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SYSTEMWIDE BASELINE
CHANGE NOTICE (SBCN)

DOCUMENT/TITLE/NUMBER/REVISION:

METRO RAIL DESIGN CRITERIA/SECTION 4 GUIDEWAY AND TRACKWORK/REV. 1

CHANGE IMPACT ASSESSMENT SUMMARY: (Attach written explanation of impacts identified)

SCHEDULE ISSUES?:	N	OTHER DOCUMENT REVISIONS REQUIRED?:			
ROM (RANGE):	**NO COST**	DESIGN ISSUES?:	N	COST RECOVERY POTENTIAL:	N
TIME IMPACT:	N/A	SAFETY ISSUES?:	N	OTHER CONTRACTS/PROJECTS?:	N/A
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Related Request(s)-For-Change: **NONE**

JUSTIFICATION (including benefit or impact if not pursued):

- Additional requirements for track drainage and special trackwork have been introduced, based on lesson learned from Eastside and Expo Projects (4.1.3.1.C, 4.1.3.2.A, 4.1.3.2.C, 4.1.4.4, 4.2.4, 4.2.4.2 & 4.2.11 and Figure 4.14)
- Typing errors have been found and fixed

PROJECTS/CONTRACTS AFFECTED: For new projects only

PROJ CONTRACT CN # ACTION STATUS

TOTAL ESTIMATED CHANGE COST: (DIRECT)

TOTAL ESTIMATED CHANGE COST: (INDIRECT: POTENTIAL COST RECOVERY)

TOTAL ESTIMATED CHANGE COST: (INDIRECT+ DIRECT)

RECOMMENDATION AND APPROVAL SIGNATURES: (R = RECOMMEND, A = APPROVE)

RTG	APPROVAL	NAME/TITLE	SIGNATURE	DATE
R	DIRECTOR CONSTR. MGMT	G. ROY	SEE SEPARATE SHEET	
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R	DIRECTOR PROJ. ENG. SYSTEMS	F. CASTRO	[signature]	7/29/11
R	DIRECTOR QUALITY MANAGEMENT	W. MOORE	W. Moore	8/29/11
R	MGR. DOCUMENT CONTROL	D. CURZON	[signature]	7/29/11
A	EXECUTIVE DIRECTOR PROJECT TRANSIT DELIVERY	K.N. MURTHY	[signature]	8/30/11
A	IMPACTED PROJECT MANAGER – N/A			
R	EO, RAIL WAYSIDE SYSTEMS	M. HARRIS-GIFFORD	SEE SEPARATE SHEET	

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Related Request(s)-For-Change: **NONE**

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RTG	APPROVAL	NAME/TITLE	SIGNATURE	DATE
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A	IMPACTED PROJECT MANAGER – N/A			

[GIRISH ROY SIGN-OFF]

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Related Request(s)-For-Change: NONE

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RTG	APPROVAL	NAME/TITLE	SIGNATURE	DATE
R	DIRECTOR CONSTR. MGMT	G. ROY	SEE SEPARATE SHEET	
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R	DIRECTOR QUALITY MANAGEMENT	W. MOORE		
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A	EXECUTIVE DIRECTOR PROJECT TRANSIT DELIVERY	K.N. MURTHY		
A	IMPACTED PROJECT MANAGER – N/A			
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[HARRIS- GIFFORD SIGN-OFF]

METRO RAIL DESIGN CRITERIA

SECTION 4

GUIDEWAY AND TRACKWORK

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GUIDEWAY AND TRACKWORK

4.1 GUIDEWAY

4.1.1 Basis for Criteria

This section of the Criteria is based on requirements, established by California Public Utilities Commission (CPUC), recommendations of American Railway Engineering and Maintenance Association (AREMA) and other applicable Federal (i.e. ADA), State (i.e. PUC) and local jurisdictions' (i.e. city) requirements and recommendations.

Guideway design may be divided in two main elements: alignment (track geometry) and cross sections. Alignment defines the route and the cross section defines the size (mostly width) of the guideway. This Section of the Criteria provides directions (establish requirements) for design of track geometry and guideway cross sections. Requirements to the cross section are set up in Sections 4.1.5 & 4.1.6, to track geometry design – in Section 4.1.6.

Purpose of the Criteria is to provide designers of various Metro Rail projects with unified directions to design **efficient**, **safe** and **comfortable** transit system.

