Trackway Infrastructure Guidelines
for
Light Rail Circulator Systems

A Report Prepared by

J. H. Graebner
R. E. Jackson
L. G. Lovejoy

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FOREWORD

In the array of land, water and air transport methods, a major position is occupied by railway technology that is based upon the proven and time-tested concept of flanged metal wheels rolling on a pair of metal rails. The provenance and first major application of this excellent (some might say, ingenious) technology occurred during the latter half of the 19th century when the majority of intercity and transcontinental railroads were constructed. As the 20th century dawned its most popular use shifted to the development of urban streetcar lines. In the larger cities, it was also used by the designers of rapid transit elevated and underground rail lines. Toward the end of the last century the same technology was utilized in the design of light rail transit (LRT) systems that are still growing in number worldwide. Through all of the evolution of these somewhat diverse railway modes, the fundamental technology has endured and it promises to do so for the foreseeable future.

However, as railways in their various versions matured the technology evolved and was adapted. New design skills, products and applications emerged while some of the older ones faded. The application that declined the most steeply was the street railway. By the beginning of the last quarter of the 20th century, outside of Europe, streetcar lines had largely vanished.

Now, as we move into the 21st century and many urban cores are experiencing revitalization, new streetcar lines are being developed to provide circulator service in these dense and often constricted districts. In the course of planning and developing these railways it has become apparent that some of the needed manufacturing skills and design expertise, which were once readily available to the street railway industry, have eroded and that some of them need to be recaptured and updated.

With that purpose in mind, an assemblage of rail transit professionals with skills and practical experience in street railway practices began researching this matter to identify areas where issues with current technologies and practices exist and to recommend measures to address those issues. One of the issues identified was the need for trackway infrastructure designs and materials specifically related to the environments in which circulators often operate. The findings of that research are set forth in the following guideline document.

LIGHT RAIL CIRCULATOR SYSTEMS

TRACKWAY INFRASTRUCTURE GUIDELINES

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1. Introduction

Light Rail Transit (LRT) is a well-established mode, with many representative systems in operation in North America. The Light Rail mode is essentially distinguished by providing rail transport between urban centers and suburban communities at distances sometimes exceeding 32 kilometers (20 miles) or more at speeds of up to 110 kilometers (68 miles) per hour. Typically light rail follows a basically linear corridor into or through the urban center, usually utilizing paved track in the central business area, but located in reservations free of motor vehicle traffic where possible. When not on reservations, as much as possible the paved tracks are segregated from vehicular traffic lanes to enhance service regularity. Light Rail Circulator systems, while utilizing basically the same technology, are designed to provide a transport function within a single urban district, connecting activity centers of all types that produce a flow of passengers worthy of the rail transit mode. Light Rail Circulator Systems may connect with other transport nodes and stations, including those of a light rail transit system. Providing this function may not always require the speed, capacity and multiple-unit capability required of line-haul light rail transit systems, but may impose two other requirements, which are the ability to negotiate the urban center street pattern and to "fit in" with the scale of peripheral residential areas that may be contiguous with the urban center. Meeting the first requirement may result in the Light Rail Circulator System track and cars needing to have the ability to negotiate smaller radius curves than present light rail standards recommend, while the second may be achieved by the use of shorter, single car, rather than multi-car, trains. Portland, Tacoma, Little Rock, and Tampa have examples of recently constructed Light Rail Circulator type systems.

The description of the Light Rail Circulator System service described above will be recognized as describing to a great degree the characteristics of what has historically been known as the streetcar. This is not to be unexpected as the technology employed is basically the same. There remain in North America three cities operating "classic" streetcar-type transit operations, Philadelphia, Toronto, and San Francisco. Each has at least one operating section that could be considered a Light Rail Circulator type in that it does not function solely to transport passengers from outlying areas to the city center, and the overall system utilizes paved track in streets for the majority of its operations. Boston and New Orleans also operate streetcar type vehicles suitable for Light Rail Circulator System operation, although Boston has no lengthy sections of track in general traffic lanes and the New Orleans cars are historic and primarily on reserved track. The cars used on all these systems could be used in Light Rail Circulator-type operations, whereas most light rail transit cars could not. Of the new systems in Portland, Tacoma, and Tampa, the last has been designed to be a modern "Heritage" (tourist-oriented) type of system, although its geometry, as with other heritage lines constructed in Little Rock, Galveston, Memphis, Kenosha, and Charlotte, is such that it functions like a Light Rail Circulator System. To date, Portland and Tacoma are the only new Light Rail Circulator Systems employing modern low floor rolling stock.

The intent of this document is to be supplementary to TRB TCRP Report 57, Track Design Handbook for Light Rail Transit, and it is therefore focused on the important differences between "line-haul" light rail systems and Circulator light rail systems as they relate to trackway infrastructure. The guidelines, narrative, and illustrations provided in this report are intended to highlight many of the principal issues and concerns that should receive attention when designing a Light Rail Circulator System's trackway infrastructure. Past experience of a number of transit agencies with wheel-rail incompatibilities requiring extra effort and cost to resolve have indicated that the attention to detail required to achieve the successful construction of such infrastructure is not to be underestimated.

2. Vehicle Size and Curving Considerations

De facto standards have been informally established for LRT in the US for minimum curve radius (25 m./82 ft.) and car width (2.65 m./8.7 ft.), based on general European practices. These informal standards have been adhered to even in cases where the vehicles acquired were a brand new design and there were no alignment constraints on either dimension. An analysis of European vehicles finds widths varying from 2.2 to 2.65 m. and with curving capabilities having a similarly wide variance. Streetcar widths in the US varied from 2.53 m. (8.3 ft.) to 2.74 m. (9 feet).

Guideline – *Do not unnecessarily constrain vehicle width in specifications. While recognizing and respecting the physical constraints of the operating environment, allow for the range of widths judged to be the maximum and minimum that are desired and feasible for the system. This allows for the possibility of a wholly new design to be supplied with the maximum width, which enhances the passenger comfort aspect of a rail car.*

Examples of curving capability currently existing are found below.

a. Existing transit agencies with minimum center line track radius below 25 m. (82 ft.)

Philadelphia – 10.8 m. (35.4 ft.)
Toronto – 11 m. (36.1 ft.)
Boston – 12.8 m. (42 ft.)
San Francisco – 12.8 m. (42 ft.)
Portland & Tacoma - car capability 18 meters (59 ft.)
Newark – 19 m. (62 ft.)
Melbourne – 16.8.m, (55 ft.)
Sydney – 20 m. (65 ft.)

b. Some existing low floor cars with minimum radius capability below 25 m. (82 ft.)

Brussels Bombardier Flexity – 14.5 m. (47.5 ft.)
Boston Type 8 – 12.8 m. (42 ft.)
Nordhausen Combino – 15 m. (49.2 ft.)
Ansaldobreda “Sirio” – 15 m. (49.2 ft.)
Portland Skoda “Astra” – 18 m. (59 ft.)
Alstom Citadis – 18 m. (59 ft.)
NJT Kinki Sharyo car – 18 m. (59 ft.)
Melbourne - Combino and Citadis – 16.8 m. (55 ft.)

