December 2005

TRANSIT COOPERATIVE RESEARCH PROGRAM
Sponsored by the Federal Transit Administration

Subject Areas: VI Public Transit, VII Rail

Responsible Senior Program Officer: Christopher W. Jenks

Research Results Digest 72

GUIDELINES FOR AN ALTERNATIVE TRANSIT SWITCH DESIGN

This digest summarizes the results of TCRP Project D-7/Task 5, "Transit Switch Design Evaluation." The design guidelines described in this digest build on technical analyses conducted and published in *TCRP Report 71, Volume 2: Transit Switch Design Analysis (Phase I).* The digest was prepared by the Transportation Technology Center, Inc. (TTCI) in Pueblo, Colorado. David Davis served as principal author.

INTRODUCTION

This digest offers design guidelines for a new transit switch based partially on longer-lasting, better-performing switches that were developed in the early 20th century, some of which are still in operation today at transit systems such as the Southeastern Pennsylvania Transportation Authority (SEPTA). The design guidelines described herein build on technical analyses conducted and published in *TCRP Report 71, Volume 2: Transit Switch Design Analysis (Phase I).* An electronic copy of this report can be found at: http://trb.org/publications/tcrp/tcrp_rpt_71v2.pdf.

As part of this project, Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads (AAR), developed design guidelines for rapid (heavy rail) transit switches. These guidelines were developed by studying successful designs from the early 1900s. The early designs performed much better than the designs that replaced them.

This digest summarizes the work done to develop guidelines and recommendations for an improved performance 13-ft switch for heavy rail transit service. Progress to date includes the following steps:

1. Analysis of early 20th century transit switch designs to determine design elements that made the earlier designs successful,
2. Evaluation of a specific switch in current service to suggest alternative switch and turnout alignments for the particular case analyzed, and
3. Development of general design guidelines for a 13-ft switch

The results from the first two steps are documented in *TCRP Report 71, Volume 2: Transit Switch Design Analysis, Phase 1* (*1*). General design guidelines are included in this follow-up document.

The essential design elements that provided good performance in early 20th century switches have been incorporated into the general design guidelines and recommendations. The principals advocated here can be applied to other size switches.

BACKGROUND

Transit switch designs in the early 1900s were quite sophisticated by today's

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standards, with features that have been rediscovered and are being implemented in modern high-speed heavy rail switch designs. These switches gave excellent service for many years, often outliving the lower-cost but simpler replacement designs that followed. Many of the earlier designs became obsolete as they were replaced by these simpler designs with lower initial costs.

Rail transit track engineers observed that often the best-performing switches on their systems are the oldest switches. The original tangential and spiral geometry switches often had service lives of 50 years or more. Additionally, these switches outlived their replacement designs by 100 to 1,000 percent.

The switches produced in the 1900s share some or all of the following features:

- Tangential geometry (no entry kink angle)
- Spiral geometry (variable switch curvature)
- Housed switch points (switch points that are recessed into the gage line of the stock rail)
- Austenitic manganese steel (AMS) switch points and stock rails
- Guard rails in front of the switch
- Guard rails in the switch

The advantages of each of these design features are discussed in more detail below.

Summary of Design Analysis (Phase I) Findings (*1*)

TTCI modeled the performance of a rapid rail operation switch. A switch in SEPTA's Broad Street subway with tangential and spiral geometry was analyzed for operation with SEPTA's Kawasaki B-IV cars. TTCI modeled (1) a tangential, spiral geometry No. 8 lateral switch turnout; (2) an American Railway Engineering Maintenance of Way Association (AREMA) No. 8 lateral switch turnout; and (3) several variations of these two designs. The study was designed to learn which switch design features contribute to the good performance and long service life of the SEPTA switches. These design elements will be applied to a modern switch design to develop a low-cost, high-performance switch for future use.

The as-built SEPTA No. 8 tangential, spiral geometry switch turnout performs well in comparison to the per-plan AREMA No. 8 secant, circular-geometry switch turnout. In its intended service of 5- to 15-mph operation, the switch is superior to the AREMA switch in minimizing maximum loads and accelerations. However, the SEPTA switch turnout's advantage in performance over AREMA-style switches diminishes rapidly above 15 mph. Thus, the designer must know the specifics of the intended service environment (including vehicle characteristics and turnout lengths) to optimize the performance of the switch.

Parametric studies of some design features were conducted to determine their effects on switch performance.

