Region of Waterloo

Stage 1 Light Rail Transit Project

Design and Construction Performance Output Specifications

Article 11

Track Alignment and Wayside Clearances

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ARTICLE 11 TRACK ALIGNMENT AND WAYSIDE CLEARANCES

11.1 Alignment - General

(a) Introduction

The purpose of this Article and the alignment drawings provided to Project Co is to provide design guidelines for the design of the track alignment and wayside clearance work. Project Co's solution to track alignment and wayside clearance design work shall expand on these guidelines. Project Co shall prepare a Basis of Design Report – Alignment and Wayside Clearances and the revised alignment drawings, which explains Project Co's approach to track alignment and wayside clearance design work in greater detail and in a site specific manner as part of Project Co's Submission. The presentation of specific track alignment and wayside clearance design requirements within this Article must not be construed to limit or modify in any way Project Co's responsibility to provide a holistic, comprehensive, and fully functional solutions to all track alignment and wayside clearance conditions. The Basis of Design Report – Alignment and Wayside Clearances shall address every aspect of the track alignment and wayside clearance design requirements cited in this Article. The rationale for all deviations or variances from any requirement cited this Article must be fully described in the Basis of Design Report – Alignment and Wayside Clearances, which is referred to within this Article as the Basis of Design Report.

(b) Design Methodology

(i) Specific design values and instructions in this document will govern track alignment design. Criteria not specifically described in this document shall follow the methodology and criteria of Transit Cooperative Research Program (TCRP) Report 155 - Track Design Handbook for Light Rail Transit. It is recognized the alignment for an LRT system, especially in an urban environment, will encounter situations, which require some deviation from the strict adherence to the alignment requirements cited herein. To develop a viable alignment requires the use of sound engineering judgment. Since the track alignment establishes the basis of design for other disciplines, the preparation and updating of the Basis of Design Report is essential to successful interdisciplinary design coordination.

(ii) Other references sourced in the development of this document include:

A. AREMA Manual for Railway Engineering

B. CN – Engineering Specifications for Industrial Tracks

(iii) Project Co shall ensure the track alignment design is compatible with the design requirements of other systems that interface with the track such as the Overhead Contact System, the signaling system, the vehicle, etc. Project Co shall identify the design interfaces between track and the wayside and include these interfaces in the Systems Integration and Interface Management Plan.

(iv) Project Co shall coordinate with the vehicle supplier to ensure the alignment is fully compatible with the LRT car.

(v) Project Co shall coordinate its alignment design with the CN railroad to ensure compatibility with type of freight railroad service being provided along the Waterloo Spur, Huron Spur and King Street Grade Separation. Project Co shall finalize all the track connections with the CN for the relocation of the CN tracks along the Waterloo Spur, Huron Spur and King Street Grade Separation.

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(vi) Project Co's alignment and station location in their base technical submission shall generally adhere to the alignment and station location and station platform configuration as shown in the appendices to Schedule 15-2. Alignments that deviate from the main street, railroad, or utility corridors shall only be shown as an innovation. Stations with different configurations shall only be shown as an innovation. Failure to comply with the above requirements may result in a major contract compliance issue.

(c) Design Priorities

(i) Design criteria in this document have been developed based on the following design priorities, not necessarily listed in order of importance:

A. Safety including protection against derailment and having adequate wayside clearances.

B. Conformity with vehicle clearance envelope.

C. Ride quality

D. Minimizing alignments causing speed reduction, while maintaining a reasonable roadway cross-section.

E. Maintainability and performance of the track.

F. Compatibility with overhead contact system design.

G. Conformance with rail vehicle performance maintainability requirements

H. Integration into the existing road network and urban environment.

I Design that promotes trackway drainage and resistance to frost heaving.

(d) Design Goals

(i) Horizontal Alignment

A. In developing the most desirable horizontal alignment, consideration shall be given, but not limited to, the following factors:

1. Passenger comfort and convenience
2. Capital and operating costs
3. Maximizing train velocity and minimizing running times
4. Minimizing noise and vibration (squeal due to curved track)
5. Type of construction
6. Station location and spacing
7. Possible future extensions
8. Roadway interfaces with trackway
9. Soil conditions
10. Property and buildings, both existing and proposed
11. Safety
12. Utilities

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13. Vehicle capabilities

(ii) Vertical Alignment

A. In developing the most desirable vertical alignment, consideration shall be given, but not limited to, the following factors:

1. Horizontal alignment
2. Drainage
3. Vehicle capabilities
4. Adjacent structures
5. Integration into the existing roadway and urban topography

(iii) Curvature and Superelevation

A. Curvature and superelevation shall be coordinated with the actual operating speed with consideration given to train operator behavior and the acceleration and deceleration characteristics of the design vehicle.

B. Consideration shall be given to:

1. Vehicle performance
2. Location and types of special trackwork
3. Horizontal alignment
4. Vertical alignment
5. Passenger Comfort

(e) Use of a Minimum or Maximum Criterion

(i) Where specific numbers are given for limitations on grade, curvature, tangent lengths, spiral lengths, etc.; such limitations are not targets to be achieved, but limits to be avoided if at all practical. Project Co should in all cases strive to exceed the minimum requirements.

(ii) Desired, Acceptable and Absolute Values

A. Desired values described in this document are based on industry practices and passenger comfort. Designs shall meet or exceed desired values to provide a robust operating environment. Project Co shall to achieve desired targets where practical. Project Co shall clearly identify the design elements which do not meet the desired criteria values.

B. Acceptable values define a limit beyond which a tangible operating benefit is either gained or lost (e.g., Acceptable limits for curves may define the radius at which a restraining rail must be installed).

C. A Basis of Design Report shall clearly identify design elements which do not meet the Acceptable values; including a detailed explanation of what alternatives were considered; and why it was not possible to do better. The use of any parameter that does not meet the Acceptable threshold shall be considered conditional until accepted in writing by the Region.