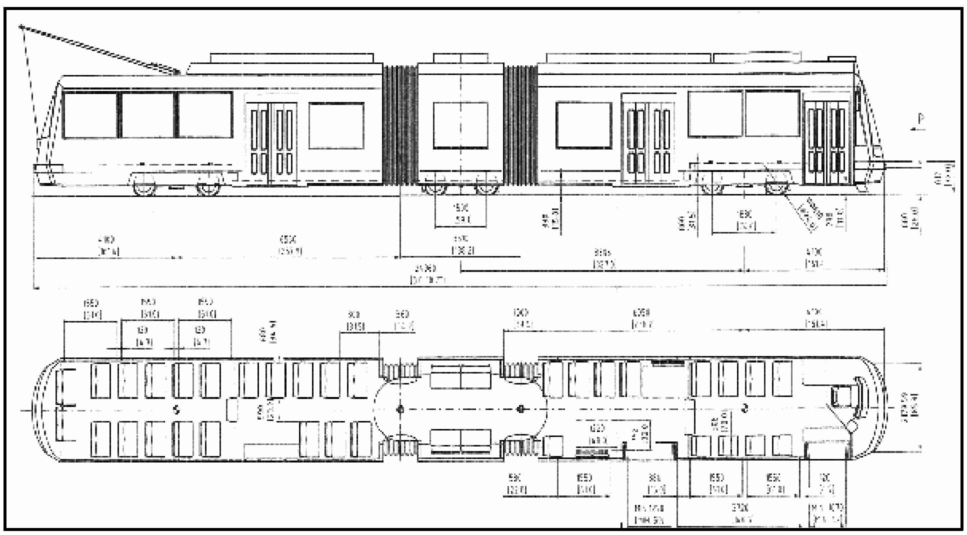

Figure 1. - Low floor car design capable of small radius curves.

From the above, it can be seen that there are a number of current vehicle designs that are suitable for Light Rail Circulator Systems in which the use of a smaller curve radius can be of benefit. Figure 1 shows a low floor car design that was proposed by a prospective bidder for one of the major US transit systems, and Figure 2 illustrates its ability to negotiate a worst case curve of 10.8 meters (35.4 feet).

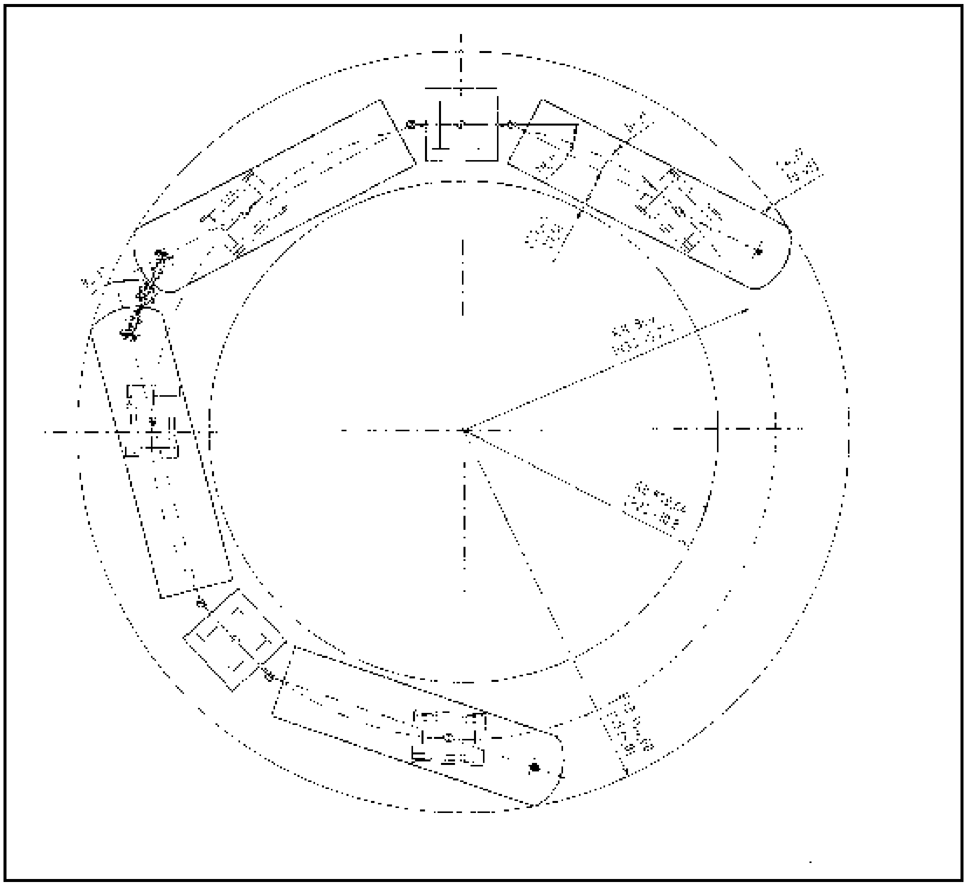

Figure 2. - Low floor car design of Figure 1 on 10.8 m. (35.4 ft.) radius curve.

3. System Expansion Considerations

The primary quality of a Light Rail Circulator System, the ability to turn sharp curves and thus fit into an urban street pattern with a maximum of flexibility and a minimum of impact on existing traffic patterns, does not necessarily inhibit system expansion into a full scale light rail system. The articulation designs that provide for small radius curving capability do not carry any penalty in terms of speed capability. Existing designs have capabilities of 70 to 75 kilometers per hour (43.5 to 46.6 mph) speed. These are ample speeds for Light Rail Circulator system branches into adjacent districts. For branches extending farther with greater station spacing, it is possible with relatively minor changes to the propulsion equipment to extend the speed range to 80 to 90 km/h (50 to 56 mph). Therefore, adopting Light Rail Circulator system parameters for the initial system will not put any constraints upon future system expansion in most cases.

Guideline – *Evaluate potential for system expansion that might suggest a need for higher speed potential and whether it is prudent to purchase a first order of rolling stock with that potential, which likely will incur an additional cost. Consider whether it will be beneficial in the future to have whole-system operating capability on all cars of the fleet.*

4. Trackway Considerations for Light Rail Circulator Systems

Since by definition Light Rail Circulator Systems are to have the capability to thread their way through an urban area where the ability to acquire land is minimal and where street widths and traffic patterns inhibit the use of wide radius curves, the first major characteristic required is an ability to traverse curves with a smaller radius than the 25 meters

(82 feet) that has often been the de facto Light Rail Transit standard. As has been indicated above, there are available on the world market low floor rail vehicles with better curving capability than most contemporary LRT vehicles. The evolution into low-floor vehicles has resulted in designs with smaller body sections and a greater number of articulations than are found on traditional LRT vehicles. This has provided a synergy with curving capabilities in that it allows the angle between body sections at the articulations to be kept within reasonable limits.

Guideline – *A key word in the title "Light Rail Circulator System" is the word "system". Preliminary system engineering and meetings with potential vehicle suppliers should take place simultaneously to ensure that the resulting minimum radius car capability is such that a maximum number of leading car suppliers can participate. Re-engineering a vehicle to meet a slightly smaller radius entails supplier cost and can result in a supplier not bidding if the procurement is for a small number of vehicles. Optimizing the trackway infrastructure/vehicle relationship may thus be an iterative process.*

While the ability of a Light Rail Circulator vehicle to negotiate smaller curves may be beneficial to constructing such a system in an urban area, another not insignificant benefit can arise with regard to the storage and maintenance facility. LRT systems are typically able to find land for yards and shops in outlying areas or in old industrial zones adjacent to the right-of-way being used. A Light Rail Circulator System may find itself in a much more constrained situation. Historically, urban streetcar systems have had to use very small radius curves in order to provide the needed space and functionality in relatively small parcels of land. The Light Rail Circulator System vehicle ability to traverse small radius curves will provide greater flexibility in locating a site in a more urbanized area.

Guideline – *In optimizing the trackway/vehicle relationship ensure that the chosen vehicle curving capabilities do not excessively constrain site selection for the maintenance facilities and storage yards. Evaluate the trade-offs of a reduced number of vehicle suppliers and possibly higher vehicle prices versus greater costs for the fixed facilities if the site location is constrained by the vehicle capabilities.*

5. Track Design Considerations for Light Rail Circulator Systems

While seemingly simple, wheel-rail relationships can be highly complex and sophisticated. This is especially true when curves of very small radius, and site-constrained, compact special work arrangements are employed. Both of these characteristics are likely to be found on Light Rail Circulator Systems. Wheel and rail must function as a system, and when that is not adequately addressed, problems can arise that result in increased rates of wear and even derailments. At least five transit agencies have experienced significant problems with rail-wheel interactions that required engineering attention and expense to resolve. Causes have related to both the design and construction aspects of the project.

