

Examination of Figure 12 reveals some observations. The switch heel flange clearance is:

$$h_F = S_{SH} - w_{HD} - t \qquad \text{(I-50)}$$

In equation (I-50) w_{HD} is the railhead width and t is the flange thickness. While equation (I-50) is geometrically correct, the AREA plans give no information suggesting that it is used to set the heel spread or heel rail clearance h_W.

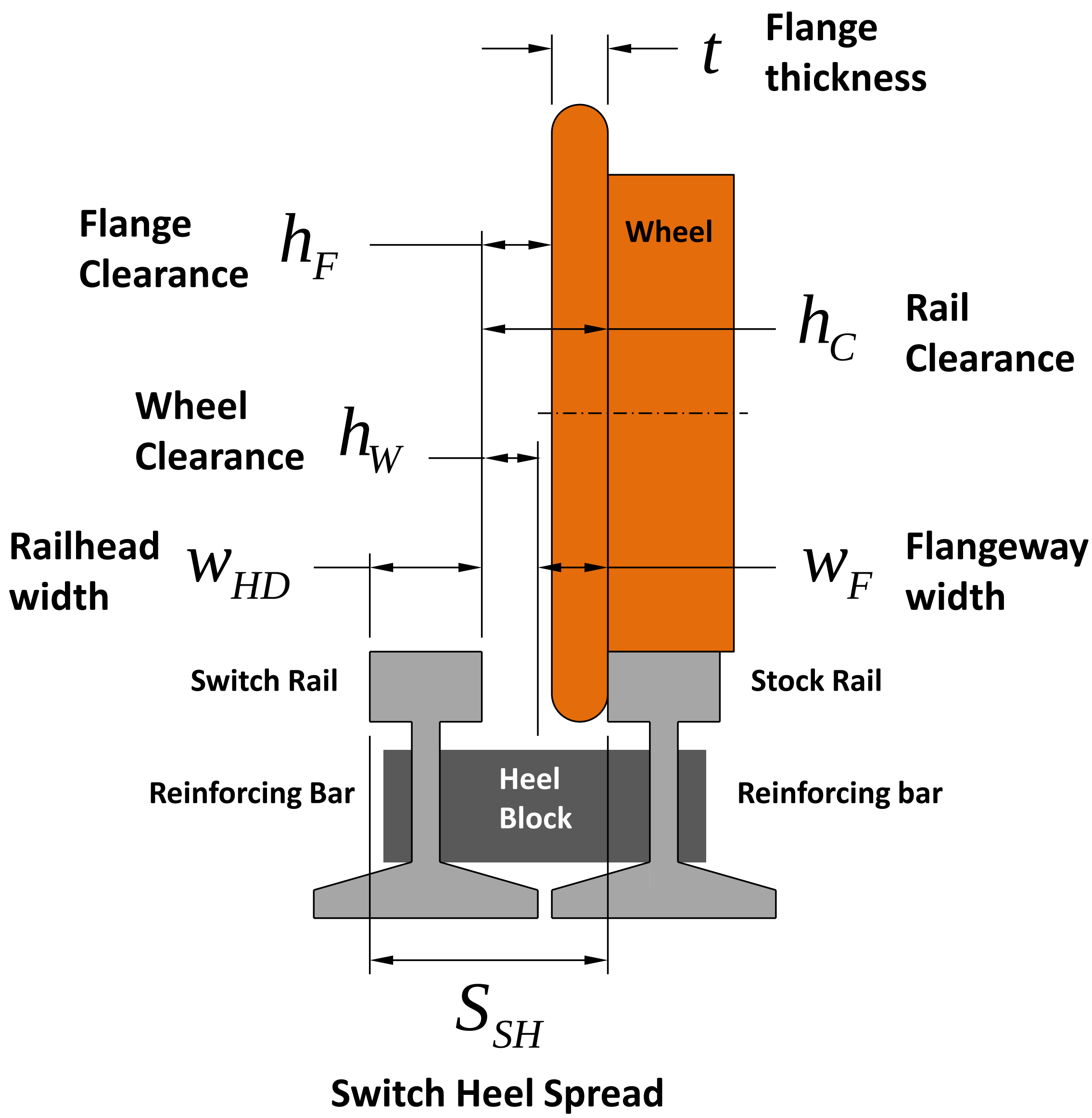


Figure 12: Switch Heel Spread Diagram (no scale)

However, there are some AREA dimensions that can be used with equation (I-50) to compute a nominal switch heel rail clearance. AREA Plan 793 shows 1-5/32 inch and 1⅜ inch flange thicknesses for narrow and wide flanges, respectively. AREA Plan 1001 specifies railhead widths of no more than three inches for 100 lb. rail or heavier, and slightly narrower for lighter rail.

Conservatively using the widest railhead (3 inches for 131 lb. rail) and the thickest wheel flange $t = 1.375$ inches, the switch heel flange clearance becomes:

$$h_F = 6.25 - 3.0 - 1.375 = 1.875 \text{ inches}$$

Perhaps coincidentally, this clearance is also the AREA standard flangeway width, $w_F = 1.875$ inches, although there is no flangeway present at the switch heel. Additionally, the wheel clearance h_W, in terms of the flangeway width is:

$$h_W = 6.25 - 3.0 - 1.875 = 1.375 \text{ inches}$$

Looking ahead to the model, these observations suggest two methods for setting switch heel spread, both fully described in **PART III**.

Switch Heel Angle Relationship

Equations (I-28) and (I-48) express the relationships between the switch length and switch angles

Table 8: Switch Heel Angle Relationship

Switch Length (ft)	Curved Switch ϕ_C (deg.)	Straight Switch ϕ_S (deg.)	Ratio, ϕ_C / ϕ_S
11	3.924167	2.659566	1.475491
19.5	2.226944	1.499901	1.484728
30	1.406111	0.974871	1.442356
39	1.113611	0.749886	1.485040
		Average:	**1.471904**

for straight and curved switches, respectively. Both are dependent on the switch heel spread and point thickness expressed by equation (I-39). These equations suggest there is a relationship between the curved switch and straight switch heel angles.

Consider Table 8 that lists the four switch lengths the AREA specifies for curved switches in the first column. The second column lists the corresponding curved switch heel angles, converted to decimal form. Column three lists the straight switch angles computed using equation (I-28) with the standard 6¼ inch heel spread and a ⅛ inch straight switch point thickness. Finally, column four lists the ratio of the curved switch heel angle to the straight switch angle.

Notice that the ratio is nearly constant, suggesting that the curved switch heel angle is proportional to the straight switch angle:

$$\phi_C = k\phi_S \qquad \text{(I-51)}$$

Taking the proportionality factor k as the average of the ratio values in column four:

$$k = 1.471904$$

This does not explain how the AREA sets curved switch heel angles, but looking ahead this relationship is useful for model turnout design calculations discussed **in PART III**.

Turnout Lead

According to Droege [3], the AREA lead values are somewhat arbitrary, close to "computed" leads, but selected to minimize rail cutting by using standard rail-stock lengths of 18, 24, 27 and 30 feet. Droege does not explain how lead is computed. Achieving a desired lead may be another explanation for the short tangents sometimes specified ahead of the frog and/or after the switch heel.

Described earlier, turnout *lead* is the distance from the point of switch to the ½-inch point of frog, measured along the normal route of the turnout. The theoretical lead, used as a mathematical convenience in this section, is the distance from the point of switch to the theoretical point of frog.

Figure 13 shows the positions of the switch and frog in a turnout. For each of its turnout designs, the AREA defines points **PC** and **PT** at the ends of the curved closure rail. As described earlier, their positions relative to the switch and frog points are a direct consequence of the switch and frog dimensions. The distance between the switch heel and the frog toe, measured along the straight closure rail (normal route), is the *closure lead*. This is also the length of the straight closure rail.

Determining the lead dimension requires two fundamental and reasonable assumptions made at the outset:

1. Specified (given) quantities are the track gauge, switch dimensions, and frog dimensions.
2. The mathematical shape of the curved closure rail is continuous and differentiable.

The first assumption is consistent with the dimensions the AREA presents in its *Trackwork Plans & Specifications* portfolio [4]. For each turnout, identified by its frog number, the AREA specifies only one set of corresponding frog dimensions. That set of frog dimensions applies whether the switch is the curved or straight type. There is only one set of straight switch dimensions for each specified frog number, characterized by the switch rail length and switch angle (at its heel). There are three sets of curved switch dimensions the AREA labels as Design A, Design B, and Alternate Design. Nevertheless, each of these three designs has the same switch rail length and the same switch heel angle. That means the reverse route curvature and turnout lead

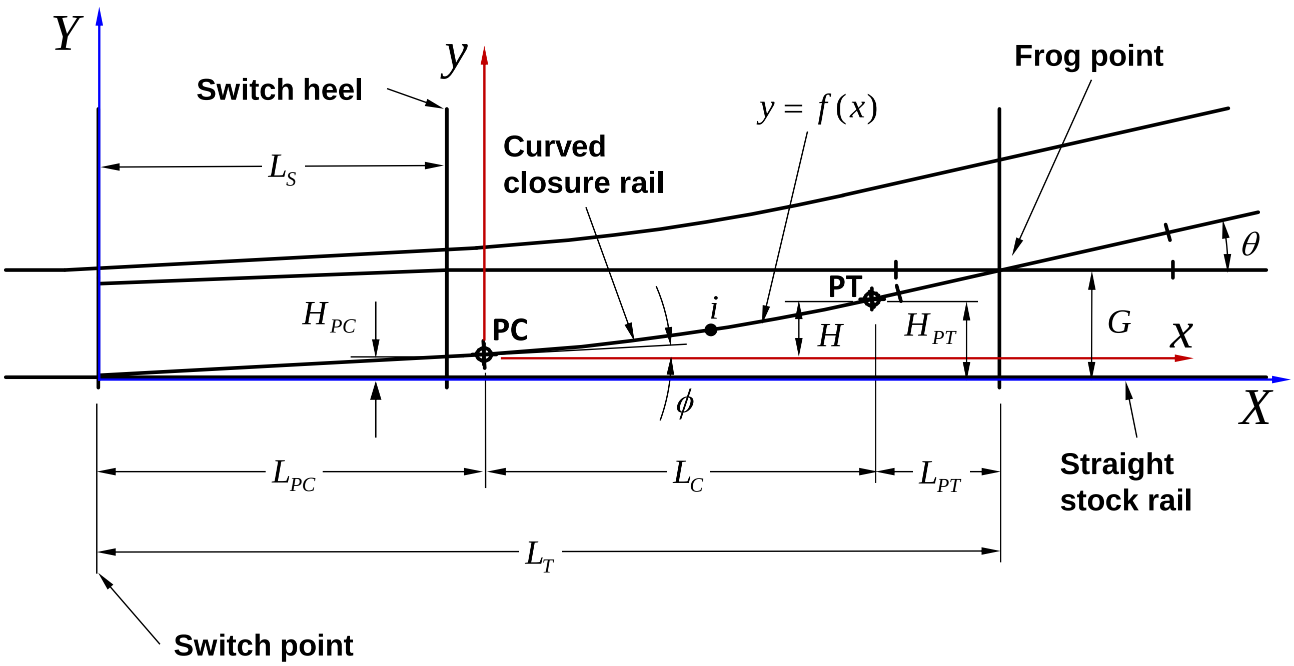


Figure 13: Turnout geometry for lead determination

are independent of the type of curved switch design (A, B or Alternate).

Except for the acceptably shallow switch point angle, the second assumption ensures rolling stock encounters no lateral or angular discontinuities (offsets or kinks) in the rails. This minimizes the potential for derailments and excessive wear. For straight switches, the point angle is the same as the heel angle. The AREA specifies a different point angle for each curved switch design.

Frog and Switch Locations

The earlier sections on frogs and switches developed equations for the locations of point **PC** and **PT**, repeated here for convenience. The location of point **PT**, relative to the theoretical point of frog, is:

$$L_{PT} = \left(L_{FT} + t_F\right)\cos\theta \qquad \text{(I-52)}$$

$$H_{PT} = G - \left(L_{FT} + t_F\right)\sin\theta \qquad \text{(I-53)}$$

The location of point **PC**, for a straight switch, relative to the point of switch, is:

$$L_{PC} = L_S + t_S\cos\phi_S \qquad \text{(I-54)}$$

$$H_{PC} = S_{SH} + t_S\sin\phi_S \qquad \text{(I-55)}$$

Recall there is no short tangent specified for curved switches. That means the equations locating point **PC** for a straight switch apply to a curved switch with $t_S = 0$.

Curved Closure Rail

As another mathematical convenience, the curved closure rail is located in a rectangular *xy*-coordinate system whose origin is coincident with point **PC**. The *x*-axis is parallel to the normal route (see Figure 13).

The *y*-direction distance *H*, which is independent of the type of curved closure rail curve, is then:

$$H = H_{PT} - H_{PC} \qquad \text{(I-56)}$$

The distance L_C, measured along the *x*-axis between **PC** and **PT**, depends on the shape of the curved closure rail. This distance is not the same as the straight closure rail length.

To be acceptable as a smooth reverse route curve (assumption 2), *any* curved closure rail shape $y = f(x)$ must pass through the point **PC** at the switch (or heel) angle and pass through the point **PT** at the frog angle. These requirements define four *boundary conditions* expressed mathematically as:

At $x = 0, y = 0$ (I-57)

At $x = 0, y' = \tan\phi$ (I-58)

At $x = L_C, y = H$ (I-59)

At $x = L_C, y' = \tan\theta$ (I-60)

In these boundary condition equations, y' indicates the first derivative of y with respect to x (i.e., the slope). Note the absence of the subscript on the heel angle ϕ in equation (I-58). In this case, and in equations (I-61) through (I-64), and (I-75) through (I-78) below, the subscript is not necessary because the equations apply to both switch types.

In Figure 13, the shape of the curved portion of the reverse route closure rail is labeled with the general expression $y = f(x)$. That the AREA specifies a *radius* for the curved portion of the reverse route centerline implies the shape of that centerline is a *circular arc*. Thus, the shape of the curved closure rail between points **PC** and **PT** is also a circular arc. Then $y = f(x)$ becomes the equation of a circle with a constant radius R_{CCR}. What follows derives that radius, but not the unneeded full equation of the circle.

Where there is a tangent extension at the switch heel or the frog toe, the reverse route closure rail is circular between points **PC** and **PT**, and straight along the tangent extensions. Where there are no tangent extensions, the points **PC** and **PT** lie on the switch heel and frog toe, respectively. Even though the center of the circular arc connecting them does not lie on the vertical axis through the *y*-axis, the length L_C is:

$$L_C = R_{CCR}(\sin\theta - \sin\phi) \tag{I-61}$$

Also:

$$R_{CCR}(\cos\phi - \cos\theta) = H \tag{I-62}$$

Because the radius of a circle is perpendicular to the tangent of a circle at all points around the circumference, equations (I-61) and (I-62) satisfy the four boundary conditions. Solving (I-62) for the radius R_{CCR}:

$$R_{CCR} = \frac{H}{(\cos\phi - \cos\theta)} \tag{I-63}$$

Substitute (I-63) into (I-61) to get the distance L_C :

$$L_C = H\left(\frac{\sin\theta - \sin\phi}{\cos\phi - \cos\theta}\right) \tag{I-64}$$

Equation (I-64) produces the *only* value of distance L_C that is a result of using the radius R_{CCR} from equation (I-63), and satisfies the four boundary conditions. For any other value of L_C the curve *cannot* be circular.

Theoretical and Actual Lead

With given switch and frog dimensions and the distance L_C from equation (I-64), the theoretical lead is immediately:

$$L_T = L_{PC} + L_C + L_{PT} \tag{I-65}$$

The actual lead (in feet), from the switch point to the frog ½-inch point is then:

$$L_A = L_T + \frac{d}{12\cos(\theta/2)} \tag{I-66}$$

While the AREA specifies a lead for each of its turnout designs, prototype railroads sometimes specify a different lead value for their turnouts. Model railroaders sometimes do this to match the lead of their favorite prototype railroad's lead values.

The **APPENDIX B: ALTERNATE CLOSURE RAIL CURVE AND LEAD LIMITS** investigates turnout geometric properties that determine lead and lead limitations. It examines an alternate shape for the curved closure rail, the cubic polynomial, and shows the following for a specified switch and frog design:

1. For a cubic polynomial, any L_C greater than zero produces a smooth closure rail curve.
2. To avoid an undesirable *S*-curve along the curved closure rail, there are defined minimum and maximum lead values. **APPENDIX B** develops the equations.

Table 9: AREA Leads and Calculated Third-order Polynomial Lead Limits (feet)

	Straight Switches			Curved Switches		
Frog No.	AREA Lead (circ. arc)	Minimum Lead 3rd-order	Maximum Lead 3rd-order	AREA Lead (circ. arc)	Minimum Lead 3rd-order	Maximum Lead 3rd-order
5	42.54	37.76	49.46	40.65	36.91	45.61
6	47.50	42.53	54.55	45.29	41.51	50.15
7	62.08	54.79	73.07	62.98	56.79	71.86
8	68.00	60.28	79.38	68.38	61.79	77.58
9	72.29	64.45	83.60	73.08	66.42	82.17
10	78.75	70.67	90.14	77.52	70.88	86.34
11	91.85	81.45	107.21	81.94	75.33	90.50
12	96.67	86.12	111.98	103.79	93.70	118.23
14	107.06	95.97	122.61	113.56	103.13	127.96
15	126.38	112.25	147.36	118.38	107.81	132.71
16	131.33	116.69	152.77	123.38	112.59	137.75
18	140.96	125.99	162.28	146.00	132.83	164.13
20	151.96	136.66	173.21	156.04	142.43	174.29

Table 9 summarizes the results of the investigation of lead values. Lead values calculated by the equations developed above for circular arcs are within 0.03% of those specified by the AREA [4]. Notice that the lead values for turnouts using circular arcs fall between the minimum and maximum lead values for turnouts using a cubic polynomial.

Other Lead Equations

Tratman [1] provides three other equations for the theoretical lead, but without derivation or further explanation. The first he states in words, expressed here as an equation:

$$L_T = 2nG \qquad \text{(I-67)}$$

Equation (I-67), easily derived, expresses the lead of a turnout having a circular arc closure rail that is tangent to the straight stock rail at the switch point, and has the slope of the frog angle at the theoretical frog point. As such, it does not account for the switch or frog geometry. A turnout with this closure rail shape would have impossibly thin switch rails and no straight portion guiding the approach to the frog throat and frog point.

Tratman's second equation, incorporating the throw of the switch T_{SW}, is:

$$L_T = 2n\left(G - \sqrt{GT_{SW}}\right) + L_S \qquad \text{(I-68)}$$

The third is:

$$L_T = 6n + \left(L_S + L_{FT}\right) \qquad \text{(I-69)}$$

All quantities (except the non-dimensional frog number) in Tratman's formulas must all have units of feet. Equations (I-67), (I-68) and (I-69) produce lead values that are considerably different from those specified by the AREA, and by inference, the NMRA. As such, they are only of passing interest, and warrant no further discussion.

Closure Rails

Closure rails connect the heel of the switch to the toe of the frog. Because switches and frogs are separate assemblies, a joint fastened with joint bars is required at each end of each closure rail. Then, depending on the frog number and the standard rail stock lengths, the AREA specifies joints at intermediate locations. Plan 911-41 shows joint locations for turnouts with straight split switches, and Plan 921-41 for curved switches.

Closure Rail Dimensions

Even though some turnouts have additional tangent lengths specified at the switch heel and/or frog toe, there are no rail joints at the ends of these tangents. That means the closure rail lengths are the distances between the switch heel and frog toe.

The straight closure rail length L_{SCR} is then the actual (practical) lead L_A minus the practical frog toe length minus the switch rail length:

$$L_{SCR} = L_A - L_{toe} - L_S \quad \text{(I-70)}$$

Because the reverse route centerline is a circular arc of radius R_C, the radius R_{CCR} of the curved portion of the curved closure rail is:

$$R_{CCR} = R_C + \frac{G}{2} \quad \text{(I-71)}$$

The AREA plans do not tabulate this radius, but tabulate the centerline radius R_C instead. The centerline degree-of-curvature θ_D (in degrees) and radius (in feet) are related by the prototype definition:

$$\theta_D = 2\arcsin\left(\frac{50}{R_C}\right) \quad \text{(I-72)}$$

The length of the curved closure rail L_{CCR} depends on the heel and frog angles ϕ and θ, respectively, plus any tangent extensions t_S at the switch heel and/or t_F at the frog toe:

$$L_{CCR} = R_{CCR}(\theta - \phi) + t_S + t_F \quad \text{(I-73)}$$

In equation (I-73), the frog and switch heel angles must be expressed in radians.

Curved Closure Rail Gauge Points

The AREA turnout plans 910-41 and 920-41 tabulate three gauge points that assist construction crews in positioning the curved closure rail. The gauge points fall on the gauge side of the curved closure rail. The plans locate each gauge point in an *XY*-coordinate system (see Figure 13) at a specified distance from the point of switch in the direction of the normal route centerline, and a corresponding perpendicular offset from the straight stock rail gauge line.

A cursory examination of the tabulated dimensions suggests the AREA turnout designers may have set gauge points at roughly equal intervals along the *straight* closure rail length, the middle point located at approximately ½ its length. However, this is not uniformly true for each frog number.

For curved switches, Plan 920-41 presents gauge points at somewhat arbitrary locations, with increments no smaller than three inches (¼ foot). Not surprisingly, those locations increase with increasing frog numbers. On the other hand, the corresponding offsets vary only a little with changing frog number.

Plan 910-41, for straight switches, presents gauge points whose locations appear more arbitrary. Like those on Plan 920-41, offsets vary only a little with changing frog number. Because the offsets do vary, it is not likely there is some standard tool used to check them during turnout construction.

Precise deduction of the AREA gauge point location rationale has proved elusive. Until further research or information uncovers that rationale, one logical choice is to locate three equally-spaced gauge points along the straight closure rail length. For this choice the locations of the gauge points, X_1, X_2 and X_3, measured from the switch point, are:

$$\begin{aligned} X_1 &= L_S + 0.25L_{SCR} \\ X_2 &= L_S + 0.50L_{SCR} \\ X_3 &= L_S + 0.75L_{SCR} \end{aligned} \quad \text{(I-74)}$$

Because the curved closure rail falls on a circular arc, finding a mathematical expression for the offsets at each of these locations is a straightforward process. Consider Figure 14. The equations for the coordinates of point **PC,** L_{PC} and H_{PC} are repeated here as a convenience:

$$L_{PC} = L_S + t_S \cos\phi \quad \text{(I-75)}$$

$$H_{PC} = S_{SH} + t_S \sin\phi \quad \text{(I-76)}$$

The variable t_S is a short tangent following the heel of the switch the AREA specifies for some turnouts. From the geometry in Figure 14:

$$a = L_{PC} - R_{CCR}\sin\phi \quad \text{(I-77)}$$

And:

$$b = H_{PC} - R_{CCR}(1 - \cos\phi) \quad \text{(I-78)}$$

Then for a gauge point located at X_i the corresponding offset Y_i is:

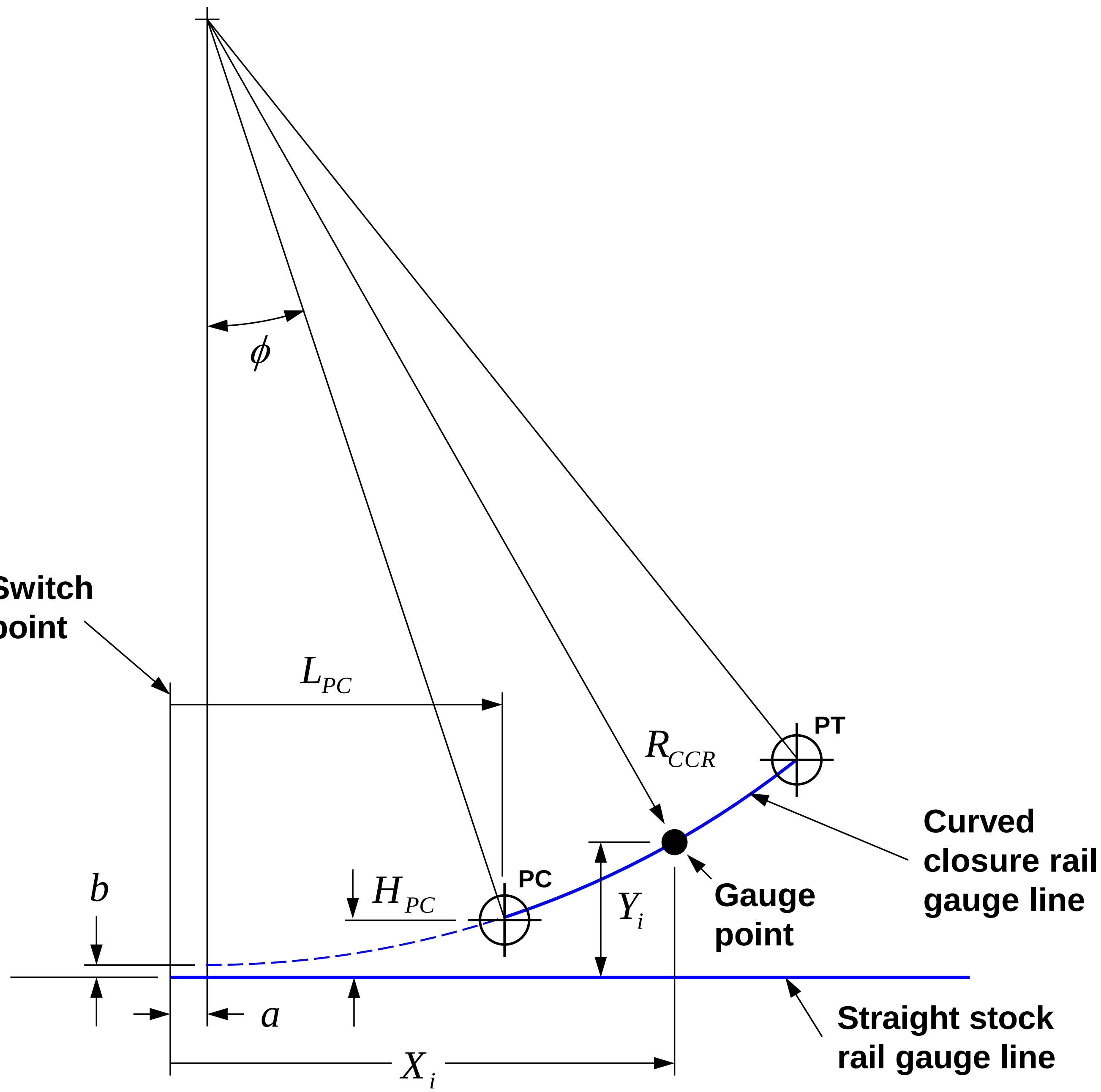


Figure 14: Curved closure rail gauge point locations

$$Y_i = R_{CCR}\left[1-\sqrt{1-\left(\frac{X_i-a}{R_{CCR}}\right)^2}\,\right]+b \qquad \text{(I-79)}$$

Using the AREA gauge point *X* locations from the AREA Plans, and the curved closure rail radius computed as the AREA centerline radius plus half the track gauge, the gauge point *Y* offsets computed using equation (I-79) are very close to those specified on the AREA plans. This validates equation (I-79) when used with *any* X_i value, and specifically those in equation (I-74).