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D. Absolute values are based on either safety considerations and/or have potential impacts in terms of track and vehicle maintenance costs, noise, wheel life and track life. Extensive use of absolute values can result in service problems and unacceptable maintenance costs. The use of an Absolute value must be fully justified in the Basis of Design Report.

E. Combinations of Absolute parameters (e.g. an Absolute minimum horizontal radius curve with an Absolute maximum gradient) shall be avoided wherever possible. Project Co shall avoid any combination of horizontal and vertical alignment or curvature which exceeds the limits established by the rail car supplier.

(f) Design Variances

(i) Design standards are set to achieve the design goals and priorities noted above. It is understood that constraints in individual locations may impede Project Co's ability to meet a particular alignment requirement.

(ii) Approved variances shall only apply to the specific location(s) requested. Project Co shall provide with each design submission a table summarizing all approved design variances. Project Co shall include a recommended design speed for all alignment configurations requiring a variance.

11.2 Baselines

(a) Overview

(i) A system of controls is necessary for alignment design and construction. The control system shall consist of the following components as required:

A. Survey Control Line

B. Reference Line / Track Centre Line

(b) Survey Control Line

(i) The Survey Control Line shall be established by control survey. All primary control monuments shall be visible from adjacent primary control monuments and located in areas that will not be disturbed by future construction. See Schedule 15-2 Article 2 for detailed survey related requirements.

(c) Reference Line

(i) The Reference Line is the centre-line of the north bound track when both tracks are parallel and centre-line of each track when the tracks are in separate corridors.

(ii) The Reference Line/track centre-line must be geometrically related to the Survey Control Line.

(iii) In most cases the track centre-line line will be used to show dimensions to the proposed Work to allow a ready review of clearance and dimensions to curbs, buildings OCS poles and other wayside elements.

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(d) Stationing

(i) The centre-line of track shall be stationed with a primary stationing point every 100 metre and minor stationing points every 20 metre. Stationing of key landmarks shall be identified on the design drawings including:

A. Horizontal cardinal points (i.e. Tangent to Spiral (TS), Spiral to Curve (SC), Curve to Spiral (CS), Spiral to Tangent (ST), Point of Curve (PC), Point of Tangent (PT, etc.)

B. Vertical cardinal points (i.e. Point of Vertical Curve (PVC), Point of Vertical Tangent (PVT), Point of Vertical Intersection (PVI) etc.)

C. Special trackwork points (i.e. Point of Switch (PS), Point of Intersection Turnout (PITO), etc.)

D. Ends of station platforms

E. Catenary Poles

F. Any other point of special interest such as the intersection of roadways and the critical points for clearance transition areas.

(ii) Wayside signs or "mile posts" are required to be installed along the Right of Way at even 250 metre intervals and every wayside element shall be identified by a station location number or equivalent numbering scheme to facilitate ongoing inspection and maintenance. OCS poles can be used for mile posts. All curves shall have a posted speed limit sign on the wayside suitable for use by train operators to control the speed of the train when in manual operation.

(e) Station Equations

(i) Where the track centre-line is realigned, a station equation showing "Back" and "Ahead" stationing shall be shown at a convenient "Ahead" station equation point past the realigned section. This is done to compensate for the different lengths of track centre-line and to maintain integrity of the established stationing past the realigned section. Station equations shall be used at the end of each curve (i.e. at a PT or ST).

(ii) At turnouts, the alignment stationing shall be measured through the point of intersection of the turnout. The station equation shall be made at the point of switch.

11.3 Horizontal Alignment Criteria

(a) General Requirements

(i) Horizontal alignments shall consist of horizontal tangents joined by combinations of one or more horizontal curves. Superelevation of track on horizontal curves shall be considered during horizontal alignment design.

(ii) Horizontal alignments shall be developed for all Track Centre Lines.

(iii) It is preferred the calculated values for spiral lengths, be rounded-up to the nearest full metre, and coordinated with the amount of actual superelevation wherever practical, to facilitate inspection of cross level conditions. It is also desirable to establish an alignment with radius rounded up to a full metre and to establish speed requirements to the nearest 5 km/h. Since LRT alignments in urban areas often prevent actual superelevation from

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being utilized, the following table provides a guide for Project Co in developing an alignment which achieves these goals when Ea = 0.

Design	**Radius**	**Length of Spiral**
Speed km/h	Metres	Metres
50	395	35
45	320	32
40	252	28
35	193	25
30	142	21
25	100	18
20	63	14
15	36	11
10	25	10

(b) Track Gauge

(i) Standard tangent Track Gauge is 1435.1 mm.

(ii) Project Co shall coordinate with the rail car supplier to determine if other track gauge requirements are necessary.

(c) Tangent Track and Other Minimum Spacing requirements

(i) The standard tangent track centre line spacing with overhead poles located between the LRT tracks is 4.27 metres. This spacing allows the alignment to negotiate most curves without the need to changing the track centres. The standard tangent track centre line spacing with overhead poles located between the LRT tracks shared with freight railroad is 5.2 metres. Where the tracks are significantly curved, track centre spacing will vary depending on the clearance requirements. CN standards for one track require 25.4 mm per degree of curve and 25.0 mm per 10.0 mm of superelevation. See Sections 11.5 (b) and 11.5 (c) for LRT clearance requirements.

(ii) Where curves or other conditions require a deviation from the standard track centres, adequate spacing from one track to another can be achieved by using:

A. Non-concentric curves,

B. Concentric curves with different length spirals at either end, or

C. Reverse curves

(iii) Where there are two or more tracks adjacent to each other and there are no OCS poles between the tracks, Project Co shall establish the track spacing on the wayside and vehicle clearance requirements cited Section 11.6 and as required by the freight railroad if applicable.

(iv) The design distance from the edge of platform to tangent track centre-line is 1.4 metre.