Guideline – *Ensure that those parties responsible for wheels and rails are working in concert to produce optimum compatibility between the two subsystems. Wheel gauge, track gauge, check gauge, and all new and worn dimensions should all be mutually agreed to and initial drawings documenting all parameters should be developed before any serious design work takes place.*

5.1 Preliminary Design Considerations

A review of industry experience indicates that LRT systems that have had the least difficulties relating to the wheel/rail interface are those that have employed purely railroad standards for wheels and rails. In such a case, all the critical dimensions have been long established and, if track is properly constructed, the likelihood of problems arising is small. However, constructing to railroad standards requires that there be ample room along the line and in yards and shops, as curve radii are larger. These standards may not be compatible with Light Rail Circulator environments. Further, those operations using railroad standards have either used T-rail in their paved track, or have no paved track except at crossings.

Where agencies have encountered problems with the wheel-rail interface, either design or construction details have typically been the cause. When an agency employs an outside firm to design the Light Rail Circulator track there are a number of considerations that should weigh heavily in the selection of the firm. Problems typically found on track of questionable design and/or construction are:

Improper gauging of track and guard rails.

Use of apparently railroad-based designs not suitable for Light Rail Circulator System rolling stock with street railway wheels and/or the curvature employed on the system. (See Figure 3.)

Failure to understand the criticality of certain crucial track dimensions and tolerances under small radius circumstances.

Employment of design details that increase the cost and complexity but have no payback in terms of performance or utility. (See Figure 4.)

Guideline – *When choosing a track designer, it is of great importance that the one chosen has demonstrable knowledge of streetcar track and successful design experience. Many track designers have primarily a railroad background, which by itself is not qualification for design of Light Rail Circulator System track with small radius curves and possibly complex and compact shop and yard layout.*

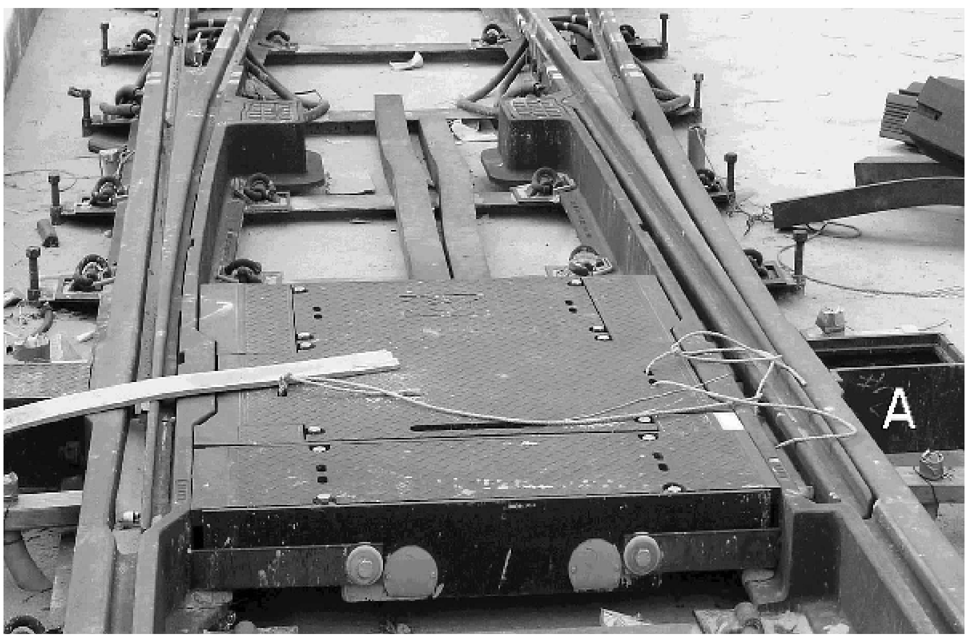

Figure 3. - Switch points apparently based on railroad designs and used on a light rail system in conjunction with grooved rail. The jog in the rail gauge face at A could cause the trailing axle flange to climb onto the railhead in situations where the curve radii are small. Correct design for a Circulator will provide a guiding surface for the back of the wheel that is opposite A which will hold the trailing axle wheel flange away from the guidance surface jog at A.

5.2 Rail Options

Very often, streetcar and light rail lines that use public streets are constructed using girder rail rather than conventional T-rail. Modern girder rails provide a groove in the head of the rail for the rail car wheel flange. The

Figure 4. - The complex and expensive guard rail construction on tangent rail opposite the frog appears to provide no more useful guarding than the grooved rail itself would provide. Noteworthy is that in this instance the axles taking the diverging path through the frog are in fact guided by the grooved rail opposite the frog.

decision as to whether to use T-rail or girder rail can be site-specific. Historically, large municipalities sometimes required that street railway track be constructed using girder rail, while some smaller towns had no such regulation. Grooved girder rail has several advantages that have made it almost universally used in paved track world-wide:

It provides a minimum width of flangeway which produces the least hazard to small-wheeled vehicles (such as baby carriages and wheel chairs) and bicycles. While it is possible to form flangeways in paving material adjacent to T-rail, it is necessary to make them wider than optimum so as to avoid damage to the paving due to abrasion by the back faces of the rail car wheels. Also, paving materials other than stone or concrete will eventually collapse into the flangeway under the impact of rubber-tired traffic.

Its use in curves for the guard rail function requires less labor for both fabrication and installation than the use of T-rail and a separate restraining rail. Restraining rails can take many forms but will always require additional fabrication work such as drilled holes in the running rail. The large number of fittings will require many labor-hours for assembly. Grooved girder guard rail is one integral piece that can just be laid in place. Figures 5 and 6 illustrate this difference.

Grooved rail provides a steel flangeway that is not easily damaged by the impact of steel wheel flanges on foreign material in the flangeway, or by the effects of salt, traffic, etc., that over time can cause even concrete to disintegrate. On tangent track, grooved rail effectively provides a continuous guard rail with maximum protection against possible derailment resulting from non-crushable objects lying in one of the flangeways.

Because of the near-universal use of grooved rail for street railways and light rail lines outside of North America, all the designs and dimensions found on small radius curves and special work used in compact yard and shop situations are long-developed, and so can be delivered almost fully engineered with little chance of error. Thus design engineering and installation costs can be lower if the designers have appropriate experience.

Circulators that are part of a larger LRT system that employs railroad track standards may find that readily-available rails and special trackwork that is based on the use of grooved rails is incompatible with the railroad type wheels used on the vehicle fleet. Customized special trackwork designs and/or wheel designs may be necessary.

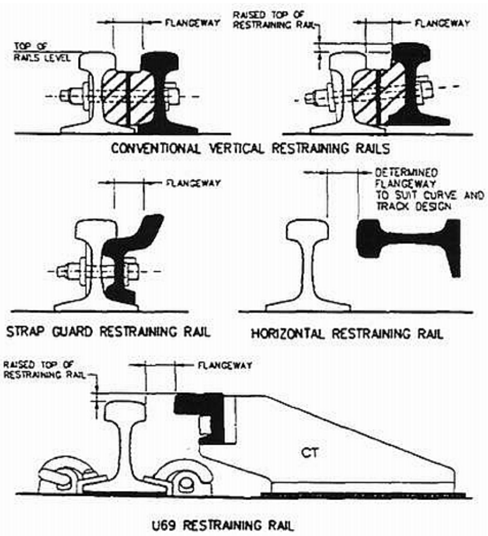

Figure 5. - T-rail guard rails.