Crossover Data

A crossover is a pair of same-hand turnouts whose reverse routes oppose one another, allowing a train to cross from one track to another in a pair of parallel tangent tracks. The AREA turnout Plans 910-41 and 920-41 provide dimensions for crossover construction from two turnouts having the same frog number, called *equal-frog* crossovers. Such cros-

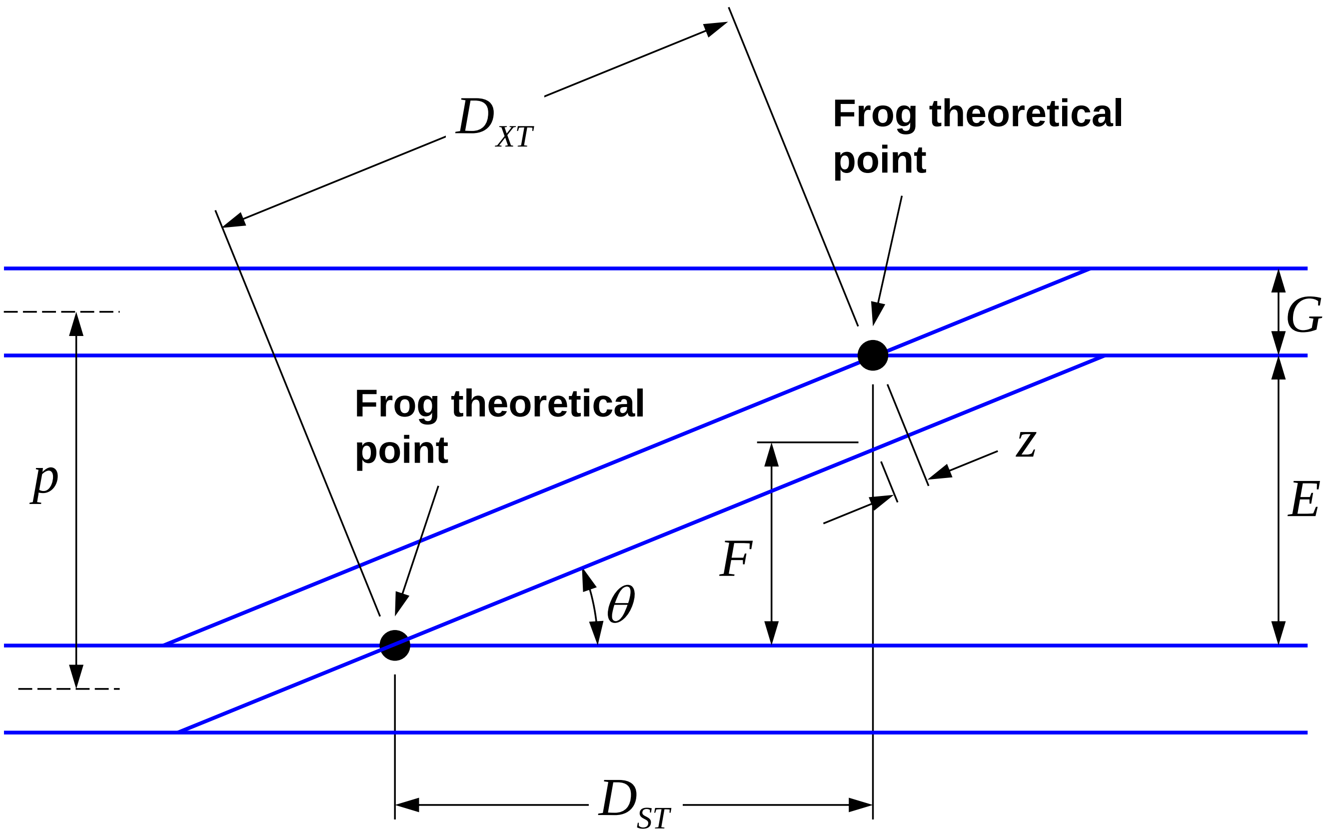


Figure 15: Crossover Data

sovers contain an inherent *S*-curve, so their frog number selection must consider the lengths of rolling stock traversing them. Hay [2] discusses crossovers with unequal frogs, but because they produce an undesirable *additional* *S*-curve, this TN does not discuss them further.

The geometry of crossovers does not depend on switch type, so both AREA plans show the same crossover dimensions. In particular, they show two measurements between the two frogs. One is the distance along the straight track, and the other is the distance along the crossover track. The presented dimensions are for parallel tangent tracks spaced at 13 feet. Because parallel track spacing varies with location, by state regulations, and by railroad practice, the plans provide an incremental increase in each measurement for each one-foot change in parallel track spacing.

Figure 15 illustrates a crossover with the frog angle exaggerated to show the geometric details clearly. As drawn, the frog points are in their theoretical position. Adjustments to the ½-inch point appear later in the development that follows.

From the geometry and nomenclature in Figure 15:

$$E = p - G \qquad \text{(I-80)}$$

The dimension F is then:

$$F = E - \frac{G}{\cos\theta} \qquad \text{(I-81)}$$

From trigonometry:

$$\tan\theta = \frac{F}{D_{ST}} \qquad \text{(I-82)}$$

Substituting equations (I-80) and (I-81) into (I-82) and solving for the straight distance:

$$D_{ST} = \frac{(p - G)\cos\theta - G}{\sin\theta} \qquad \text{(I-83)}$$

Noting that:

$$z = G\tan\theta \quad \text{(I-84)}$$

The crossover distance is then:

$$D_{XT} = \frac{D_{ST}}{\cos\theta} + G\tan\theta \quad \text{(I-85)}$$

Equations (I-83) and (I-85) represent distances between the theoretical frog points. Recall the distance from the theoretical frog point to the ½-inch point is along the bisector of the frog angle. That means the distance along a gauge line, needed here, is (in feet):

$$d_{GL} = \frac{n}{24\cos(\theta/2)} \quad \text{(I-86)}$$

Because there are two frogs on a crossover, the distance to two ½ -inch points is twice that in (I-86). Thus, subtracting the two ½-inch point distances along the gauge lies from equations (I-83) and (I-85), the respective distances between the practical points are:

$$D_{SP} = D_{ST} - 2d_{GL} \quad \text{(I-87)}$$

$$D_{XP} = D_{XT} - 2d_{GL} \quad \text{(I-88)}$$

Determination of the straight and crossover track length increase for a specified increment in track spacing Δp is straightforward. For the straight track, simple trigonometry gives:

$$\Delta S = \frac{\Delta p}{\tan\theta} \quad \text{(I-89)}$$

For the crossover track:

$$\Delta X = \frac{\Delta p}{\sin\theta} \quad \text{(I-90)}$$

The incremental distances expressed by equations (I-89) and (I-90), for a specified incremental increase in track spacing, depend only on the frog angle.

AREA Turnout Consistency Evaluation

Evaluation of the AREA designs requires calculations using the equations developed above. The companion spreadsheet *NMRA TN-12 AREA Turnout Consistency Evaluation.xls* [29] makes those calculations for both straight and curved switch turnouts. Like the switch consistency evaluation, It has two computational approaches, one that calculates exact values and another that rounds the exact values in the same manner as the AREA, specifically:

Angles: Nearest second of arc
Radii and extra tangents: Nearest 1/100th foot
All Others: Nearest feet-inches:
- Lead and closure distances: nearest ¼ inch
- Gage line offsets (location): nearest ¼ inch
- Gage line offsets (lateral): nearest 1/16 inch
- Frog lengths: nearest ½ inch
- Frog spreads: nearest 1/16 inch
- Crossover dimensions: 1/16 inch

To be fair, the evaluation compares the exact rounded values to the AREA tabulated values. The spreadsheet shows the differences between rounded calculated values and tabulated values for both curved switch and straight switch turnouts are in the range of -0.4831% to 1.8576%. Closer examination of the results show these extremes are due to the gage line offsets. Percent differences with absolute values under 0.5% are simply small round-off errors, which are considered in the consistency definition (see **EXECUTIVE SUMMARY** for definition). The larger percent differences, in excess of 1.0%, occur in the gage line offsets for only a few frog numbers. Because these few inconsistent offsets are a function of the curved closure rail radius, which is consistent, these differences must be due to errors in the AREA calculations. Ignoring the percent differences exceeding 1.0%, the remaining percent differences for gage line offsets are mostly zero, while those not are within 0.5%. Thus, the AREA turnouts are consistent.

Taken with the switch evaluations, these turnout evaluations demonstrate that the AREA designs are consistent, and that the equations developed in this TN are correct. Because the equations are scale-independent, they apply to model turnouts of any scale.

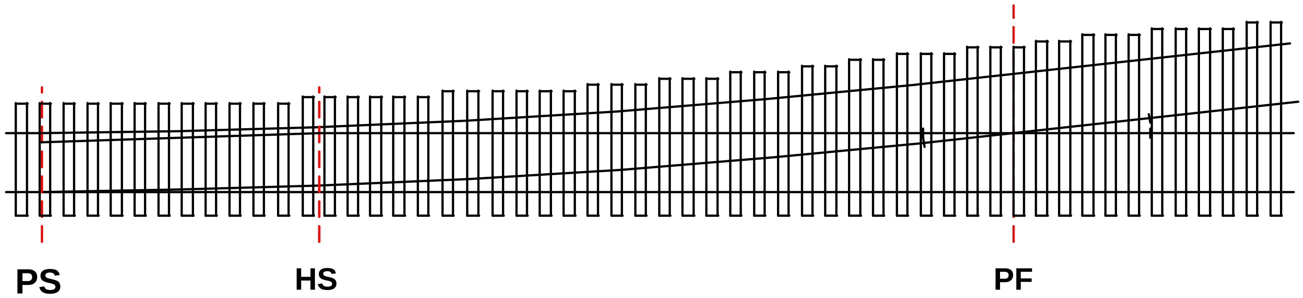


Figure 16: AREA No. 8 Curved Switch Turnout Tie Arrangement

Tie Spacing

Tie spacing does not affect turnout geometry, except for the position of the guard rails discussed below. The discussion here serves as background for the model guard rail position discussed in **PART II**.

AREA Plan 912-41 calls out "Bills of Timber for Turnouts and Crossovers," basically the number and lengths of timbers (ties) required for a turnout (or crossover) having a specified frog number. Tie lengths come in six-inch increments. Note 7 on that plan states "Tie spacing approximately 20 [inches] center to center." The word "approximately" implies this spacing is not rigorous and likely means "unless otherwise specified." Examination of the frog and switch details confirm this notion.

All the AREA frog design plans call for a tie whose center is located back (towards the heel) four inches from the ½-inch point of the frog, presumably so the tie provides adequate support for the frog point. Further, all frog plans indicate a center-to-center tie spacing of 19½ inches, except the No. 9 spring rail frog. The No. 9 spring rail frog shows one space of 22 inches on the toe side and two spaces of 22 inches on the heel side. The rest of the spaces are 19½ inches. Why this frog is different from all the others is unknown.

All the switch plans show the switch heel centered between two ties spaced center-to-center at 18 inches, presumably for adequate support of the heel blocks. They also show varying tie spaces for some ties before and beyond the switch heels, the spacing distances depending on whether the switch is of the hand throw or interlocking type. With other turnout dimensions being variable, an adjustment of tie spacing becomes necessary over part of the distance between the switch and frog. The AREA plans tabulate these adjustments.

AREA Plan 912-41 lists the total number of ties, but does not indicate the location of "Tie No. 1." The tie layout drawing at the upper left is generic and indicates two longer ties (headblocks) near the point of switch, presumably straddling the first switch rod. Whether the first headblock, probably 14 or 15 feet long, is "Tie No. 1" is unclear. The tables do not list switch timbers that long at the switch end of the turnout. Switch timber lengths increase in six-inch increments.

Figure 16 illustrates an AREMA No. 8 Curved Switch turnout tie arrangement, drawn to scale at the prescribed tie spacing. The differences in tie spacing are difficult to see.

Guard Rails

A guard rail holds a passing wheel against the adjacent running rail opposite the frog. This ensures the opposite wheel passing through the frog proceeds along the proper route. AREA plans 910-41 and 920-41 do not show guard rails on their turnout diagrams, perhaps because one choice of frog design is self-guarding and does not require them.

The AREA specifies two types of guard rails, the *tee rail guard rail* with planed flares and the *one piece guard rail*. While the AREA specifies five standard guard rail lengths, none longer than 13 feet, lengths used by various railroads can vary widely. For example, Tratman [1] reports that the Norfolk & Western Railway used 15-foot guard rails for turnouts up to No. 9, 16½-foot for No. 10 turnouts and progressively longer for higher numbered turnouts.

Tee Rail Guard Rails

AREA Plans 503-40 and 504-40 show designs for three tee rail guard rail lengths, 8'-3", 11'-0" and 13'-0". Both plans show the same guard rail designs,

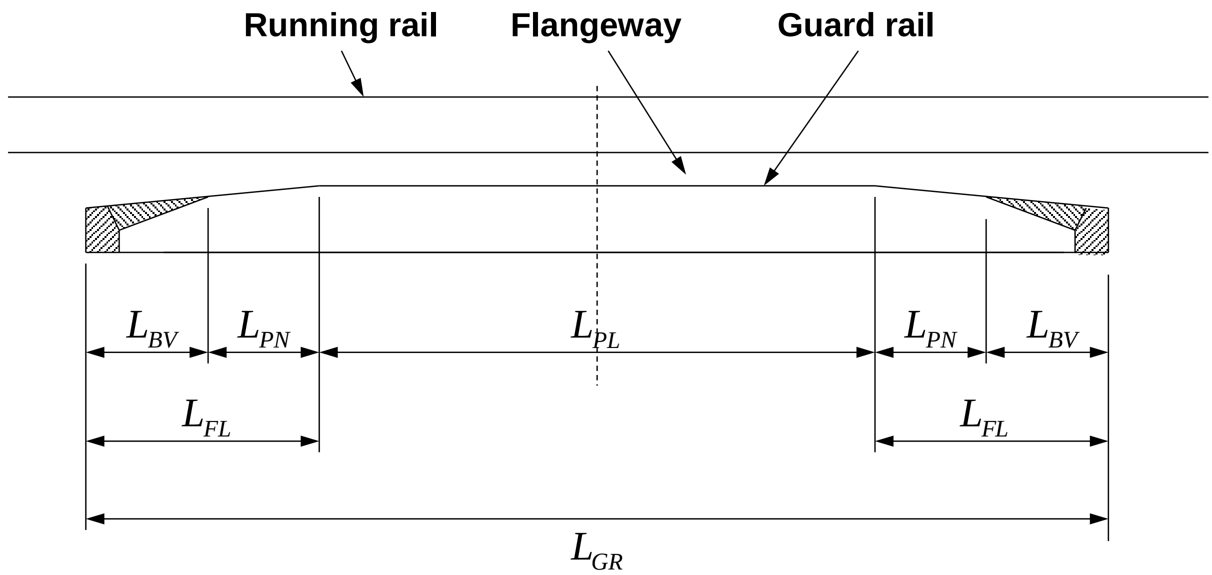


Figure 17: Tee Rail Guard Rail Geometry (not to scale)

the difference being that one plan specifies canted tie plates and the other flat tie plates.

The AREA apparently selected these lengths because they can be cut from standard 33-foot or 39-foot rails, much in the same way it selected switch rail lengths. These guard rails are of the planed-flare design that consists of a straight portion of length l_{PL} in the middle plus a planed section of length L_{PN} and a beveled section of length L_{BV} on each end, as Figure 17 illustrates.

The plans show values for the flare lengths and parallel (straight) length such that the total tee rail guard rail length L_{GR} is:

$$L_{GR} = l_{PL} + 2\left(L_{PN} + L_{BV}\right) \tag{I-91}$$

Examination of the three guard rail designs shows the parallel length l_{PL} and planed flare length L_{PN} vary linearly with guard rail length l_{GR}. The bevel length L_{BV} is a constant 13 inches.

While the AREA does not specify a designs for longer guard rails, but looking ahead to the model guard rail suggests one or more may be useful. The next length is likely 16'-6" (198 inches), obtained by cutting a 33' rail in half. Using the observed linearity, the corresponding parallel length becomes 9'-8" (116 inches) and the inner flare length 2'-4" (28 inches). The next longest guard rail is half of a 39' rail, or 19'-6", with similarly extrapolated dimensions. Table 10 summarizes these dimensions, the last two rows including those for the 16'-6" and 19'-6" designs.

The notes on Plan 502-40 specify the minimum guard rail lengths for specific frogs, 8'-3" for frog numbers 14 and lower, and 11'-0" for frog numbers 15 and higher, but do not prohibit longer guard rails. These sizes apply to rigid frogs, and with the longer 13'-0" guard rail, also apply to spring frogs.

These rules are logical because the parallel length for the 8'-3" guard rail exceeds the total flangeway width plus the 6-inch setback for frog numbers 14 and lower. Frog numbers 15 through 20 require the 11'-0" guard rail so its parallel length exceeds the

Table 10: AREA Tee Rail Guard Rail Design Dimensions

L_{GR} **(ft.-in.)**	L_{GR} **(in.)**	L_{PL} **(in.)**	L_{PN} **(in.)**	L_{BV} **(in.)**
8'-3"	99	41	16	13
11'-0"	132	66	20	13
13'-0"	156	84	23	13
16'-6"	198	116	28	13
19'-6"	234	142	33	13

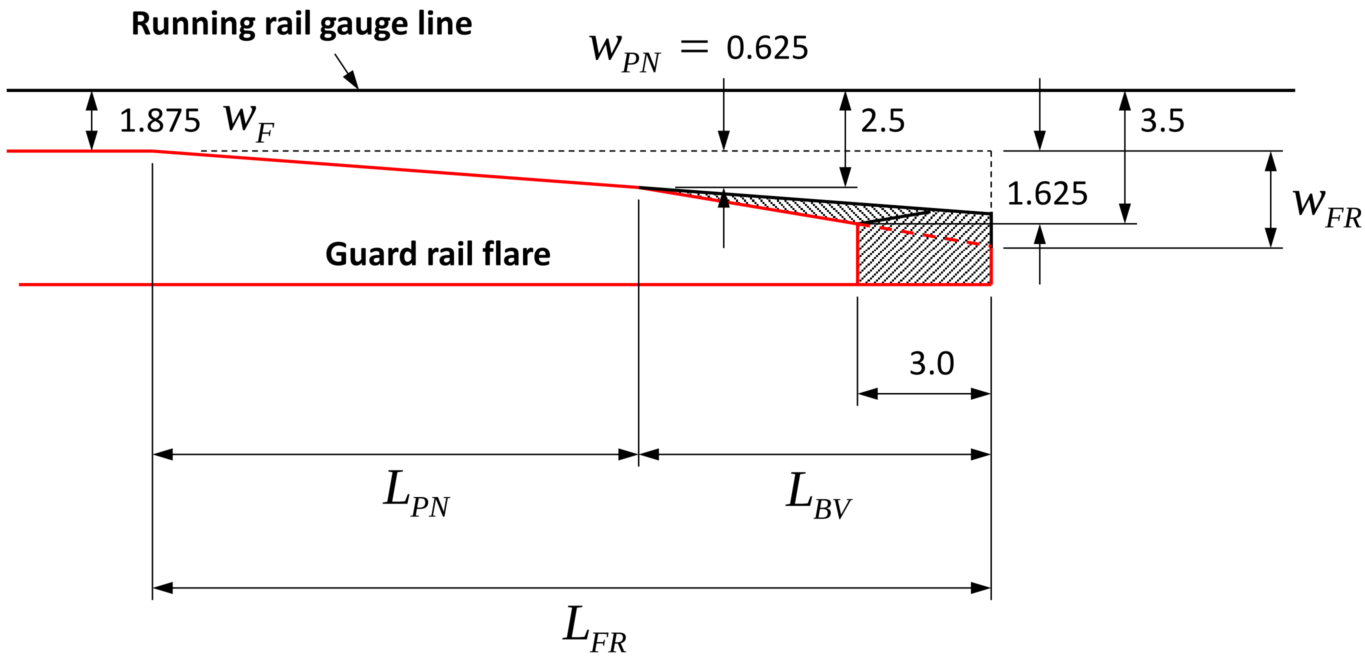


Figure 18: Tee Rail Guard Rail End Flare (not to scale)

total flangeway width plus the 6-inch setback.

Tee Rail Guard Rail Flares

Figure 17 and Figure 18 show the geometric details of a Tee Rail Guard Rail, likely constructed as follows.

After cutting the guard rail to its full overall length, the manufacturer makes a 3-inch. 45-degree end bevel. Following that is planing of the inner flare, parallel to the vertical face of the rail head, over the full flare length such that it reaches a depth w_{PN} of 0.625 inches at distance L_{PN} from the end of the parallel length. Then the manufacturer makes the final bevel cut, at an angle of 25 degrees to the vertical, over the distance L_{BV} such that it reaches a flare width of 1.625 inches where it intersects the top edge of the end bevel cut, and a flare width of 0.625 inches at the end of the inner flare. Planing and cutting of the other end follows the same process.

Because of the inner flare cut, the flare at the end is not affected by the depth where the gauge line is normally measured. This makes the guard rail flare geometry differ slightly from the wing rail flares. From Figure 18 and similar triangles:

$$w_{FL} = \frac{L_{BV}}{L_{BV} - 3.0} + 0.625 \qquad \text{(I-92)}$$

Because the bevel length is 13 inches for all tee rail guard rails, the flare is also the same. Thus, equation (I-92) produces a constant flare value of $w_{FL} = 1.925$ inches.

One-Piece (Cast) Guard Rails

Plan 510-40 shows the details of the one piece cast manganese steel guard rail, specified in two lengths, 8'-4½" for a "6-tie" guard rail and 10'-0" for a "7-tie" guard rail. Both designs utilize a cast-in double bend at the ends to lead approaching wheels through the flangeway. As the name implies, the tie plates are integral with the guard rail. Turnouts up to and including no. 14 use the 8'-4½" one piece guard rail and turnouts No. 15 and above use the 10'-0" guard rail.

The plans show values for the flare lengths and straight length such that the total one piece guard rail length is (using the same nomenclature as the Tee Rail type):

$$L_{GR} = l_{PL} + 2\left(L_{PN} + L_{BV} + l_{ext}\right) \qquad \text{(I-93)}$$

The variable l_{ext} represents the 4¼ inch extension on each end that is the equivalent of the end bevel on a Tee Rail design.

Guard Rail Setting

For a guard rail to function properly, its parallel (straight) portion must be in proper position relative to the ½-inch point of the frog it is guarding. Tratman [1] states the center of the guard rail should normally be located about a foot in front of the frog point. Hay [2] states the center should be a few inches ahead of the frog point.

The AREA is more specific. Notes on the guard rail plans in [4] specify minimum distances the ends of the straight portion of a guard rail must be from the rigid frog ½-inch point.

Guard Rail Setting – Tee Rails

Quoting the notes on Plan 502-40 for tee rail guard rails:

Parallel portion of Guard Rails to extend:

(a) In back of ½" frog point, not less than 6", for all frogs

(b) In advance of ½" frog point for rigid frogs and the Guard Rail opposite the spring flangeway of spring frogs:

(1) Not less than (twice frog number in inches) for frogs of smaller angle than No. 9.

(2) Not less than 18" for No. 9 frogs and frogs of larger angle.

From the detail drawings on Plan 502-40, *in back of* means towards the frog heel and *in advance of* means towards the frog toe. While the wording in notes *(1)* and *(2)* above is precise, it can be misinterpreted unless the reader realizes that *frogs of smaller angle* means frogs of *higher number*, and vice versa. Thus note *(b)(1)* applies to frogs No. 10 through No. 20 and note *(b)(2)* applies to frogs No. 5 through No. 9.

The presumed purpose of these minimums is to ensure that the guard rail properly protects the flangeway gap through the frog. Because the straight length is considerably longer than the flangeway gap, these minimums allow the position of the guard rail relative to the frog point to vary considerably.