Tangential switch entry is essential to the good performance of the SEPTA switch. Elimination of a kink angle and its resultant abrupt spike in dynamic loading produces a smooth ride and more even switch wear. The spiral switch entry and exit curves are effective at smoothing the ride through the switch by minimizing the change in acceleration (jerk). However, the disadvantage of a small entry angle is a small radius curve into the heel of the switch. This may adversely affect ride quality for certain types of equipment (i.e., longer cars) or service (i.e., higher speeds).

In this particular case, the advantages of the SEPTA switch turnout are not fully realized because of the long length of the B-IV cars in relation to the SEPTA 13-ft switch turnout length. The extremely short radius closure curves of the turnout cause the cars to "string line," creating relatively high lateral forces. These forces increase rapidly with speed. The AREMA designs, with their larger radius closure curves, better accommodate the longer cars at higher speeds.

The housed switch point is a feature that provides benefits for switches with significant diverging traffic. As mentioned earlier, housed switch points are those recessed into the gage line of the stock rail. The switch point is thickened to make it more robust and diminish the risk of split switch derailments. The stock rail is diminished or bent out of alignment to accomplish this, which may result in a foreshortened life for this component. Housing will help to eliminate the sharp dynamic loading spike and localized wear at the point of switch on AREMA switches seen in the field, as well as those seen in NUCARS™ dynamic vehicle simulations done for this study. The running surface discontinuity at the point of switch seen at the gage face is especially important if guard rails are not used in the switch. Housing and good point slope design also allow the designer to keep entry angles low while also having a robust enough

switch point to carry wheel loads without excessive contact stresses.

The use of AMS castings for the switch points in the SEPTA switch produces a tough and durable switch point. When introduced, the AMS point was vastly superior to rail steels of the time. However, modern rail steels perform better than AMS in curve wear. Depending on wheel loads, rail steel may also have less metal flow. The layout of the switch, with good geometry and guard rails, make the advantages of AMS almost redundant. The high cost of fabricating AMS switch points makes it an uneconomic choice for modern switches.

Use of guard rails in the switch is needed for safety reasons. The guard rails assure that a safe operation is maintained as the switch wears and deforms. The guard rail and back of wheel flange contact are nearly vertical, even on worn components. Thus, wheel climb is less likely than with worn wheel flange/switch point contact. As for switch performance, the dynamic loads in the switch are little changed. Switch-point life is improved by transferring wear from switch point to guard rail, especially on the diverging route of the switch.

Use of guard rails in front of the switch protects the switch points from impacts. The good switch geometry and housed point design of the SEPTA switch diminishes the need or effectiveness of the guard rails.

Separating the point of switch from the point of curvature (or point of spiral in the case of the SEPTA switch), where the point of curvature comes first, is good for relatively low-speed mainline operations. The mainline trains have to negotiate a small curve as penalty for making the diverging route curve somewhat larger. This separate point of switch/point of curvature design is a compromise between a lateral switch and an equilateral switch, but it is based heavily toward a lateral switch configuration. This design also helps the curved switch point at the expense of the straight switch point by lining up wheels for the diverging route curve prior to the switch point. This contributes to the good wear performance of the SEPTA switches.

GENERAL GUIDELINES FOR AN ALTERNATIVE STANDARD 13-FT SWITCH

Within the confines of a 13-ft switch, many alignments are possible. This section discusses general features of a good performing switch under typical operating conditions. While design of a switch for a particular line is greatly dependent on local conditions—such as operating speeds, vehicle types, and wheel profiles used—some general guidelines can be applied. Listed below are general recommendations and discussion of factors that may affect these recommendations.

Switch Entry Angle

Effective switch entry angle should be kept as small as practical. Effective entry angle is the angle that the vehicle actually sees as it traverses the switch. Effective entry angle can differ from theoretical entry angle because of the shape of the switch point. For example, many tangential switches, as the name implies, have a theoretical entry angle of zero degrees. The actual switches have truncated points, rather than extremely long points with razor thin ends. Thus, they have an effective entry angle. The entry angle most wheels "see" is the angle of the switch point to the stock rail at the location the wheel encounters it. Effective entry angle is a function of the wheel back-to-back and track gage tolerances of the system. A centered wheelset will not encounter a switch point until the point has deviated from the mainline route by about 1/2 in. Thus, the alignment of the switch behind the entry angle is also of importance. Preferred geometries are ones that deviate from the mainline route at lower rates initially. Spiral geometries are best for minimizing car accelerations and forces.

There is always a trade-off between low entry angle and the sharpness of the following curve(s) to the switch heel and the frog. The entry angle generates a localized, high-frequency dynamic lateral load, which is typically the highest lateral load in the turnout. However, making the closure curve(s) too sharp can result in these areas generating the highest lateral forces. Balancing the two scenarios is the goal of a good design, requiring some knowledge of the turnout design the switch will be used in and the characteristics of the vehicles used on the line.