(v) Minimum tangent yard storage tracks spacing shall provide space between each tracks for the safety of workers in the yard areas and for a continuous serviceway on one side of each track to be utilized by maintenance staff and train operators.

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(vi) Nontangent track spacing may require adjustment to account for curvature and superelevation effects in conjunction with clearance requirements.

(d) Design Speed and Actual Operating Speed

(i) The alignment shall be designed to maximize speed. Speed restrictions may be necessary due to existing site features, curves, OCS limitations, special trackwork, urban environmental conditions, and other factors such as areas with approved alignment design variances. Speed restrictions, where required, should ideally be located near stations where vehicles, by necessity, are more likely to travel in a reduced speed mode. Design speed for every tangent and every curve shall be clearly shown on all Alignment Design Submissions. Project Co shall evaluate the sight distances where safe train operations are governed by the line of sight of the train operator and establish a design speed appropriate to any limitation on the train operator's line of sight. The supporting design calculations shall also be included in the updated Basis of Design Report for review with each alignment design submission. A speed plot for the entire alignment which compares the design speed for LRT trains to the actual operating speed determined by train simulations and/or VISSIM type of analyses shall also be produced by Project Co. In addition to the operating speed for the LRT trains, the speed plot shall also indicate the speed for freight railroad trains where applicable.

(ii) Project Co should strive to match design speed with the desired operating speed to the greatest extent reasonable including any anticipated speed reductions attributable to manual train operations. In Semi Exclusive Roadway Right of Way, the design speed should match the legal vehicular speed wherever possible. If there are areas, where Project Co has determined that the design speed may safely and reasonably exceed the legal adjacent vehicular speed; those areas shall be identified in the Basis of Design Report and are subject to acceptance by the Region. Likewise if there are areas where a safe and reasonable design speed is less than the legal adjacent vehicular speed those areas shall be identified in the Basis of Design Report and are also subject to acceptance by the Region.

(iii) Alignment design shall be coordinated by Project Co such that variances between the design speed and operating speed avoids negative superelevation.

(iv) Alignment areas shared with freight railroad must also consider that freight railroad service will generally operate at a much slower speed compared to LRT train service. Project Co must not superelevated the track for LRT speeds to an extent that it negatively impacts freight railroad train moments or wayside clearance conditions.

(e) Minimum Horizontal Tangent Lengths

(i) At Platforms

A. Tangent track is required through entire length of platform

B. DESIRED tangent beyond platform = 65 metre

C. ACCEPTABLE tangent beyond platform = 30 metre

D. ABSOLUTE minimum tangent beyond platform = 14 metre

(ii) Between Curves

A. DESIRED minimum tangent between curves = 65 metre

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B. ACCEPTABLE minimum tangent between curves = 30 metre

C. MAINLINE ABSOLUTE minimum tangent between curves = 14 metre

D. YARD ACCEPTABLE tangent distance between curves or turnout with curvature in same direction shall be coordinated with the car supplier; particularly in cases where rail cars are being pushed by another rail car or car mover.

E. YARD ACCEPTABLE tangent between reverse curves or turnout configurations with a reverse curve alignment should fall between 9-15 metre. However, Project Co shall confirm this distance requirement with the rail car supplier; particularly in cases where the rail cars are being pushed by another rail car or car mover

F. For reverse curves the ACCEPTABLE minimum tangent length (LT) between curves shall also conform to the greater of the criteria above or the following formula:

$LT = 0.57V$

Where:

V= speed in km/h

The ABSOLUTE minimum tangent between reverse curves and the associated speed shall be based on passenger comfort criteria; and Project Co shall consult the rail car supplier on the minimum distance.

(iii) At Special Trackwork

A. All Special Trackwork to be constructed on tangent track.

B. DESIRABLE minimum tangent ahead/beyond Special Trackwork = length of vehicle

C. ACCEPTABLE minimum tangent ahead/beyond Special Trackwork = 14 metre

D. The ABSOLUTE minimum tangent ahead/beyond Special Trackwork shall be as agreed to by the rail car supplier.

(f) Circular Curves

(i) Curve Definition

A. Circular curves shall be defined by the arc definition of curvature and specified by their radii in metres, measured from the centerline of track.

B. In addition to the LRT data for circular curves, Project Co shall also show information circular curves that include freight railroad operations in a format as required by the freight railroad.

(ii) Minimum Radius

A. DESIRED minimum mainline radius = 3000 metre.

B. ACCEPTABLE minimum mainline radius = 150 metre.

C. ABSOLUTE minimum radius = 25 metre.

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D. Minimum Radius for Freight Railroad shall as per CN – Engineering Specifications for Industrial Tracks or as agreed to with the CN railroad.

(iii) Minimum Length of Circular Curve

A. ACCEPTABLE minimum length of circular curve (LC) = 0.57V

B. ABSOLUTE minimum length of circular curve and associated design speed shall be determined by Project Co based on rail car characteristics and passenger comfort.

(g) Formula for Speed on Curves

(i) In the design of horizontal alignments, the allowable speed through curved sections shall be determined by passenger comfort as related to superelevation. Superelevation is defined as the height difference in millimetres between the top of the high (outer) rail and the top of the low (inner) rail and divided into the following elements:

$Eq = 11.83V^2/R = Ea + Eu$

Where:

Eq = total amount of superelevation applied to the outer rail required for equilibrium, in millimetres

Ea = actual superelevation to be constructed, in millimetres

Eu = unbalanced superelevation (the difference between the equilibrium superelevation and the actual superelevation), in millimetres

V = design speed, in km/h

R = radius, in metres

(h) Superelevation Criteria

(i) The goal of actual superelevation is to limit the amount of lateral acceleration - "a_L" - experienced by the passengers to some tolerable level. The following limits shall apply:

A. DESIRED Maximum: $a_L \leq 0.10$ g

B. ACCEPTABLE Maximum: $a_L = 0.10$ g

C. ABSOLUTE Maximum: $a_L = 0.12$ g

…where "g" is the acceleration rate of gravity, i.e. 9.81 m/s^2

(ii) Using the Acceptable Maximum lateral acceleration rate of 0.10 g as an example, the total allowable unbalanced superelevation felt by the passenger, including effects of vehicle lean toward the outside of the curve, dynamic train movements from wheel and track conditions, and rounded down to the nearest 5 mm is 150 mm. The angular lean of the vehicle toward the outside of the curve coupled with dynamic train movements is equivalent to about 75 mm of unbalance. Hence, the acceptable unbalanced superelevation available to Project Co's track designer is (150 mm – 75 mm) = 75 mm.