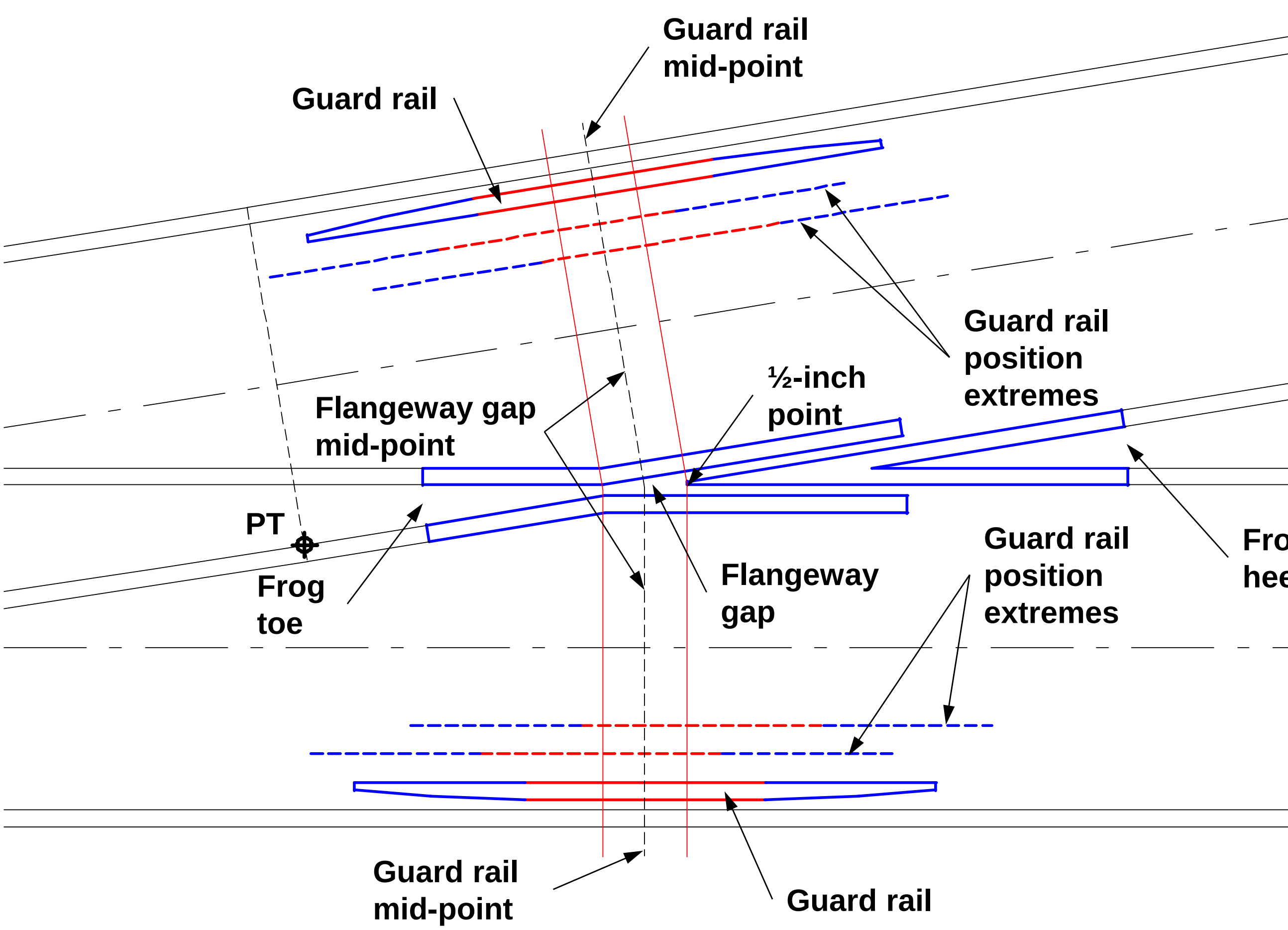


Figure 19: Guard Rail Position Extremes (prototype 8'-3" Guard Rail, No. 6, drawn to scale)

As an example, consider a No. 6 frog using an 8'-3" guard rail having a straight portion length of 41 inches per Plan 502-40. If there is the minimum 18 inches of straight portion before the frog ½-inch point there must be 23 inches behind it, far more than the required minimum. Conversely, if there is the minimum six inches after the frog ½-inch point there are 35 inches before it, almost twice the specified 18" minimum. Figure 19 (drawn to scale for a prototype No. 6 turnout) illustrates the extreme positions the guard rail can take for the specified minimums. The full guard rail shapes, drawn with solid red and blue lines, center on the flangeway gap as a logical position for which wheels approaching from either direction experience the same length of the straight portion (ref lines) before reaching the flangeway gap. The dashed red and blue lines, drawn offset from their actual distance from the running rail, show the extreme positions possible without violating the specified minimums.

The extremes allow substantial asymmetry in position relative to the flangeway gap in the frog.

For some larger frog numbers (smaller angles), rule *(b)* above allows setting a guard rail such that its parallel portion does not fully straddle the frog flangeway gap. This seems counter-intuitive, but is always avoidable by following rule *(a)* with a constant, not minimum, 6-inch setback.

Guard Rail Setting – One-Piece

AREA settings for one-piece guard rails are even more specific. In this case the minimum distance of the straight portion of the guard rail behind the ½-inch point is 2 inches. The minimum length in front of the frog ½-point is even more restrictive, as follows (per Plan 510-40):

Frogs 4-5	12 inches
Frogs 6-10	14 inches
Frog 11	16 inches
Frogs 12, 14	18 inches
Frog 15	24 inches

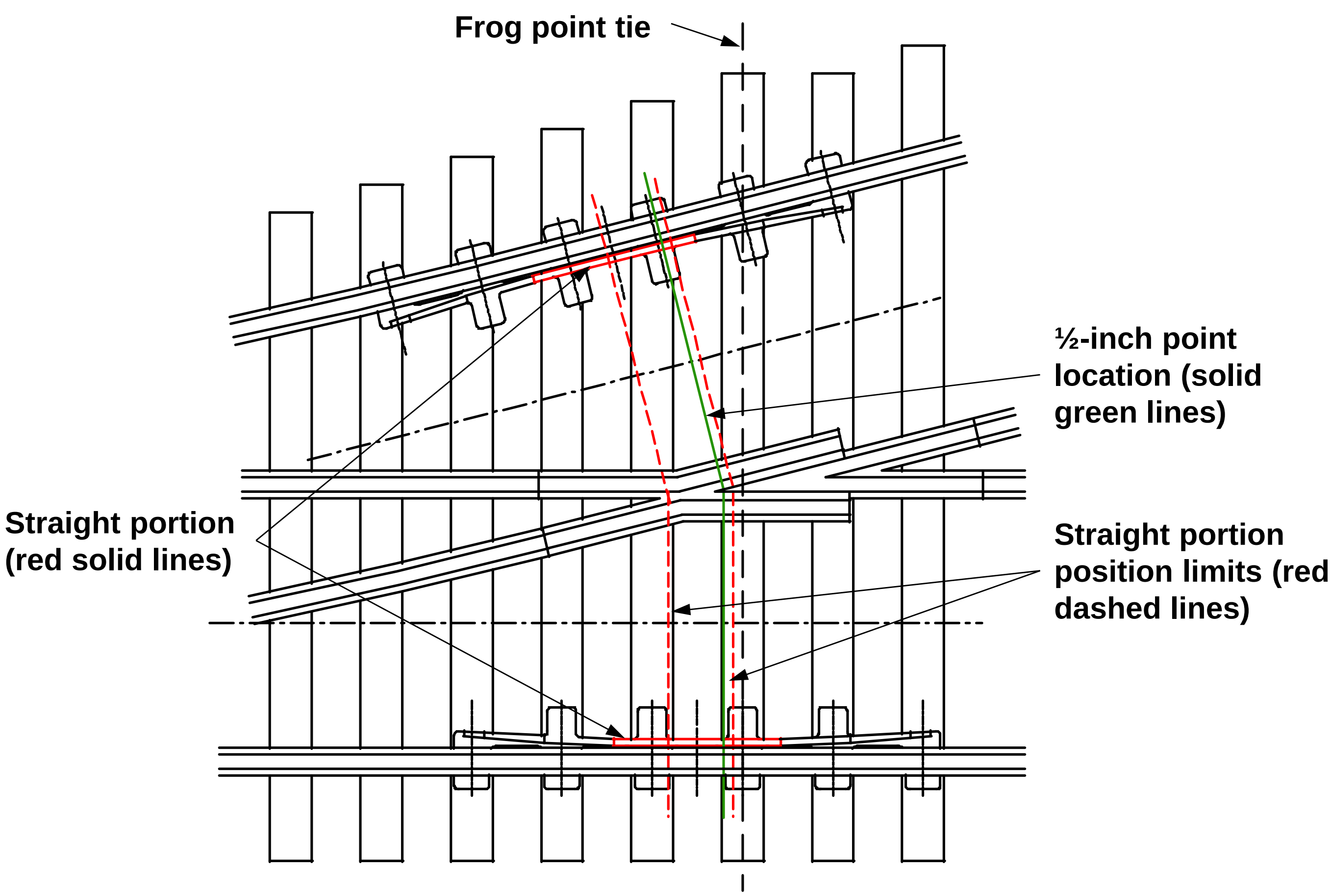


Figure 20: One-Piece Guard Rail Position (No. 4 frog shown)

Frog 16	26 inches
Frogs 18, 20	30 inches

As specific as these minimums are, the fact that the one-piece guard rail has cast-in tie plates makes setting its position even more restrictive. Because the cast-in tie plates must always rest on a tie, spaced at 19½ inches, its setting must be discrete. These restrictions presumably account for that.

Consider Figure 20 showing the position of a one-piece guard rail for a No. 4 frog turnout. Moving either guard rail one tie position to the left or right places one of the straight portion end points inside the dashed red lines, violating the positions limits.

That means the one-piece guard rail settings are actually more restrictive than the minimums imply. Notice also the difficulty in positioning the tie plates on the reverse route so they can be placed directly on a tie. The AREA allows some flexibility in the cast-in tie plate design so the turnout designer can ensure proper spiking.

PART II: MODEL RAILROAD TURNOUTS

Like the AREA, and today's AREMA, the NMRA tabulates model railroad turnout dimensions for the more popular model scales in a series of Recommended Practices [5-16] it has developed over the years. The discussion in this part addresses issues encountered in the modeling of prototype turnouts discussed in **PART I**.

Scaling Prototype Turnout Geometry

Defining the geometry of a model railroad turnout is not just a simple matter of scaling the prototype. NMRA provides *Standards and Recommended Practices* (S&RPs) that, when followed, enable interoperability of equipment from different manufacturers. The discussions in this part compare NMRA turnout designs with the AREA designs. Checking a few primary dimension in the current NMRA RPs shows the turnouts, their switches, and their frogs are not scaled versions of the AREA designs.

Direct scaling is not appropriate for several good reasons. The NMRA S&RPs take wheel contours and flangeway width into consideration. NMRA wheel flanges are considerably thicker than the scaled prototype, requiring a flangeway that is wider than the prototype. NMRA Proto scale standards prescribe more prototypical flangeway and wheel contour dimensions. NMRA turnout lead is not scaled either.

As **PART III** later discusses in detail, flangeway width affects two primary geometric parameters of a model turnout, the frog toe length and switch heel spread. Another parameter affecting switch heel spread is railhead width.

Turnout Nomenclature

Model turnouts use the same nomenclature as the prototype (Figure 1).

Frogs

Because model scale does not affect angular measurements, the prototype definition of the frog angle applies equally to the model. That means the related prototype equations apply as well.

Some model railroaders measure the distance *n* along one of the frog rails. In that case the frog angle is:

$$\theta = \arctan\left(\frac{1}{n}\right) \qquad \text{(II-1)}$$

The difference in frog angles calculated by equations (I-2) and (II-1) is negligible, especially for No. 5 frogs or higher.

Engineers often use the "small angle approximation" that states "for small angles, expressed in radians, the tangent (or sine) of the angle is approximately equal to the angle itself." Thus:

$$\tan\theta \approx \theta \qquad \text{(II-2)}$$

Making this approximation in either the prototype's or the modeler's equation, and converting the results from radians to degrees, the equation for the frog angle, in degrees, becomes:

$$\theta \approx \frac{180}{\pi n} \approx \frac{57.296}{n} \qquad \text{(II-3)}$$

As a worst case example, consider a No. 4 frog. From equation (I-2) the exact frog angle is 14.2500 degrees and from equation (II-3) the approximate angle is 14.3239 degrees. The error equation (II-3) introduces is a negligible 0.52%. As the frog number increases, the error decreases. It becomes 0.08% for a No. 10 frog and 0.02% for a No. 20. However, because a computer makes the necessary calculations using equation (I-2), there is no need to make this approximation.

Model frogs also have a theoretical point, defined the same way as the prototype. There is no formal ½-inch point in the model because the scaled cutback distance is so small. For a No. 6 frog in HO scale it is about a 0.03 inches, hardly noticeable. But a sharp frog point in the model is also not practical, so manufacturers and scratch builders dress the sharp point slightly to a blunt edge. In the model, the location of the frog ½-inch point is not significant. The location of the theoretical frog point is more meaningful. All NMRA dimensions involving the frog point are relative to its theoretical location.

Frog Flangeway Gap

The NMRA frog designs are about 30% longer than the scaled prototype frogs. NMRA RP-12

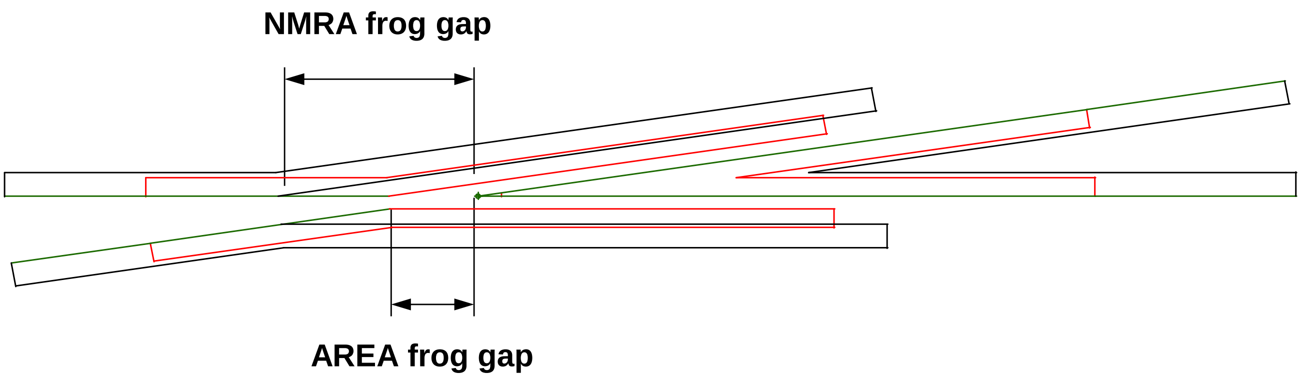


Figure 21: No. 6 Frog, AREA to NMRA Comparison (wing rail flares not shown)

"Turnouts General" [5] indicates NMRA frogs represent the "built-up" type, (probably "bolted rail") and accommodate "common slip on rail joiners." Because the flangeway width is wider in the model, the throat of the frog (see Figure 5) moves forward from the theoretical point. This shortens the effective length of the frog toe and perhaps justifies the increased frog toe length the NMRA RPs specify in comparison to the AREA. In turn, frog toe length affects the location of point **PT**.

A wider flangeway also means a wider frog flangeway gap as **PART I** equation (I-13) expresses:

$$g_T = \frac{w_F}{\sin\theta} \qquad \text{(II-4)}$$

For example, in Table 1 the prototype flangeway gap for a No. 6 frog is 14.31 inches. Scaling directly to HO this width is 0.164 inches. For an HO flangeway maximum width of 0.050 (NMRA S-3.2, "Trackwork Standard Scales" [24]), the frog flangeway gap by **PART I** equation (I-17) is 0.302 inches, almost twice as wide. This wider frog flangeway gap in the model turnout affects the guard rail setting (position) discussed later in this part.

Figure 21 compares the NMRA and AREA geometry for a No. 6 frog. The green lines, common to both frogs, are the gauge lines. The red lines represent the AREA frog and the black lines the NMRA frog. Notice the NRMA frog flangeway gap is roughly twice that of the AREA because of the wider flangeway width. For Proto scales, the flangeway gap is much closer to the scaled prototype because the flangeway width is only slightly wider than the scaled prototype flangeway width.

Wing Rails

While the AREA does not directly specify the length of the frog wing rail extension, the NMRA does. NMRA RP-13.7 "Frog & Wing Rails" [15] specifies the wing rail extension to be one-half the heel length. This value is close to the average for the AREA wing rail extensions, as quantified in Table 2. This is a reasonable choice.

Wing Rail Flares

The NMRA recommends three end-flare choices prescribed in NMRA RP-13.8 "Flangeway Flares" [16]. RP-13.8 also states the flare lengths apply to both wing rails and guard rails. The AREA wing rail flare length (see **PART I**) increases quickly with increasing frog number, becoming considerably longer than the scaled-up RP-13.8 values. NMRA flare designs are limited to frogs No. 4 through 10 and to only a few standard class model scales.

Switches

The selection of a straight or curved switch in the model is also the modeler's choice. In the prototype and the model, the switch choice influences the geometry of the turnout. For a currently unknown reason, the NMRA turnout RPs provide dimensions for curved switches, but not for straight switches.

A cursory visual examination of a few commercial HO scale turnouts at a local hobby shop showed that Peco Code 83, Walthers Code 83, and Micro Engineering Code 83 turnouts appear to be curved switch turnouts. Atlas Code 83 turnouts appear to be straight switch turnouts. According to their online drawings, both Central Valley Model Works and Fast Tracks appear to produce straight switch turnouts.

Switch Heel Spread

Recall the AREA specifies a standard switch heel spread of 6.25 inches for all frog numbers and both types of switches. Scaling this to HO scale, for example, gives 0.072 inches. For HO scale, NMRA RP-12.3 "Turnout Dimensions – HO Scale" [8] specifies a switch heel spread of 0.125 inches, considerably wider than the prototype, and equivalent to 10.886 prototype inches. Precisely how this value was determined is unclear, but it may be a combination of the NMRA flangeway width, an allowance for railhead width, wheel flange width and electrical clearance. **PART III** presents two methods for setting switch heel spread for model turnouts that are based on these parameters. For a fixed switch rail length, again for either switch type, the wider switch heel spread increases the switch (or heel) angle and affects the location of point **PC**.

Curved Switches

NMRA switch rail lengths and heel angles for curved switches are considerably different than the AREA specifications. For frog numbers 5 and 6 the AREA specifies 11-foot curved switch rails, which scale to 1.516 inches in HO scale. Conversely, the NMRA HO scale switch rail length of 2.125 inches scales to 15.421 feet in the prototype. For frog numbers 7 to 10 the AREA specifies 19½-foot rails, which scale to 2.687 inches. The NMRA switch length of 3.1875 scales to 23.132 feet. Perhaps the NMRA values are longer than the AREA values to keep the switch heel angle manageable, but the NMRA angles are still about 0.6 to 0.9 degrees larger than the AREA angles. Why the NMRA uses longer switch rails is not clear, although in part the longer switch rails may have been selected to accommodate the wider switch heel spread.

One other NMRA dimension, not specified by the AREA, is the mid-ordinate of the curved switch rail. Inferred from the diagram in NMRA RP-12 [5], the mid-ordinate is the perpendicular distance between the switch rail chord and the curved switch rail, measured along the bisector of the subtended angle. From Figure 11, the mid-ordinate is:

$$h_{MID} = R_S\left[1-\cos\left(\frac{\phi_C-\gamma}{2}\right)\right] \qquad \text{(II-5)}$$

NMRA Curved Switch Consistency Evaluation

Like the AREA, the NMRA rounds the turnout dimensions it tabulates in its RPs. Rounding is mostly uniform across scales, except N scale, to the nearest following parts of a degree or inch:

All angles:	1 arc-minute
Switch rail length:	1/16 in.
Switch heel spread:	1/64 in.
Switch radius:	1.0 in.
Switch mid-ordinate:	0.001 in.
Lead:	1/16 in.
Straight rail:	1/16 in.
Curved rail length:	1/32 in.
Curved rail radius:	1.0 in.
Gage Y-offset	1/64 in.
Gage X-offset	1/32 in.
Frog toe and heel spread:	1/64 in.
Frog point to intersection:	1/32 in.
Crossover dimensions:	1/16 in.

Where there are different rounding values across scales, the list above shows the most restrictive. For N scale, all angles are to the nearest arc-minute, switch and curved rail radii to the nearest inch, and all other dimensions are to the nearest 0.001 inch.

Also like the AREA curved switch evaluation, the evaluation here compares the exact rounded values to the NMRA tabulated values.

While the curved switch discussion in **PART I** shows that the AREA curved switch parameters *are* consistent, the companion spreadsheet *NMRA TN-12 NMRA Curved Switch Consistency Evaluation.xls* [30] shows almost all of the NMRA parameters are *not consistent* (See **EXECUTIVE SUMMARY** for definition). For the NMRA curved switch parameters, the spreadsheet shows excessive differences between calculated values and specified values, in the range of -22.4138% to 26.0417%, far too large to be declared consistent.

Turnout Lead

Turnout lead for model turnouts has the same geometric limitations as the prototype. The equations developed in **PART I** apply equally to the model and the prototype. Recall that once the locations of points **PC** and **PT** are set, there is only one lead value that produces a circular arc for the curved closure rail. Further, the NMRA measures model turnout lead to the theoretical point of frog.

While most commercial turnout manufacturers adhere to NMRA Standards, and may receive an NMRA Conformance Warrant when they do, they don't always follow Recommended Practices. Adherence to Recommended Practices is not a requirement for a Conformance Warrant. In his article *Will turnouts fit?*, Paul Dolkos [18] tabulates turnout dimensions for many commercial turnouts. Not one manufacturer listed offers HO Scale No. 6 turnouts having the NMRA recommended lead of 6¼ inches. Although not listed in [18], the Fast Tracks No. 6 template (as one example) obtained online *does* show the NMRA 6¼ inch lead.

Closure Rail Lengths

Prototype equations for the closure rail lengths apply equally to the model. The only difference is that the model does not require any tangent extensions at the switch heel or frog toe. Although unnecessary, the tangent extensions may be used for Proto scale turnouts for greater authenticity.

Curved Closure Rail Gauge Points

It is not clear how the NMRA selected gage point locations along the curved closure rail. Nevertheless, the principles discussed in **PART I** also apply to the model turnout.

Intersection of Centerlines

The normal route centerline and the straight portion of the reverse route intersect at a specific distance ahead of the theoretical point of frog given by:

$$L_{ICL} = Gn \quad \text{(II-6)}$$

This parameter is not specified by the AREA, but it is useful to modelers when laying out turnouts on track plans. It is included in the NMRA turnout RPs.

Crossover Data

Prototype equations for the crossover dimensions apply equally to the model. The only difference is that the model uses distances to the theoretical frog point rather than the prototype distances to the ½-inch point.

NMRA Turnout Consistency Evaluation

Spreadsheet NMRA TN-12 *NMRA Turnout Consistency Evaluation.xls* [31] evaluates the consistency of NMRA curved switch turnouts for each major model scale. Again, the evaluation compares rounded exact values to the tabulated dimensions, using the same rounding values listed above under **NMRA Curved Switch Consistency Evaluation**.

Again, unlike the AREA tabulated dimensions, *many* of NMRA tabulated dimensions are *not* consistent (See **EXECUTIVE SUMMARY** for definition). Overall, the maximum differences are far too large, in the range -22.4138% to 44.1860%. Some have differences in the range of about 0.5%, possibly due to rounding decimal numbers calculated in the 1961 time frame to fractional form. Other dimensions, notably lead and curved closure rail length, have differences up to about 10%, with several above 10%. One, the HOn3 curved closure rail length has a difference of 44.186%. This is the overall maximum difference for all scales and dimensions.

Tie Spacing

Turnout tie spacing in the model is a modeler's choice, at least for handlaid turnouts. Some modelers argue that the AREA's somewhat uneven spacing (Figure 16) is barely noticeable in the model and that a uniform spacing is sufficient. Modelers using commercial turnouts get whatever spacing such turnouts provide. For example, Central Valley Model Works turnout strips use closer tie spacing under the frogs, as in the AREA prototype. Modelers looking for prototypical tie spacing should examine commercial turnouts carefully for this feature.

Handlaid or not, model turnouts normally have wider spacing between the headblocks to accommodate the first switch rod. Model switch rods are frequently much wider than the typical 2½ prototype inches. A switch rod of scale width (e.g., 0.029 inches in HO scale) would likely be too weak and subject to breakage.

Because of the wide variation in tie spacing across turnouts of different frog numbers and switch lengths, it is not practical to specify tie spacing for model turnouts in the proposed turnout RPs.

Tie spacing then becomes a construction decision best left to the modeler or turnout manufacturer. **PART III** discusses four methods for doing this.

Guard Rails

NMRA RP-13.6 "Guard Rails" [14] provides a table of guard rail dimensions for each pertinent model scale, one length for frog numbers 4 through 7 and another for frogs 8 through 10.

In comparison, the AREA specifies 8'-3" guard rails for turnouts up to No. 14, and 11' guard rails for No. 15 and beyond. The NMRA guard rail parallel length for frogs 4-7 is about 4 scale inches longer (on average) than that of the AREA 8'-3" guard rail. For frogs 8-10, the parallel length is about 18 scale inches longer. The NMRA parallel length selections appear to account for the model flangeway gap that is larger than the prototype. Overall lengths are similarly longer. Presumably this is why the NMRA requires the longer guard rail for frogs 8-10 while the AREA does not require the longer length until frog No. 15.

Guard Rail Flares

For end flares, the NMRA recommends using one of three end-flare choices prescribed in NMRA RP-13.8 "Flangeway Flares" [16]. Guard rail flare lengths are comparable to the AREA flares, differing perhaps due to round off error when converting to fractional equivalents. When the scaled-up flare lengths for the specified scales in RP-13.8 are averaged, the averages are close to the AREA flare lengths. Flare widths are considerably larger than the prototype. NMRA guard rail flares are the same as wing rail flares and limited to the same frog numbers and model scales.