Efficiency of transit system is defined by its *capacity*, *construction cost* and system *operational cost*.

To achieve the full *capacity*, the design shall provide for highest travel speed and shortest possible headways. Criteria requirements for guideway design in following sections are performance oriented and provide directions to achieve high travel speed combined with considerations for vehicle stability and vehicle/track maintenance. Headways are discussed in Systems Sections of the Criteria.

Issues of *capacity, construction and operational costs* are interrelated and shall be addressed by designer on a case-by-case basis, using cost benefits analyses, under the Metro directions. Example for such a case could be a flat horizontal curve vs. a sharp one: flat curve in alignment may require real estate acquisition, installation of retaining walls – high *construction cost* for benefits of increased *capacity*, due to higher speed and low *operational cost* due to reduced maintenance.

Provisions for **safety** of the transit system are included in Criteria requirements for track geometry and clearances to achieve safe movement of the trains and means for passenger evacuation, combined with considerations for minimal necessary width of the guideway.

Passenger **comfort** provisions are included in Criteria requirements for guideway geometry, which based on AREMA recommended accelerations and travel duration through geometry element.

4.1.2 Survey Control System

Horizontal NAD83 datum and Vertical NAVD88 datum shall be used per Sections 8850, 8851, 8852 and 8853 of California Public Resources Code.

Distance accuracy (horizontal control) and elevation accuracy (vertical control) shall meet National Geodetic Survey (NGS) classification of Second-order, class I per Federal Geodetic Control Committee (FGCC) Standards and Specifications for Geodetic Control Networks, Section 2, Standards, issued in September 1984 or the latest edition.

4.1.3 Clearance Requirements

4.1.3.1 General

Notwithstanding any of following criteria, the design of Metro system shall not violate any of the regulations outlined in the CPUC General Orders. These General Orders include, but are not limited to GO 26, GO-95 and GO-143. The Rail Vehicle clearance is defined as the distance from the track centerline, measured to the face of obstruction and includes the Vehicle Dynamic Envelope (VDE), Pantograph Dynamic Envelope (PDE), construction tolerances, running clearances, evacuation walkway, safety space and operating envelopes. All horizontal and vertical clearances define the minimum allowed distance, except of floor level passenger platform side clearance, which defines the maximum allowed distance from track centerline to the edge of the platform.

A. Vehicle Dynamic Envelope – VDE

VDE (also called Maximum Dynamic Outline) represents the outermost surface of the moving vehicle, considering and including:

- failed suspension
- lateral vehicle motion
- overhang, mid-ordinate and superelevation clearance adjustments on a curved track.

1. <u>The Heavy Rail VDE</u> is based on rail vehicle which is 75 ft long, 10.50 ft wide (10.33 ft at thresholds), 12.5 ft high above top of rail and has up to 54 ft truck spacing.

   VDE diagrams are presented on Fig. 4.3.

2. <u>The Light Rail VDE</u> is based on an articulated rail vehicle which is 90 ft long, 9.39 ft wide (at the outside rear-view mirrors), 12.25 ft high above top of rail (exclusive of the pantograph) and has up to 32 ft truck spacing.

   VDE diagram on tangent track is presented on Fig. 4.4, VDE dimensions on a curved superelevated track are presented on Fig. 4.5 to 4.11.

B. Pantograph Dynamic Envelope - PDE

(Based on AREMA table 33-2-3)

For clearance purposes, half width of PDE shall be considered as:

At 14’ above top of rail	52.5”	4.38’
At 16’ above top of rail	54.2”	4.52’
At 19’ above top of rail	57.4”	4.78’

Numbers above include 6.50' wide pantograph; apply to tangent track only and shall be adjusted for curved and superelevated tracks.

C. Clearance to station platform

The clearance:

- defines the maximum allowed distance from track to the boarding edge of passenger platform;
- is based on CPUC GO 143 (for LRV only) and ADA requirements – ~~3 inches maximum space between the doorsill of the LRV and the edge of the platform;~~ **the height and position of a platform must be coordinated with the floor of the vehicles it serves to minimize the vertical and horizontal gaps, in accordance with the ADA Accessibility Guidelines for Transportation Vehicles (36 CFR Part 1192.53): such that the horizontal gap between each vehicle door at rest and the platform shall be no greater than 3 inches and the height of the vehicle floor shall be within plus or minus 5/8 inch of the platform height under all normal passenger load conditions.**
- applies to non-moving Rail Vehicle at the station stop; and
- uses average width of LA Standard Rail Vehicle (at door threshold).

