Considerations for Installing Special Trackwork on Vertical Gradients

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INTRODUCTION

Turnouts and crossovers are used to diverge or switch trains from one track to another. The most critical components are the point of switch (PS) and the frog point, where the wheel transfer between tracks takes place. These areas are risk points for derailment if not properly designed and maintained. The curved switch point on the turnout side is subject to high lateral forces transferred from the wheel negotiating the turnout curve at the point of entry. For Light Rail Transit (LRT) passenger safety and riding comfort, it is imperative that these critical components be fabricated with extremely tight tolerances.

Other than the practical and fabrication limitations, it is also essential for the designer to recognize that trackwork/alignment design is more than just a plan-and-profile design issue. The critical fourth dimension is the operating speed, which is a function of centrifugal force and vehicle characteristics, and it must also be taken into consideration in the design. This is particularly crucial on the turnout curve where the closure rail and stock rail are designed without inward rail cant bringing the resultant eccentric force closer to the rail centerline (refer to Section 4.4.3 for the illustration of Eccentric Wheel Load acting on the rail head).

In general, it is good practice to locate special trackwork on tangent track and without vertical curve wherever possible. However, in an urban light rail environment, track alignment is often restricted by system operational requirements, existing terrain, buildings, infrastructure, utilities, and the available right-of-way (ROW). As such, it is fairly common to see the installation of special trackwork on vertical gradients. This introduces a superelevation deficiency which if not assessed could compromise the integrity of the special trackwork components. The envelope of installing special trackwork on steep vertical gradients is being pushed to the limit such that operational and passenger safety could be potentially compromised. The paper discusses the considerations for installing special trackwork and is primarily based on the trackwork/alignment design experience derived from the Edmonton LRT System over the past 25 years.

PURPOSE

The most critical component of the trackwork system is special trackwork. Structurally, the switch point and frog point are the weakest track elements. They are subject to the highest load impacts resulting from wheel transfer. As a result, they are the locations that are most susceptible to train derailment.

Special trackwork design and track alignment design are closely inter-related and have a significant impact on both system efficiency and operational safety.

The intent of this discussion paper is to provide a general understanding and greater insight into the following trackwork/alignment design related issues:

- The track alignment design parameters that affect special trackwork design;
- The importance of track alignment optimization;
- The geometric integrity of turnouts, crossovers and double crossovers, specifically locating turnouts, crossovers and double crossovers on a vertical gradient and;
- The implication on operational safety for special trackwork located on a vertical gradient.

DEFINITIONS

Special trackwork is defined as trackwork structures, trackwork components or apparatus that are normally fabricated in whole or in part from regular rolled rail section. Typical examples include turnouts, crossovers, diamond crossings and sliding rail joints, etc (all dimensions are in mm).

For discussion in this paper, the term “special trackwork” specifically refers to turnouts, crossovers or double crossovers.

1. Turnouts:
   Turnouts permit two tracks to merge. The following is a typical No. 8 tangential turnout geometry used in the Edmonton LRT System.

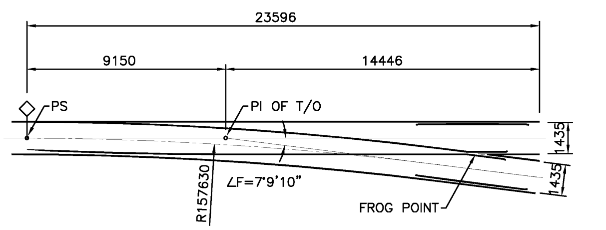

Figure 1 – Typical No. 8 Turnout with Tangential Geometry

2. Crossovers:
   Crossovers comprise two turnouts. They permit trains to switch from one track to another.

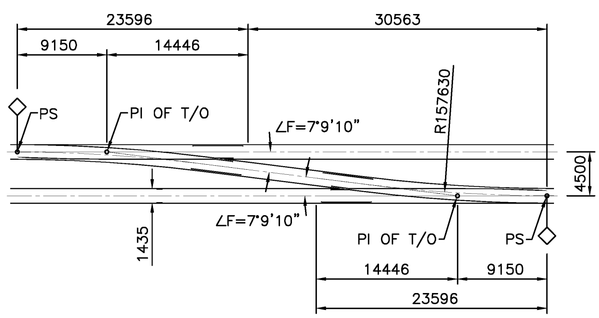

Figure 2 – Typical No. 8 Crossover

3. Double Crossovers (or scissors crossovers):
Double crossovers comprise four turnouts and a diamond. Double crossovers are mainly used in locations where there is a space or geometric restrictions.