Guard Rail Setting

Guard rails in the model serve the same purpose as in the prototype (see **PART I**). To ensure sufficient parallel length guarding the frog flangeway gap, NMRA RP-13.5 "Guard Rail & Frog Relationship" [13] provides a "minimum guard rail setback distance" for each scale. This setback is equivalent to about 6 prototype inches, measured from the theoretical point of frog. The prototype set back of 6 inches is from the ½-point, so the model setback is actually *shorter* than the prototype.

There is a semantics issue here. The minimum setback ensures a small amount of parallel length occurs after the frog point. The word "minimum" implies that any greater amount is acceptable. If the setback distance is too large, the straight portion of the guard rail may begin *after* the frog throat, defeating its purpose.

The parallel portion of the guard rail must protect the frog flangeway gap to do its job. Figure 22 shows a scale drawing of a HO scale No. 6 turnout in the region of the frog and guard rails. The frog dimensions come from NMRA RP-12.3 "Turnout Dimensions – HO Scale" [8]. The guard rail size comes from NMRA RP-13.6 "Guard Rails" [14] with the "Bend and Bevel" flare design from NMRA RP-13.8 "Flangeway Flares" [16].

In Figure 22, the parallel length is L_{PL}, the setback to the rear is L_{rear}, and the remaining amount of parallel length in front of the throat is L_{frnt}. Having a minimum setback ensures the frog flangeway point itself is properly guarded. For any setback L_{rear} the parallel length in front of the throat is:

$$L_{frnt} = L_{PL} - g_T - L_{rear} \qquad \text{(II-7)}$$

Similarly, for any parallel length in front of the throat, the setback is:

$$L_{rear} = L_{PL} - g_T - L_{frnt} \qquad \text{(II-8)}$$

Guarding the frog throat is also a purpose of the guard rail. Having some guard rail parallel length ahead of the throat ensures that an approaching wheel set is properly positioned before the wheel flange enters the frog flangeway gap. That properly positions the wheel flange to keep it from hitting (picking) the frog point. Choosing the minimum parallel length in front of the throat to be the same as the minimum length after the point gives an expression for the *maximum* setback after the point.

$$L_{\max} = L_{PL} - g_T - L_{\min} \qquad \text{(II-9)}$$

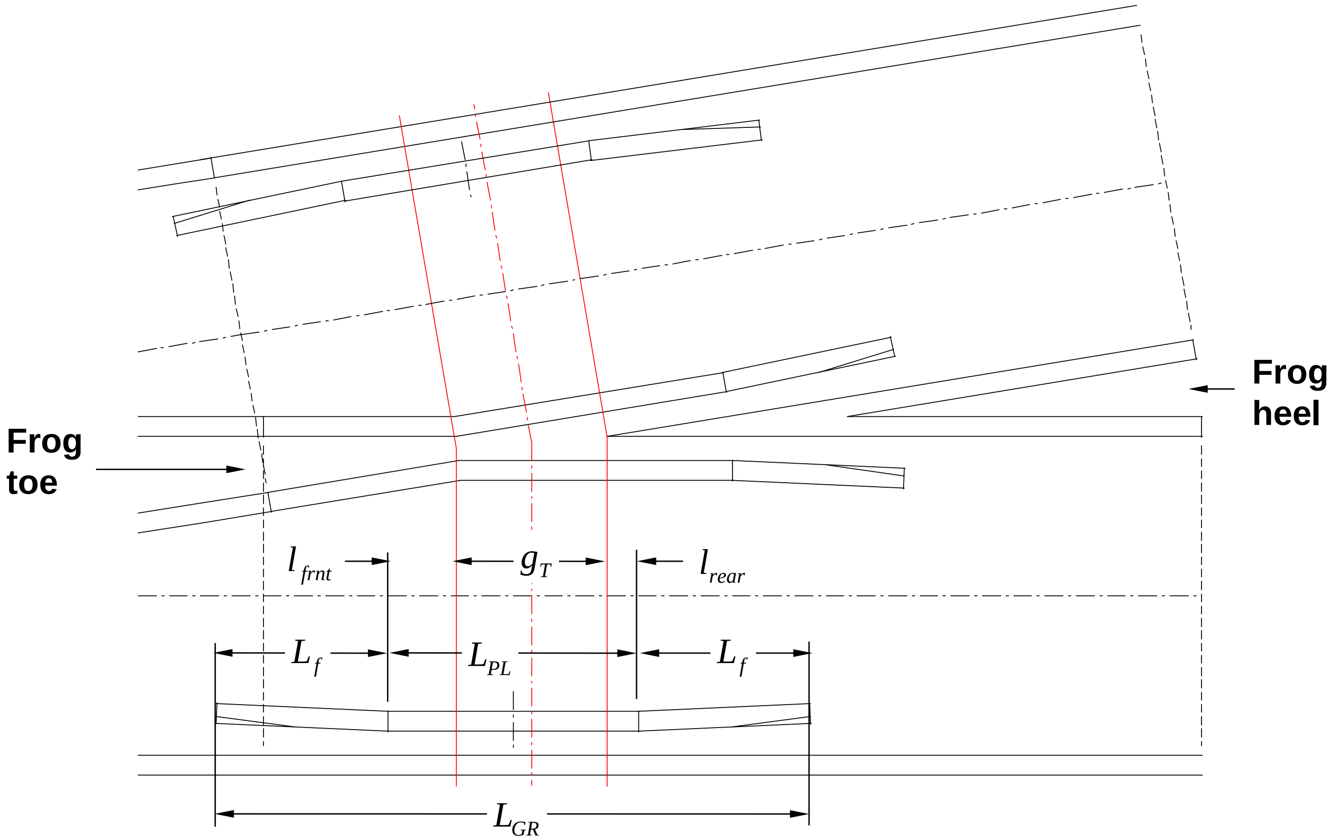


Figure 22: Guard Rail Position (HO Scale, No. 6, drawn to scale)

A study of guard rail positions for common model scales appears in the spreadsheet *NMRA TN-12 Guard Rail Position Study.xls* [32]. This study shows that while there is variability, the maximum setback is not too much larger than the minimum setback. In turn, that suggests simply dropping the word "minimum" from the description and the table heading would eliminate the semantics problem. The current setback specification still provides the required protection for the flangeway gap. This would also avoid the requirement to develop and specify a "maximum" setback.

While centering the straight portion on the flangeway gap is a logical and visually appealing choice, the asymmetrical extreme positions of the prototype do appear in some commercially produced model railroad turnouts (or kits). Those by Central Valley Model Works and Atlas are two examples.

PART III develops an improved approach that is based on prototype practice and ensures proper guarding of the flangeway gap.

PART III: MODEL TURNOUT DESIGN ISSUES AND REQUIREMENTS

PART I develops equations that describe turnout design geometry. Applying them to the AREA turnout designs shows differences between the calculated turnout dimensions and the AREA tabulated values are less than 0.50%, demonstrating that the equations are correct and the AREA dimensions are consistent. **PART II** shows that the turnout design dimensions tabulated in the NMRA RPs are *not* consistent, some surprisingly so.

Establishing a set of consistent dimensions for NMRA RPs requires a recalculation of the turnout dimensions using the equations developed in **PART I**. As discussed in **PART I**, this requires that some dimensions be specified as *given*, or accepted as-is, and used as input to those calculations. **PART III** establishes model turnout design requirements, and develops a design approach that selects those given dimensions.

Both the AREA and the NMRA specify turnouts as having circular arc closure rails, implying a circular arc reverse route centerline. While **Appendix B** demonstrates the reverse route curve can have any practical smooth shape, the circular arc is the simplest and prototypical. **PART I** shows that for a specified switch design and a specified frog design, there is only one possible value of theoretical lead. For any other lead value, the reverse route curve simply cannot be a circular arc. Conversely, for a specified lead, frog design and circular arc curved closure rail, there is only one switch design.

Primary Model Turnout Features

As **PART I** shows, the switch design, the frog design, the theoretical lead, and the switch heel spread are related to each other. The most visual features of a prototype or model turnout are its lead and its frog angle. These visual clues make the differences between any two different turnouts obvious.

The current NMRA RPs show various values for lead, some that are less than the prototype, some that are greater, and some that are about the same. Using scaled AREA theoretical leads for model turnouts is certainly appropriate for scale model railroading.

The AREA uses the same frog design in both its curved switch and straight switch turnout designs, so this is reasonable for the model turnout designs as well. However, the NMRA specifies four classes of scale fidelity (Proto, Fine, Standard and Deep Flange) with key dimensional data required by corresponding NMRA Standards. One of those standard dimensions is flangeway width, which affects the toe length of model frogs.

The AREA specifies three design choices for curved switches, fundamentally differing in the choice of switch rail point thickness. The largest point thickness is 0.25 inches, which scales to 0.0052 inches in O scale, and 0.0016 inches in N scale. This detail is too small to model, so using a curved switch design of theoretically zero point thickness for the model is a practical choice. Many modelers and manufacturers blunt the sharp edge, effectively producing a small, but not quantified, point thickness. Some notch the adjacent stock rail to protect the switch point from an approaching wheel (like Design A for the AREA curved switch).

The AREA specifies a single value for switch heel spread (6.25 inches) and applies it to both curved and straight switches, and all frog numbers. A single value is reasonable for model turnouts as well. However, because of scale class choices, the model heel spread must be adjusted not only for flangeway width, but for point spread standards as well.

Frog Design

The NMRA frogs are overly long, with toe length, heel length and total length each about 30% longer than the corresponding scaled AREA values. The NMRA flangeway widths are considerably wider than the scaled prototype. NMRA Proto scale flangeways are closer to the prototype width, but are still slightly wider. In turn, this makes the flangeway gap wider.

Making the model frog toe length longer to accommodate the wider gap is certainly reasonable. Scaling the prototype toe mechanical length and adding the model flangeway gap then sets the frog toe length. Scaling the AREA heel length is also reasonable, unless a contrary argument surfaces.

Model railroad frogs are easily designed from the AREA prototype by taking model flangeway standards into account. Recall equation (I-17) for the prototype theoretical frog toe length:

$$L_{FT} = L_{TM} + \frac{w_F}{\sin\theta} \qquad \text{(III-1)}$$

To use this in the model requires scaling the prototype frog toe mechanical length L_{TM} and substituting the maximum model frog flangeway width from the NMRA Standards. Thus the model theoretical frog toe length becomes:

$$L_{FT} = \frac{L_{TM}}{f_P} + \frac{w_F}{\sin\theta} \quad \text{(III-2)}$$

The model theoretical frog heel length is:

$$L_{FH} = \frac{L_{FH}}{f_P} \quad \text{(III-3)}$$

In the above equation the numerator of the right hand side is understood to be the prototype theoretical frog heel length.

Wing Rails

The NMRA specifies that the wing rail extension length is one-half the frog heel length. Because frog heel and toe lengths are now scaled AREA values, it is consistent to scale the AREA wing rail extension lengths as well.

The model wing rail extension length is:

$$L_{WR} = \frac{L_{WR}}{f_P} \quad \text{(III-4)}$$

In the above equation the numerator of the right hand side is understood to be the prototype theoretical wing rail extension length.

Wing Rail Flares

Model wing rail flares do not require the geometric complexity of the prototype, because the complexity is unnoticeable, even in the larger scales. What is important is having adequate gather. Taking the gather as the sum of the flangeway width and the flare width, the simplified prototype flare width becomes

$$w_{FL} = 3.5 - 1.875 = 1.625 \text{ inches}$$

The prototype flare width is slightly more than ½ the railhead width of 3 inches for 131 lb. rail, and more for narrower, lighter rail.

This flare width considerably narrower that the minimum flare the NMRA specifies in RP-13.8 (dimension (37)), which varies from 2.16 inches to 3.0 inches when scaled up to the prototype.

NMRA RP-13.8 states that dimension (37) is set to "meet the requirement of **STANDARD S-3, Note 5**, of 1.5 x Fmax" which does not exist in the current standards (Standards S-3.1, S-3.2 and S-3.3 replaced S-3 and do not contain a similar note). Were that note to still apply, the flare width for a standard scale HO flare would be 0.025, still less than the 0.030 RP-13.8 requires.

This suggests that the flare dimension (37) for the model may be too conservative and should simply be scaled from the 1.625 inch prototype value.

From **PART I**, the wing rail flare length for a specified bevel length is:

$$L_{FL} = 1.24 L_{BV} - 0.84 \quad \text{(III-5)}$$

The plane width at the end of the wing rail is:

$$w_{BP} = \frac{0.375 L_{FL}}{L_{FL} - L_{BV}} \quad \text{(III-6)}$$

These dimension are not the same as the guard rail flare lengths (see **PART I**). Making them the same is an option for a modeler or model turnout manufacturer.

Switch Heel Spread

The switch heel spread discussion and observations in **PART I** suggests two methods that could be used to set switch heel spread in model turnouts. The key to these methods is to use the flangeway width to set the rail clearance. Because flangeway width is specified by NMRA standards, the two methods apply to any scale and any scale class. Each NMRA scale and class has specified flangeway widths that accommodate recommended wheel flange thicknesses. It is thus appropriate to size the heel spread based on flange width as expressed by equation (III-4).

Method 1, the simplest, applies a factor to the flangeway width to get the rail clearance (see Figure 12):

$$h_C = 1.733333 w_F \quad \text{(III-7)}$$

The factor 1.733333 is the ratio of the prototype rail clearance to the prototype flangeway width:

$$\frac{h_C}{w_F} = \frac{3.25}{1.875} = 1.733333$$

Because the ratio is non-dimensional, no scaling is necessary when using equation (III-7) for the model turnout.

Method 2 maintains the prototype wheel clearance $h_W = 1.375$ inches (again, see Figure 12) scaled by the model proportionality factor f_P:

$$h_C = \frac{1.375}{f_P} + w_F \qquad \text{(III-8)}$$

Regardless of the method used to calculate the rail clearance, its value must be tested against the minimum rail clearance based on the point spread $P_{\max}$ specified by the NMRA Standards S-3.1, S-3.2 and S-3.3 [23-25].

The minimum rail clearance anywhere along the point rail, including at the switch heel, is:

$$h_{C\min} = G_{\min} - P_{\max} \qquad \text{(III-9)}$$

For the heel spread to meet the NMRA standard for point spread $P_{\max}$, the following inequality must always be true at the switch heel:

$$h_C \geq h_{C\min} \qquad \text{(III-10)}$$

Thus, if the value of h_C calculated by either method is less than $h_{C\min}$, it must be replaced by $h_{C\min}$. This ensures that the rail clearance is never less than the minimum rail clearance set by the point spread.

Once the rail clearance is set by either method and tested for compliance with the point spread standard, the heel spread is:

$$S_{SH} = h_C + w_{HD} \qquad \text{(III-11)}$$

Determining railhead width to use in equation (III-11) is another matter. The prototype factor derives from a heel spread of 6.25 inches and a railhead width of 3 inches, the maximum railhead width for the heaviest AREA [4] rail designs. NMRA Recommended Practice RP-15.1 "Rail" [17] specifies railhead widths (dimension **C**) for rail codes up to 297. In principle, it is possible to select a rail code for a particular model scale and use the corresponding railhead width in equation (III-11). Unfortunately, RP-15.1 does not provide rail codes for the heaviest rail used in the larger scales, so a method for sizing the railhead width as a function of rail height is required.

Figure 23 shows a graph of railhead widths versus rail height where the blue diamonds represent data from RP-15.1. The solid black line is a linear regression analysis of the data that provides a mathematical method for computing the railhead width given a rail height. The fit is quite good. Thus:

$$w_{HD} = 0.419858 h_R + 0.004885 \qquad \text{(III-12)}$$

The rail height for AREA 131 lb. rail is 7⅛ inches [4]. Thus, for the model with proportionality factor f_P, noting the scaled rail height is $h_R = 7.125 / f_P$:

$$w_{HD} = \frac{2.991488}{f_P} + 0.004885 \qquad \text{(III-13)}$$

The rationale behind doing this presumes model rail stock cross-section design for the larger scales will be similar to that in RP-15.1, should it be changed to include rail sizes larger than code 297. The purpose of equation (III-13) is to estimate a railhead width for setting the switch heel spread, but not to design larger rail sizes for RP-15.1. It produces values that are somewhat larger than the scaled prototype 3.00 inches, but when setting heel spread the larger value accommodates the sometimes wider model railhead widths. It is unlikely that model rail stock manufacturers would produce rail stock in custom sizes, but might produce rail stock in larger sizes should RP-15.1 be revised to include them.

Guard Rail Design

Guard rail design varies considerably among prototype railroads, and those designs often differ from the AREA designs. The AREA presents two types of guard rails, one constructed using rail stock and one as a casting, but in only two sizes for use with rigid frogs of any construction type. This gives the NMRA

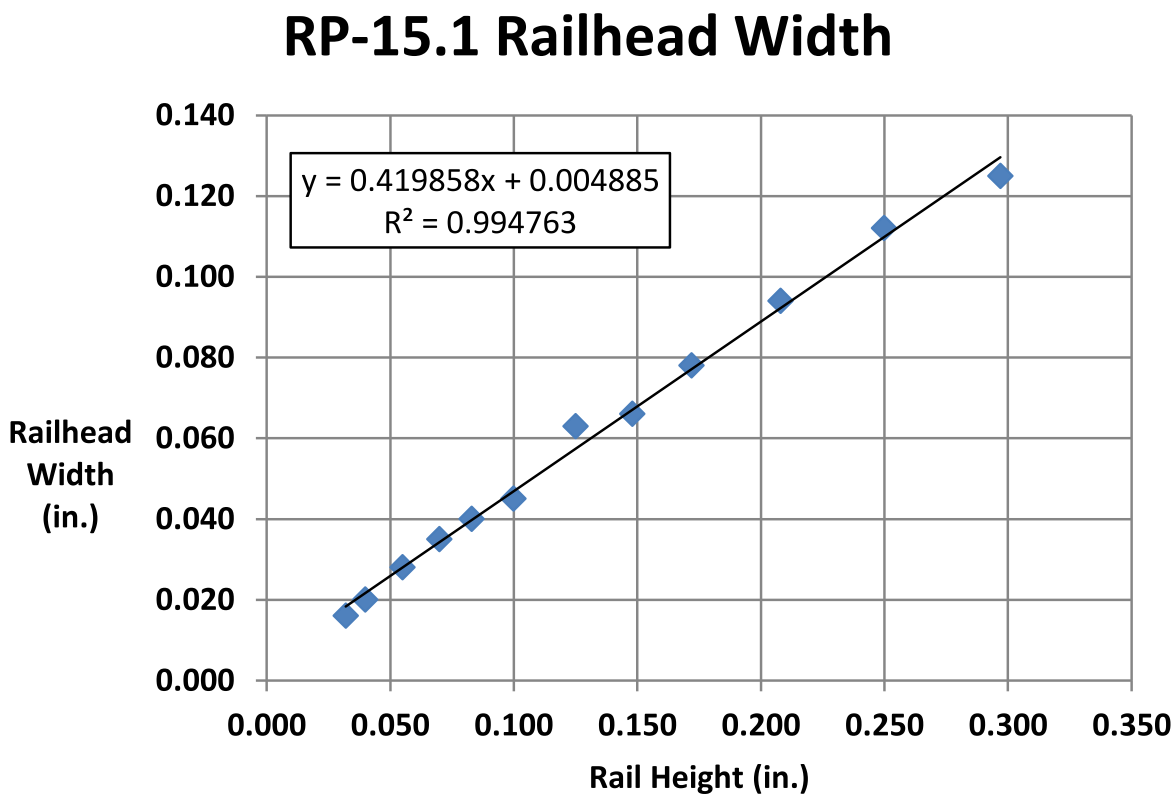


Figure 23: Railhead Width vs Rail Height

some leeway in guard rail design. As described in **PART I**, setting the one-piece guard rail position is most restrictive due to a precise tie spacing under the frog. For that reason, it is better for the NMRA to use the tee rail guard rail for the model. The tee rail design is also more accommodating of the flangeway gap that varies with varying flangeway width specifications.

Having wider flangeway widths, the model guard rail parallel length and setting must accommodate the correspondingly longer flangeway gaps.

Guard Rail Length Selection

PART I examined AREA guard rails and showed how the 6-inch setback always caused the parallel portion to always straddle the frog flangeway gap g_F (see Figure 5). **PART I** also discussed AREA choice of standard guard rail lengths of 8'-3", 11'-0", 13'-0", and extrapolated designs using 16'-6" and 19'-6" lengths, all cut from common rail stock lengths of 33' and 39'.

Noting that the flangeway gap depends on the frog number, a given guard rail length is acceptable as long as the following inequality is satisfied:

$$L_{PL} \geq \frac{w_F}{\sin\theta} + \frac{n}{2\cos(\theta/2)} + 6 \qquad \text{(III-14)}$$

The "6" in equation (III-14) is the minimum AREA setback of 6 inches from the frog ½-inch point. This requires all values in (III-14) to have units of inches. Applying this equation to the AREA turnouts shows the 8'-3" guard rail design is suitable for frogs up to number 14, and the 11'-0" design suitable for frogs 15 through 20. This is also what the AREA specifies on Plan 502-40 for rigid frogs.

The same approach works for the model as well, again noting effect of the wider flangeway widths required by NMRA specifications. For a model turnout, equation (III-14) requires selection of the next longer guard rail design at a lower frog number.

This is the anticipated reason for the extrapolated 16'-6", 19'-6" and 23'-0" guard rail designs from

PART I included in Table 10. While the prototype requires only two different guard rail lengths, the model requires up to six depending on the scale class and frog number.

Guard Rail Flares

Guard rail flares are also easily scaled from the AREA design dimensions, but they are not the same as the wing rail flares (see **PART I**).

PART I shows guard rails have a constant flare value of:

$$w_{FL} = 1.925 \text{ inches.}$$

Guard rail flares are not the same as the wing rail flares (see **PART I**). Making them the same is an option for a modeler or model manufacturer. Using the flares recommended in RP-13.8 is also an option, but they are limited to only a few model scales. When using RP-13.8 the turnout builder must ensure the parallel length properly straddles the flangeway gap.

Guard Rail Setting

In the prototype, the minimum 6-inch setback from the ½-inch point of the frog sets the position of the guard rail, ensuring proper protection of the flangeway gap. In the model, RP-13.5 sets a specific setback distance from the theoretical point. However, this setback is *fixed* for all frog numbers (in the range 4 to 10 currently specified), but it is not sufficient for higher frog numbers.

Scaling the prototype setback, measured from the theoretical point of frog, is a better choice for the model. For all frog numbers, including the higher ones, the prototype setback scaled to the model is:

$$L_{SB} = \frac{1}{f_P}\left[\frac{n}{2\cos(\theta/2)} + 6\right] \qquad \text{(III-15)}$$

While the ½-inch point distance is not normally important for other turnout dimensions, it is here. It is included as the first term in the square brackets in equation (III-15) to ensure that the flangeway gap is always protected.

Crossover Data

Calculation of crossover data requires a specification for a basic parallel track spacing p and a spacing increment Δp. With this information, calculating crossover data using the equations in **PART I** is straightforward.

The turnout RPs specify values for these parameters for each model scale, but they seem to be a mix of data from NMRA Standard S-7 “Clearances” [26], and NMRA Standard S-8 “Track Centers” [27]. Further, these standards include only the most popular scales. To cover all NMRA scales requires a consistent approach to setting track center p and track spacing increment Δp in the RPs.

Turnout RPs [6-12] specify track center spacing that seems to be the “popular” value rather than “recommended” value. For example the HO scale turnout track center spacing in [8], widely used by many modelers, is two inches. Yet Standard S-8 specifies a preferred minimum track center spacing **M** as twice the clearance dimension **A** in Standard S-7. For “Classic” era clearances in S-7, that works out to 2.0625 inches, not two inches as in popular practice. For “Old Time” (and narrow gauge) era clearances **M** becomes 1.625 inches, and for “Modern” era, 2.5 inches. None of these are values specified in [8].

Further [8] specifies a track center spacing increment of 0.125 inches for HO scale, which is equivalent to a strange value of 0.907 prototype feet. For O scale [6], the spacing is 0.25 inches or a precise 1.0 prototype feet. Other scales sometimes have similar inconsistencies.

With Standard S-7 providing clearances for three different eras, it is impractical to provide crossover data in the turnout RPs for all of them. Further, generality requires values for all NMRA scales, not just those listed in S-7 and S-8.

Thus, regardless of scale or era, the prototype AREA values of $p = 13$ feet and $\Delta p = 1.0$ foot seem best for model turnout RPs, scaled by the corresponding proportionality factor. The modeler may then calculate crossover distances for any desired track center spacing.

Design Requirements – Summary

Considering the features discussed above, the basic design requirements for a model railroad turnout of either switch type are:

1. Lead is the scaled AREA theoretical lead.
2. The frog angle is the same as the corresponding AREA frog angle, computed using the specified frog number.

3. Frog designs are scaled AREA frogs with toe length adjusted for model flangeway gap. Curved and straight switch turnout designs each use the same frog design.
4. Straight switch and curved switch turnouts use the same switch heel spread dimension for all frog numbers, adapted from the AREA but using model flangeway width and point spread standards.
5. The curved closure rail between the switch and frog has the shape of a circular arc.
6. Guard rails for all scales are scaled AREA designs with prototype flares, and scaled 6-inch setback from the ½-point. Length selection accounts for flangeway gap.

These requirements have a few ramifications that make the model turnout different from a precisely scaled prototype turnout. Because of the dependence on flangeway width, model turnout designs for Proto, Fine, Standard and Deep Flange scale classes will differ. The differences are not visually significant because of requirement 1 and 2, but do include flangeway width standards. **PART IV** fully discusses these differences.