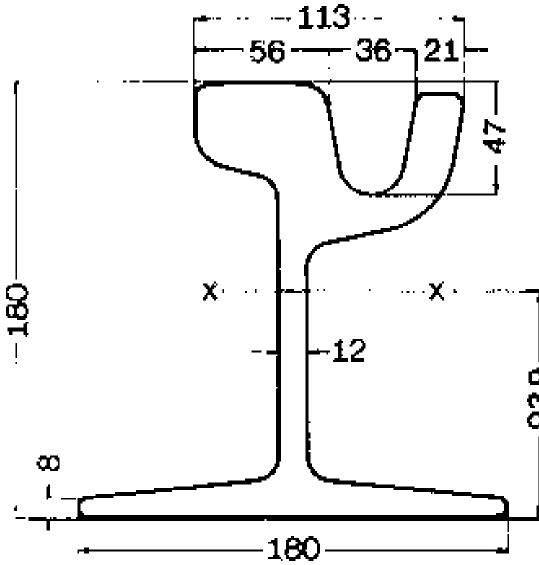

Figure 6. - Ri 60 grooved girder guard rail.

In the North American context, because there is no domestic source of supply, the use of grooved rail track and special work has some disadvantages in that:

Lead times for procurement of material may be longer.

With the existing, unfavorable exchange rate and the shipping involved, material cost may be higher.

Buy-America regulation waivers may be needed.

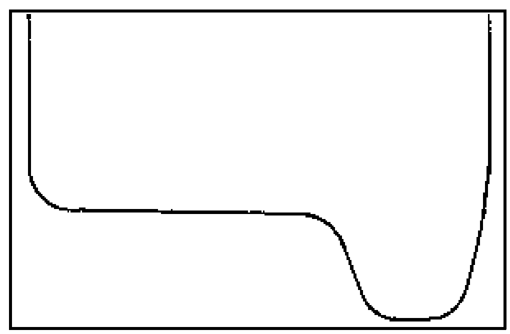

Figure 7. - Streetcar wheel profile.

The rails used in paved track on legacy streetcar lines were usually – but not always - grooved or not-grooved girder rails. The exceptions were largely driven by economics, girder rails always having been more expensive than common T-rails. In the early 20th century, it was common that lower-capitalized trolley lines would use T-rail when local regulations permitted. In such installations, the required flangeway was often formed with a specially-shaped paving brick, re-pressed so as to both fit into the web of the rail and form the flangeway. In the mid-20th century, with the number of US producers reduced to two and then one, many street railway companies began to use T-rail. Typically, this involved formation of a flangeway in a concrete or asphalt pavement surface.

There were only two major types of girder rails produced in North American after about 1930. Grooved girder rails with a sloped self-cleaning flangeway provided wheel guidance on only one side of that groove, as shown in Figure 8. Girder guard rails had the outer edge of the groove rotated vertically, and were thus able to provide guidance to both the front and the back of the wheel flange as shown in Figure 9. Thickness was increased to improve service life. Girder guard rails are used on sharp curves where two-point guidance provides superior steering of the streetcar wheels as well as reduced levels of rail and wheel wear, thereby resulting in longer service lives for both. Today, there are no North American producers of girder rails. “Grooved Rails” (as they are termed in the rest of the world) are manufactured by several European rolling mills, although not to the designs last produced in North America.

(See Figures 6, 8, and 9.) In general, the grooved rail sections that are available from Europe come in two varieties – those with flangeways that are too small for North American railroad wheel flange profiles and those with flangeways that are too large to satisfy guidelines of the Americans with Disabilities Act (ADA) for walking surfaces. Use of these European rails will usually require adoption of a European type of flange profile as is

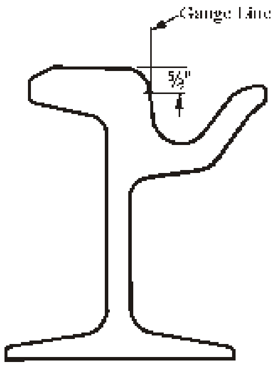

Figure 8. – US Grooved Girder Rail.

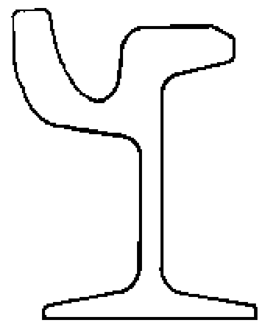

Figure 9. – US Grooved Girder Guard Rail.

currently in use on a US transit system and illustrated in Figure 7. Grooved rails are sometimes made of softer steel than common T-rails. This is because the more complex shape of the grooved rail requires more passes through the rolls compared to T-rail. The temperature of the nascent rail is reduced with each pass and if the rail steel chemistry isn't soft enough, it may not be possible to make the last few passes without fracturing the rail. Some European suppliers can provide surface weldments to increase the durability of grooved rails, but results have been mixed. One manufacturer had just recently begun offering a heat treatment process for grooved rails, but the product has not been on the market long enough to be considered proven.

Most North American LRT projects have used T-rail for paved track installations, usually because railroad flange profiles were adopted. Methods for providing the requisite flangeway have varied, as have results. Similarly, methods and results for providing a guard rail in curves have varied by project. One method consists of a vertically-mounted restraining rail that is bolted to the running rail every two to three feet. A few projects have used a special rolled shape – strap guard – that mates with common 115RE T-rail and provides a flangeway that mimics that once provided by North American girder guard rails as is shown in Figure 5.

Guideline – *If grooved rail is used, then a wheel flange profile optimized for the girder guard rail should be adopted. Both the gauge and guard side flange angles from vertical and the tip radii on both the running rail and guard side of the flange should be analyzed for use on curve radii below 15 meters (49 feet) and adjusted for perfect compatibility if found necessary. Alternatively, a flange profile in use on a European property with curve radii equal to that to be used on the Light Rail Circulator System can be adopted. The flange should include the typical flat tip that works best with flange-bearing frogs, crossings, and switch point mates. (See Figure 7.) Such flanges are used at speeds of up to 100 km/h (62 mph) in Europe, so pose no constraints on system expansion. If grooved rail is used, attention should be given to its carbon content to ensure procurement of rail that is no softer than is necessary.*

5.3 Use of Bolted Connections

Light Rail Circulator System track embedded in concrete is not very maintenance-friendly. Access is only by jackhammer. Therefore, a goal of the track designer should be to design potential maintenance out of the system. One key component of the design should be to minimize bolted rail connections. Figure 10 illustrates a design in which bolted connections predominate. When alloy castings are used in special work (not a universal approach), it is still possible to electrically weld them if the right welding rod is used and the welder is skilled. The transit agency should have its track designer evaluate the best techniques and locations for use of bolted and welded joints. Figures 11 and 12 illustrate two different approaches to this task. Thermit welding can also be used if frogs and points are made with carbon steel

Guideline – Bolted joints should be minimized as much as possible. Any decisions regarding welding to castings should be contingent upon conversations with the potential casting supplier to confirm that the material composition being used lends itself to being welded without risk of thermal damage. The welding rod used should be recommended or approved by the casting supplier.

5.4 Control of Gauge

A common cause of difficulty in construction of Light Rail Circulator System track can arise from inadequate control of gauge during track construction. In small radius track arrangements the track must be very accurately gauged. Traditional railroad tolerances will often not suffice, particularly in maximally compacted arrangements featuring doubly-curved frogs, a technique which offers increased tangent track lengths for car storage and increased land for

Figure 10. - Crossover consisting of grooved rail sections and castings, all bolted together.

storage buildings. Excessive gauge play increases the angle of attack of the flanges on the rails and results in increased wear. Figure 13 illustrates an extreme example of excessive gauge play, as can be deduced by the wide spacing of the flange paths on the diagonal rail. Figure 14 illustrates a typical compact storage yard layout. In construction of this type, without gauging devices, aggressive contractor monitoring is critical to achieving accurate gauging. Even greater compactness and land-use efficiency can be achieved by reversing the locations of switch point and mate and achieving a greater degree of interlace. Figure 15 illustrates this technique. The potential for gauge-related problems can be minimized by application of gauge bars, gauge rods, or steel ties, which remove the workmanship element from the track installation site and shift it to the gauging device manufacturing process. With any of these methods, fabrication errors made up to that point in the process can be detected at the pre-assembly checks. However, the use of gauge bars or rods significantly complicates the process of insulating the rails so as to deter stray currents Attempts to insulate gauge rods with sleeves have had mixed results. Steel ties have fewer

Figure 11. - Cast crossing frog electrically welded to carbon steel grooved rail.