1. HRT Clearance to station platform is defined as a distance from the track center to the boarding edge of passenger platform at ~~3.71~~**3.67** ft above top of rail.

   Clearance calculations:

Vehicle half width (average)	62.0"	5.167'
CPUC/ADA clearance	2.50"	0.208'
Total	64.50"	5.38'

2. LRT Clearance to station platform is defined as a distance from the track center to the boarding edge of passenger platform at 3.25 ft above top of rail.

   Clearance calculations:

Vehicle half width (average)	52.27"	4.356'
CPUC/ADA clearance	2.50"	0.208'
Total	54.77"	4.56'

4.1.3.2 Side Clearances – Heavy Rail Vehicle

HRT Typical Sections with clearance requirements are presented on Fig.4.14 & 4.16. According to VDE diagram on Fig.4.3, the most critical point is located at the vehicle floor level (for floor-level walkway clearance) at ~~3.71~~**3.67** ft above top of rail and at the top of the vehicle, at 12.50 ft above top of rail.

A. Construction tolerance

1. Track construction tolerances per Design Criteria Section 4.2 Table 4.1.

2. Wall and roof slabs - 0,+2”, variations to not exceed ¼” in any 10’ of surface.

3. Curved concrete surfaces of bored tunnels – 0,+3”, variations to not exceed 1/2” in any 10’ of surface.

B. Safety space

1. Preferable clearance (per GO 26-D sections 9 & 10) from track center to face of obstruction on a tangent track.

Vehicle half width	62.0”	5.167’
Safety space	30”	2.50’
Total	92.0”	7.68’
Use		8.0 ft

2. Acceptable minimum with proper justification (per deviation, granted by CPUC to Metro for Red Line Transit System for areas, inaccessible for any person, when trains are in motion):

a. Outside the tunnel clearance from track center to face of obstruction on a tangent track

Vehicle half width	62.0”	5.167’
Safety space	14”	1.167’
Total	76.0”	6.33’
Use		6.50 ft

b. In the tunnel clearance from track center to obstruction on a tangent track

VDE half width	69.42”	5.79’
Safety space	0	0
Total	69.42”	5.79’
Use		6.0 ft

Track side clearances presented above are for tangent track only and require adjustment for a curved track.

C. Evacuation walkway

An evacuation walkway, accessible to persons getting off the disabled train shall be provided along all tracks at-grade, in tunnels and bridges. Evacuation walkway envelope shall be 2.5 ft wide and 6.67 ft tall, unobstructed by VDE or any part of guideway fixed facilities. A single walkway may serve more than one adjacent track. An evacuation walkway between the tracks (center walkway) shall be minimum 3 ft wide. The width of the center evacuation walkway may be reduced to 2.5 ft along the fixed objects less than 5 ft in length. Evacuation walkway in subways (boxes and tunnels) shall be provided at vehicle floor level and equipped with a handrail. Maintenance walkway shall occupy the space of evacuation walkway. ~~Excavation~~ **Evacuation** walkway shall not cross special trackwork elements, such as switches, switch machines, frogs and diamonds. AREMA No. 5 ballast shall be used for walkway on a ballasted guideway.

D. Chorded construction

When chorded construction is specified, walls and walkways shall be constructed in chords, whose length shall be measured along the inside face of the wall nearest the curve.

The maximum allowable chord lengths shall be:

For curves with radii 2,500 ft or greater – 50 ft

For curves, with radii, less than 2,500 ft – 25 ft

Clearance from track center to the face of the chorded wall shall fit VDE, adjusted for curvature and accommodate evacuation walkway, where it applies (See Fig. 4.12 and 4.13).

4.1.3.3 Side Clearances – Light Rail Vehicle

LRT Typical Sections with clearance requirements are presented on Fig.4.21 and 4.22. According to VDE diagram on Fig. 4.4, the most critical points are located at the vehicle floor level (for floor-level walkway clearance) at 3.25 ft above top of rail and at the top of outside rear-view mirror, at 9.25 ft above top of rail.