PART IV: DESIGN CALCULATIONS FOR MODEL RAILROAD TURNOUTS

This part presents an algorithmic summary of the turnout equations developed in earlier sections as they apply to the model turnout designs. These algorithmic equations form the basis for the Visual Basic code programmed into the companion spreadsheet *NMRA TN-12 Generalized Model Turnout Design.xls* [34]. This spreadsheet makes the design calculations for all model scales and scale classes (fidelities) for turnouts No. 4 through 20, inclusive, in a format suitable for straightforward copy-paste into a revised RP format. The turnout designs meet the requirements established in **PART III**.

Table 11 shows the specified or given input information (and its sources) used in the equations that follow.

Switch Heel Spread

Switch heel spread is the same for all turnout (frog) numbers. Two methods set the switch heel rail clearance that in turn leads to the switch heel spread. The first produces heel spreads that are close to those specified in the current turnout RPs. The second method produces values that are narrower, and closer to the prototype. Both methods ensure that the NMRA point rail spread standards are met.

The spreadsheet [34] provides both methods as an input option, even though the second method is preferred.

Method 1 switch heel rail clearance:

$$h_C = 1.733333 w_F \qquad \text{(IV-1)}$$

Because the ratio is non-dimensional, no scaling is necessary to use equation (IV-1) for the model turnout.

Method 2 switch heel rail clearance:

$$h_C = \frac{1.375}{f_P} + w_F \qquad \text{(IV-2)}$$

Minimum rail spacing at heel:

$$h_{C\min} = G - P_{\max} \qquad \text{(IV-3)}$$

Set the rail clearance h_C to the larger of h_C calculated for the selected method or $h_{C\min}$.

Railhead width:

Table 11: Input Information and Sources

Variable	Independent of frog number:	Source:
f_P	NMRA model scale proportionality factor	NMRA Standard S-1.1, S-1.2, S-1.3
G	NMRA *minimum* track gauge standard	NMRA Standard S-3.1, S-3.2, S-3.3
k	Curved switch heel angle factor, k = 1.471904	This TN
$P_{\max}$	NMRA *maximum* point rail spread standard	NMRA Standard S-3.1, S-3.2, S-3.3
t_P	AREA switch point thickness	AREA Trackwork Plans & Specifications
w_F	Maximum flangeway width at frog	NMRA Standard S-3.1, S-3.2, S-3.3
	Dependent on specified frog number *n*:	**Source:**
L_{heel}	AREA frog heel length to ½-inch point	AREA Trackwork Plans & Specifications
L_T	AREA theoretical lead	AREA Trackwork Plans & Specifications
L_{toe}	AREA frog toe length to ½-inch point	AREA Trackwork Plans & Specifications
L_{BV}	AREA wing or guard rail bevel length	AREA Trackwork Plans & Specifications
L_{WR}	AREA wing rail length to ½-inch point	AREA Trackwork Plans & Specifications
t_S	AREA extra tangent after switch heel	AREA Trackwork Plans & Specifications
t_F	AREA extra tangent before/after frog toe	AREA Trackwork Plans & Specifications

$$w_{HD} = \frac{2.991488}{f_P} + 0.004885 \quad \text{(IV-4)}$$

The switch heel spread:

$$S_{SH} = h_C + w_{HD} \quad \text{(IV-5)}$$

Frog Angle

Frog angle:

$$\theta = 2\arctan\left(\frac{1}{2n}\right) \quad \text{(IV-6)}$$

Frog Design

The following are calculations of prototype parameters which require scaling as noted later.

The distance from the theoretical point to the ½-inch point measured along a gauge line:

$$d_{GL} = \frac{n}{2\cos(\theta/2)} \quad \text{(IV-7)}$$

Theoretical heel length:

$$L_{FH} = L_{heel} + d_{GL} \quad \text{(IV-8)}$$

Theoretical toe length:

$$L_{FT} = L_{toe} - d_{GL} \quad \text{(IV-9)}$$

Flangeway gap to the theoretical point of frog:

$$g_T = \frac{1.875}{\sin\theta} \quad \text{(IV-10)}$$

Toe mechanical length:

$$L_{TM} = L_{FT} - g_T \quad \text{(IV-11)}$$

Scaled frog toe, heel and wing rail lengths (Note: w_F is input as the model scale value, so no scaling is required):

$$L_{FT} = \frac{L_{TM}}{f_P} + \frac{w_F}{\sin\theta} \quad \text{(IV-12)}$$

$$L_{FH} = \frac{L_{FH}}{f_P} \quad \text{(IV-13)}$$

$$L_{WR} = \frac{L_{WR}}{f_P} \quad \text{(IV-14)}$$

Total length, toe and heel spread:

$$L_F = L_{FT} + L_{FH} \quad \text{(IV-15)}$$

$$S_{FT} = 2L_{FT}\sin(\theta/2) \quad \text{(IV-16)}$$

$$S_{FH} = 2L_{FH}\sin(\theta/2) \quad \text{(IV-17)}$$

The two frog types most useful to model railroads, the bolted rail frog and the rail bound manganese steel insert frog, have different wing rail flare geometry. The AREA limits bolted rail frogs to numbers 12 and smaller, and allows rail-bound manganese insert frogs for all numbers 4 through 20. When bolted frog flares are used for frog numbers up to 12, rail bound frog flares are used for frog numbers 13 and larger. The spreadsheet *NMRA TN-12 Generalized Model Turnout Design.xls* [34] provides both choices as an input option.

Prototype wing rail flare length and flare width for **bolted rail** frogs are:

$$L_{FL} = L_{BV} \quad \text{(IV-18)}$$

$$w_{FL} = \frac{1.9375L_{BV}}{L_{FL} - 3.5} \quad \text{(IV-19)}$$

$$w_{BP} = 0.0 \quad \text{(IV-20)}$$

$$w_{EB} = 3.5 \quad \text{(IV-21)}$$

Wing rail flare length and flare width for **rail bound manganese** frogs are:

$$L_{FL} = \frac{1.5625L_{BV}}{L_{BV} - 3.5} + 0.375 \quad \text{(IV-22)}$$

$$w_{FL} = 1.24L_{BV} - 0.84 \quad \text{(IV-23)}$$

$$w_{BP} = \frac{0.375L_{FL}}{L_{FL} - L_{BV}} \quad \text{(IV-24)}$$

$$w_{EB} = 3.5 \quad \text{(IV-25)}$$

After the above prototype values are computed, they are divided by f_P to convert them to the selected model scale.

Guard Rail Design

Guard rail designs depend on the frog number as well.

Setback from theoretical point of frog:

$$L_{SB} = \frac{1}{f_P}\left(d_{GL} + 6\right) \quad \text{(IV-26)}$$

Total flangeway gap

$$w_{FG} = \frac{w_F}{\sin\theta} + L_{SB} \quad \text{(IV-27)}$$

There are four possible guard rail lengths and associate flare dimensions whose choice depends on the total flangeway gap they must protect. From Table 10 the guard rail dimensions are:

When $w_{FG} \le \frac{41}{f_P}$ use 8'-3" guard rail:

$$L_{GR} = 99 / f_P$$
$$L_{FL} = 29 / f_P \quad \text{(IV-28)}$$
$$L_{PL} = 41 / f_P$$

When $\frac{41}{f_P} < w_{FG} \le \frac{66}{f_P}$ use 11'-0" guard rail:

$$L_{GR} = 132 / f_P$$
$$L_{FL} = 33 / f_P \quad \text{(IV-29)}$$
$$L_{PL} = 66 / f_P$$

When $\frac{66}{f_P} < w_{FG} \le \frac{84}{f_P}$ use 13'-0" guard rail:

$$L_{GR} = 156 / f_P$$
$$L_{FL} = 36 / f_P \quad \text{(IV-30)}$$
$$L_{PL} = 84 / f_P$$

When $\frac{84}{f_P} < w_{FG} \le \frac{116}{f_P}$ use 16'-6" guard rail:

$$L_{GR} = 198 / f_P$$
$$L_{FL} = 41 / f_P \quad \text{(IV-31)}$$
$$L_{PL} = 116 / f_P$$

When $\frac{116}{f_P} < w_{FG} \le \frac{142}{f_P}$ use 19'-6" guard rail:

$$L_{GR} = 234 / f_P$$
$$L_{FL} = 46 / f_P \quad \text{(IV-32)}$$
$$L_{PL} = 142 / f_P$$

Finally,

when $\frac{142}{f_P} < w_{FG} \le \frac{174}{f_P}$ use 23'-0" guard rail:

$$L_{GR} = 276 / f_P$$
$$L_{FL} = 51 / f_P \quad \text{(IV-32a)}$$
$$L_{PL} = 174 / f_P$$

Equation (IV-32a) affects only model scales O27 and Odf for frog numbers 18 and higher. The especially wide flangeways for these scales requires the longer length guard rails at these high frog numbers.

The bevel length is always:

$$L_{BV} = 13 / f_P \quad \text{(IV-33)}$$

The plane width is:

$$w_{BP} = \frac{1}{f_P}\left(\frac{0.625L_{FL}}{L_{FL} - 13}\right) \quad \text{(IV-34)}$$

The flare width is the same for all guard rails:

$$w_{FL} = 1.925 / f_P \quad \text{(IV-35)}$$

The end bevel (all guard rails):

$$w_{EB} = 3.0 / f_P \tag{IV-36}$$

The position of point **PT**:

$$L_{PT} = (L_{FT} + t_F)\cos\theta \tag{IV-37}$$

$$H_{PT} = G - (L_{FT} + t_F)\sin\theta \tag{IV-38}$$

Curved Switch Turnouts

Solve (IV-39) below for the switch heel angle ϕ_C using a nonlinear root finder:

$$\begin{aligned}&(S_{SH} - t_P)(\cos\phi_C - \cos\theta)\\ &-\sin\left(\frac{\phi_C}{k}\right)\begin{bmatrix}(L_T - t_S\cos\phi_C - L_{PT})\\ (\cos\phi_C - \cos\theta)\\ -(H_{PT} - S_{SH} - t_S\sin\phi_C)\\ (\sin\theta - \sin\phi_C)\end{bmatrix}\\ &= 0\end{aligned} \tag{IV-39}$$

Similarly, solve (IV-40) below for the switch point angle γ:

$$(\cos\gamma - \cos\phi_C) - (\phi_C - \gamma)\sin\left(\frac{\phi_C}{k}\right) = 0 \tag{IV-40}$$

Switch rail length:

$$L_S = \frac{(S_{SH} - t_P)(\phi_C - \gamma)}{(\cos\gamma - \cos\phi_C)} \tag{IV-41}$$

Switch rail radius:

$$R_S = \frac{L_S}{(\phi_C - \gamma)} \tag{IV-42}$$

Switch rail mid-ordinate:

$$h_{MID} = R_S\left[1 - \cos\left(\frac{\phi_C - \gamma}{2}\right)\right] \tag{IV-43}$$

Location of point **PC**:

$$L_{PC} = L_S + t_S\cos\phi_C \tag{IV-44}$$

$$H_{PC} = H_{heel} + t_S\sin\phi_C \tag{IV-45}$$

The distance L_C:

$$L_C = (H_{PT} - H_{PC})\left(\frac{\sin\theta - \sin\phi_C}{\cos\phi_C - \cos\theta}\right) \tag{IV-46}$$

Curved closure rail radius:

$$R_{CCR} = \frac{L_C}{(\sin\theta - \sin\phi_C)} \tag{IV-47}$$

Straight Switch Turnouts

Solve (IV-48) below for the switch heel angle ϕ_S using a nonlinear root finder:

$$\begin{aligned}&(S_{SH} - t_P)(\cos\phi_S - \cos\theta) -\\ &\sin\phi_S\begin{bmatrix}(L_T - t_S\cos\phi_S - L_{PT})\\ (\cos\phi_S - \cos\theta)\\ -(H_{PT} - S_{SH} - t_S\sin\phi_S)\\ (\sin\theta - \sin\phi_S)\end{bmatrix}\\ &= 0\end{aligned} \tag{IV-48}$$

Switch rail length:

$$L_S = \frac{S_{SH} - t_P}{\sin\phi_S} \tag{IV-49}$$

Location of point **PC**:

$$L_{PC} = L_S + t_S\cos\phi_S \tag{IV-50}$$

$$H_{PC} = S_{SH} + t_S\sin\phi_S \tag{IV-51}$$

The distance L_C:

$$L_C = (H_{PT} - H_{PC})\left(\frac{\sin\theta - \sin\phi_S}{\cos\phi_S - \cos\theta}\right) \tag{IV-52}$$

Additional Dimensional Data

After making the calculations for a curved switch turnout, set the generic switch heel angle ϕ to:

$$\phi = \phi_C \qquad \text{(IV-53)}$$

Also, after making the calculations for a straight switch turnout, set the generic switch heel angle ϕ to:

$$\phi = \phi_S \qquad \text{(IV-54)}$$

Then make the calculations for the remaining curved or straight switch dimensional data starting with equation (IV-55) below.

Length of the straight closure rail:

$$L_{SCR} = L_T - L_S - L_{FT} \qquad \text{(IV-55)}$$

Length of the curved closure rail:

$$L_{CCR} = R_{CCR}(\theta - \phi) \qquad \text{(IV- 56)}$$

Curved closure rail gauge point locations:

$$\begin{aligned} X_1 &= L_S + 0.25L_{SCR} \\ X_2 &= L_S + 0.50L_{SCR} \\ X_3 &= L_S + 0.75L_{SCR} \end{aligned} \qquad \text{(IV-57)}$$

Compute intermediate values:

$$a = L_{PC} - R_{CCR}\sin\phi \qquad \text{(IV-58)}$$

$$b = H_{PC} - R_{CCR}(1 - \cos\phi) \qquad \text{(IV-59)}$$

For a gauge point located at X_i, the corresponding offset Y_i is:

$$Y_i = R_{CCR}\left[1 - \sqrt{1 - \left(\frac{X_i - a}{R_{CCR}}\right)^2}\right] + b \qquad \text{(IV-60)}$$

Point of frog to intersection of centerlines:

$$L_{ICL} = Gn \qquad \text{(IV-61)}$$

For crossovers between parallel tracks at specified spacing p, the straight dimension between the theoretical frog points is:

$$D_{ST} = \frac{(p - G)\cos\theta - G}{\sin\theta} \qquad \text{(IV-62)}$$

The crossover dimension is:

$$D_{XT} = \frac{D_{ST}}{\cos\theta} + G\tan\theta \qquad \text{(IV-63)}$$

For a specified incremental track spacing Δp, the straight incremental distance is:

$$\Delta S = \frac{\Delta p}{\tan\theta} \qquad \text{(IV-64)}$$

The crossover incremental distance is:

$$\Delta X = \frac{\Delta p}{\sin\theta} \qquad \text{(IV-65)}$$

Planning Template

A turnout template for layout planning is useful. One can be drawn to scale by hand or with a CAD program with just the few dimensions Figure 24 illustrates.

There is no official definition of turnout overall length L_{OA}. The overall length dimension no doubt begins at the points, and ends at least where the guard or frog wing rail flares end. Because guard rails have such variable lengths, and may end on either side of the end of the frog wing rails, neither suggests a reliable definition.

Turnouts direct trains from one track to a second that often runs parallel to the first. Examples are crossovers, sidings and yard tracks. A crossover suggests one possible definition of overall length that depends of the parallel track spacing p. This definition says "The overall length is distance from the frog point to the place where the reverse route diverges to one-half the track spacing."

Figure 24 illustrates a template that uses this definition Another reason this definition is useful is because it can take advantage of the dimensions already established in the RPs (see **APPENDIX A** for

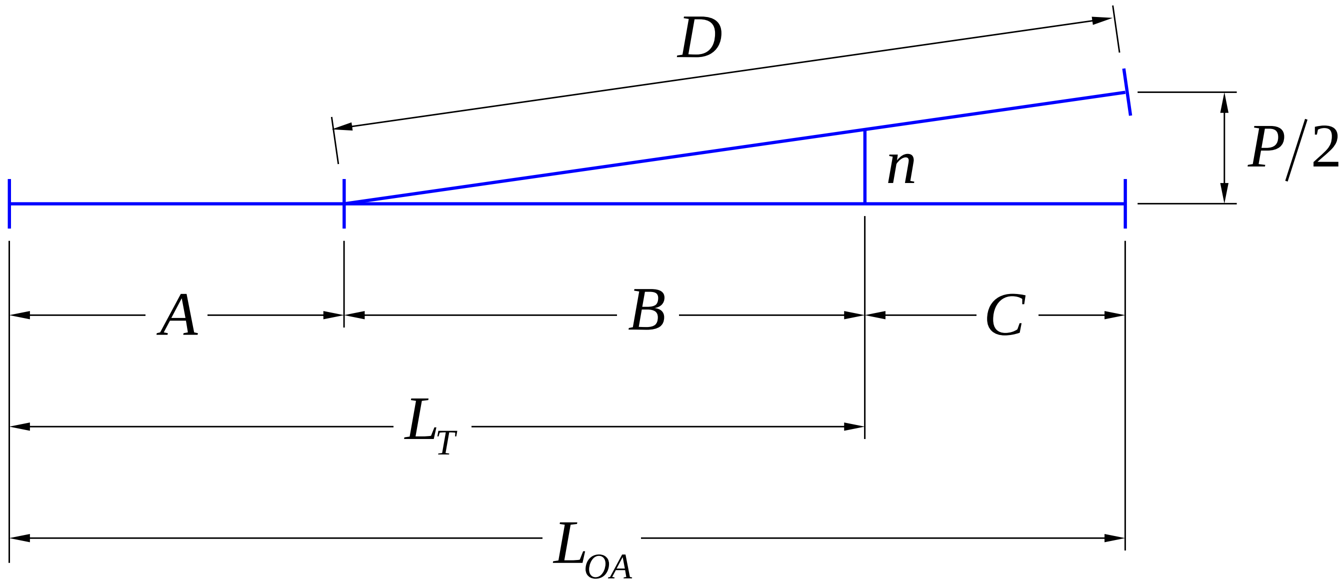


Figure 24: Turnout Template

examples). Using the geometry developed earlier, and the expression for the cosine of the frog angle in terms of the frog number, the equations immediately below define the dimensions in Figure 24. In them, n is the frog number, the dimension $B = Gn$ is the same as (24) in the RPs, "PF to ICL," L_T is the same as (8) "Lead," and the parallel track spacing p is part of the "Data for Crossovers." Then:

$$A = L_T - B \tag{IV-66}$$

$$C = \frac{p}{8n}\left(4n^2 - 1\right) - B \tag{IV-67}$$

$$D = \left(B + C\right)\frac{4n^2 + 1}{4n^2 - 1} \tag{IV-68}$$

The overall length is then:

$$L_{OA} = L_T + C \tag{IV-69}$$

The useful thing about this definition is that the overall length of a crossover is twice the overall length of one of its turnouts. As noted earlier, the overall length depends on the track spacing p. When the track spacing is different from the 13 prototype feet used in the RP "Data for Crossovers," use *one-half* of the "Straight Track Incr." values to adjust the overall turnout length.

While implemented in [34] for convenience, the template dimensions produced by the equations above are not part of the turnout RPs.

Tie Spacing

Tie spacing is problematical (see **PART I** and **PART II**). Prototype turnout tie spacing is not uniform, but averages about 20 inches. Prototype turnouts locate a headblock tie, approximately centered under the switch point. Two ties, spaced on 18 inch centers, straddle the switch heel. Another tie, approximately centered, falls under the frog ½-inch point. Ties in the vicinity of the frog are 19½ inches on center. The remaining ties are nominally spaced at 20 inches, but adjusted for available space, perhaps to accommodate a limited set of tie plate designs.

Constructing a model turnout that locates ties accordingly is possible, but it means the tie arrangement for each turnout number and switch type is different, as it is in the prototype. There are other approaches that are more useful for turnout modeling.

Model Tie Spacing Methods

This section develops methods for setting a uniform tie spacing for turnouts. The methods documented here are simply suggestions. Like the planning template dimensions, tie spacing dimensions are implemented in [34], but are not part of the turnout RPs.

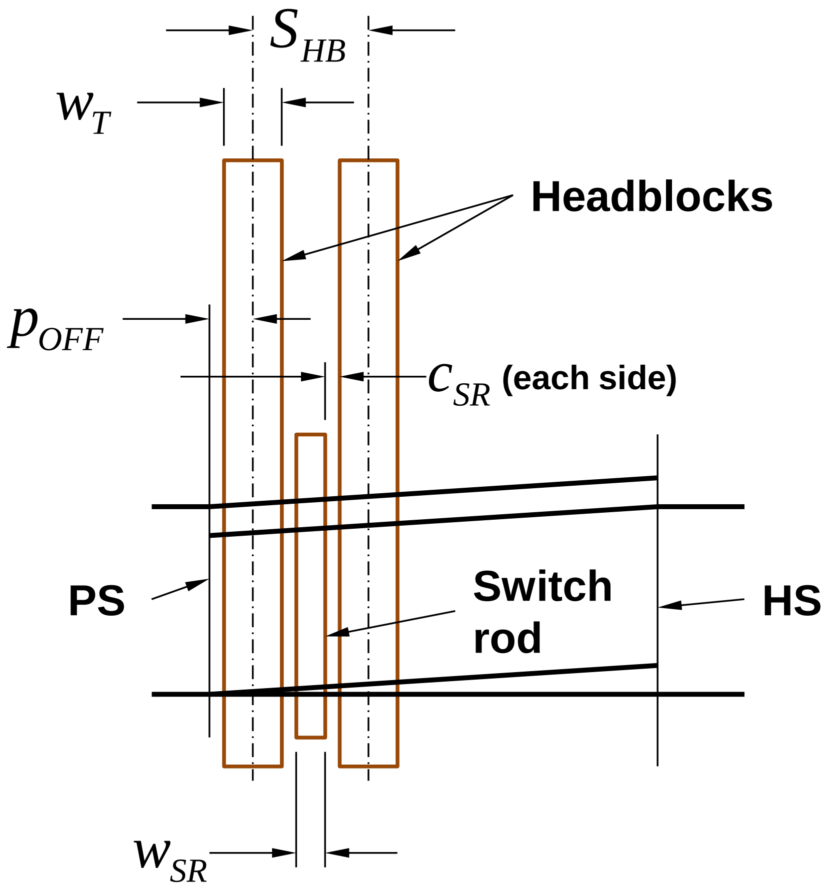


Figure 25: Headblock Spacing

Whether designing a turnout for commercial manufacturing or scratchbuilding, the first tie-spacing design decision that must be made is headblock centerline spacing S_{HB}. Headblock spacing depends on three dimensions: Headblock width (same as tie width) w_T, switch rod width w_{SR}, and switch rod clearance c_{SR}. Figure 25 illustrates these dimensions.

Prototype ties are typically 9 inches wide and easily modeled. Prototype switch rods, made from steel, are typically 2½ inches wide. In most model scales, using a scaled switch rod width will likely produce a switch rod that is not stiff enough to serve its mechanical purpose. Model switch rods, made from plastic or printed circuit board material, are much wider. Switch rod spacing, on each side, must be wide enough so the switch rod does not rub on the headblocks and affect the ability of the points to close against the stock rails. Once established, these three dimensions set the headblock centerline spacing using:

$$S_{HB} = w_T + 2c_{SR} + w_{SR} \qquad \text{(IV-70)}$$

The second decision is the offset of the switch point relative to the center of the first headblock, p_{OFF}. In the prototype, this dimension is 6½ inches for interlocked switches and 3 inches for hand throw switches. For 9 inch wide ties these dimensions place the switch points in front of the first headblock for interlocked switches and within it for hand throw switches. For a model turnout, a dimension for p_{OFF} anywhere in this range is workable, and its value depends on the fidelity desired by the manufacturer or modeler.

Four possible methods for establishing a uniform spacing of the remaining turnout ties follow in order of increasing complexity.