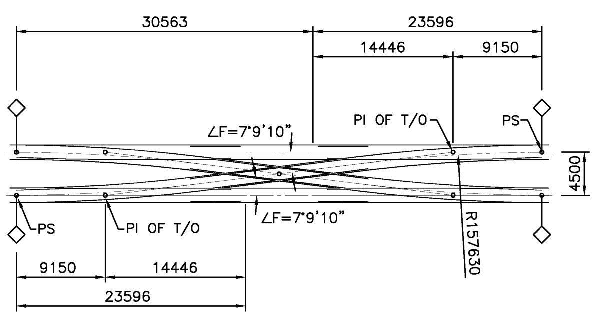

Figure 3 – Typical No. 8 Double Crossover

4. Sliding Rail Joints:
   Sliding rail joints are split rail components similar to switches, fabricated from a standard running rail section. The rails are allowed to slide relative to each other and are held in place to maintain the rail gauge by baseplates incorporated with lateral and/or vertical bracing.
   Sliding rail joints are normally installed on bridge abutments to relieve longitudinal rail stresses resulting from thermal movement of the bridge structure.

TRACKWORK/ALIGNMENT INTER-RELATED ISSUES

Special Trackwork Fabrication

Special Trackwork Design and Turnout Geometry

The initial phase of the Edmonton LRT System was built along a shared ROW with Canadian National (CN) Rail in northeast Edmonton. The system was opened for revenue service in April 1978. The trackwork system was primarily based on the heavy rail system constructed to CN Rail standards.

Special trackwork was fabricated using 100 lb. ARA-A rail in accordance with AREMA (formally AREA) Turnout Standards using heel blocks and tight turnout curve radii.

In the subsequent system extensions starting in 1984, Edmonton LRT adopted the philosophy that special trackwork should be based on European or UIC Standards with continuous flexible switch points fabricated from special rolled asymmetrical rail sections.

Special trackwork is fabricated with zero inward rail cant. Rails connecting to the regular trackage with 1:40 inward rail cant are transitioned, allowing the connecting rail sections to twist in natural form, and supported by ties or direct fixation fasteners utilizing either variable canted rail seats or shims. In comparison to regular trackage, the eccentric wheel load acting on the rail head through the special trackwork will be further away from the rail centerline (refer to Section 4.4.3, Eccentric Wheel Load). Subsequently, the lateral forces contributing to the rail bending and tilting in special trackwork are higher.

The fundamental difference between the AREMA and UIC special trackwork standards is that all rail sections within the UIC turnout (with the exception of insulated joint locations for train signaling) are continuously welded or forged. Also, in UIC turnouts, the rigid frog is a fully cast or a single welded block to eliminate rail joints on the frog component. The only gaps in the rigid frog component are the flangeway gaps at the wheel transfer points. The elimination of bolted rail joints helps to minimize the wheel transfer impact through the frog point and also reduces noise and vibration generated from the rail-wheel interfaces.

Since UIC Turnout Standards eliminate the bolted joint at the heel block, the special trackwork designer is able to incorporate tangential turnout geometry with longer lead distances and larger turnout curve radii. This reduces the wheel set's angle of attack at the turnout entry point. Consequently it reduces the maintenance requirements for switches, improves passenger riding comfort and allows increased train speeds through the diverging track.

UIC turnouts are designed and manufactured in accordance with the stipulated turnout radii, gauge tolerances and the groove (i.e. flangeway) dimensions by considering rail-wheel interfaces and the track-train interface dynamics as follows:

- Wheel profile and coning – Edmonton LRT uses an AAR wheel for its maintenance equipment and a LRV wheel for passenger carrying vehicle;
- Wheel back-to-back distance to determine the amount of wheel play and the appropriate flangeway gap;
- Number of axles, axle spacing and wheel spacing to determine the safe passing of the wheel at the frog point and the minimum frog spacing in the crossover configuration (refer to Section 4.3.3);
- Curve-passing behavior of the rolling stock in service to address the switch entry angle, flange nosing and lateral wheel slip on turnout curve.

Anti-creep Devices and Anchoring Assemblies

UIC Turnout Standards usually specify that anti-creep devices be incorporated at the interface between the rail base and the baseplate. Anti-creep devices are designed to prevent the relative movement of rail under thermal forces, vehicle dynamic traction/braking forces transferred from the wheels and the slippage of rails. This design feature is particularly important in the situation where the special trackwork is located on a slope.

Similarly, to prevent rail movement of an AREMA turnout installed on slopes, it is a good practice to provide anchoring devices for the stock rail or for the running rail at locations ahead of the switch points and beyond the limits of the turnout.

Track Supporting Structures

Ballasted Track

The Edmonton LRT System uses ballasted track for yard tracks, mainline surface tracks installed on grade and for special trackwork. A ballasted track structure is more economical and suitable for areas where space is adequate to perform track maintenance.