A. DESIRED Maximum E_u = 50 mm

B. ACCEPTABLE Maximum E_u = 75 mm

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C. ABSOLUTE Maximum E_u = the value determined by Project Co in consultation with the Rail Car Supplier, submitted as a design variance and accepted by the Region.

D. At turnouts, which are typically constructed without either actual superelevation or spirals, the design speed should be limited to a speed with an unbalanced superelevation that does not exceed 50 mm.

(iii) The upper limit on actual superelevation is limited depending on whether the track is embedded track, direct fixation track or ballasted track and the operating environment. The following shall apply:

A. Semi-Exclusive LRT Right-of-Way (ballasted track or direct fixation track):

1. PREFERRED Maximum Ea = 75 mm
2. ACCEPTABLE Maximum Ea = 100 mm
3. ABSOLUTE Maximum Ea = 150 mm

B. Semi-Exclusive Roadway Right-of-Way (embedded track located in the roadway median.)

1. PREFERRED Maximum Ea = 50 mm
2. ACCEPTABLE Maximum Ea = 75 mm
3. ABSOLUTE Maximum Ea = 100 mm

C. Semi-exclusive Roadway Right-of-Way (embedded track side running and at intersections)

1. PREFERRED Maximum: Ea = 0 mm
2. ACCEPTABLE Maximum: Ea = 30 mm (normal 2% cross-slope on the roadway pavement)

   Where necessary to maintain transverse drainage of the roadway surface, the design may include a deviation in track cross level up to 30 mm in tangent track. Although this will result in a negative unbalance condition, this is considered acceptable tradeoff to achieve appropriate drainage. However the preferred condition is to avoid such deviations in cross level. Note that where embedded track has a cross slope, the profile grade line will be below the roadway surface and that difference must be accounted for when considering the pavement design. Where necessary to maintain transverse drainage of the roadway surface in curves, up to 30 mm of negative superelevation is allowed. However, the preferred condition is to have a positive superelevation, as appropriate, to the curve and the operating speed. Instances of negative superelevation shall be extensively justified in the Basis of Design Report and be accounted for in the determination of both the unbalanced superelevation Eu and the operating speed.

3. ABSOLUTE Maximum: Maximum acceptable Ea is the value determined by Project Co in consultation with the Rail Car Supplier, submitted as a design variance and accepted by the Region.

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(iv) Other limitations, subject to approval of the rail car supplier, regardless of the type of track:

A. Where the horizontal radius is less than or equal to 150 meters, the ABSOLUTE Maximum Ea = 100 mm.

B. Where the horizontal radius is less than or equal to 75 metre, the ABSOLUTE Maximum Ea = 75 mm.

C. Where the horizontal radius is 25 metre, the ABSOLUTE Maximum Ea = 25 mm. For curves of horizontal radius between 25 and 75 metre, the ABSOLUTE Maximum Ea shall be interpolated between the values stipulated for those radii.

D. On any curve where the light rail vehicles might routinely be stopping, the ABSOLUTE Maximum Ea = 75 mm.

E. Tracks in the maintenance facility, storage yard, and other non-revenue tracks should typically exhibit no superelevation, but for high-traffic areas more than 10 meters from special trackwork may use up to 25 mm of superelevation, if beneficial.

F. It is preferred Eu not be introduced until after Ea has reached 15 mm. Thereafter, Ea and Eu shall be both increased linearly to their maximums.

G. In embedded track in Semi Exclusive Roadway Right-of-Way, the introduction of Ea shall generally follow the roadway requirements. In such cases, it is acceptable to not introduce any Ea until after ABSOLUTE Maximum Eu has been fully applied.

H. It is preferred that Ea shall be attained and reduced linearly throughout the full length of the spiral curve by raising the rail farthest from the curve centre, while maintaining the top of the inside rail at the vertical track profile. This is also the preferred method for embedded track however uniformly achieving the superelevation by simultaneously raising the outer rail and lowering the inner rail may be considered in special situations. Such methods shall be fully explained in the Basis of Design Report.

I. Superelevation shall be uniform through circular curves except for curves immediately adjacent to stations or where changes in the train speed will occur in a particular curve. In those cases, Ea and Eu shall be varied and optimized for the midpoint of an accelerating (or decelerating) two car train.

J. Ea shall be rounded to the nearest 5 mm increment.

K. Do not provide actual superelevation (Ea) where the alignment crosses a roadway intersection at grade, unless the proposed alignment improves track design speed without negatively impacting the profile of the intersecting roadway. Project Co can request that the Region grant an exception to this requirement; if the roadway is considered a minor roadway.

L. Superelevation runoff length shall be proportional to the magnitude of actual superelevation, and not less than the following (expressed in millimeters of track length per millimeter of superelevation):

1. DESIRED minimum runoff $\geq$ 1:500

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2. ACCEPTABLE minimum runoff ≥ 1:380

3. ABSOLUTE minimum runoff the value determined by Project Co in consultation with the Rail Car Supplier, submitted as a design variance and accepted by the Region.

M. The same criteria shall be used to determine the requisite transition lengths for other types of track twist, such as where embedded track transitions from zero cross-level to a condition where it is matching a 2% cross slope in the roadway movement.