Tie Spacing Method 1

This method assumes a tie is centered at the overall length (the midpoint of a crossover). There must

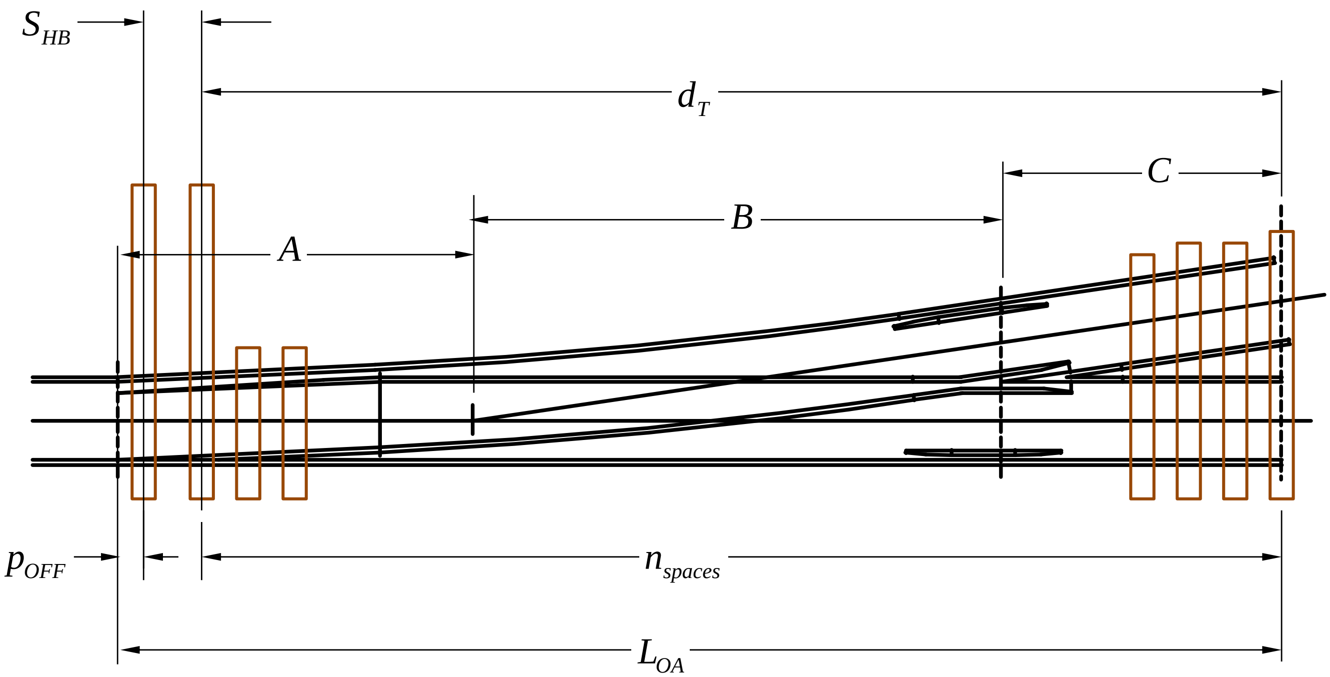


Figure 26: Tie Spacing Methods 1 and 3

always be an integer (whole) number of ties, so tie spacing must be adjusted accordingly. Consider Figure 26. The distance between the centerlines of the second headblock and the tie at the overall length is:

$$d_T = L_{OA} - \left(S_{HB} + p_{OFF}\right) \quad \text{(IV-71)}$$

The desired nominal tie spacing is $S_{nom} = 20$ prototype inches. The number of tie spaces in distance d_T is:

$$n_{spaces} = \frac{d_T\, f_P}{S_{nom}} \quad \text{(IV-72)}$$

In equation (IV-72), recall that f_P is the scale proportionality factor. Further, equation (IV-72) will produce a non-integer value for the number of tie spaces. Round this result to the nearest whole number to get the actual number of tie spaces, n_{spaces}. Finally adjust the tie spacing to:

$$S_{TIE} = \frac{d_T}{n_{spaces}} \quad \text{(IV-73)}$$

Tie Spacing Method 2

This method is similar to Method 1, except a tie *space* is centered at the overall length location as Figure 27 shows. In this case the number of tie spaces in distance d_T is:

$$n_{spaces} = \frac{d_T\, f_P}{S_{nom}} - \frac{1}{2} \quad \text{(IV-74)}$$

Round this result to the nearest whole number to get the actual number of tie spaces, n_{spaces}. Finally adjust the tie spacing to:

$$S_{TIE} = \frac{d_T}{n_{spaces} + \frac{1}{2}} \quad \text{(IV-75)}$$

Tie Spacing Method 3

This method also assumes a tie is centered at the overall length (the midpoint of a crossover), but adjusts the theoretical lead to force the tie spacing to a specific value. In doing so, the turnout will no longer have the scaled AREA lead value, and the other turnout parameters must be recalculated. In this case the number of tie spaces in distance d_T is:

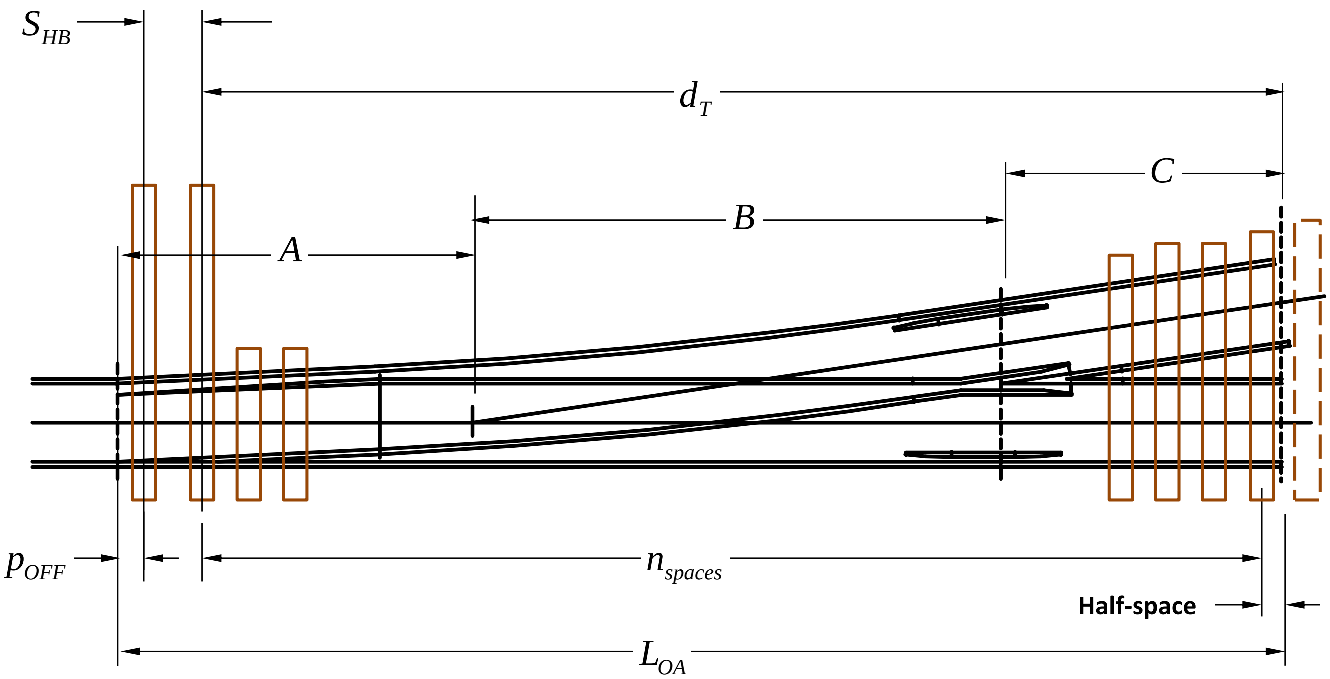


Figure 27: Tie Spacing Methods 2 and 4

$$n_{spaces} = \frac{A - (S_{HB} + p_{OFF}) + (B + C)}{S_{spec}} \qquad \text{(IV-76)}$$

Round this result to the nearest whole number to get the actual number of tie spaces, n_{spaces}. The adjusted distance A is:

$$A_{ADJ} = n_{spaces} S_{spec} + (S_{HB} + p_{off}) - (B + C) \qquad \text{(IV-77)}$$

The adjusted theoretical lead is then:

$$L_{ADJ} = A_{ADJ} + B \qquad \text{(IV-78)}$$

New template dimensions and other turnout dimensions require recalculation using the adjusted theoretical lead.

Tie Spacing Method 4

This method is similar to Method 3, except a tie space is centered at the overall length location. It, too, requires an adjustment to the theoretical lead to force tie spacing to a specified value, and a recalculation of the other turnout parameters. Here the number of tie spaces in distance d_T is:

$$n_{spaces} = \frac{A - (S_{HB} + p_{OFF}) + (B + C)}{S_{spec}} - \frac{1}{2} \qquad \text{(IV-79)}$$

Round this result to the nearest whole number to get the actual number of tie spaces, n_{spaces}. The adjusted distance A is:

$$A_{ADJ} = \left(n_{spaces} + \frac{1}{2}\right) S_{spec} + (S_{HB} + p_{off}) - (B + C) \qquad \text{(IV-80)}$$

The adjusted theoretical lead is again:

$$L_{ADJ} = A_{ADJ} + B \qquad \text{(IV-81)}$$

As in Method 3, new template dimensions and other turnout dimensions require recalculation using the adjusted theoretical lead.

Method Comparison

Methods 1 and 2, which retain the scaled AREA lead, are suitable for manufactured turnouts where tooling is different for each turnout (frog) number. The adjusted theoretical lead values for Methods 3 and 4 differ at most by perhaps one-half the tie space distance from the scaled AREA theoretical lead values, making them "close enough." Methods 3 and 4 are useful for scratch builders who wish to use the same turnout tie spacing fixture for all turnout numbers. Scratch builders will have to accept the small deviation from the scaled AREA lead that these methods require.

Finally, recall that template dimension C depends on the track spacing p. That means the number of spaces tie spacing, overall length, and the adjusted lead values determined by all four methods all vary slightly for different track spacing. The maximum variation is about one-half a tie space.

PART V: CHECKING FINAL DESIGN CONSISTENCY WITH CAD DRAWINGS

Final Design Consistency Checks

Reevaluating the new design dimensions using the consistency evaluation spreadsheets determines their consistency. The first reevaluation uses the exact dimensions obtained from the design spreadsheets. The second uses the dimensions from the design spreadsheets rounded to the nearest 0.001 inches or degrees. Because using those spreadsheets will produce the same results for all scales, only the curved switch HO scale designs were reevaluated.

Using the *exact* dimensions from the design spreadsheet, consistency reevaluation showed percent differences for ALL dimensions to be identically zero. This is an expected result because the design and evaluation spreadsheets use the same validated equations.

Using the *rounded* (to nearest 0.001 inch) dimensions from the design spreadsheets, and given in the HO Scale RP examples, showed that percent differences for all dimensions except one were consistent (0.5% or less). The exception was the mid-ordinate dimension for the curved switch rail. Because this dimension is small, on the order of a few thousandths of an inch, rounding to the nearest thousandth cuts off the ten thousandths part or less, producing percent differences of several percent. The ability to measure or construct this dimension to more than the nearest one thousandth is not necessary, so this inconsistency is ignored. This also shows that rounding to the nearest 0.001 inch is reasonable for the turnout designs presented in any new or updated NMRA RPs.

Computer Aided Design Drawings

The consistency of the new designs is demonstrated as described above. A final visual and graphical check of the turnout designs using a Computer Aided Design (CAD) program is appropriate, in this case *DesignCAD 3D*. This is also in keeping with the earlier assertion that the most visual aspects of a turnout design are the lead and frog angle.

Figure 28 and Figure 29 illustrate the effect of turnout design rationale on curved and straight switch turnout geometry for the Deep Flange, Fine, Proto and Standard scale classes (fidelities). For reference, the scale at the bottom of each figure is in inches. These figures compare design results for HO No. 6 turnouts. At first glance they all look the same, as they should, because by design intent they all have the same lead and frog angle. Because the design rationale and equations are the same for all scales, similar drawings of the other scales will show the same relationships. The only exception would be for Proto:48 and O scale having different track gauges.

In Figure 28 and Figure 29, the left-most vertical dashed line locates the point of switch. Moving to the right, the next vertical dashed line, for reference, locates the scaled AREA switch heel location. Finally, the last vertical dashed line locates the theoretical point of frog.

Less obvious, but noticeable, is the switch rail length. Because the switch heel spread in the model is larger than in the prototype, and the lead is scaled to the AREA value, the switch rail lengths are longer than the scaled AREA lengths. This locates the switch heel to the right of the scaled AREA location, as the short solid vertical line indicates. The Proto:87 switch rail length is closest to the AREA value, but not precisely so because the switch heel spread is set by the NMRA switch point standards. This is true for all the Proto scales. The heel spread for all other scales is set by the flangeway width method discussed in **PART III**.

Figure 28 also shows the HO scale No. 6 curved turnout from the 1961 NMRA RP-12.3. The lead value for that turnout is slightly longer than the scaled AREA value, indicated by the short solid vertical line at the frog point.

The more subtle differences are in the frogs and guard rails. The most subtle difference is in the frog toe length. Frog toe length is determined by the flangeway width that varies with scale class in accordance with the method also discussed in **PART III**.

Even though the CAD drawings are highly accurate, these features are more difficult to discern in these figures because of digitization and the difficulty computer screens and printers sometimes have resolving lines at small angles from the horizontal. Figure 30 shows a comparison of the HO No. 6 standard class and Proto:87 class frogs and guard rails. In this zoomed-in view, the shorter frog toe length and flangeway gap, and narrower flangeway width of the Proto:87 frog and guard rail are clearly visible.

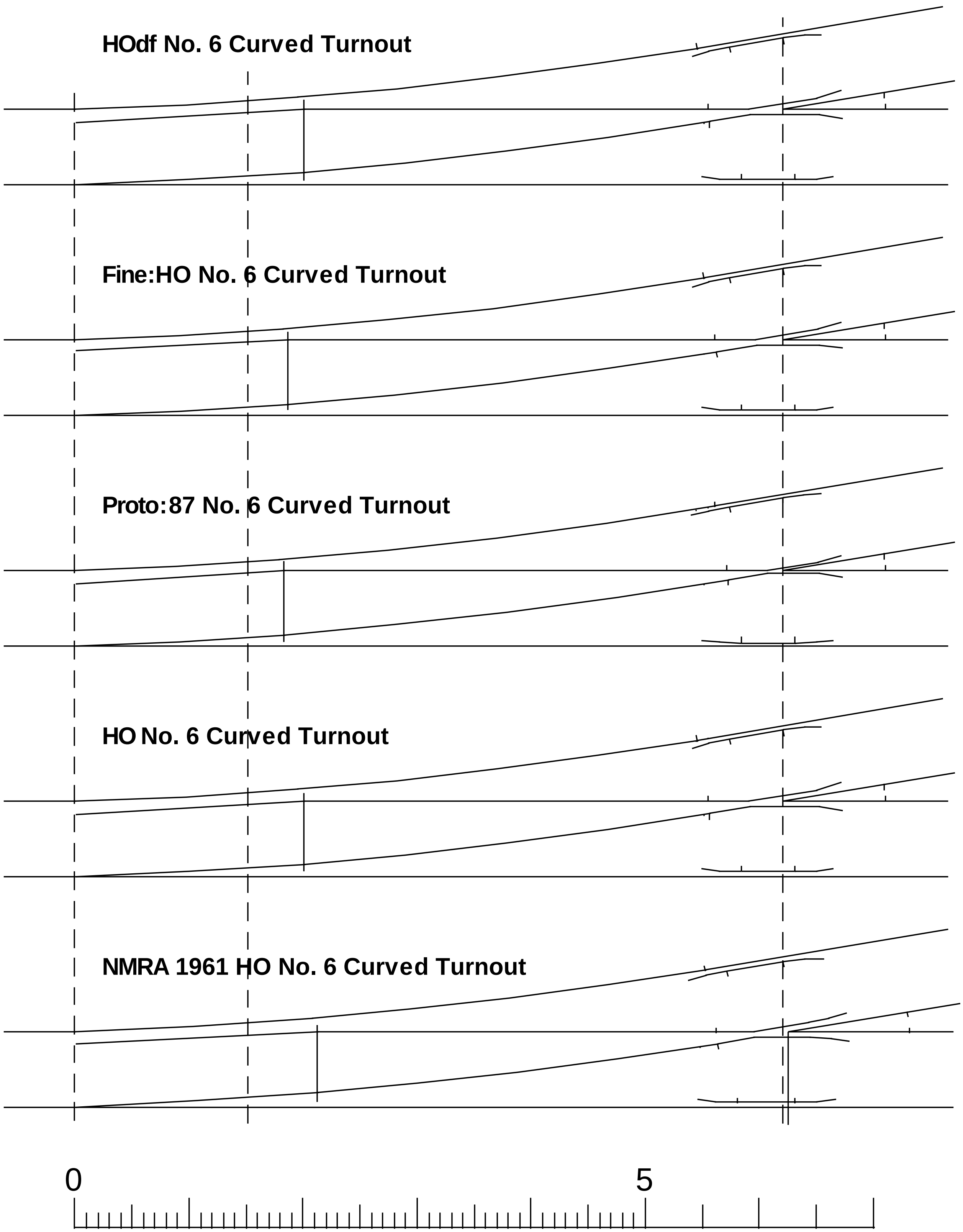


Figure 28: Scale Class Comparison – No. 6 Curved Turnout

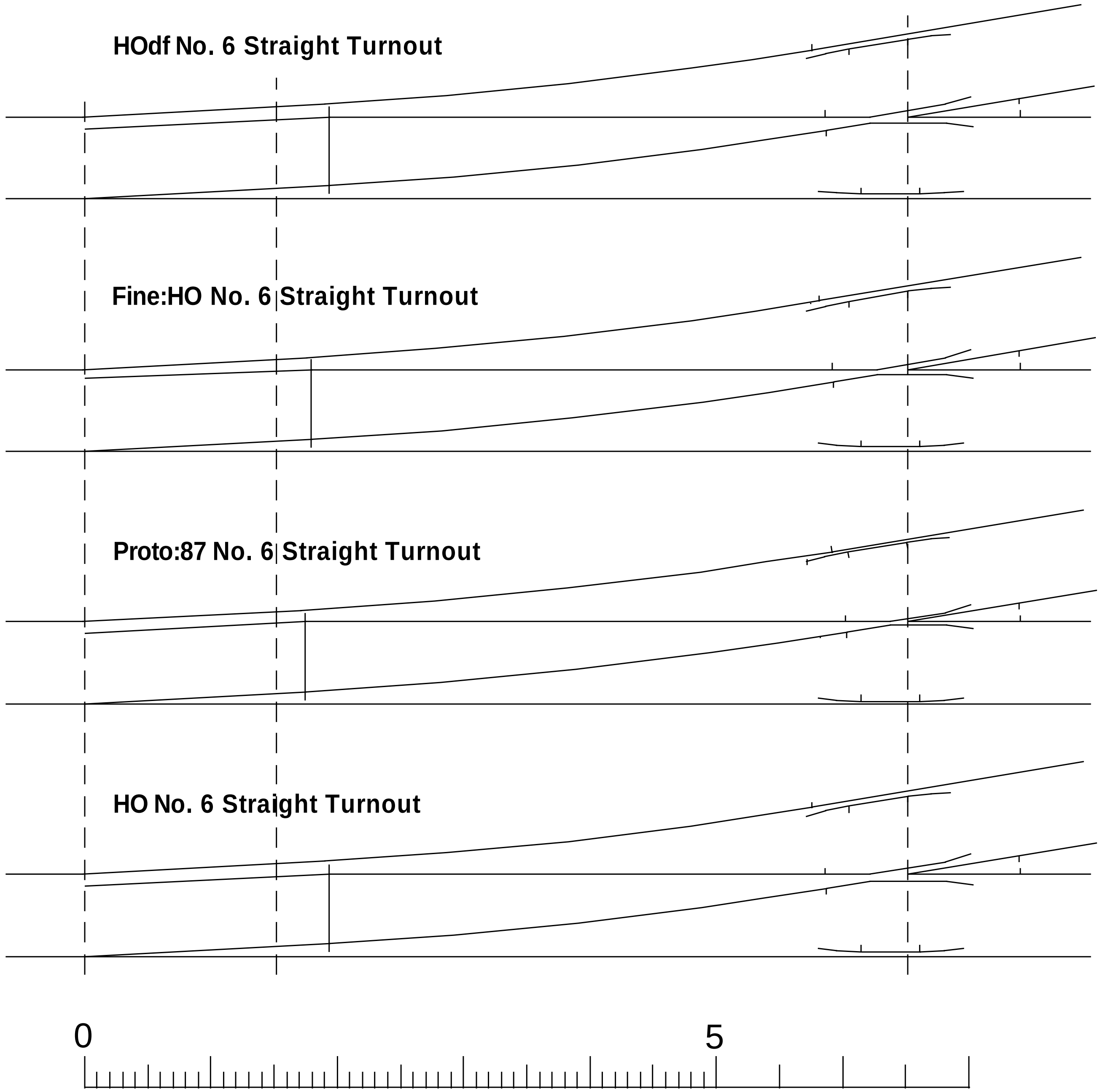


Figure 29: Scale Class Comparison – No. 6 Straight Turnout

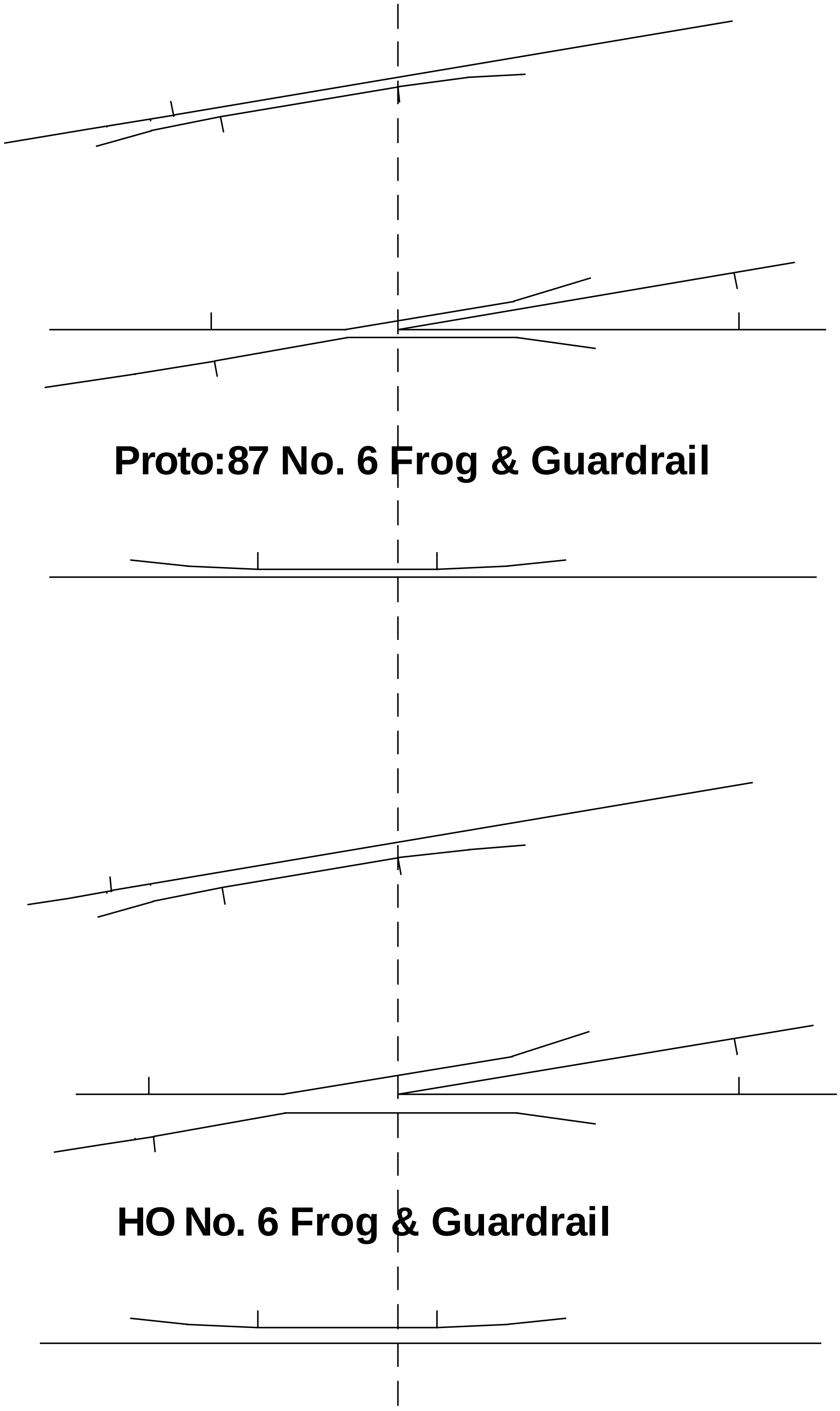


Figure 30: Scale Class Comparison – Zoomed to Clarify Frog & Guardrail Flangeways

APPENDIX A: REVISED TURNOUT RP FORMAT AND EXAMPLES

This appendix shows the format of the revised turnout RP format using Proto:87 and HO scale turnouts as examples. Because the turnouts are numbered 4 through 20, two pages are required for each scale class and switch type. The first page tabulates dimensions for frogs numbered 4 through 12 and the second page frogs numbered 13 through 20.

Following the examples, Figure 31 shows the **Diagram of Turnouts** for turnouts with either curved or straight switch rails, and identifies wing and guard rail dimensions.