Figure 12. - Electrically welded connections between grooved rail sections and frog castings.

problems in this regard. In addition, when T-rail is used, steel ties are usually preferred as they can better accommodate the guard rails, as Figure 5 illustrates. Figure 16 illustrates a typical application of gauge bars. When coupled with careful shop bending of rails, gauge bars or rods can provide assurance that the as-built gauge is correct. However, bars or rods typically cannot correct a tight gauge situation since they have insufficient strength against buckling under compressive loads. Sharp radius curves, typically anything under 91.5 m. (300 ft.) radius, will usually require that the rails be pre-bent in a fabrication shop. Such bending is done with the rail "cold", using either a gag press or a roller bender. Rail bending is somewhat of an art form and careful measurements must be made during the process to verify whether the correct radius is being achieved. Due to their non-symmetric cross section, grooved rails, when bent horizontally, will usually twist about their longitudinal axis. The result is that the rail base will not lay flat. To counteract that, grooved rails must be cambered vertically before horizontal bending is

Figure 13. - Example of excessive gauge play.

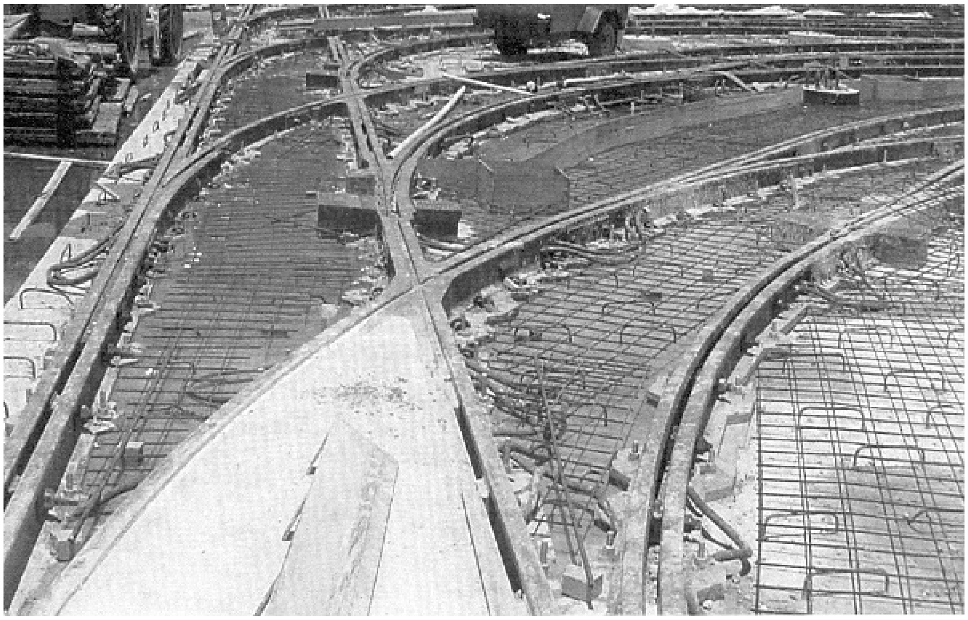

Figure 14. - Typical compact track fan at a storage facility but without gauging devices.

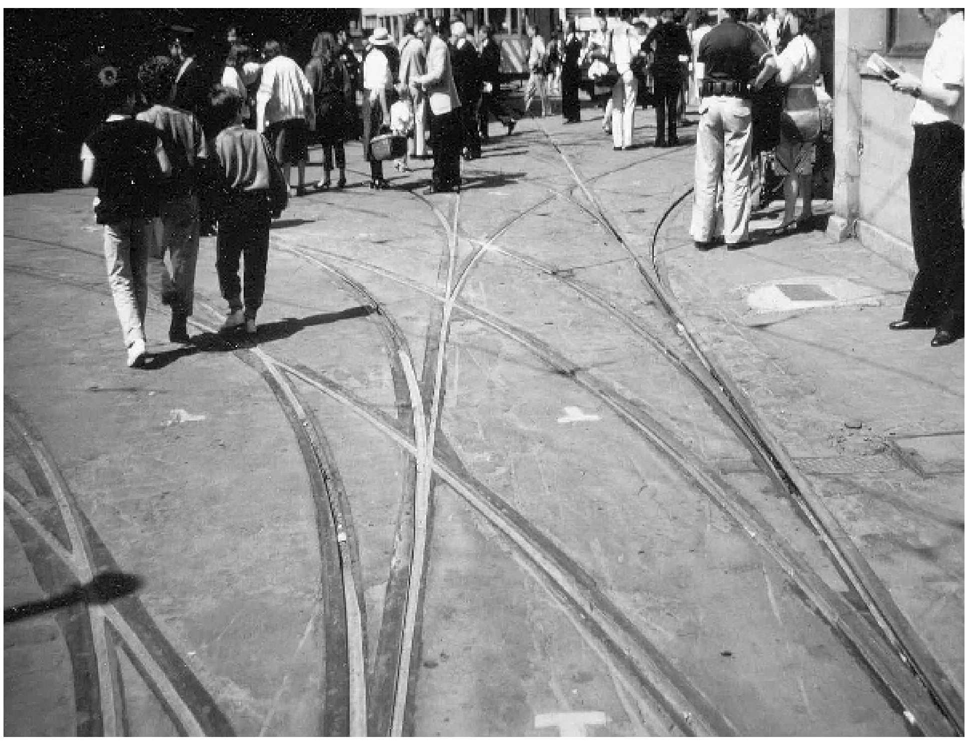

Figure 15. - Example of a maximally-compacted depot track fan. Noteworthy is the reversal of the point and mate locations for some of the turnouts to minimize the use of space.

done, with the amount and direction of the camber being dependent on the horizontal radius and whether the finished rail is on the inside or outside of the curve. Cambering is also necessary when it is desired to maintain a specific cant in the rail. Extreme vertical curvature – generally any curve sharper than the natural sag of the rail when supported only at its ends – will also require shop fabrication.

<u>Guideline</u> – *To avoid potential problems due to gauge inaccuracies, all special work containing turnouts and small radius curves should be designed and constructed with a positive means of maintaining the gauge. Full assembly including the gauging devices should be accomplished before they are embedded or are fastened to a concrete slab or invert. All gauging should be carefully checked during pre-installation assembly so as to detect any gauge device dimensional errors. Consideration should be given to constructing wheel-pair templates that will accurately simulate both new and worn wheel conditions. Supply of these can be made a part of the track supply contract. Alternatively, a Circulator vehicle truck (if available) can be pushed around through the track layout to determine if appropriate rail/wheel interaction is occurring, but it should be recognized that the worn wheel condition will not be present without modification. If it is decided to build plain curves without gauging devices, the templates or a truck can be used to check gauging of running and guard rail surfaces. With new wheels, both flanges should be in contact with their respective guidance surfaces. Regardless of the verification method employed, these checks should be done prior to the time when placement of embedding paving makes corrective actions extremely difficult and costly.*

<u>5.5 Special Work and Gauging Considerations</u>

As can be seen in Figures 3, 14, and 15, LRT and Light Rail Circulator System turnouts can be found with both double points and with “point and mate” (single point) arrangements. Generally, double points are preferred for

Figure 16. - Typical gauge bar application in a turnout.