When ballasted tracks are installed on a vertical gradient greater than 3.5%, it becomes increasingly difficult to maintain the ballast in place. If appropriate measures are not installed, ballast and track will tend to move down-slope over time as a result of the dynamic vehicle loading and track vibration. This movement can be more prominent in areas where there is poor trackway drainage. Ballasted track on a steep vertical gradient is particularly vulnerable to wash-out conditions during flash flooding or unexpected heavy rain storms.

In conclusion, it is not a good practice to install special trackwork on a steep vertical gradient with ballasted track structure. Due to the design differences in LRT systems and their applied maintenance practices, the recommendations as described in Section 5.0 may be used as general guidance for trackwork/alignment design purposes.

Ballastless Track

Ballastless track structures are mainly used in areas where maintenance access is difficult and available space is an issue. Edmonton LRT uses ballastless track structures in their shop, tunnels and grade separation structures. Ballastless track can be installed to meet the tight trackwork tolerances of LRT system and performs well in holding track geometry under high stress conditions imposed by severe temperature extremes. From a safety perspective, its use is more suitable when installing special trackwork on vertical gradients greater than 1.5%.

Despite its higher cost and more rigid construction requirements, ballastless track has been proven to be very effective in reducing track maintenance costs. Edmonton LRT's concrete plinth system with direct fixation fasteners has performed flawlessly since revenue service began in 1992 for the South LRT Extension from Downtown to University Station.

The use of ballastless track structure is very much dependent on the cost-benefit consideration, the influence of trackway element design and maintenance practices. The preferences for using ballastless track structures will vary from LRT system to LRT system and should be evaluated on a case by case basis.

Track Alignment Design Controls and Constraints

Operation Requirements

Prior to the design layout of special trackwork, the intent of the special trackwork operation requirements must be defined. It is important to determine whether the special trackwork is intended to be used occasionally as emergency switching or as part of the normal mainline operation. This will help to select the appropriate turnout size based on the desirable turnout speed and to determine the operational efficiency of the system.

In a situation where physical or track geometric restrictions exist, the operating speed of train movements through the special trackwork should be evaluated in order to validate the overall system operational efficiency. If necessary, speed restrictions may have to be imposed on the motorman through the special trackwork. It is extremely critical to ensure that train movements through the double crossover, particularly if installed on grade, are within the acceptable safe speeds.

Effects of Alignment Controls on Special Trackwork

The track centerline and the top of low rail (TOR) are the references for constructing all the trackway elements and system infrastructure components. The linear nature of track alignment and stringent trackwork construction tolerances of a LRT track system warrant the establishment of a survey control network so that every LRT infrastructure component designer can correlate the designs on the basis of the track alignment.

In linear alignment design, a localized coordinate system with x and y is normally established as the control network to facilitate the horizontal alignment design. The vertical elevation, z for each and every coordinate point is referenced back to an established network's common datum for the design of the vertical alignment.

However, it is important to recognize that plane coordinates are points on the surface of the earth, which is not a level surface that provides true ground references. Depending on the geographic location of the work, it may be necessary to convert the ellipsoidal surface of the earth in a grid coordinate system (commonly referred to as sea level) to a plane coordinate system that eliminates any distortion. This small amount of distortion in the coordinate system may have an impact on the design layout versus the actual construction layout of special trackwork and should be verified by the trackwork/alignment designer. The Edmonton LRT's Survey Control Network is typically based on the Alberta Survey Control grid which uses sea level datum and 3° Transverse Mercator Projection. Furthermore, this alignment design approach using a coordinate system of x, y and z, does not recognize the linear difference in length due to changes in vertical elevations. Special trackwork geometry and configuration are normally designed by the trackwork/alignment designer according to the plan view using the established coordinate system. But special trackwork is fabricated and assembled on a flat surface in the factory to true ground distances.

For the installation of special trackwork on a vertical gradient, it is important to make a length adjustment to compensate for the steep vertical gradient. This ensures that the integrity of special trackwork geometry is maintained in accordance with the special trackwork configuration during construction. If necessary, the designer should also make coordinate adjustments of the key turnout reference elements, such as point of switch (PS) and theoretical turnout intersection point (PI of T/O) for construction layout purposes. These adjustments are necessary so that the special trackwork configuration does not end up in a forced-to-fit situation (refer to Section 4.5.1, Effects on Turnout Layout Length on 6% Grade). Special trackwork installed in a forced-to-fit condition will introduce internal rail stresses and could possibly alter the fittings of the turnout components.