NMRA Recommended Practices

Proto:87 Scale

Curved Switch Turnout

TURNOUT DIMENSIONS	
Revised: MMM. 20YY	RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	4	5	6	7	8	9	10	11	12
PROPERTIES OF CURVED SWITCHES										
(2)	Switch Rail Length	1.797	1.794	1.830	3.069	3.143	3.209	3.216	3.257	4.834
(3)	Switch Point Angle (deg.)	1.588	1.591	1.559	0.929	0.907	0.889	0.887	0.876	0.590
(4)	Switch Heel Spread	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
(5)	Switch Heel Angle (deg.)	4.425	4.432	4.345	2.590	2.529	2.477	2.472	2.440	1.644
(6)	Switch Rail Radius	36.295	36.172	37.643	105.898	111.090	115.740	116.274	119.258	262.708
(7)	Switch Mid-Ordinate	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
LEAD TO THEORETICAL POINT OF FROG										
(8)	Lead	4.937	5.572	6.206	8.638	9.376	10.019	10.625	11.227	14.233
CLOSURE DISTANCE										
(9)	Straight Rail Length	2.698	3.311	3.885	4.950	5.566	5.970	6.567	7.053	8.377
(10)	Curved Rail Length	2.752	3.355	3.922	4.980	5.593	5.994	6.589	7.073	8.395
(11)	Curved Rail Radius	16.047	27.503	43.362	51.124	69.298	88.465	116.046	146.585	153.779
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL										
(12)	1st Point Y1 [+]	0.161	0.171	0.179	0.165	0.170	0.171	0.177	0.180	0.169
(13)	1st Point X1	2.472	2.622	2.801	4.307	4.535	4.701	4.858	5.020	6.928
(14)	Mid-Point Y2 [+]	0.256	0.273	0.286	0.266	0.273	0.274	0.283	0.287	0.272
(15)	Mid-Point X2	3.146	3.450	3.773	5.544	5.926	6.194	6.500	6.783	9.022
(16)	3rd Point Y3	0.381	0.401	0.415	0.398	0.405	0.402	0.412	0.416	0.403
(17)	3rd Point X3 [+]	3.821	4.277	4.744	6.782	7.318	7.686	8.141	8.547	11.116
PROPERTIES OF FROGS										
(18)	Frog Angle (deg.)	14.250	11.421	9.527	8.171	7.153	6.360	5.725	5.205	4.772
(19)	Overall Length	1.108	1.248	1.387	1.664	1.803	2.218	2.288	2.594	2.820
(20)	Toe Length	0.442	0.467	0.491	0.619	0.666	0.840	0.841	0.918	1.022
(21)	Heel Length	0.666	0.781	0.896	1.045	1.137	1.378	1.447	1.677	1.797
(22)	Toe Spread	0.110	0.093	0.082	0.088	0.083	0.093	0.084	0.083	0.085
(23)	Heel Spread	0.165	0.155	0.149	0.149	0.142	0.153	0.145	0.152	0.150
(35)	Wing Rail Extension	0.408	0.462	0.517	0.571	0.626	0.680	0.735	0.790	0.844
(36)	Wing Rail Flare Length	0.207	0.207	0.207	0.207	0.276	0.276	0.367	0.367	0.413
(37)	Wing Rail Flare Width	0.028	0.028	0.028	0.028	0.026	0.026	0.025	0.025	0.025
(38)	Wing Rail Bend Width	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES										
(24)	PF to ICL	2.596	3.245	3.894	4.543	5.192	5.841	6.490	7.139	7.788
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS										
	For Track Centers of:	1.791	(13 prototype feet)							
(25)	Straight Track Dist.	1.861	2.377	2.885	3.389	3.891	4.390	4.889	5.386	5.883
(26)	Crossover Track Dist.	2.085	2.556	3.035	3.517	4.003	4.490	4.978	5.467	5.957
	For Track Center Increment of:	0.138	(1 prototype foot)							
(28)	Straight Track Incr.	0.543	0.682	0.821	0.960	1.098	1.236	1.375	1.513	1.651
(29)	Crossover Track Incr.	0.560	0.696	0.833	0.969	1.107	1.244	1.381	1.519	1.656
GUARD RAILS										
(30)	Parallel End Setback	0.092	0.098	0.103	0.109	0.115	0.121	0.126	0.132	0.138
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
(33)	Overall Length	1.137	1.137	1.137	1.137	1.137	1.137	1.137	1.137	1.137
(34)	Parallel Length	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471
(37)	Flare Width	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Plane Width	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

Proto:87 Scale

Curved Switch Turnout

TURNOUT DIMENSIONS

Revised: MMM. 20YY | RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	13	14	15	16	17	18	19	20
PROPERTIES OF CURVED SWITCHES									
(2)	Switch Rail Length	4.873	4.924	4.992	5.056	6.245	6.326	6.383	6.448
(3)	Switch Point Angle (deg.)	0.585	0.579	0.571	0.564	0.457	0.451	0.447	0.442
(4)	Switch Heel Spread	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
(5)	Switch Heel Angle (deg.)	1.631	1.614	1.592	1.572	1.273	1.256	1.245	1.233
(6)	Switch Rail Radius	266.980	272.600	280.175	287.437	438.513	449.981	458.106	467.467
(7)	Switch Mid-Ordinate	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
LEAD TO THEORETICAL POINT OF FROG									
(8)	Lead	14.900	15.568	16.225	16.909	19.329	20.015	20.701	21.387
CLOSURE DISTANCE									
(9)	Straight Rail Length	8.952	9.515	10.000	10.623	11.747	12.244	12.877	13.503
(10)	Curved Rail Length	8.968	9.531	10.014	10.637	11.759	12.256	12.889	13.514
(11)	Curved Rail Radius	185.226	220.479	257.742	303.516	321.327	364.592	417.264	474.540
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL									
(12)	1st Point Y1 [+]	0.172	0.174	0.176	0.179	0.173	0.174	0.177	0.179
(13)	1st Point X1	7.111	7.303	7.492	7.712	9.182	9.387	9.603	9.824
(14)	Mid-Point Y2 [+]	0.276	0.280	0.282	0.287	0.278	0.280	0.284	0.288
(15)	Mid-Point X2	9.349	9.682	9.992	10.368	12.118	12.448	12.822	13.199
(16)	3rd Point Y3	0.407	0.411	0.412	0.418	0.411	0.411	0.416	0.420
(17)	3rd Point X3 [+]	11.587	12.060	12.492	13.024	15.055	15.509	16.041	16.575
PROPERTIES OF FROGS									
(18)	Frog Angle (deg.)	4.405	4.091	3.818	3.580	3.369	3.182	3.015	2.864
(19)	Overall Length	3.045	3.270	3.381	3.606	3.832	4.057	4.170	4.284
(20)	Toe Length	1.076	1.129	1.233	1.229	1.337	1.445	1.440	1.436
(21)	Heel Length	1.969	2.142	2.147	2.377	2.495	2.612	2.730	2.848
(22)	Toe Spread	0.083	0.081	0.082	0.077	0.079	0.080	0.076	0.072
(23)	Heel Spread	0.151	0.153	0.143	0.148	0.147	0.145	0.144	0.142
(35)	Wing Rail Extension	0.936	1.028	1.082	1.194	1.249	1.303	1.395	1.487
(36)	Wing Rail Flare Length	0.539	0.610	0.636	0.713	0.738	0.763	0.835	0.907
(37)	Wing Rail Flare Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(38)	Wing Rail Bend Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES									
(24)	PF to ICL	8.437	9.086	9.735	10.384	11.033	11.682	12.331	12.980
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS									
	For Track Centers of:	1.791	(13 prototype feet)						
(25)	Straight Track Dist.	6.379	6.875	7.370	7.865	8.360	8.855	9.350	9.844
(26)	Crossover Track Dist.	6.448	6.939	7.430	7.921	8.413	8.905	9.397	9.889
For Track Center Increment of:		0.138	(1 prototype foot)						
(28)	Straight Track Incr.	1.789	1.927	2.065	2.203	2.340	2.478	2.616	2.754
(29)	Crossover Track Incr.	1.794	1.932	2.069	2.207	2.345	2.482	2.620	2.758
GUARD RAILS									
(30)	Parallel End Setback	0.144	0.149	0.155	0.161	0.167	0.172	0.178	0.184
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.379	0.379	0.379	0.379	0.379	0.379	0.379
(33)	Overall Length	1.137	1.516	1.516	1.516	1.516	1.516	1.516	1.516
(34)	Parallel Length	0.471	0.758	0.758	0.758	0.758	0.758	0.758	0.758
(37)	Total Flare at End	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Bevel Cut at End	0.013	0.012	0.012	0.012	0.012	0.012	0.012	0.012
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

Proto:87 Scale

Straight Switch Turnout

TURNOUT DIMENSIONS	
Revised: MMM. 20YY	RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	4	5	6	7	8	9	10	11	12
PROPERTIES OF CURVED SWITCHES										
(2)	Switch Rail Length	1.790	1.745	1.745	2.669	2.747	2.737	2.872	3.621	3.638
(4)	Switch Heel Spread	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
(5)	Switch Heel Angle (deg.)	3.017	3.095	3.095	2.024	1.966	1.973	1.880	1.491	1.484
LEAD TO THEORETICAL POINT OF FROG										
(8)	Lead	5.156	5.833	6.511	8.514	9.324	9.910	10.794	12.594	13.251
CLOSURE DISTANCE										
(9)	Straight Rail Length	2.923	3.621	4.274	5.227	5.911	6.333	7.080	8.056	8.591
(10)	Curved Rail Length	2.975	3.663	4.309	5.256	5.937	6.357	7.101	8.075	8.609
(11)	Curved Rail Radius	15.177	25.206	38.388	48.990	65.590	83.032	105.823	124.579	150.040
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL										
(12)	1st Point Y1 [+]	0.150	0.160	0.167	0.158	0.162	0.164	0.167	0.163	0.165
(13)	1st Point X1	2.521	2.651	2.814	3.975	4.224	4.320	4.642	5.635	5.785
(14)	Mid-Point Y2 [+]	0.242	0.258	0.270	0.257	0.263	0.264	0.270	0.264	0.267
(15)	Mid-Point X2	3.252	3.556	3.882	5.282	5.702	5.903	6.412	7.648	7.933
(16)	3rd Point Y3	0.371	0.389	0.403	0.391	0.397	0.394	0.402	0.398	0.400
(17)	3rd Point X3 [+]	3.983	4.461	4.951	6.589	7.180	7.486	8.182	9.662	10.081
PROPERTIES OF FROGS										
(18)	Frog Angle (deg.)	14.250	11.421	9.527	8.171	7.153	6.360	5.725	5.205	4.772
(19)	Overall Length	1.108	1.248	1.387	1.664	1.803	2.218	2.288	2.594	2.820
(20)	Toe Length	0.442	0.467	0.491	0.619	0.666	0.840	0.841	0.918	1.022
(21)	Heel Length	0.666	0.781	0.896	1.045	1.137	1.378	1.447	1.677	1.797
(22)	Toe Spread	0.110	0.093	0.082	0.088	0.083	0.093	0.084	0.083	0.085
(23)	Heel Spread	0.165	0.155	0.149	0.149	0.142	0.153	0.145	0.152	0.150
(35)	Wing Rail Extension	0.408	0.462	0.517	0.571	0.626	0.680	0.735	0.790	0.844
(36)	Wing Rail Flare Length	0.207	0.207	0.207	0.207	0.276	0.276	0.367	0.367	0.413
(37)	Wing Rail Flare Width	0.028	0.028	0.028	0.028	0.026	0.026	0.025	0.025	0.025
(38)	Wing Rail Bend Width	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES										
(24)	PF to ICL	2.596	3.245	3.894	4.543	5.192	5.841	6.490	7.139	7.788
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS										
	For Track Centers of:	1.791	(13 prototype feet)							
(25)	Straight Track Dist.	1.861	2.377	2.885	3.389	3.891	4.390	4.889	5.386	5.883
(26)	Crossover Track Dist.	2.085	2.556	3.035	3.517	4.003	4.490	4.978	5.467	5.957
	For Track Center Increment of:	0.138	(1 prototype foot)							
(28)	Straight Track Incr.	0.543	0.682	0.821	0.960	1.098	1.236	1.375	1.513	1.651
(29)	Crossover Track Incr.	0.560	0.696	0.833	0.969	1.107	1.244	1.381	1.519	1.656
GUARD RAILS										
(30)	Parallel End Setback	0.092	0.098	0.103	0.109	0.115	0.121	0.126	0.132	0.138
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
(33)	Overall Length	1.137	1.137	1.137	1.137	1.137	1.137	1.137	1.137	1.137
(34)	Parallel Length	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471	0.471
(37)	Flare Width	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Plane Width	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013	0.013
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

Proto:87 Scale

Straight Switch Turnout

TURNOUT DIMENSIONS	
Revised: MMM. 20YY	RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	13	14	15	16	17	18	19	20
PROPERTIES OF CURVED SWITCHES									
(2)	Switch Rail Length	3.683	3.737	5.032	5.019	5.044	5.076	5.139	5.208
(4)	Switch Heel Spread	0.094	0.094	0.094	0.094	0.094	0.094	0.094	0.094
(5)	Switch Heel Angle (deg.)	1.466	1.445	1.073	1.076	1.071	1.064	1.051	1.037
LEAD TO THEORETICAL POINT OF FROG									
(8)	Lead	13.962	14.672	17.328	18.005	18.663	19.320	20.072	20.824
CLOSURE DISTANCE									
(9)	Straight Rail Length	9.204	9.807	11.063	11.757	12.282	12.800	13.493	14.181
(10)	Curved Rail Length	9.220	9.822	11.077	11.770	12.294	12.811	13.504	14.191
(11)	Curved Rail Radius	179.748	212.688	231.185	269.311	306.417	346.487	393.954	444.975
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL									
(12)	1st Point Y1 [+]	0.168	0.170	0.163	0.165	0.167	0.168	0.171	0.173
(13)	1st Point X1	5.984	6.189	7.797	7.958	8.114	8.276	8.512	8.753
(14)	Mid-Point Y2 [+]	0.271	0.275	0.264	0.269	0.271	0.272	0.276	0.279
(15)	Mid-Point X2	8.284	8.640	10.563	10.898	11.185	11.476	11.885	12.298
(16)	3rd Point Y3	0.404	0.407	0.399	0.404	0.405	0.406	0.410	0.414
(17)	3rd Point X3 [+]	10.585	11.092	13.329	13.837	14.255	14.676	15.259	15.843
PROPERTIES OF FROGS									
(18)	Frog Angle (deg.)	4.405	4.091	3.818	3.580	3.369	3.182	3.015	2.864
(19)	Overall Length	3.045	3.270	3.381	3.606	3.832	4.057	4.170	4.284
(20)	Toe Length	1.076	1.129	1.233	1.229	1.337	1.445	1.440	1.436
(21)	Heel Length	1.969	2.142	2.147	2.377	2.495	2.612	2.730	2.848
(22)	Toe Spread	0.083	0.081	0.082	0.077	0.079	0.080	0.076	0.072
(23)	Heel Spread	0.151	0.153	0.143	0.148	0.147	0.145	0.144	0.142
(35)	Wing Rail Extension	0.936	1.028	1.082	1.194	1.249	1.303	1.395	1.487
(36)	Wing Rail Flare Length	0.539	0.610	0.636	0.713	0.738	0.763	0.835	0.907
(37)	Wing Rail Flare Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(38)	Wing Rail Bend Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES									
(24)	PF to ICL	8.437	9.086	9.735	10.384	11.033	11.682	12.331	12.980
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS									
	For Track Centers of:	1.791	(13 prototype feet)						
(25)	Straight Track Dist.	6.379	6.875	7.370	7.865	8.360	8.855	9.350	9.844
(26)	Crossover Track Dist.	6.448	6.939	7.430	7.921	8.413	8.905	9.397	9.889
For Track Center Increment of:		0.138	(1 prototype foot)						
(28)	Straight Track Incr.	1.789	1.927	2.065	2.203	2.340	2.478	2.616	2.754
(29)	Crossover Track Incr.	1.794	1.932	2.069	2.207	2.345	2.482	2.620	2.758
GUARD RAILS									
(30)	Parallel End Setback	0.144	0.149	0.155	0.161	0.167	0.172	0.178	0.184
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.379	0.379	0.379	0.379	0.379	0.379	0.379
(33)	Overall Length	1.137	1.516	1.516	1.516	1.516	1.516	1.516	1.516
(34)	Parallel Length	0.471	0.758	0.758	0.758	0.758	0.758	0.758	0.758
(37)	Total Flare at End	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Bevel Cut at End	0.013	0.012	0.012	0.012	0.012	0.012	0.012	0.012
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

HO Scale

Curved Switch Turnout

TURNOUT DIMENSIONS

Revised: MMM. 20YY | **RP-12.XXX**

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	4	5	6	7	8	9	10	11	12
PROPERTIES OF CURVED SWITCHES										
(2)	Switch Rail Length	1.940	1.952	2.001	3.317	3.411	3.492	3.512	3.564	5.240
(3)	Switch Point Angle (deg.)	1.640	1.629	1.589	0.958	0.932	0.910	0.905	0.892	0.607
(4)	Switch Heel Spread	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
(5)	Switch Heel Angle (deg.)	4.568	4.539	4.428	2.671	2.597	2.537	2.523	2.485	1.690
(6)	Switch Rail Radius	37.948	38.441	40.395	110.961	117.352	123.019	124.393	128.146	276.984
(7)	Switch Mid-Ordinate	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
LEAD TO THEORETICAL POINT OF FROG										
(8)	Lead	4.937	5.572	6.206	8.638	9.376	10.019	10.625	11.227	14.233
CLOSURE DISTANCE										
(9)	Straight Rail Length	2.446	3.017	3.551	4.513	5.082	5.443	6.001	6.448	7.646
(10)	Curved Rail Length	2.499	3.060	3.588	4.543	5.109	5.467	6.023	6.468	7.664
(11)	Curved Rail Radius	14.792	25.476	40.311	47.322	64.253	81.936	107.764	136.266	142.503
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL										
(12)	1st Point Y1 [+]	0.167	0.176	0.184	0.171	0.175	0.177	0.182	0.185	0.174
(13)	1st Point X1	2.551	2.706	2.889	4.445	4.681	4.853	5.012	5.176	7.151
(14)	Mid-Point Y2 [+]	0.254	0.270	0.282	0.264	0.271	0.271	0.279	0.283	0.269
(15)	Mid-Point X2	3.163	3.461	3.777	5.573	5.952	6.214	6.512	6.788	9.063
(16)	3rd Point Y3	0.368	0.387	0.401	0.385	0.392	0.388	0.398	0.401	0.390
(17)	3rd Point X3 [+]	3.774	4.215	4.664	6.701	7.222	7.574	8.012	8.400	10.975
PROPERTIES OF FROGS										
(18)	Frog Angle (deg.)	14.250	11.421	9.527	8.171	7.153	6.360	5.725	5.205	4.772
(19)	Overall Length	1.218	1.384	1.550	1.854	2.020	2.462	2.559	2.892	3.144
(20)	Toe Length	0.552	0.603	0.654	0.809	0.883	1.084	1.112	1.215	1.347
(21)	Heel Length	0.666	0.781	0.896	1.045	1.137	1.378	1.447	1.677	1.797
(22)	Toe Spread	0.137	0.120	0.109	0.115	0.110	0.120	0.111	0.110	0.112
(23)	Heel Spread	0.165	0.155	0.149	0.149	0.142	0.153	0.145	0.152	0.150
(35)	Wing Rail Extension	0.408	0.462	0.517	0.571	0.626	0.680	0.735	0.790	0.844
(36)	Wing Rail Flare Length	0.207	0.207	0.207	0.207	0.276	0.276	0.367	0.367	0.413
(37)	Wing Rail Flare Width	0.028	0.028	0.028	0.028	0.026	0.026	0.025	0.025	0.025
(38)	Wing Rail Bend Width	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES										
(24)	PF to ICL	2.596	3.245	3.894	4.543	5.192	5.841	6.490	7.139	7.788
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS										
	For Track Centers of:	1.791	(13 prototype feet)							
(25)	Straight Track Dist.	1.861	2.377	2.885	3.389	3.891	4.390	4.889	5.386	5.883
(26)	Crossover Track Dist.	2.085	2.556	3.035	3.517	4.003	4.490	4.978	5.467	5.957
	For Track Center Increment of:	0.138	(1 prototype foot)							
(28)	Straight Track Incr.	0.543	0.682	0.821	0.960	1.098	1.236	1.375	1.513	1.651
(29)	Crossover Track Incr.	0.560	0.696	0.833	0.969	1.107	1.244	1.381	1.519	1.656
GUARD RAILS										
(30)	Parallel End Setback	0.092	0.098	0.103	0.109	0.115	0.121	0.126	0.132	0.138
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.333	0.333	0.333	0.379	0.379	0.379	0.379	0.379
(33)	Overall Length	1.137	1.137	1.137	1.137	1.516	1.516	1.516	1.516	1.516
(34)	Parallel Length	0.471	0.471	0.471	0.471	0.758	0.758	0.758	0.758	0.758
(37)	Flare Width	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Plane Width	0.013	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

HO Scale

Curved Switch Turnout

TURNOUT DIMENSIONS

Revised: MMM. 20YY | RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	13	14	15	16	17	18	19	20
PROPERTIES OF CURVED SWITCHES									
(2)	Switch Rail Length	5.296	5.363	5.446	5.524	6.792	6.890	6.962	7.042
(3)	Switch Point Angle (deg.)	0.600	0.593	0.584	0.575	0.468	0.461	0.456	0.451
(4)	Switch Heel Spread	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
(5)	Switch Heel Angle (deg.)	1.673	1.652	1.627	1.603	1.304	1.286	1.272	1.258
(6)	Switch Rail Radius	282.923	290.101	299.153	307.866	465.379	478.889	488.960	500.210
(7)	Switch Mid-Ordinate	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
LEAD TO THEORETICAL POINT OF FROG									
(8)	Lead	14.900	15.568	16.225	16.909	19.329	20.015	20.701	21.387
CLOSURE DISTANCE									
(9)	Straight Rail Length	8.178	8.698	9.141	9.723	10.740	11.194	11.785	12.369
(10)	Curved Rail Length	8.194	8.714	9.155	9.736	10.753	11.206	11.797	12.380
(11)	Curved Rail Radius	171.812	204.695	239.341	282.255	298.317	338.511	387.870	441.583
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL									
(12)	1st Point Y1 [+]	0.177	0.179	0.181	0.184	0.178	0.179	0.182	0.184
(13)	1st Point X1	7.340	7.537	7.731	7.955	9.477	9.688	9.908	10.134
(14)	Mid-Point Y2 [+]	0.273	0.277	0.279	0.283	0.276	0.277	0.281	0.284
(15)	Mid-Point X2	9.385	9.712	10.016	10.386	12.162	12.487	12.855	13.226
(16)	3rd Point Y3	0.394	0.397	0.398	0.404	0.397	0.398	0.402	0.406
(17)	3rd Point X3 [+]	11.429	11.886	12.301	12.816	14.847	15.285	15.801	16.318
PROPERTIES OF FROGS									
(18)	Frog Angle (deg.)	4.405	4.091	3.818	3.580	3.369	3.182	3.015	2.864
(19)	Overall Length	3.396	3.649	3.786	4.039	4.291	4.543	4.684	4.824
(20)	Toe Length	1.427	1.507	1.639	1.662	1.796	1.931	1.954	1.976
(21)	Heel Length	1.969	2.142	2.147	2.377	2.495	2.612	2.730	2.848
(22)	Toe Spread	0.110	0.108	0.109	0.104	0.106	0.107	0.103	0.099
(23)	Heel Spread	0.151	0.153	0.143	0.148	0.147	0.145	0.144	0.142
(35)	Wing Rail Extension	0.936	1.028	1.082	1.194	1.249	1.303	1.395	1.487
(36)	Wing Rail Flare Length	0.539	0.610	0.636	0.713	0.738	0.763	0.835	0.907
(37)	Wing Rail Flare Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(38)	Wing Rail Bend Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES									
(24)	PF to ICL	8.437	9.086	9.735	10.384	11.033	11.682	12.331	12.980
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS									
	For Track Centers of:	1.791	(13 prototype feet)						
(25)	Straight Track Dist.	6.379	6.875	7.370	7.865	8.360	8.855	9.350	9.844
(26)	Crossover Track Dist.	6.448	6.939	7.430	7.921	8.413	8.905	9.397	9.889
For Track Center Increment of:		0.138	(1 prototype foot)						
(28)	Straight Track Incr.	1.789	1.927	2.065	2.203	2.340	2.478	2.616	2.754
(29)	Crossover Track Incr.	1.794	1.932	2.069	2.207	2.345	2.482	2.620	2.758
GUARD RAILS									
(30)	Parallel End Setback	0.144	0.149	0.155	0.161	0.167	0.172	0.178	0.184
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.413	0.413	0.413	0.413	0.471	0.471	0.471	0.471
(33)	Overall Length	1.791	1.791	1.791	1.791	2.274	2.274	2.274	2.274
(34)	Parallel Length	0.965	0.965	0.965	0.965	1.332	1.332	1.332	1.332
(37)	Total Flare at End	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Bevel Cut at End	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

HO Scale

Straight Switch Turnout

TURNOUT DIMENSIONS	
Revised: MMM. 20YY	RP-12.XXX

New Design and Calculations by Van S. Fehr

(1)	FROG NUMBERS	4	5	6	7	8	9	10	11	12
PROPERTIES OF CURVED SWITCHES										
(2)	Switch Rail Length	1.945	1.918	1.932	2.922	3.021	3.025	3.182	3.989	4.021
(4)	Switch Heel Spread	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
(5)	Switch Heel Angle (deg.)	3.095	3.138	3.115	2.060	1.992	1.990	1.892	1.509	1.497
LEAD TO THEORETICAL POINT OF FROG										
(8)	Lead	5.156	5.833	6.511	8.514	9.324	9.910	10.794	12.594	13.251
CLOSURE DISTANCE										
(9)	Straight Rail Length	2.659	3.312	3.924	4.784	5.420	5.801	6.500	7.390	7.883
(10)	Curved Rail Length	2.711	3.354	3.959	4.814	5.446	5.825	6.521	7.409	7.901
(11)	Curved Rail Radius	13.925	23.198	35.379	45.132	60.469	76.373	97.475	114.833	138.214
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL										
(12)	1st Point Y1 [+]	0.157	0.165	0.172	0.164	0.167	0.169	0.172	0.169	0.171
(13)	1st Point X1	2.610	2.746	2.913	4.118	4.376	4.475	4.807	5.837	5.992
(14)	Mid-Point Y2 [+]	0.241	0.255	0.267	0.255	0.260	0.261	0.267	0.262	0.264
(15)	Mid-Point X2	3.274	3.574	3.895	5.314	5.731	5.925	6.432	7.684	7.963
(16)	3rd Point Y3	0.358	0.376	0.389	0.378	0.384	0.381	0.388	0.385	0.386
(17)	3rd Point X3 [+]	3.939	4.402	4.876	6.510	7.086	7.376	8.057	9.531	9.934
PROPERTIES OF FROGS										
(18)	Frog Angle (deg.)	14.250	11.421	9.527	8.171	7.153	6.360	5.725	5.205	4.772
(19)	Overall Length	1.218	1.384	1.550	1.854	2.020	2.462	2.559	2.892	3.144
(20)	Toe Length	0.552	0.603	0.654	0.809	0.883	1.084	1.112	1.215	1.347
(21)	Heel Length	0.666	0.781	0.896	1.045	1.137	1.378	1.447	1.677	1.797
(22)	Toe Spread	0.137	0.120	0.109	0.115	0.110	0.120	0.111	0.110	0.112
(23)	Heel Spread	0.165	0.155	0.149	0.149	0.142	0.153	0.145	0.152	0.150
(35)	Wing Rail Extension	0.408	0.462	0.517	0.571	0.626	0.680	0.735	0.790	0.844
(36)	Wing Rail Flare Length	0.207	0.207	0.207	0.207	0.276	0.276	0.367	0.367	0.413
(37)	Wing Rail Flare Width	0.028	0.028	0.028	0.028	0.026	0.026	0.025	0.025	0.025
(38)	Wing Rail Bend Width	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES										
(24)	PF to ICL	2.596	3.245	3.894	4.543	5.192	5.841	6.490	7.139	7.788
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS										
	For Track Centers of:	1.791	(13 prototype feet)							
(25)	Straight Track Dist.	1.861	2.377	2.885	3.389	3.891	4.390	4.889	5.386	5.883
(26)	Crossover Track Dist.	2.085	2.556	3.035	3.517	4.003	4.490	4.978	5.467	5.957
	For Track Center Increment of:	0.138	(1 prototype foot)							
(28)	Straight Track Incr.	0.543	0.682	0.821	0.960	1.098	1.236	1.375	1.513	1.651
(29)	Crossover Track Incr.	0.560	0.696	0.833	0.969	1.107	1.244	1.381	1.519	1.656
GUARD RAILS										
(30)	Parallel End Setback	0.092	0.098	0.103	0.109	0.115	0.121	0.126	0.132	0.138
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.333	0.333	0.333	0.333	0.379	0.379	0.379	0.379	0.379
(33)	Overall Length	1.137	1.137	1.137	1.137	1.516	1.516	1.516	1.516	1.516
(34)	Parallel Length	0.471	0.471	0.471	0.471	0.758	0.758	0.758	0.758	0.758
(37)	Flare Width	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Plane Width	0.013	0.013	0.013	0.013	0.012	0.012	0.012	0.012	0.012
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