main track use, while single point designs are usually used in yards. Compact yard track layouts are sometimes only possible with single point turnouts. Mates are typically a casting, and flange-running through the mate compensates for the inability of the wheel tread to bridge the running surface gap that exists where the two flangeways join. Point and mate construction typically puts the point on the inside of the curve, as can be seen in Figure 14. From a ground vibration standpoint, the use of a mate is inferior to the use of a double-pointed turnout. Although the flangeway depth of the mate can be made to perfectly match the new wheel flange depth, wheel wear can result in a flange becoming deeper. Ramping the flangeway largely compensates for this at low speeds. In addition, transfer from the normal running radius of the wheel tread to the larger flange tip radius produces slippage since the two wheels of the

axle are running with different radii. It has not been uncommon in Europe to insert flange-bearing running rail opposite a flange-bearing frog to alleviate this. With the passage of time, these factors tend to result in the flange-bearing running surface of the mate having a rougher surface than a railhead would. Therefore, use of mates in other than low speed track is not common and they are best-suited to use in low speed turnouts at junctions and yards.
Wheel tread widths on Light Rail Circulator System vehicles typically are smaller than railroad standard. Seventy six mm. (3 inches) is typical for paved track use, although historically many properties used 63 mm. (2 ½ inches). A typical profile is shown in Figure 7. The purpose of this reduced width is to minimize overhang of the wheel beyond the railhead and over the paving, as it is undesirable for the steel wheels to be crushing street debris into the paving. As a result, frogs used in turnouts and crossings are typically flange-bearing to minimize ground vibration caused when wheels drop into a gap when crossing an intersecting flangeway. At the point of intersection of the flangeways, cold-rolling and wear will in time produce a "dimple" at that location. Where minimum ground vibration is desired, consideration should be given to having frogs made of weldable material. This allows fill-in of the "dimple" with welding followed by grinding to restore a smooth flange running surface. The turnout shown in Figure 16 contains such a frog. As with mates, frog decisions should be based on location and operating speed.

Where small radius curves and compact yard layouts are concerned, track gauging is very important. Likewise, girder rail flangeways are small and allow only limited lateral motion to occur before the flange contacts either the gauge face of the rail or the guard face. Typically, lateral motion of a streetcar wheel set is restricted to 3-6 mm. (1/8 to 1/4 inch), i.e., the wheelset gauge is 6-13 mm. (1/4 to ½ inch) less than the nominal track gauge. This value is known as the "Gauge Play". It increases with flange wear, and must be considered in designing the track. It should be noted that railroad Gauge Play is 17 mm. (11/16 inch), and if this is applied to paved track wider flangeways must be provided, or the track gauge can be reduced. It is important to note that while girder rails that accommodate railroad wheel flanges without requiring track gauge reduction are available, they come with flangeways wider than are appropriate in a street environment.

Guideline – *In locations where ground vibration is a concern and turnouts are installed solely for operational flexibility under abnormal conditions, a design in which the frog has no flangeway for the abnormal traffic path should be considered. In such a design the flangeways of the abnormal path are ramped up on either side so that the diverging movement flange is lifted to the height of the normal path railhead so that it may roll across it. Alternately, if a shallow angle frog is used and the flangeway width is minimized, it may be possible for the chosen wheel profile to bridge the flangeway and make flange bearing unnecessary. Single point turnouts, which are used to minimize cost and maintenance requirements, are best restricted to low speed locations.*

5.6 Trackway Paving

5.6.1 Purpose of the Paving

A light rail transit track might be embedded in paving for one or more purposes.

Roadway driving surfaces for general traffic - If the Circulator lane is shared with rubber tired traffic (either along the track in a shared lane or transverse to the tracks at an intersecting street) paving provides a generally-smooth riding surface for the general traffic, concealing all but the top horizontal surfaces of the rails.

Pedestrian crosswalks - Providing a safe path for pedestrians across tracks requires careful attention not only when they are is in private right-of-way but also when the trackway is in an urban street. Because of safety considerations, including compliance with the Americans with Disabilities Act (ADA) guidelines in the US, or similar legislation in other countries, the physical location of crosswalks relative to track hardware, as well as the pavement surface provided for pedestrians, must be carefully considered. It is desirable to avoid placing crosswalks in areas of special trackwork and vice versa. In particular movable switch points (either power or manually operated) should not be installed in pedestrian paths. Because steel surfaces can be slippery when wet, large special trackwork fabrications should also be segregated from crosswalks. When T-rail is used, fitting metal edging to the flangeways at pedestrian crossings should be considered. This serves to minimize the flangeway width and ensures that the width will not widen with age-related wear. Figure 17 illustrates excessive flangeway width in a pedestrian crossing zone.

Trackway housekeeping - Sometimes it is desirable to embed a light rail track in paving even if rubber tired or pedestrian traffic is not a consideration. Most often this it done for housekeeping purposes in urban environments where an open track structure – such as tie and ballast track or direct fixation track – would tend to collect trash or

Figure 17 - Flangeway with excessive width that is incompatible with small wheels in a pedestrian crossing area.

present problems for street drainage. If rubber tired traffic is not a consideration in such areas, the paving structure can sometimes be less robust than a shared traffic area although this could inhibit both the ability of public safety vehicles (e.g. police, fire and ambulance) to use the trackway in an emergency. It could also restrict railway maintenance forces from driving rubber tired equipment along the trackway while performing inspection and maintenance on the overhead contact wire systems.

5.6.2 Types of Paving Materials

Reinforced Concrete - Concrete is arguably the most structurally durable type of trackway paving and has been used for LRT and Circulator tracks in many cities. It is particularly well-adapted to use with the popular rubber rail boot method for electrical insulation and vibration isolation of the rail. However, concrete paving can have problems related to improper design and construction. Cracking is common unless concrete control joints are carefully positioned on the plans and similarly constructed in the field. Disintegration of the surface of the concrete – particularly in corners of slabs and at control joints – is a common problem that is directly related to poor construction controls. In northern climates, these problems are abetted by freeze-thaw conditions and the use of de-icing chemicals in the street. If a concrete trackway surface is desired, the responsible agency needs to make certain that the construction specifications are rigorous and that sufficient construction inspection resources are budgeted to make certain that those specifications are followed to the letter. In urban districts, where there are numerous utility lines within the street right-of-way, there are drawbacks to concrete as compared with other paving materials. Repaving following excavations for utility maintenance/repair work not only leaves a noticeable blemish, but also can allow seepage of water leading to erosion and (in colder climates) mechanical damage from freezing and thawing. Cosmetic issues can be addressed to some extent by adding color pigmentation to the concrete.