Effects of Track Separation, Vehicle Dimensions and Rail-Wheel Interface on Special Trackwork

Track separation limits the spacing between turnouts and subsequently limits the overlapping distance of turnout frogs and the diamond of the double crossover. The angle of the diamond crossing, frog to frog spacing and the physical vehicle dimensions such as truck-to-truck spacing and the vehicle wheel base will have a significant influence on the safe passing of wheels over the unrestrained gap between the theoretical point and the frog point at the gauge line level. The following figures obtained from the Edmonton North LRT Project demonstrate the analyses of wheel/rail interfaces at the frog and the diamond crossing to ensure a safe passing of the wheels (all dimensions are in mm):

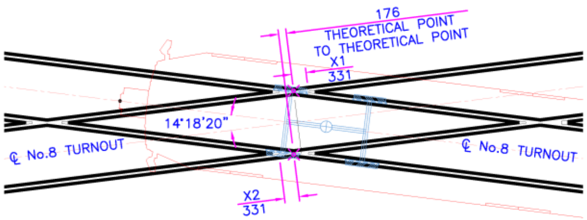

Figure 4 – Wheel/Rail Interface at No. 8 Diamond Crossing

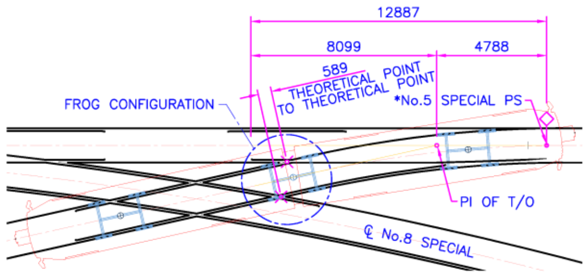

Figure 5 – Turnout Frog/Diamond Configuration

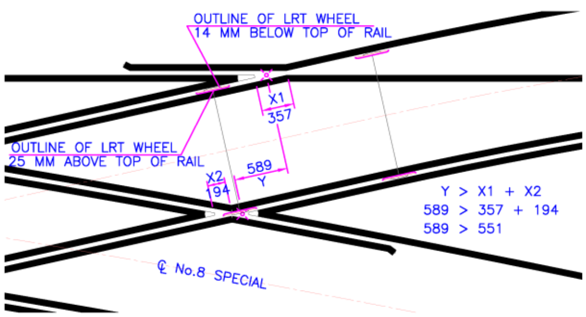

Figure 6 – Details of Wheel/Rail Interface at Turnout Frog/DiamondCrossing

To guarantee a safe wheel transfer over the unrestrained “gap”, the frog point overlapping distance must be sufficient to avoid wheels of the same wheel set from crossing the “gap” at the same time (refer to Figure 6, the theoretical point offset distance Y should be greater than the sum of X1 + X2). In the case of a diamond crossing at the two middle frogs as shown in Figure 4, where the theoretical offset point distance Y is 176 mm which is less than the sum of X1 + X2 of 662 mm, a provision of wing rails higher than the top of running rail are required to guide the wheel safely across the unrestrained “gap” onto the opposite frog.

Consequently, the special trackwork configuration whether it is located flat at-grade or on a steep vertical gradient, should all be assessed in details based on the following criteria:

1. Turnout size – the selection of turnout size is governed by the location, track separation, system operational requirements and operating speed;
2. Track Separation – the special trackwork configuration is restricted by the track separation, which limits the operating speed through the crossover;
3. The design vehicle truck-to-truck spacing – the crossover track must have sufficient tangent distance to accommodate the front wheel of the leading truck and the back wheel of the trailing truck in order to avoid the scenario that the trucks travel in a reverse direction between frogs;
4. The wheel base spacing (i.e. center of wheel to wheel of a given truck for the system) – with rigid frog design, the wheel is transferring under unconstrained condition. It is crucial that wheels of the same wheel set are not crossing the unrestrained “gap” of two middle frogs of a diamond at the same time.

This detailed assessment of the special trackwork configuration is absolutely essential in optimizing the crossover or double crossover location and to ensure that there is sufficient frog overlapping distance between the turnout frogs and/or the frog at the diamond for the safe passing of wheels. In general, the turnout size should be as large as possible within the physical and track geometric constraints.

Centrifugal Force Effect and Track Alignment Optimization

Lateral Phenomena

Turnout speed is based on theoretical centrifugal force (which is a function of V^2/R, where V is the speed and R is the curve radius) and the allowable unbalanced superelevation, E_u on curve for a given system. As mentioned earlier, track design considerations are not only three dimensional (i.e. x, y and z), but there is also a fourth dimension V, the speed to be considered.

For example, even on a regular mainline track design, the trackwork/alignment for LRT systems must be optimized based on the vehicle performance (i.e. acceleration and braking on different vertical gradients) and the maximum allowable unbalanced speed, V_u on curved tracks (as described in the Section 4.4.2 below). Consideration should also be given to the following:

- The possibility of bi-directional train movements on single track operation;
- Appropriate actual superelevation and track maintenance related issues.