NMRA Recommended Practices

HO Scale

Straight Switch Turnout

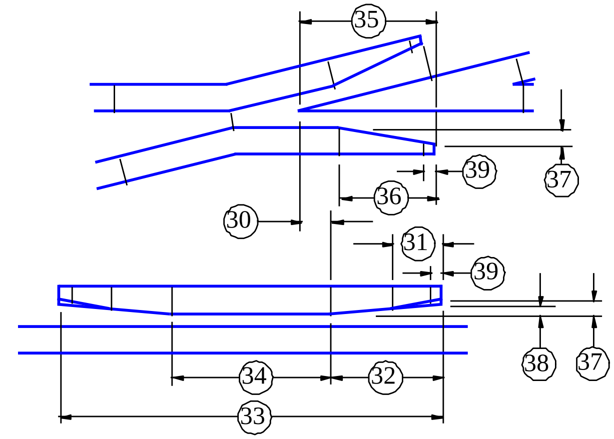
TURNOUT DIMENSIONS	
Revised: MMM. 20YY	RP-12.XXX

New Design and Calculations by Van S. Fehr

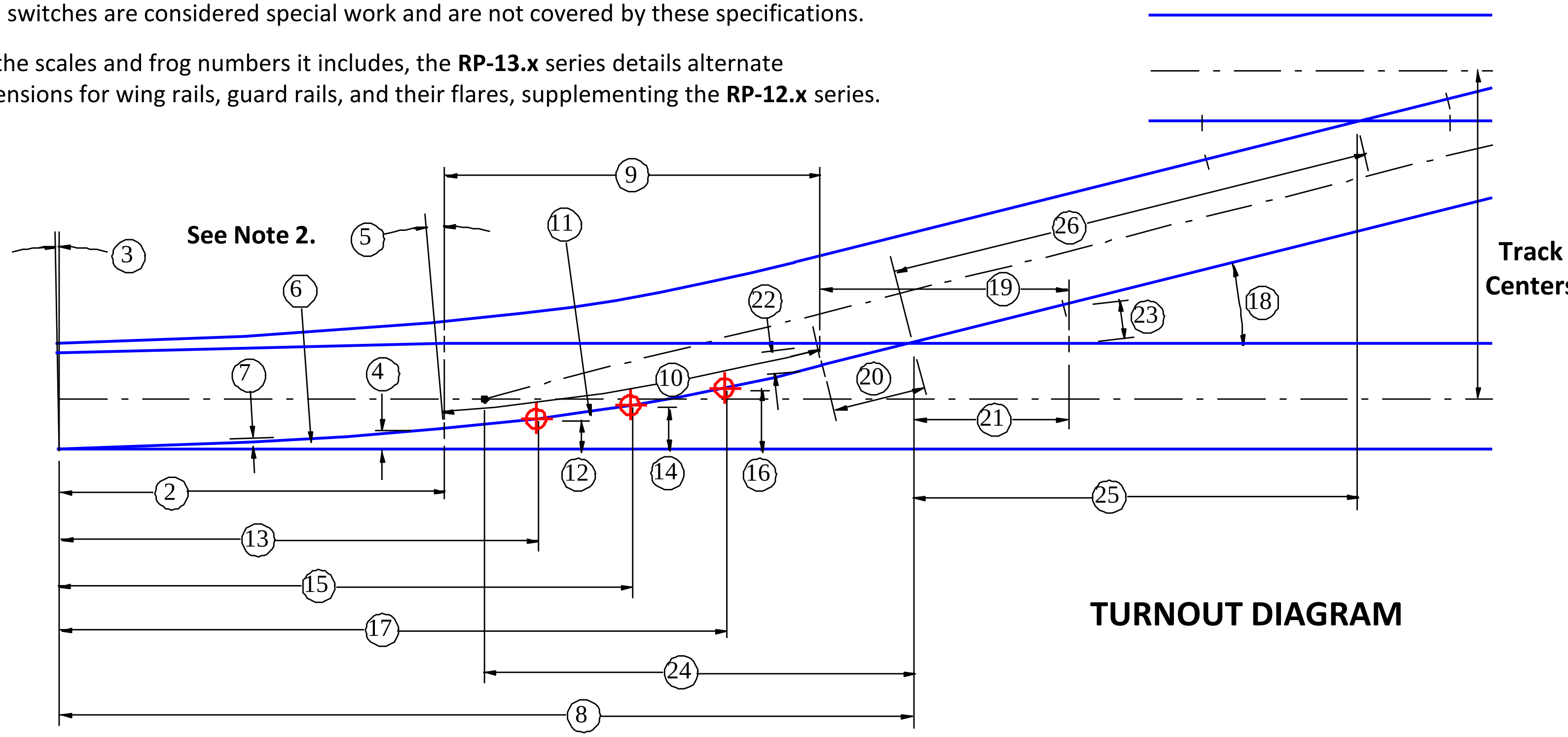
(1)	FROG NUMBERS	13	14	15	16	17	18	19	20
PROPERTIES OF CURVED SWITCHES									
(2)	Switch Rail Length	4.081	4.150	5.539	5.541	5.580	5.626	5.704	5.787
(4)	Switch Heel Spread	0.105	0.105	0.105	0.105	0.105	0.105	0.105	0.105
(5)	Switch Heel Angle (deg.)	1.475	1.450	1.086	1.086	1.078	1.070	1.055	1.040
LEAD TO THEORETICAL POINT OF FROG									
(8)	Lead	13.962	14.672	17.328	18.005	18.663	19.320	20.072	20.824
CLOSURE DISTANCE									
(9)	Straight Rail Length	8.454	9.015	10.149	10.803	11.286	11.763	12.415	13.061
(10)	Curved Rail Length	8.470	9.031	10.163	10.816	11.298	11.775	12.426	13.071
(11)	Curved Rail Radius	165.598	195.945	213.155	248.493	282.571	319.342	363.285	410.513
GAGE LINE OFFSETS ON CURVED CLOSURE RAIL									
(12)	1st Point Y1 [+]	0.173	0.175	0.168	0.171	0.172	0.173	0.175	0.177
(13)	1st Point X1	6.194	6.404	8.077	8.242	8.402	8.567	8.807	9.052
(14)	Mid-Point Y2 [+]	0.268	0.271	0.262	0.266	0.268	0.269	0.272	0.276
(15)	Mid-Point X2	8.308	8.657	10.614	10.942	11.223	11.507	11.911	12.318
(16)	3rd Point Y3	0.390	0.393	0.386	0.391	0.391	0.392	0.396	0.400
(17)	3rd Point X3 [+]	10.421	10.911	13.151	13.643	14.045	14.448	15.015	15.583
PROPERTIES OF FROGS									
(18)	Frog Angle (deg.)	4.405	4.091	3.818	3.580	3.369	3.182	3.015	2.864
(19)	Overall Length	3.396	3.649	3.786	4.039	4.291	4.543	4.684	4.824
(20)	Toe Length	1.427	1.507	1.639	1.662	1.796	1.931	1.954	1.976
(21)	Heel Length	1.969	2.142	2.147	2.377	2.495	2.612	2.730	2.848
(22)	Toe Spread	0.110	0.108	0.109	0.104	0.106	0.107	0.103	0.099
(23)	Heel Spread	0.151	0.153	0.143	0.148	0.147	0.145	0.144	0.142
(35)	Wing Rail Extension	0.936	1.028	1.082	1.194	1.249	1.303	1.395	1.487
(36)	Wing Rail Flare Length	0.539	0.610	0.636	0.713	0.738	0.763	0.835	0.907
(37)	Wing Rail Flare Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(38)	Wing Rail Bend Width	0.024	0.024	0.024	0.024	0.024	0.023	0.023	0.023
(39)	Wing Rail End Chamfer	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
POINT OF FROG TO INTERSECTION OF CENTERLINES									
(24)	PF to ICL	8.437	9.086	9.735	10.384	11.033	11.682	12.331	12.980
DATA FOR CROSSOVERS: PF TO PF ON PARALLEL TRACKS									
	For Track Centers of:	1.791	(13 prototype feet)						
(25)	Straight Track Dist.	6.379	6.875	7.370	7.865	8.360	8.855	9.350	9.844
(26)	Crossover Track Dist.	6.448	6.939	7.430	7.921	8.413	8.905	9.397	9.889
For Track Center Increment of:		0.138	(1 prototype foot)						
(28)	Straight Track Incr.	1.789	1.927	2.065	2.203	2.340	2.478	2.616	2.754
(29)	Crossover Track Incr.	1.794	1.932	2.069	2.207	2.345	2.482	2.620	2.758
GUARD RAILS									
(30)	Parallel End Setback	0.144	0.149	0.155	0.161	0.167	0.172	0.178	0.184
(31)	Bevel Length	0.149	0.149	0.149	0.149	0.149	0.149	0.149	0.149
(32)	Flare Length	0.413	0.413	0.413	0.413	0.471	0.471	0.471	0.471
(33)	Overall Length	1.791	1.791	1.791	1.791	2.274	2.274	2.274	2.274
(34)	Parallel Length	0.965	0.965	0.965	0.965	1.332	1.332	1.332	1.332
(37)	Total Flare at End	0.022	0.022	0.022	0.022	0.022	0.022	0.022	0.022
(38)	Bevel Cut at End	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
(39)	End Chamfer	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034

DIAGRAM of TURNOUTS
ALL TRACK GAUGES
CURVED OR STRAIGHT SWITCH RAILS

1. The heavy lines of the Turnout Diagram represent the railhead gauge lines only. The Wing and Guard Rail Diagram includes an exaggerated railhead width to clarify the flare dimensions.
2. Circled numbers refer to the line numbers contained in parentheses in the **RP-12.x** series. Circle 3, circle 6 and circle 7 apply only to curved switch rails. For straight switch rails the Point Angle is the same as the Switch Angle, circle 5. All other circle numbers apply to turnouts with either type of switch rails.
3. Turnouts with continuous curved closure rail and switch rail use Rail Length (circle 2) for the straight leg only. All other dimensions apply with the switch in thrown position.
4. "High Speed" turnouts with closed frog points should follow these dimensions for the thrown position.
5. Stub switches are considered special work and are not covered by these specifications.
6. For the scales and frog numbers it includes, the **RP-13.x** series details alternate dimensions for wing rails, guard rails, and their flares, supplementing the **RP-12.x** series.



WING AND GUARD RAIL DIAGRAM



TURNOUT DIAGRAM

Figure 31: Diagram of Turnouts - Curved or Straight Switch Rails

APPENDIX B: ALTERNATE CLOSURE RAIL CURVE AND LEAD LIMITS

Cubic Polynomial

While the AREA and NMRA specify circular arcs for the curved closure rail, there is another practical curve for its shape. That curve is a *cubic polynomial*, the same mathematical curve used to approximate spiral easements connecting tangents to circular curves:

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \qquad \text{(A-1)}$$

In this case, equation (A-1) replaces the general curve $y = f(x)$ defined in the *xy*-coordinate system in Figure 13. Its properties are such that it can *always* satisfy the turnout boundary conditions as long as the distance between the points **PC** and **PT** is greater than zero, which it is. In principle, also for a given frog number, switch angle (or heel angle) and frog dimensions, that means there is a wide range of lead dimensions that provide a theoretically smooth reverse route curve. However, there is only a limited range of lead dimensions that prevent the inherent and undesirable *S*-curve of a cubic polynomial from occurring between the points **PC** and **PT**.

In Figure 13 the point ***i*** indicates a possible location of the inflection point. The inflection point is where the cubic polynomial transitions from concave down to concave up, or vice versa, forming an undesirable *S*-curve in the curved closure rail. As long as the chosen distance L_C produces an inflection point that is *not* between **PC** and **PT**, there is no *S*-curve anywhere along the curved closure rail.

The first two derivatives of equation (A-1), required to establish expressions for the polynomial coefficients and to locate the inflection point, are:

$$y' = a_1 + 2a_2 x + 3a_3 x^2 \qquad \text{(A-2)}$$

$$y'' = 2a_2 + 6a_3 x \qquad \text{(A-3)}$$

The boundary conditions, established in **PART I**, are repeated here as a convenience:

$$\text{At } x = 0, y = 0 \qquad \text{(A-4)}$$

$$\text{At } x = 0, y' = \tan\phi \qquad \text{(A-5)}$$

$$\text{At } x = L_C, y = H \qquad \text{(A-6)}$$

$$\text{At } x = L_C, y' = \tan\theta \qquad \text{(A-7)}$$

These four boundary conditions force the polynomial to pass through the points **PC** and **PT**, and to match their respective slopes. Note the absence of the subscript on the heel angle in equation (A-5). In this case, and in subsequent equations below, it is not necessary because the equations apply to both switch types.

Substituting (A-4) into (A-1):

$$0 = a_0 + a_1 0 + a_2 0^2 + a_3 0^3 \qquad \text{(A-8)}$$

Thus:

$$a_0 = 0 \qquad \text{(A-9)}$$

Substituting (A-5) into (A-2):

$$\tan\phi = a_1 + 2a_2 0 + 3a_3 0^2 \qquad \text{(A-10)}$$

Thus:

$$a_1 = \tan\phi \qquad \text{(A-11)}$$

Next, using (A-6), (A-7), (A-1), (A-2) and (A-11) produces two equations to solve simultaneously for the remaining two unknown polynomial coefficients a_2 and a_3:

$$\begin{aligned} H &= (\tan\phi)L_C + a_2 L_C^2 + a_3 L_C^3 \\ \tan\theta &= \tan\phi + 2a_2 L_C + 3a_3 L_C^2 \end{aligned} \qquad \text{(A-12)}$$

After algebraic manipulation of (A-12) the solution for a_2 and a_3 is:

$$a_2 = \frac{1}{L_C^2}\left[3H - L_C\left(\tan\theta + 2\tan\phi\right)\right] \qquad \text{(A-13)}$$

$$a_3 = \frac{1}{L_C^3}\left[L_C\left(\tan\theta + \tan\phi\right) - 2H\right] \qquad \text{(A-14)}$$

Lead Limits

The value of x_i that makes the second derivative of the polynomial zero locates the inflection point:

$$2a_2 + 6a_3 x_i = 0 \quad \text{(A-15)}$$

Or:

$$x_i = -\frac{a_2}{3a_3} \quad \text{(A-16)}$$

Substituting equations (A-13) and (A-14) into (A-16), the location of the inflection point is:

$$x_i = -\frac{L_C}{3}\frac{\left[3H - L_C(\tan\theta + 2\tan\phi)\right]}{\left[L_C(\tan\theta + \tan\phi) - 2H\right]} \quad \text{(A-17)}$$

To avoid the unwanted *S*-curve, the inflection point must *not* fall between $x = 0$ and $x = L_C$ (i.e., between points **PC** and **PT**). To ensure this requires an expression for the value L_C that causes the inflection point to lie at point **PC** and another that causes it to lie at point **PT**.

First, substitute $x_i = 0$ (the location of point **PC**) into equation (A-17):

$$0 = -\frac{L_C}{3}\frac{\left[3H - L_C(\tan\theta + 2\tan\phi)\right]}{\left[L_C(\tan\theta + \tan\phi) - 2H\right]} \quad \text{(A-18)}$$

Because L_C is not zero, the only non-trivial solution for L_C in (A-18) occurs when:

$$3H - L_C(\tan\theta + 2\tan\phi) = 0 \quad \text{(A-19)}$$

So, with the subscript 0 indicating the result for $x_i = 0$ (point **PC**), solving (A-19) for $L_0 = L_C$ gives:

$$L_0 = \frac{3H}{\tan\theta + 2\tan\phi} \quad \text{(A-20)}$$

Next, substitute $x_i = L_C$ (the location of point **PT**) into equation (A-17) to get:

$$L_C = -\frac{L_C}{3}\frac{\left[3H - L_C(\tan\theta + 2\tan\phi)\right]}{\left[L_C(\tan\theta + \tan\phi) - 2H\right]} \quad \text{(A-21)}$$

After some algebraic manipulation, with the subscript 1 indicating the result for $x_i = L_C$ (point **PT**), solving (A-21) for $L_1 = L_C$ gives:

$$L_1 = \frac{3H}{2\tan\theta + \tan\phi} \quad \text{(A-22)}$$

Values of L_0 and L_1 represent maximum and minimum distances L_C that keep the inflection point out of the region between **PC** and **PT**. Corresponding lead dimensions come from (IV-10) or (V-10).

To determine the radius of curvature, consider again the equation for the third-order polynomial and its derivatives (plus one more), repeated and given here:

$$y = a_0 + a_1 x + a_2 x^2 + a_3 x^3 \quad \text{(A-23)}$$

$$y' = a_1 + 2a_2 x + 3a_3 x^2 \quad \text{(A-24)}$$

$$y'' = 2a_2 + 6a_3 x \quad \text{(A-25)}$$

$$y''' = 6a_3 \quad \text{(A-26)}$$

The radius of curvature for any function $y = f(x)$ is:

$$R_{OC} = \left|\frac{\left[1 + (y')^2\right]^{3/2}}{y''}\right| \quad \text{(A-27)}$$

The next step would normally require substitution for y and its derivatives, and then solving for the roots (x values) of equation (A-27). That process is unwieldy and prone to error, so a numerical solution, programmed in a spreadsheet, is a better choice.

Only those radii of curvature that lie between **PC** and **PT** (inclusive) are of interest. That means the numerical solution need only search between **PC** and **PT** for the roots. If no roots exist in that interval, the maximum radius of curvature occurs at **PC** and the minimum at **PT**, or vice versa.

The companion spreadsheet *NMRA TN-12 AREA Turnout Reverse Curve Analysis.xls* [33] makes these calculations. Tabs located along the bottom contain plots of the reverse route centerline for both straight and curved switch turnout designs.

APPENDIX C: VARIABLE DEFINITIONS

English Variables

a Distance from switch point for curved closure rail gauge point determination
a_0 Constant term in polynomial
a_1 Coefficient of x in polynomial
a_2 Coefficient of x^2 in polynomial
a_3 Coefficient of x^3 in polynomial
A Dimension A in turnout template diagram (Figure 24)
A_{ADJ} Dimension A in turnout template diagram (Figure 24) adjusted for turnout tie spacing

b Offset from straight stock rail for curved closure rail gauge point determination
B Dimension B in turnout template diagram (Figure 24)

c_{SR} Switch rod clearance (each side)
C Curved switch rail chord. Also dimension C in turnout template diagram (Figure 24)

d Frog point cutback (inches) along frog centerline
d_{GL} Frog point cutback (inches) along frog gauge line
d_T 2nd headblock centerline to L_{OA} distance
D Dimension D in turnout template diagram (Figure 24)
D_{SP} Straight track distance between crossover frog practical points
D_{ST} Straight track distance between crossover frog theoretical points
D_T Distance **PC** to **PF** with extra tangent at frog
D_{XP} Straight track distance between crossover frog practical points
D_{XT} Crossover track distance between crossover frog theoretical points

E Parallel track inner rail gauge side spacing

f_P Model scale proportionality factor
$f(x)$ Generic curved closure rail curve, expressed as a function of x
F Distance between inner track rail and crossover track rail gauge sides at second frog point

g_F Total frog flangeway gap measured along a gauge line in inches to the ½-inch point
g_T Frog flangeway gap measured along a gauge line in inches to the theoretical point
G Minimum track gauge

h Switch heel gauge side distance above point thickness
h_C Switch heel rail clearance
$h_{C\min}$ Minimum switch heel rail clearance
h_F Switch heel flange clearance
h_{MID} Curved switch mid-ordinate
h_R Railhead height

h_W Switch heel wheel clearance

H Height (lateral) distance between point **PT** and **PC**

H_{PC} Point **PC** distance above normal route centerline

H_{PT} Point **PT** distance above normal route centerline

k Curved switch heel angle proportionality factor

l Curved switch rail chord projection along normal route

l_{ext} Guard rail extension length

l_{frnt} Amount of straight portion of guard rail in front of throat

l_{rear} Amount of straight portion of guard rail after frog point

L_A Turnout actual (or practical) lead (to ½-inch point of frog)

L_{ADJ} Theoretical lead adjusted for turnout tie spacing

L_{BV} Wing or guard rail bevel length

L_C Length of circular portion of reverse route centerline, projected along normal route

L_{CCR} Curved closure rail length (arc length)

L_D Chord for symmetric equal-tangent parabola

L_F Frog total length

L_{FH} Frog heel length, measured from theoretical point of frog

L_{FL} Total wing or guard rail flare length

L_{FT} Frog toe length, measured from theoretical point of frog

L_{GR} Guard rail length

L_{Heel} Frog heel length, measured from ½-inch point of frog

L_{ICL} Distance from theoretical point of frog to centerline intersection

$L_{\max}$ Guard rail straight portion maximum setback after frog point

$L_{\min}$ Guard rail straight portion minimum setback after frog point

L_{OA} Turnout overall length

L_{PC} Point **PC** distance from switch point

L_{PL} Guard rail parallel (straight) portion length

L_{PN} Wing or guard rail planing length

L_{PT} Point **PT** distance from theoretical point of frog (towards switch)

L_S Switch rail length, either type

L_{SB} Guard rail parallel length setback from theoretical point

L_{SCR} Straight closure rail length

L_T Turnout theoretical lead (to theoretical point of frog)

L_{Toe} Frog toe length, measured from ½-inch point of frog

L_T Turnout theoretical lead (to theoretical point of frog)

L_{TM} Part of frog toe length for mechanical features

L_{WR} Wing rail length

L_0 Length of curved portion of reverse route centerline for inflection point at point **PC**

L_1 Length of curved portion of reverse route centerline for inflection point at point **PT**

n Frog number

n_{spaces} Number of tie spaces in distance d_T

p Parallel track spacing

p_{OFF} Switch point offset from center of first headblock

$P_{\max}$ Maximum switch point clearance (per NMRA standard)

R_C Reverse route circular arc centerline radius

R_{CCR} Curved closure rail radius

R_{OC} Radius of curvature for any function $y = f(x)$

R_S Curved switch rail radius

R_{SCL} Curved switch centerline radius

R_{STK} Curved switch curved stock rail radius

S_{FH} Frog heel spread

S_{FT} Frog toe spread

S_{HB} Headblock spacing

S_{nom} Headblock spacing

S_{SH} Switch heel spread, either switch type

S_{spec} Specified tie spacing

S_{TIE} Calculated tie spacing

t Wheel flange thickness

t_F Additional tangent length before (or after) frog toe

t_S Additional tangent length after switch heel

t_P Switch rail point thickness

T_{SW} Switch rail throw

w_{BP} Wing or guard rail bevel or bend depth (perpendicular to rail gauge line)

w_{EB} Wing or guard rail end bevel

w_F Flangeway width (perpendicular to rail gauge line)

w_{FG} Total flangeway gap

w_{FL} Total flare from side of railhead (for wing and guard rails)

w_{HD} Railhead width

w_{PN} Flare at end of guard rail flare planed length

w_{SR} Switch rod width

w_T Tie or headblock width

x *x*-coordinate in *xy*-coordinate system

x_i location of inflection point for 3rd-order polynomial
X_1 First curved closure rail gauge point location
X_2 Second curved closure rail gauge point location
X_3 Third curved closure rail gauge point location

y *y*-coordinate in *xy*-coordinate system
y' First derivative of $y = f(x)$
y'' Second derivative of $y = f(x)$
y''' Third derivative of $y = f(x)$
Y_1 First curved closure rail gauge point offset
Y_2 Second curved closure rail gauge point offset
Y_3 Third curved closure rail gauge point offset

z Extra distance at dimension F along crossover track to second frog point

Greek Variables

α Curved switch rail subtended angle

Δp Incremental change in parallel track spacing
ΔS Incremental change in straight track distance corresponding to Δp
ΔX Incremental change in crossover track distance corresponding to Δp

ϕ Switch angle (straight switch) or heel angle (curved switch)
ϕ_C Heel angle, specifically for a curved switch
ϕ_S Switch angle, specifically for a straight switch

θ Frog angle
θ_D Degree-of-curvature (degrees)

γ Switch point angle, either switch type

ψ Curved switch rail chord angle

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CHANGE RECORD

October 2014 Original issue (Van S. Fehr)

March 2015 Added special guard rail length needed for Odf and O27 scales ONLY.
Removed links to old Turnout RPs in References Section (Van S. Fehr)