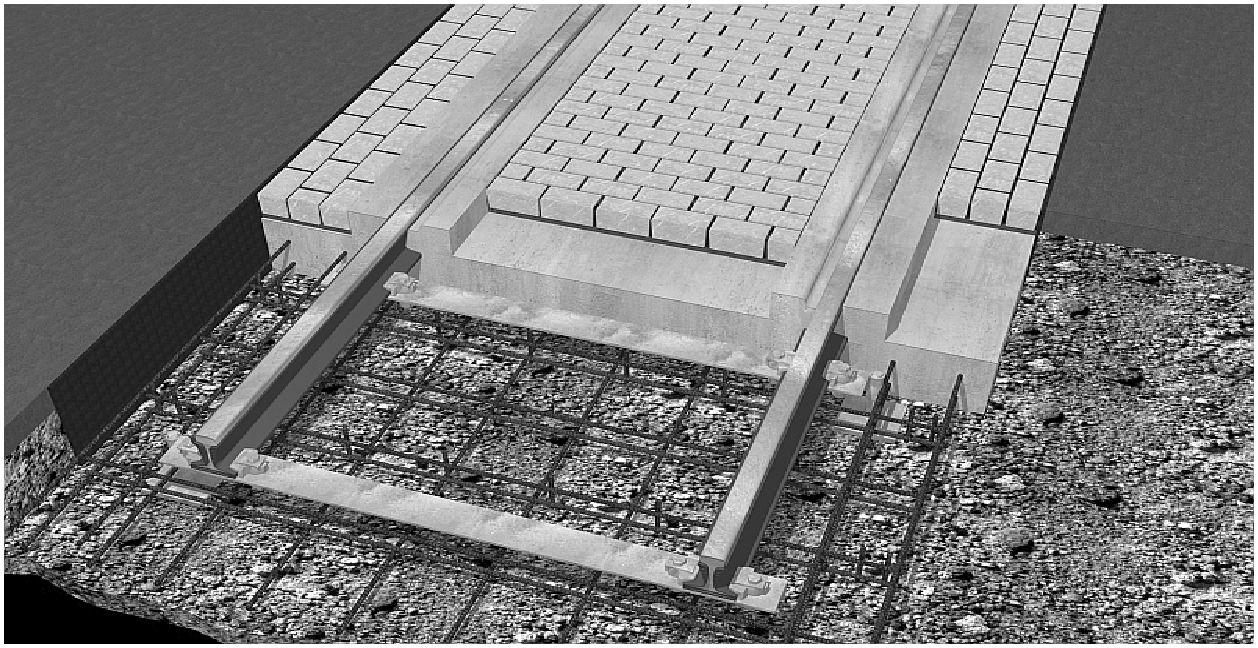

Figure 18. - Track design with T-rail and block pavers.

Bituminous Concrete/Hot-Mix Asphalt/Blacktop - Known by various names, asphalt was often a paving choice on legacy streetcar systems. Many systems used full-depth asphalt directly over ballasted track of conventional construction although such expedient construction generally had a short service life. A more durable variation on this placed plain cement concrete up to within about five centimeters (two inches) of the top of rail, and then placed an asphalt overlay up to the top of rail. That type of construction generally works well, provided that all concerned recognize that the asphalt is a sacrificial layer that will have a much faster rate of wear than the steel rail and will usually need to be removed and replaced periodically – possibly as often as every five years. This type of construction could be adapted to the use of the rubber rail boot, although extreme care would need to be taken to avoid damage to the top edges of the boot during placement of the hot asphalt and during later milling of adjacent deteriorated asphalt.

Pavers - Various type of pavers (e.g. granite blocks, cobblestones, bricks, etc.) are popular choices for decorative paving in urban areas and such materials are thus often specified for paving of LRT tracks in sensitive zones. One such use is the preservation or restoration of historical street paving. Traditionally, brick or block pavers were often used as paving around tracks on legacy streetcar systems, often long after municipal authorities elected to use concrete or asphalt on street reconstructions. Various types of pavers have been employed on both legacy and modern light rail lines. These include granite blocks or slabs of various depths/heights, fired clay brick, and manufactured pavers made of concrete and other materials. Figure 18 illustrates a typical design using block pavers.

Designers who are interested in clay brick pavers should first understand that the type of brick used in street construction 60-plus years ago is no longer commercially available. That material was called re-pressed brick, had a formed and glazed finish on all six sides, and was manufactured in accordance with ASTM C-7. Modern clay paving brick does not go through the manual re-pressing process and hence has two wire-cut faces that are porous and less durable. Traditional pavers also had lugs extending out from the sides of the brick so as to provide a 3 mm. (1/8 inch) gap between each brick and its neighbors. This gap allowed relative movement between the bricks and saved them from mechanically damaging each other as heavy wheel loads pass down the street. The other major difference between the way brick streets were constructed 60 years ago and the methods now used has to do with construction details.

Contemporary paver streets are often laid on a bed of sand which in turn is directly above a compacted granular subbase. Such construction is seldom up to the rigors of heavy loading such as from trucks or buses. Seventy-five years ago, a typical brick street would have had a granular base, covered by a reinforced concrete slab. Above the concrete, a thin layer of asphalt would have been placed to provide a level setting bed for the brick pavers. Today, sand or a sand/mortar mixture is usually employed to fill the joints between the bricks. This kind of hard material makes it difficult to for the bricks to move relative to each other, particularly if the pavers do not have lugs to keep them apart. It also does not exclude moisture from penetrating the surface of the street. First class construction 75 years ago would have filled the joints between the lugged bricks with hot tar, which retains some flexibility even at low temperatures. It is also self-healing so that even if the tar cracks, it will flow back together and maintain a impermeable surface on the street. A lime whitewash was typically applied over the top surface of the bricks prior to spreading the hot tar so as to keep the tar from adhering to the visible surface.

While it may be possible that some manufacturer could be persuaded to tool up for making re-pressed paving brick, it is certain that they would be quite expensive compared to alternatives with less visual appeal. Small projects might be able to use recycled brick from old streets, but on larger projects it would likely be impossible to come up with enough brick that is both in good condition and all of the same color.

Stone pavers are subject to some of the same sorts of considerations as clay brick. The stone pavers used on legacy streetcar systems were usually close to the size of a loaf of bread, sometimes larger or smaller. Their vertical dimension was often between 18 and 20 cm. (7 and 8 inches), largely because of the 23 cm. (nine-inch) tall girder rails that were commonly used for city streetcar lines. Because of manufacturing tolerances at the quarry, these stone block pavers resulted in a street surface that was equally rugged to view and to drive upon. Many streetcar companies continued to use recycled stone block paving for years, possibly in part because the rugged surface discouraged timid motorists from driving in the trackway and getting in the way of the streetcars. Architectural paving stones that are less than 13 cm. (5 inches) thick are probably not suitable pavers for track areas that are subjected to any significant amount of roadway traffic. If track is installed in an area in which horse-drawn tourist carriages are used, consideration should be given to the use of granite block paving, as even concrete will not long survive the horse’s steel shoes.

Stamped concrete and stamped asphalt – This technology attempts to achieve the visual appeal of genuine pavers in track areas at relatively low cost. However, it is probably not suitable for areas with high levels of motor vehicle traffic.

Track in Grass - While strictly speaking, grass is not a paving material, it has an obvious appeal for areas where paving isn’t needed for either rubber-tired or pedestrian traffic but an attractive appearance is desired. Like all designs, it has its place but it also has some shortcomings. The following issues are offered for thought by those who might be considering track in grass on some portion of a Circulator project:

It is probably best limited to temperate climates where snow and snow removal is not an issue. The usual snowplow truck would likely destroy the turf in the track area during a winter of frequent plowing. In addition, it would be very easy for snowplow drivers to absentmindedly activate their truck’s salt spreader while plowing the tracks, doing even further damage to the trackway.

Achieving electrical isolation of the rails in grassed track is possible, but doing so correctly and in a manner that will prevail over the long term is expensive.

Grass should be kept at some distance from the rails in order to avoid lubricating the rail/wheel interface. Accordingly, contrary to what is the common impression, more than just the top of the rail surface will be visible.
The grassed track area will often blend in so well with the urban fabric that the fact that it is NOT a public park area may be lost on a significant percentage of the population. Some grassed track areas in New Orleans have become popular jogging trails, much to the dismay of streetcar operators.

5.6.3 Flexible Materials

It is often pointed out that extruded rubber products are commercially available that can be inserted in a flangeway, leaving a level surface. These products deflect under the weight of the rail vehicle and then spring back up after passage. Such products are designed for use indoors and in outdoors in temperate climates. They are also intended for very slow rail movements – 8 km/hr (5 mph) maximum. They are not suitable for outdoor areas that are subject to freezing, nor are intended for areas where rail car velocity is higher than walking speed. They also are not likely to be durable under very frequent repeated use such as would be encountered on a Circulator rail line.