Allowable Unbalanced Speed

Most LRT operating systems are either equipped with automatic train control (i.e. the Vancouver SkyTrain driverless system) or a conventional central traffic control (CTC) (i.e. with trains operated by a motorman). Trains that are operated by a motorman such as Edmonton LRT are likely to operate at different speeds on the same section of track. The question of what is considered as safe and comfortable operating speed through curved tracks is very much system dependent and can vary in accordance with track-train dynamics, rail-wheel interfaces, the type of trackwork system used and track conditions. These fundamentals of track-train dynamics and rail-wheel interfaces have been described in great detail by Dr. William W. Hay in Railroad Engineering, Second Edition 1982.

To accommodate the fact that motormen can operate trains at a wide range of speeds, it is generally accepted in design practice to include a certain amount of artificial superelevation (i.e. unbalanced superelevation, E_u) on top of the actual superelevation, E_a counteracting the centrifugal force to calculate a safe comfortable speed.

The allowable unbalanced speed for each individual system is based on the combination of acceptable unbalanced superelevation, E_u and actual superelevation, E_a, and is derived from the centrifugal force formula as follows:

$V_u = \sqrt{[((Ea + E_u) \times R) / 11.83]}$
Where,
V_u = Allowable unbalanced speed (in Km/hr)
R = Radius of curve (in m)
E_a = Actual superelevation in the equilibrium stage with resultant force acting on the rail heads (in mm)
E_u = Allowable unbalanced superelevation (in mm)

Note:

1. The acceptable E_u varies in different rail systems due to the inherent number of factors which contributes to the stability of the track-train dynamics. It is an arbitrary number based on experience and observation for the system that the system operator is comfortable with. The intent is to create a more comfortable ride by moving the vehicle outward at an acceptable safe speed that is greater than the balanced speed. A train travelling below the balanced speed will tend to slide to the inside curve and ride on the low rail.
2. For the Edmonton LRT System, the maximum allowable unbalanced superelevation, E_u is 100 mm.
3. To prevent excessive operating speeds and minimize the potential contravention in operating procedure, the Edmonton LRT relies on a speed enforcement system that incorporates wayside speed check magnets to trigger the LRV's automatic train braking system.

1.1.1 Eccentric Wheel Load

An eccentric wheel load is caused by the contact point of rail/wheel, which is not directly centered on the rail head as illustrated in the Figure below.

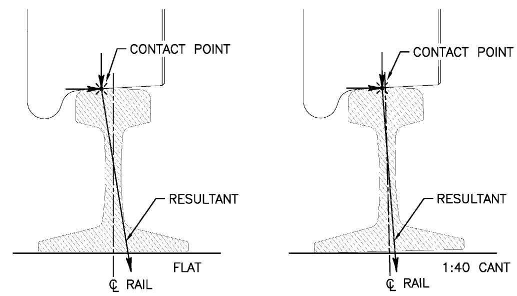

Figure 7 – Eccentric Wheel Load Exerted on Rail Head

The eccentric wheel load and wheel coning contribute to the lateral forces or outward thrust on the rail head. The incorporation of inward rail cant helps to reduce tilting and the bending moment, and thereby improves the stability of the track-train dynamics.

1.1.2 Inward Rail Cant

For standard track, there is an inward rail cant incorporated in the rail seat of the baseplates or fasteners. The inward rail cant helps to bring the resulting eccentric force exerted on the rail closer to the rail centerline. This promotes a better rail stability by resisting tilting and rotating actions from the lateral forces.

However, there is no inward rail cant incorporated in the special trackwork baseplates. The centrifugal force transferred to the gauge point of the rail head, compounded with a high center of gravity of a fully loaded train, will be substantially higher in the special trackwork in comparison to a standard track on a curve with an inward rail cant.

In addition, switch point and frog point are structurally the weak elements where lateral forces are usually at a maximum. Excessive operating speed through the crossover tracks will increase the risk of train derailment at the switch when special trackwork is installed on a vertical gradient.