(i) Length of Spirals

(i) Spiral transition curves shall be applied in every mainline curve wherever practical, including curves without actual superelevation.

(ii) Spiral curves are not required in maintenance facility storage yard and shop areas. However, they are preferred whenever possible so as to limit lateral forces and related maintenance issues.

(iii) The minimum length of spiral shall be determined by consideration of three conditions, any one of which might control. These conditions are:

A. Track Twist

B. Rate of change of lateral acceleration (AKA: "jerk rate")

C. Rotational acceleration

D. Whichever condition results in the longest minimum spiral length shall govern.

(iv) Track Twist:

A. The criteria for superelevation runoff length shall apply.

(v) Jerk Rate

A. The PREFERRED maximum jerk rate = 0.033 g/sec. Hence, if the lateral acceleration in the full body of the curve is limited to 0.10g; the spiral shall be traversed in a minimum of 3 seconds.

B. The ACCEPTABLE maximum jerk rate = 0.04 g/s which equates to a transverse time of 2.5 seconds

(vi) Rotational acceleration

A. The ACCEPTABLE maximum rate of rotation = 1.5 degrees per second of time.

(vii) Based on the above, the ACCEPTABLE minimum length of spiral, LS, to be provided using the greatest of the following three formulae:

$L_S = 0.38\ E_a$

$L_S = 0.009\ E_u V$

$L_S = 0.009\ E_a V$

Where:

L_S = spiral length, in metre

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V = design speed, in km/h

E_a = actual superelevation, in mm

E_u =unbalanced superelevation, in mm

(viii) ABSOLUTE minimum length of spiral, LS = 10 metre.

(ix) Wherever practical round-up the calculated length of spiral to the nearest metre and coordinate with the magnitude of actual superelevation to assist construction and inspection efforts.

(x) For simplicity of alignment calculation and construction, the centerline of horizontal track curves and the Reference Line should be concentric.

(xi) Where the track centres of these concentric horizontal curves are the same as the track centres of the approach and leaving tangents, it is preferred the spirals connecting the different curve radii be of different lengths, such that the spiral offsets are equal. Ensure the inside track spiral meets the minimum length requirements.

(xii) Where the track centres of these concentric horizontal curves are wider than the track centres of the approach and leaving tangents, it is preferred the spirals connecting the different curve radii be of different lengths such that the spiral offsets differ by the increase in track centres. Ensure the inside track spiral meets the minimum length requirements.

(xiii) In special cases, it may not be possible to include a spiral on one or both ends of a curve. This is particularly the situation encountered when locating stations in an urban environment or curves with a small intersecting angle. In those cases, Project Co may reduce the length of the spiral or eliminate the spiral with an appropriate adjustment in the design speed. The design speed through any curve without a spiral shall be limited to the speed calculated using Eu = 25 mm. All such situations must be included in the Basis of Design Report.

(j) Compound Circular Curves

(i) Compound circular curves consist of two or more simple circular curves that turn in the same direction and join at a common tangent point, known as the point of compound curvature (PCC).

(ii) Compound circular curves are preferred over curves separated by a short tangent (“broken-back” curves).

(iii) Unequal superelevation (either Ea or Eu) between compound curves shall be developed linearly over the full length of a spiral transition.

(k) Reverse Curves

(i) Reverse curves consist of two adjacent simple or spiraled circular curves that turn in opposite directions with a tangent section less than a car length or in special cases join at a common tangent, known as the Point of Reverse Curve (PRC). Double crossovers are considered as a special case of reverse curvature.

(ii) Where provision of a tangent between legs of a reverse curve is particularly problematic, Project Co may consider joining the curves at a common tangent point known as the Point

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of Reverse Curve (PRC), or, preferably, a Point of Reverse Spiral (PRS). Reverse curves without a spiral are not to be used without prior approval. In all cases where a PRC is recommended by Project Co, the operating speed is limited to ensure the lateral acceleration is held to a maximum of 0.10 g; and the jerk rate is not greater than 0.033 g/s. Actual superelevation shall be designed so a vehicle straddling a PRS does not exceed the track twist criteria.

11.4 Vertical Alignment Criteria

(a) General Requirements

(i) Vertical alignments, or profiles, shall consist of vertical tangents joined by vertical parabolic curves.

(ii) Vertical profiles shall be developed for the track centre-line, based on track centre-line stationing. Vertical profiles for track shall represent elevations of the top of the low rail.

(iii) Calculated values for vertical curve lengths, tangent lengths, etc. shall be rounded-up to the nearest full metre, wherever practical.

(iv) It is preferred Project Co avoid the use of vertical curves within the limits of the station platform. If Project Co has determined vertical curvature is needed to avoid impacts to the adjacent roadways and urban environment; the design of the alignment shall be coordinated with the station design to ensure the station platform, access to the rail car from the platform, and the access ramps to the station platform comply with all requirements in the Accessibility for Ontarians with Disabilities Act (AODA). Those areas shall be identified in the Basis of Design Report and subject to the approval of the Region.

(b) Vertical Tangents

(i) Minimum Vertical Tangent Lengths

A. Main Line DESIRED Minimum Vertical Tangent Length (VLT) = greater of 30 metre or 0.57V

B. Main Line ABSOLUTE Minimum Vertical Tangent Length (VLT) = 14 metre or the value determined by Project Co in consultation with the Rail Car Supplier, submitted as a design variance and accepted by the Region. The Absolute minimum vertical tangent length shall not be used in combination with absolute minimum convex/concave limits on the adjoining vertical curves.