5.6.4 Drainage

The flangeways interrupt the normal flow of storm water across the surface of the street and act as gutters that convey water to a low point along the track. The flangeways must be drained at the low point of any sag vertical curve, particularly in northern climates where water could freeze in the flangeway and cause a derailment. Drains must also be provided immediately upstream of any switches in paved track so that the street detritus that accompanies the run-off isn't washed into the switch mechanism. Drains are also recommended immediately upstream of any point where embedded track changes to open track so that this residue does not foul the open track area and possibly become the origin of stray current leakage. Drains must connect with nearby drain lines for the adjacent pavement lanes, and the drain entrance ways must be sufficiently large so as to not be easily blocked by dirt and leaves. When grooved rails are used, a slot of appropriate length should be cut into the bottom of the flangeway and made as wide as the rail design allows so that the drains will not be easily blocked, as can happen with smaller drilled holes.

5.6.5 Climate Factors and Paving Durability

Designers of paved track systems have far more latitude in temperate climates than in frost belt cities. If the paving will be subject to freeze-thaw cycles and de-icing chemicals, the design must recognize those factors.

5.6.6 Paving Maintenance Responsibility

At the beginning of the 20th century, it was uncommon for city streets to be paved. In exchange for municipal permission to build and operate a streetcar line, legacy systems were therefore usually saddled with the responsibility of both constructing and maintaining the paving in the trackway. Some paving designs are far more expensive to construct and/or maintain than other. Designers of Circulator rail lines with paved track should consider who will be responsible for both the cost and the action of maintaining the paving in the track area before finalizing a design.

In situations where the transit agency is responsible for maintaining the paving in the track area, it is sometimes a good practice to have a visually-obvious line of demarcation between the transit agency's paving and paving that is maintained by the municipality or highway agency. That line should never be inboard of the dynamic envelope of the Circulator vehicle.

5.6.7 Paving Cross Slope and Track Superelevation

Ideally, the two rails of a tangent Circulator track will be at the same elevation. This is rarely possible when the track is embedded in a street since most pavements have cross-slopes so as to promote surface drainage. In the past, it was very common for streets to have a parabolic crown with the actual side slope of the pavement varying from near nothing at the center of the street to a significant figure at the curb lines. Since the tracks of legacy streetcar systems were usually located in the center of the street, there would be relatively little cross slope between the rails. Today, a straight percentage cross slope is the usual pavement design - 2% is common. That much cross slope across a track effectively introduces about 3 cm. ($1^{1}/_{8}$ inch) of superelevation in the track, regardless of whether it is needed. Negative superelevation can result if the normal pavement crown is carried through a curved track area. The track and pavement designers must carefully coordinate their efforts to minimize any need for excessive cross slope in the track areas. Their analysis should include recognition of how the flangeways intercept storm water runoff and hence change the paths for storm water compared to a street without rails.

Typically, it will not be possible to incorporate much superelevation in a track that is constructed in a public street and must conform to existing street pavement elevations. A common error is to presume that since no superelevation is used, that there is no reason for using spiraled transition curves. To the contrary, it is even more important to use a transition curve leading into very sharp radii so as to reduce the rate of change of lateral acceleration experienced by

Figure 19. - Turnout with housed point.

both the vehicle and its passengers. Aptly called "jerk rate", this factor can be controlled through use of transition curves of appropriate design. Usually, the transition curves used on street railway curves are not mathematical spirals, but rather a series of compound curves that decrease in radius and then increase following a set pattern. These transition curves can also be used to control the "end-overhang" of the circulator vehicle where it enters and exits curves so as to avoid or minimize clearance conflicts with trackside obstructions or general vehicular traffic in an adjacent lane.

6. Use Of Vehicles With Independent-Wheel Trucks

Some transit agencies have had incidents of derailments of the center truck of their low-floor LRT and Light Rail Circulator System type cars. In both cases the center truck is of the type in which the wheels are independent of each other, that is, not mounted on the same axle, but mounted on four short axles, two on each side of the truck. This design allows for the low floor to be continued through the short body section that is carried on the center truck. Figure 1 illustrates such a car design. It appears that forces on the flanges are greater on independent wheels when traversing curves than on conventional 2-wheel axle sets. At one agency this appears to be substantiated by a greater rate of wear of the flanges on the independent wheels. The Interface Journal paper "Flange Climb and Independently Rotating Wheels" is an examination of the factors involved. It is a fact that there are hundreds of Light Rail Circulator type cars with independently rotating wheels in successful operation in other parts of the world, which raises the question as to why such a design should be problematic in North America. A common thread might be that overseas they operate on track which possesses greater margins of safety against derailment by use of very high percentages of grooved rail. (As noted previously, European grooved rail provides the equivalent of double-guarding at all points in the track structure.) Further, in Europe, where T-rail is used on open track, curves are typically gentle and well guarded where needed. If cars of this type are to be used on a Light Rail Circulator System, it will prudent to carefully consider the track design in all aspects to ensure its suitability. An area to be given strong consideration is rate of change in track cross-level, typically encountered in the build up or run-off of superelevation. Modern multi-truck light rail cars are less tolerant in this area than earlier double-trucked cars. Track and vehicle design should be coordinated at an early stage to ensure that both parts of the system are fully compatible.

Guideline – *If T-rail track construction is used, sharp curves should be double-guarded. (See Figure 14.) Switches should have curved points and at least one should be housed. (See Figure 19.) Gauging should be such that it is impossible for a flange to climb on top of the running rail. If single point turnouts are used, points should be placed on the inside of the curve. If the point must be placed on the outside of the curve, the point should be recessed (See Figure 3.) and application of a friction modifier to the mate surfaces is desirable to reduce flange forces. The mate design should provide a guarding surface that ensures that the point-side flanges cannot travel into the recessed area. Ensure that the vehicle and track designs are fully compatible in the area of rate of change of cross-level.*

7. - Compatibility of LRT and Light Rail Circulator Systems

As noted previously, Light Rail Circulator Systems can be expanded into broader areas and function as line-haul LRT systems. If a Light Rail Circulator System is added to an existing LRT system it will be necessary to consider carefully the physical interfaces of the two. Primary areas of concern are the track interface and the platform interface. Some Light Rail Circulator System-suitable car floor heights now existing are:

Portland Streetcar – 350 mm. (13.8 inches)
Brussels Bombardier Flexity – 350 mm. (13.8 inches)
Boston Type 8 – 355 mm. (14 inches)
Nordhausen Combino – 300 mm. (11.8 inches)
Ansaldobreda Sirio – 350 mm. (13.8 inches)
Alstom Citadis – 350 mm. (13.8 inches)

Note - Some cars have the floor ramped downward at doorways to achieve a lower threshold height.

In addition to the need to match the height of the vehicle and the car floor, the relative width of the vehicles must be considered. For example, the Skoda-Inekon vehicles used by the Portland Streetcar line are 190 mm. (7.5 inches) narrower than the low floor light rail vehicles used in the same city. The light rail vehicles would not be able to fit past the streetcar route’s platforms. The streetcar would easily pass the light rail platforms, but the resulting wide stepping gap between the door sill and the platform edge would require an on-demand bridge plate to be deployed to satisfy ADA requirements. This situation has not arisen thus far in Portland because the streetcar vehicles do not run on the light rail tracks in revenue service.

The wheel-rail interface compatibilities will also need to be considered. At present only one city, Portland, has both LRT and Circulator type systems in operation, however no joint track use occurs in revenue service, so the issue of platform compatibility has not arisen, and both wheel-rail and power supply compatibilities have been accomplished. Since Portland Streetcar has a relatively generous minimum radius of 18 m. (59 ft.), wheel-rail compatibility has been easily obtained by using the LRT wheel profile on the Light Rail Circulator System cars. Also, the Portland LRT cars can be considered as having a Light Rail Circulator System wheel profile, as grooved rail is used on paved track. In cases where the existing LRT has been built to railroad standards of wheel and track, existing tangent track will not present any problems, but curves and special work may need careful analysis to determine if any problem areas exist, followed by deciding how to deal with them.