1.2 Induced Superelevation Effect

1.2.1 Analysis on induced Superelevation Effect on Turnout at 6% Grade

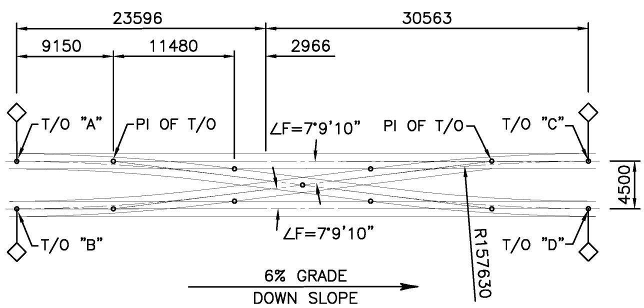

Figure 8 - Double crossover Schematic Plan

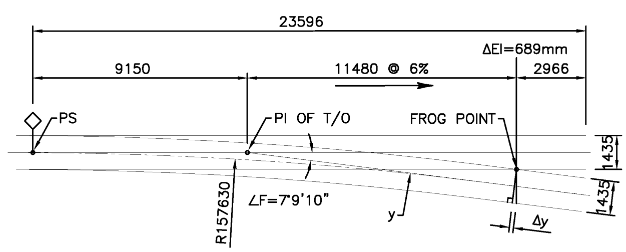

Figure 9 - T/O "A" Schematic Plan

y = 11480 / Cos ∠F = 11570 mm (along the centerline on the turnout side)
At 6% Grade, $\Delta El = 11480 \times 6 / 100 = 689$ mm (change of elevation from PI to the theoretical frog point)
Turnout Diverging Grade = $\Delta El / y = 689 / 11570 \times 100 =$ 5.955%

$\tan \angle F = \Delta y / 1505$

$\Delta y = 1505 \tan \angle F = 189$ mm

Therefore, the difference in cross level between inside and outside rail on turnout curve at the theoretical frog point for a Grade of 6%:
= 189 mm x 5.955% = 11.3 mm

By proportion in the difference in grade:
For a Grade of 3%, the cross level difference is 5.6 mm
For a Grade of 1.5%, the cross level difference is 2.8 mm

1.2.2 Impacts on Diverging Track:

1. The net effect on Turnouts "C" and "D" (see Figure 8) constructed at the bottom end of a 6% grade is a positive superelevation of 11.3 mm introduced on the diverging track.
2. For a single turnout constructed at the down-slope end of a 6% grade, the difference in cross level can be adjusted in accordance to the rate of change (1 mm in 2 m or in a distance of 22 m). The cross level must be maintained the same across the track before any reverse horizontal curve can be introduced in the alignment design.
3. However, where the turnout is constructed on the up-slope end of a 6% grade, (see Turnout "A" or "B" in Figure 8), the change in cross level is exactly in the reverse situation in comparison to Turnout "C" and "D". A negative superelevation of 11.3 mm will be introduced on the diverging train movement. There is not enough tangent distance between turnouts to run off the difference in cross level. This will create an undesirable operational condition for wheel transfer at the nose of the frog. There will be a tendency for the wheel to slide towards the lower rail and bear against the nose of the frog. The normal deterioration of the track surface, combined with any imperfection in the installation or manufacturing of the frog will compound the effect of the negative superelevation on the diverging track. This could result in the diverging track becoming operationally unsafe.

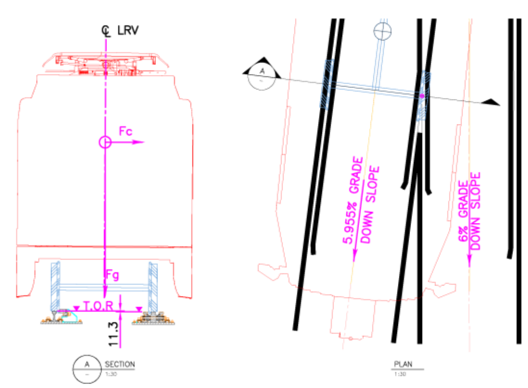

Figure 10 - Section of Vehicle through Diverging Track of T/O "A" on Negative Plane

4. For a double crossover situation, the frogs of the turnouts and the diamond are aligned in close proximity to each other. In the diverging train movement, the wheel set will have to transfer

over six frogs. The unsafe condition noted above is consequently further compounded.

1.3 Special Trackwork Installation and Constructability

1.3.1 Effect on Turnout Layout Length at 6% Grade

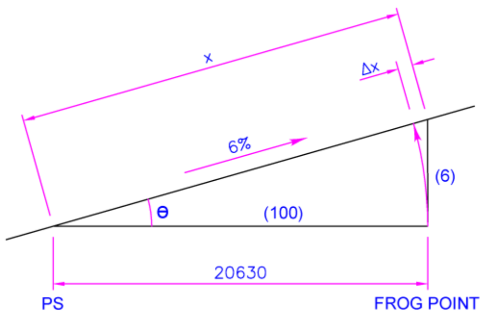

Figure 11 – Schematic Profile of Turnout on 6% Plane

$\text{Tan } \theta = 6 / 100$
$\theta = \text{Tan}^{-1} (6 / 100) = 3.4336°$
$\text{Cos } \theta = 20630 / x$
$x = 20630 / \text{Cos } \theta = 20667$
$\Delta x = 20667 - 20630 = 37 \text{ mm}$

1.3.2 Impacts on Construction Layout for Turnout on Grade:

- The location of special trackwork is normally designed and laid out in accordance with a coordinate system. The coordinate system only accounts for information on the plan view (i.e. horizontal plane at 0 % grade).
- Δx as calculated in Section 4.6.1 is the difference in the physical layout length of turnout at 6% grade.
- The only practical reference point for a layout of turnout is at the PS. When the trackwork contractor uses the PS to layout the turnout on a 6% grade, he will be approximately 37 mm short in the horizontal plane at the point of frog. If direct fixation is to be installed, the second pour concrete layout must also be consistent on the same plane.
- The difference in layout length must be adjusted otherwise there will be a misalignment in the turnout components. This is particularly important in the case of crossover and double crossover.