C. Vertical tangents in station platforms are not required to continue beyond ends of the platform.

(c) Gradients

(i) Main Line

A. Main Line ABSOLUTE Maximum Grade = 6%

B. Grades between 4-5% may be sustained for an ABSOLUTE Maximum distance of 250 metre.

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C. Main Line ABSOLUTE Maximum Sustained Grade up to 250 metre long, unless otherwise approved by the Region, = 5%

D. Where a continuously ascending or descending profile is composed of a series of vertical tangents of varying grades, the weighted average gradient shall not exceed 4%. Calculation of the weighted average gradient shall ignore vertical curves and consider gradients from PVI to PVI.

(ii) Yards (OMSF)

A. Yard storage tracks shall either be level or create a sag condition whenever possible so parked rolling stock cannot drift out onto mainline track.

B. Track gradient entering yards shall be either level, pitched forward away from the mainline, or dished to prevent any vehicles from rolling on to the main-line track.

C. Maximum grade on yard storage tracks = 0.3%.

(iii) Routine Starting and Stopping Locations

A. At signalized intersections and other locations where light rail vehicles can be routinely expected to need to stop and restart, the following shall apply.

B. DESIRED Maximum Grade = 1%

C. ACCEPTABLE Maximum Grade = 2%

D. ABSOLUTE Maximum Grade = 4%

(iv) At Platforms – exclusive and semi-exclusive alignments

A. The track grades used at station stop platform areas shall be coordinated with the station designer to ensure the station platform and the access ramps to the station platform comply with all requirements in the Accessibility for Ontarians with Disabilities Act (AODA).

(d) Length of Vertical Curves

(i) Changes in gradients shall be connected by parabolic vertical curves. The rate of change of grade shall generally be constant over equal horizontal lengths of vertical curve. Non-symmetrical or circular vertical curves may only be used if fully justified in the Basis of Design Report and accepted by the Region.

(ii) Length of Vertical Curve (LVC):

A. DESIRED LVC = 60A

B. ACCEPTABLE LVC = 30A

C. ABSOLUTE Minimum LVC = $AV^2/215$ (at crests), = $AV^2/387$ (at sags)

Where:

LVC = a minimum length of vertical curve required, in metres

V = the design speed, in km/h

A = (G2-G1) = algebraic difference in gradients connected by the vertical curve, in percent;

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G1 = percent grade of approaching tangent

G2 = percent grade of departing tangent

$|G2-G1|$ = absolute value of the algebraic difference between the gradients being connected

D. The minimum radius of any vertical curve occurs at its apex and is approximated by:

$R_{min} \approx 100\ (LVC) / |G2-G1|$

E. K = a constant equal to the length of a section of curve over which there is a 1% change in gradient.

$$K = \frac{LVC}{|G2 - G1|}$$

F. ABSOLUTE minimum equivalent radius of vertical curvature Rmin = 285 metre for crest curves (K=2.85) and

G. ABSOLUTE minimum equivalent radius of vertical curvature Rmin = 521 metre for sag curves (K=5.21).

H. Broken back vertical curves to be avoided.

I. It is preferred that short horizontal curves are avoided at vertical curves where possible.

(iii) Vertical curves and gradients shall be checked against overhead catenary system requirements prior to being submitted for review. Project Co shall clearly highlight alignment designs that cause OCS pole spacing to shorten below typical values.

(iv) Grades ascending in the direction of increasing stationing shall be positive. Due consideration shall be given to the algebraic sign of (G_2-G_1).

A. If (G_2-G_1) < 0, the vertical curve is a summit curve or crest curve.

B. If (G_2-G_1) > 0, the vertical curve is a sag curve.

(e) Reverse Vertical Curves

(i) Reverse vertical curves may be used, provided the minimum length of each curve is not less than defined above.

(f) Vertical Requirement for Special Trackwork

(i) Special trackwork layouts shall be designed and constructed in a uniform vertical plane. Under no circumstances shall vertical curves or changes of grade be permitted within the turnouts.

(ii) All special trackwork shall be designed with zero actual superelevation (Ea) above that resulting from placement of switches on grades.

(iii) Mainline:

A. ACCEPTABLE maximum grade through Mainline turnout is less than 2%.

B. ABSOLUTE maximum grade through Mainline turnouts is 4.5%.

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(iv) Yard:

A. ACCEPTABLE maximum grade through Yard turnout is less than 1%.

B. ABSOLUTE maximum grade through Yard turnout is 2%.

(g) Combined Horizontal and Vertical Curvature

(i) It is preferred that overlapping of horizontal and vertical curvature be avoided wherever practical. Where this situation is unavoidable; it is preferred Project Co avoid placing vertical curves within spirals, and endeavor to provide as gentle an alignment as practical. If the resulting alignment exhibits one of the following characteristics:

A. Horizontal or vertical curvature value is close to the ABSOLUTE limit

B. Vertical curve radius is similar to, or smaller than the horizontal radius

C. Then Project Co shall perform dynamic modeling to assign the appropriate speed restriction to ensure passenger comfort and safety requirements are achieved.

11.5 Wayside and Vehicle Clearances

(a) General Requirements

(i) The Vehicle Clearance Envelope (VCE) is defined as the space occupied by the Maximum Vehicle Dynamic Envelop (MVDE) plus an additional running clearance of 50 mm. All as-built structures, permanent equipment, and wayside elements shall be maintained clear of the VCE with the exception of the edge of the platform. The design shall provide sufficient clearances throughout the system to avoid any physical contact between the LRT vehicle and the wayside, between LRT vehicles, or encroachment into any designated areas for passengers or employees. This section provides the guidelines for assessing clearance conditions. However, this section is not intended to cover all possible combinations of clearance conditions that may be required. Project Co shall address each clearance condition and include in their design the appropriate clearances to avoid LRV to LRV impacts, LRV to freight railroad impacts, freight railroad to wayside impacts and LRV to wayside impacts.

(ii) The actual car floor elevation based on new vehicles is 320-336 mm ±11 mm from the top-of-rail. The final dimension of the top of platform to the top of unloaded running rail shall be investigated by Project Co in consultation with the rail car supplier to provide the proper relationship between the rail car floor and the platform edge and include the results in the Basis of Design Report.