To develop an effective "standard" switch design portfolio, the transit industry should consider developing an intended operating scenario and a design vehicle. These are essential for defining the service environment of the switch. The switch designer's task is essentially one of balancing the

requirements of smooth train operation and switch service reliability.

Smooth operation demands a smooth track (i.e., switch and turnout) alignment. The lowest switch entry angle possible is desired to reduce lateral forces and accelerations in the vehicles. Additionally, a smooth alignment provided by tangential or pseudo-tangential alignments is needed to minimize running surface discontinuities and the accompanying high wear of the switch point and stock rail.

A robust switch point is also needed to withstand the combined vertical and lateral stresses imposed by traffic. Thin section switch points will generally have higher contact stresses, leading to shortened service lives. Effective use of design techniques that limit switch-point contact stresses must be used. These include good point cross-section and point slope design. Housing of switch points makes the switch point thicker at the expense of the stock rail. The designer re-allocates material from the stock rail to the switch point. This is an effective method of lengthening switch-point life at locations where diverging traffic is significant. Switch-point slope lets designers determine where vertical loading will first be applied. Coordination of these two design elements allows designers to limit contact stresses in the switch. However, many characteristics of the design vehicle, such as wheel load and wheel profile, must be known.

Thus, an optimal design must be a compromise between vehicle performance requirements and switch service reliability.

For 13-ft switches, an effective entry angle of 1 degree maximum is recommended. Smaller values should be considered when the vehicle characteristics are known.

Switch Geometry

As important as entry angle is the geometry of the switch behind the entry angle. Straight switch-point alignments are not recommended for diverging route passenger service, except for slow speed operations. The entry angles are too high for the length of switch and desired speeds. These switch alignments are fine for mainline movements. Circular curve geometries are better, but generally result in a lateral load spike near the front of the switch. This high lateral load area will cause poor ride quality and spot wear of the switch point.

Spiral geometry switches are preferred for the typical speeds likely to be operated by traffic in No. 6 and 8 turnouts with 13-ft switches.

TABLE 1 General Guidelines for an Alternative 13-ft Switch

Switch Design Feature	Recommendation	Comments/Alternate Design
Type	Lateral	Most locations now have lateral switches
Switch Entry Configuration	Tangential	Truncated or pseudo-tangential
Switch Entry Angle	As low as possible. Must balance entry lateral forces with closure curve lateral forces	Maximum 1 degree
Geometry: Curvature	Spiral	Circular curves
Point Slope	Use extended point slope or "second cut" to keep contact stresses on point below 200 ksi	Use extended point slope or "second cut" to keep contact stresses on point below 300 ksi
Point: Configuration	Housed: allowing a thicker switch point	Undercut
Point: Material	High hardness rail steel	Rail steel
Point: Guarding	Yes–House tops: guards that engage the back of flange of the wheel opposite the switch point	No
Closure Curve Guarding	Yes	No
Switch-Point Lubrication	Applied to gage face	Dry

Point Slope to Minimize Point Wear

Regardless of the switch geometry, the point slope chosen can be a significant factor in the metal flow and wear on a switch. Again, a design vehicle or loading conditions and a switch-point cross section and material properties are needed to optimize a particular switch for the intended traffic. Studies conducted by TTCI for the AAR suggest that wheel–rail contact stresses should remain below 300 ksi for good performance with head-hardened steel, AREMA-style switch points. This value will keep plastic flow to a minimum after the switch point has work hardened under traffic. If minimization of the initial metal flow is desired as well, then a lower contact stress should be specified. Perhaps 180 to 200 ksi could be used. This lower limit will require larger cross-section switch points and highly conformal running surfaces.

Good gage face lubrication can significantly raise the allowable stress on curve rails and switch points. If lubrication can be assured, then higher contact stresses (up to 450 ksi) and shorter point slopes are allowed.

Use of Guard Rails in the Switch

The use of guard rails in the switch, especially at the point of switch, can improve the performance and safety of switch points. Guard rails reduce wear on the switch points and inhibit wheel climb of worn switches and reduce the relative importance of low-entry angle switches by providing an alternate surface for steering the wheelsets through the switch. Thus, the guardrail allows for a cruder switch-point design to be used.

Table 1 summarizes the general guidelines for an alternative 13-ft switch.

REFERENCE

1. Singh, S. P., D. D. Davis, and S. F. Kalay. *TCRP Report 71, Volume 2: Transit Switch Design Analysis, Phase 1.* Transportation Research Board of the National Academies, Washington, DC (2002).

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