1.3.3 Installation of Trackwork Supporting Structures

Based on experience and discussions with trackwork contractors, installing a ballasted track structure on a steep vertical gradient for special trackwork is not much different than installing regular ballasted track. However, the concern is the effort required in retaining the ballast and maintaining the integrity of the track geometry.

In contrast to ballasted track, it is more difficult to construct a ballastless track structure on a steep vertical gradient. Placing concrete to adhere to the tight direct fixation tolerances necessary for installing special trackwork on vertical gradients requires breaking up the precision second pour into smaller blocks. Notwithstanding, concerted effort is required to prevent freshly poured concrete from flowing down the slope. The concrete mix design requires a low slump and a fast setting mix formula. Trackwork contractors have also expressed difficulty in grinding the second pour concrete to consistently meet the design vertical gradient for the installation of special trackwork.

1.4 Track-Train Dynamics

1.4.1 Vehicle Performance, Vehicle Traction/ Braking and Down-Slope Momentum Effects

Vehicle acceleration and deceleration performance is a critical part of the track alignment design methodology. This methodology assesses the attainable speed and stopping distance of a vehicle travelling on different gradients. This will have a direct impact on the curve design and/or the safe diverging turnout speed through special trackwork (i.e. the amount of superelevation to properly counteract the centrifugal force exerted on the running rail), track maintenance and passenger riding comfort.

Trains travelling on a down-slope momentum on a steep vertical gradient will require substantial dynamic braking effort to adhere to the restricted operating speed zoning. Likewise, trains travelling up-slope on a steep vertical gradient will require more traction effort. The Edmonton LRT vehicle fleet comprises the older Duewag U2 LRVs and the new SD 160 LRVs. To accommodate vertical gradients of up to an absolute maximum grade of 6.7%, the disc brakes of the center truck for all Duewag U2 LRVs were retrofitted to provide more braking capacity under the crush load condition.

In addition, the axial rail forces due to the increase in traction and braking effort will increase the possibility of rail creep on slope. It is critical to select the appropriate track supporting structures that have the ability to restrain the track movement by taking the severity of the vertical gradient into consideration. Track movement on slopes can alter the integrity of the trackwork/alignment geometry. This becomes more of an issue if the train operation involves a diverging train movement through a double crossover on the slope. Other than the fact that there is also an inherent negative plane induced on the turnout curve on slopes, the train will tend to ride on the down-slope side of the rail through crossover movement. Consequently, there is a greater tendency for the wheel to impact on the switch points and frog points.

To protect against excessive speed that could cause train derailment, it may be necessary to fully guard the crossover tracks to restrain high speed train movements.

1.5 Climate and Maintenance Considerations

Trackwork infrastructure that is subjected to temperature extremes can significantly affect the operation of equipment such as switches, electrical and mechanical systems. The variation of extreme temperatures in a cold climate region also creates tremendous internal rail stresses for continuously welded rail. A wide range of temperatures has to be considered in the design of trackwork. Trackwork systems in cold climate regions must be designed to resist rail expansion and contraction in order to prevent the rail from buckling in the summer and “rail breaks” in the winter. The trackwork system for the Edmonton LRT is designed for a temperature range of +40° C to -40° C with an installation neutral temperature of +18° C to +22° C. A major train derailment concern for transit systems located in a cold climate region is that the rail will pull apart and create a gap in the rail.

Where special trackwork is installed in more severe climate conditions and on vertical grades, more regular maintenance effort will be required in switches to maintain safe operations. Typically, snow removal and ice build-up at switch points, sanding and track/wheel inspections are major maintenance concerns for the rail system operators during the winter months.

In the City of Edmonton, sand and salt are frequently spread on the roads to improve the road conditions. Sand is also discharged from the Light Rail Vehicles (LRVs) onto the tracks to improve vehicle braking/traction ability. If special trackwork is installed too close to a roadway or station, sand and salt from the roadway during winter operations can be splashed and deposited on switches and switch machine. This contributes to equipment corrosion problems due to the potential stray current leakage; it also hinders the operation of switches.