(iii) The elevation of the top of platform shall address any temporary lowering of the actual car floor from wheel wear and rail wear. In-service vehicle floor elevations are targeted to be within ±16 mm of the platform elevation, with a preference for the vehicle floor elevation to be higher than the platform elevation.

(iv) Some of the factors which affect clearances required in an LRT structure are not included in the VCE or the MVDE are:

A. Outswing and inswing of a vehicle occur as the train travels along horizontal curves. The effects of this increase, as curve radii decrease, results in an increased clearance requirement.

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B. Superelevation applied along horizontal curves, to obtain maximum operating velocity while maintaining stability of the vehicle and passenger comfort, also results in an increased clearance requirement.

C. The running clearance requirements to be maintained

D. Construction and maintenance tolerances beyond that included in the table and for wayside elements.

E. The VCE shall be maintained clear of any raised walkway or serviceway, while the MVDE shall be maintained clear of the service walkway.

(b) Control Points for the MVDE

(i) Project Co shall use the composite MVDE information as provided below to adjust for outswing (exterior) and inswing (interior) as a result of curvature. The composite MVDE points generally include a construction and maintenance allowance of 12 mm for track horizontal and 12 mm cross level deviations from the design condition for embedded track and 30 mm for cross level deviations from the design condition for ballasted track. In order to avoid clearance issues with any future LRV purchases, the MVDE and the adjustments for curvature represent a composite LRV and were not exclusively developed for the LRV being purchased for the Stage 1 LRT Project.

Embedded Track		
MVDE = 1600 mm		
Radius	Exterior	Interior
Meters	**Add (mm)**	**Add (mm)**
25	**503**	**363**
30	**413**	**297**
45	**254**	**188**
50	**223**	**167**
100	**60**	**60**
125	**48**	**48**
150	**41**	**41**
175	**34**	**34**
200	**29**	**29**
250	**21**	**21**
275	**18**	**18**
300	**16**	**16**
350	**13**	**13**
450	**8**	**8**
600	**4**	**4**
1500	**0**	**0**
10000	**0**	**0**

Ballasted Track		
MVDE = 1618 mm		
Radius	Exterior	Interior
Meters	**Add (mm)**	**Add (mm)**
25	**521**	**381**
30	**431**	**315**
45	**272**	**206**
50	**241**	**185**
100	**65**	**65**
125	**57**	**57**
150	**49**	**49**
175	**42**	**42**
200	**37**	**37**
250	**30**	**30**
275	**27**	**27**
300	**25**	**25**
350	**22**	**22**
450	**17**	**17**
600	**13**	**13**
1500	**5**	**5**
10000	**0**	**0**

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(c) Adjustment for Actual Superelevation

(i) In addition to adjusting in the magnitude of the MVDE for curvature, the increase in interior clearance for superelevation or interior or exterior clearance for intentional cross level shall be determined by the formula

Additional Wayside Clearance = 2.23*Ea.

(d) Determination of Design Offsets

(i) The design offset is determined by summing the adjusted MVDE plus construction and maintenance tolerances for wayside elements and the requirements for running clearance. Project Co shall determine if additional allowances are required for rail wear and wheel wear beyond the allowances included in the above table.

(e) Measurement of Horizontal and Vertical Clearances

(i) All horizontal clearances shall be measured in a horizontal plane from the centre line of track and apply only to a radial line of the centre line of track arc, or a 90-degree offset line to the centre line of track tangent.

(ii) All vertical clearances shall be measured in a vertical plane.

11.6 Minimum Clearances

(a) General Requirements

(i) The analysis shall include, but not be limited to, discussion of dimensions and configurations for the elements described below, complete with dimensioned drawings.

(ii) Structure Width

A. The minimum structure width shall be determined by the sum of MVDE adjusted for curvature and superelevation/cross level, required clearances for the serviceway, walkway, and where applicable, clearance envelope, permanent equipment not accommodated by the serviceway, construction tolerances, and chorded construction. The minimum clear width of a walkway is 765 mm.

(b) LRT Stop Platform Zones

(i) Distance from track centerline to edge of platform = 1400 mm. Project Co shall provide dimensioned drawings showing all critical dimensions at the vehicle-platform interface.

(c) Transition of Clearances

(i) The full clearance distance required for curvature and superelevation and all other factors shall be applied throughout the curve and maintained until to a point 7 meters prior to the SC (PC) or after the CS (PT) points. The transition distance from these points to tangent condition shall be 14 metre prior to the TS (PC) and after the ST (PT). To determine additional clearance along the spiral or at the end of a simple curve, Project Co shall apply a linear interpolation between the point of full clearance requirement to the point 14 meters beyond curve measured radially for the centreline of the alignment.

(d) Running Clearances

(i) The design offset for wayside clearances from the centre-line of track shall be determined by following requirements:

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A. A minimum spatial allowance of 530 mm for OCS poles is required for all poles located between two tracks. This allowance includes construction tolerances for the OCS poles.

B. The running clearance to the spatial allowance for the OCS poles shall be 150 mm.

C. The minimum running clearance to all wayside structures shall be 150 mm and the design offset include an allowance for wall mounted equipment and construction tolerances for all wayside elements. Maintenance tolerances are not required for fixed wayside structures unless structural movement is expected such as frost heaving.

D. The minimum dimension from the top of low rail to the clearance point of an overhead structure shall be determined by the Project Co's Overhead Contact Systems designer.

E. The MVDE point shall not protrude beyond the back of curb in the median running configuration.

F. The MVDE point shall not protrude beyond the back of curb in the street side curb when siding running or the face of curb on the sidewalk side.

G. A safety zone parallel to the track 765 mm in width over a walkable surface shall be included wherever possible

(ii) The Desired minimum running clearances between two the MVDE of LRT rail cars in revenue service in tangent track is 765 mm. The absolute minimum running clearance between two LRT rail cars in revenue service in tangent track shall 300 mm in areas where the design speed is 50 km/h and 500 mm where the design speed is greater than 50 km/h. Project Co shall identify zones where the desired minimum running clearance is not provided and post signs indicating the close clearance condition.

(e) Elevated and Below Grade Sections

(i) Bridges or underpasses carrying rail vehicles shall have clearances and curbs as required by the Authority having jurisdiction for that bridge.

(f) Railroad

(i) Vertical clearance requirements in all other jurisdictions and all horizontal clearance requirements shall be verified with the specific railroad and other appropriate authorities with jurisdiction railroad matters.

(ii) The equipment operated by freight railroad service along the Waterloo Spur will be restricted to a height of 16'-0" and a width consistent with the 8'-6" clearance requirements. Gauntlet tracks shall provide a horizontal offset to achieve sufficient clearance between the freight railroad traffic and the LRT Stop platforms. The minimum horizontal design offset provided by the gauntlet track shall be 0.457 meters throughout the entire LRT Stop Platforms.

(g) Highways and other structures

(i) Highway bridges over Waterloo Right-of-Way, use of existing highway structures, and highway requirements under Waterloo bridges shall conform Canadian Highway Bridge

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Design Code CAN/CSA-S6-06(R11), Ministry of Transportation of Ontario Guidelines.

(ii) Other vertical clearance requirements and all horizontal clearance requirements shall be verified with the appropriate authorities. For structures under the jurisdiction of agencies other than highways, the design shall be coordinated with the appropriate owner or agency involved.

11.7 Alignment – Site Specific Design

(a) Site Specific Requirements

In addition to other design direction provided within this Article and the alignment drawings provided to Project Co, there are some areas of the project in which site specific direction is required. There are seven (7) specific areas in which the current information provided in the alignment drawings requires modification when Project Co submits their Technical Submission. The areas are:

(i) Waterloo Town Square Stop

(ii) South Bound track along the Waterloo Spur

(iii) King Street Grade Separation and the CN Guelph Subdivision Tracks

(iv) CN Replacement Track along the Huron Spur

(v) Benton Street LRT Stop

(vi) King St. West and Wellington Intersection

(vii) Seagram LRT Stop.

The CN and the Region have reached a general consensus on the work requirements with respect to freight railroad trackage. The formal agreements are still in process and Project Co shall base their Technical Submission on the currently available information.

(b) Waterloo Town Square Stop

The alignment drawings in Appendix I have been updated to reflect the LRT Stop formerly shown in Appendix S. The Region has determined that the alternative LRT Stop formerly in Appendix S shall be the basis of design for this location. In their Technical Submission, Project Co shall modify their plan and profile alignment drawings, LRT Stop drawings, and all other aspects of their Technical Submission to incorporate the LRT Stop platform location shown in Appendix S.

(c) South Bound track along the Waterloo Spur

The CN/GEXR freight trains are assigned to use the North Bound LRT Track from Kings Street to Erb Street and the South Bound LRT Track from Erb Street to Northfield Drive. The CN has advised that would like to increase the minimum tangent distance between curves to 30 meters on tracks where their trains will operate. In their Technical Submission, Project Co shall retain the minimum tangent distance between curves of 14 meters. Thirty (30) days after financial close, Project Co shall prepare and submit an alternative alignment based on a minimum tangent distance of 30 meters between curves on tracks where CN trains will operate. This submission is for information purposes only.

(d) King Street Grade Separation and the CN Guelph Subdivision Tracks

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In their Technical Submission, Project Co shall modify their plan and profile alignment drawings, and all other aspects of their Technical Submission to incorporate the information provided in Appendix X and the following design requirements:

(i) Project Co's design for the road profile for King Street shall provide at least the minimum vertical clearance from top of pavement to bottom of structure as per the Appendix I.

(ii) The road profile for King Street shall not be lower than the road profile as per Appendix I.

(iii) At King Street, the top of rail for the CN Guelph Subdivision tracks may be raised to a maximum elevation of 336 while adhering to the grade limitation of 1%.

(iv) The track profile for the temporary track profile at the future Transit Hub must allow an at-grade crossing of Duke Street close to the current elevation of the existing tracks at Duke Street.

(v) The CN track centers at Duke Street shall not be closer than 6.1 meters.

(vi) The CN track centers at King Street shall not be closer than 6.1 meters.

(e) CN Replacement Track along the Huron Spur

In their Technical Submission, Project Co shall modify their plan and profile alignment drawings, and all other aspects of their Technical Submission to incorporate the information provided in Appendix X with respect to the CN replacement track for the Huron Spur.

(f) Benton Street LRT Stop

The alignment drawings (Appendix I) illustrate a location for the platform on Charles St. This location does not indicate access for the parking lot located adjacent to the LRT Stop. The Region and City Transportation Departments have indicated that access to this parking lot from Queen St. is not permissible. As part of the Phase 1 design work, Project Co. shall illustrate an alternative plan to the base bid that maintains safe access/egress from the parking lot.

(g) King St. West and Wellington Intersection

The alignment drawings (Appendix I) illustrate a minimum length left turn lane southbound from King St. W. to Wellington St. with the passenger vehicle desires to complete U-turns and left turns at that intersection, there is a desire by the City to re-route left turns from King St. W and Moore Ave. Intersection. As part of the Phase 1 design effort Project Co shall illustrate an alternative plan to the base bid that maximizes left turn storage at the King and Wellington and minimizes the storage requirements at King and Moore. Additional land requirements shall be identified in the drawings for action for acquisition by the Region.

(h) Seagram LRT Stop

As part of the Phase 1 design work, Project Co shall develop up to three site plan alternatives for the Seagram LRT Stop. The site plan alternatives shall address different road, trail and parking layout configurations. For each site plan alternative, Project Co shall identify property and utility impacts.

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