Furthermore, winter conditions will also impair the vehicle braking/traction ability on slope. Under icy conditions, vehicles can slip and slide when negotiating the diverging train movement through the tight turnout curve of special trackwork installed on steep vertical gradients. The increase in lateral friction between the wheel flange and the gauge face of the switch rail due to vehicle slip and slide motions could increase the tendency of the wheel to climb at the switches. Coupled with the high center of gravity of LRV, the induced negative superelevation on diverging track as described in Section 4.6 and possible ice built-up at switches, the risk of potential train derailment will be substantially increased.

1.6 Implications on Operational Safety for Locating Special Trackwork on Slope

Based on the design grade and the cross level difference between the inside and outside rail, the turnout curve on the up-slope end will have physical negative plane. Conversely, the turnout curve on the down-slope end will have an induced positive plane.

In the case of a crossover installed on a vertical gradient, the train going down-slope on a physical negative plane will be experiencing centrifugal force. The train will be constantly riding on the rail on the lower side of the slope or on the curved closure rail. The wheel flange will have a tendency to hit the switch point at the switch entry and the frog point during the wheel transferring at the frog.

This situation will repeat itself on a double crossover set-up on a vertical gradient, except the impacts are further compounded with the presence of a diamond with four frogs. In addition, as the rail components of special trackwork are not fabricated with an inward rail cant, the down-slope train movement momentum through the crossover track and the train dynamic braking will exert a higher lateral force on the rail head. This could have a serious implication on operational safety, unless a slow order is imposed on the motorman.

Depending on the severity of the gradient and track support structure, the special trackwork may have to be fully guarded with guard rail through the turnout curves and the diamond in order to mitigate the potential for a train derailment.

2.0 CONCLUSIONS

There are numerous system specific factors that could influence the decision on special trackwork configuration and its design location. The following recommendations and criteria are based on the design experience derived from the Edmonton LRT System. They should only be used as a general guidance for installing special trackwork on vertical gradients.

1. Criteria for locating special trackwork on vertical gradients are system specific. The system operator should determine the criteria based on acceptable cross level difference on the diverging track on special trackwork, and the assessment of vehicle design, trackwork /alignment design, special trackwork design and track supporting structure.
2. Special Trackwork should be located on tangent track with 0% grade whenever possible.
3. If it is necessary to locate special trackwork on grade due to track geometric restrictions, the design grade should be as flat as possible.
4. The track support structure for special trackwork located on a vertical gradient greater than 1.5% should consider the use of a direct fixation system to restrain movements contributed by thermal and lateral load phenomena.
5. Special trackwork should have built-in anti-creep devices or be incorporated with a rail anchoring system in the track design to mitigate rail axial load that could change the turnout geometry due to thermal and vehicle dynamic braking.
6. The absolute maximum vertical grade for a turnout located at the down-slope end for a diverging train movement should not exceed 6%. No reverse horizontal curve should be introduced until the cross level deficiency has been run off in accordance with an acceptable rate of change. The preferred rate of change for adjusting cross level is no more than 1 mm in 2 m.
7. A turnout located at the up-slope end of a 6% grade for diverging train movement is not recommended. A negative plane introduced by the 6% grade will create a tendency for the wheel to slide towards the lower rail and bear against the point of frog during a diverging train movement.
8. A crossover located on a vertical gradient higher than 1.5% is not recommended. 1.5% grade will introduce a cross level deficiency of 2.8 mm, which is approximately equal to the cross level construction tolerance of 2 mm. A crossover located on a grade greater than 1.5% could result in the diverging track becoming operationally unsafe.

3.0 REFERENCE CRITERIA

The following reference criteria from the Edmonton LRT System should only be used as a general guidance:

Classification	Direct Fixation	Ballasted Track
MAINLINE		
Turnout:		
With diverging track running uphill	Desirable Max. 2.0% Abs. Max. 3.0%	Desirable Max. 1.5% Abs. Max. 2.5%
With diverging track running downhill	Abs. Max. 2.0%	Abs. Max. 1.5%
Crossover:	Desirable Max. 1.0% Abs. Max. 1.5%	Desirable Max. 0.5% Abs. Max. 1.0%
Double Crossover:	Abs. Max. 0.5%	Abs. Max. 0.3%
YARD		
Turnout:	Not applicable	Desirable Max. 2.0%
Crossover:	Not applicable	Desirable Max. 0.5%

Note: Speed restrictions are required if grades exceed these limits.

4.0 STANDARDS AND REFERENCES

1. City of Edmonton LRT Design Guidelines
2. TCRP 57, Track Design Handbook for Light Rail Transit by Transportation Research Board
3. TCRP Project D-5 Design Guidelines
4. Railroad Engineering by William W. Hay
5. American Railway Engineering and Maintenance-of-Way Association (AREMA) – Manual for Railway Engineering
6. RTD LRT Design Guidelines and Criteria, Light Rail Design Guidelines, Section 4 - Trackwork
7. Basic Designs of Switches and Crossings by Vereinigte Weichenbau GmbH

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