A. Construction tolerance

1. Track construction tolerances below are based on Design Criteria Section 4.6 Table 4-1:

a. At 3.25 ft above top of rail – vehicle floor level

Gauge variation		1/16”	0.005’
Alignment		1/8”	0.010’
Cross level	0.01x3.25/4.723	1/12”	0.007’
Total:		1/4”	0.02’

b. At 9.25 ft above top of rail – top of outside mirror

Gauge variation		1/16”	0.005’
Alignment		1/8”	0.010’
Cross level	0.01x9.25/4.723	1/4”	0.021’
Total:		7/16”	0.04’

2. Fence or wall construction tolerance	2”	0.17’
3. Walkway construction tolerance	1”	0.08’
4. OCS pole construction tolerance	¾”	0.06’

B. Running clearances

Running clearances between VDE and any fixed object or another VDE:

Preferred	6”	0.50’
Minimum	2”	0.17’
Absolute minimum, allowed only to floor-level walkway	1”	0.08’

C. Evacuation/emergency walkway (based on CPUC GO 143 Rule 9.05)

An unobstructed evacuation walkway minimum 2.5 ft wide and accessible to persons getting off the disabled train shall be provided along all tracks in subways, tunnels and bridges. Also, the same walkway shall be provided along all at-grade tracks, except for tracks in a street without the fence or barrier between the track and the street. A single walkway may serve more than one adjacent track. An evacuation walkway between the tracks (center walkway) shall be minimum 3 ft wide. The width of the center evacuation walkway may be reduced to 2.5 ft along the fixed objects less than 5 ft in length. The height of evacuation walkway envelope (head room) shall be not less than 6 ft 8 inches. Maintenance walkway shall occupy the space of evacuation walkway. Evacuation walkway shall not cross special trackwork elements, such as switches, switch machines, frogs and diamonds. AREMA No. 5 ballast shall be used for walkway along the tracks on a ballasted guideway.

D. Safety space (based on CPUC GO 143 Rule 9.06)

1. Clearance shall include 2.5 ft space (including an evacuation walkway) in the areas, where passengers, employees or other persons are permitted or required to be, while trains are in motion.

2. Clearance shall include 1.5 ft space in the areas, where passengers, employees or other persons are normally prohibited, while trains are in motion. Fixed wayside structures, less than 5 ft in length shall be excluded from this requirement, provided approved measures are taken to give warning of restricted clearances.

3. Clearance may not include an additional space in exclusive right-of-ways, including subways, tunnels, and portions of surface and elevated alignment, which are equally inaccessible to persons.

E. Operating envelopes for Overhead Contact System (OCS) support poles

OCS pole operating envelope is defined as a space, occupied by the pole with considerations of it’s deflection in all directions due to pole flexure and foundation rotation. OCS operating envelope is considered symmetrical around pole centerline.

The operating envelope for OCS poles (total space, which occupies part of track cross section), to be considered in design, shall be:

1.	Counterweight and feeder poles	17”	1.42’
2.	All other poles	15”	1.25’

F. Overhead canopies at station platforms

Edge of the canopy shall be aligned with boarding edge of the platform; therefore track center to edge of the canopy clearance shall not be less, than 4.56 ft, unless Metro directs otherwise.

G. Pantograph air clearance

Minimum 4 inches of air clearance shall be provided between PDE and grounded structures, which include among others, reinforced concrete tunnels, boxes, walls and station canopies.

H. Sample calculations

All the clearances below represent the distance from tangent track centerline, unless otherwise noted.

1. Clearance to the outer face of curb of adjacent traffic lane when tracks are in a street without fence or barrier separation from street traffic:

VDE half width @ 9.25' above top of rail	5.36'
Running clearance	0.50'
Total	5.86'
Use	6.0 ft

2. Clearance to a face of a fence (wall or barrier), over 8 inches above top of rail, with an evacuation walkway:

VDE half width @ 9.25' above top of rail	5.36'
Track construction tolerance	0.04'
Evacuation walkway	2.50'
Fence construction tolerance	0.17'
Total	8.07'
Use	8.0 ft

3. Clearance to a face of fence (wall or barrier) over 8 inches above top of rail, without a walkway, per D.3 above:

VDE half width @ 9.25' above top of rail	5.36'
Track construction tolerance	0.04'
Fence construction tolerance	0.17'
Minimum running clearance	0.17'
Total	5.74'
Use	6.0 ft

4. Clearance to an edge of car floor level walkway @ 3.25' above top of rail:

VDE half width @ 3.25' above top of rail	4.73'
Track construction tolerance @ 3.25' above top of rail	0.02'
Walkway construction tolerance	0.08'
Minimum running clearance	0.17'
Total	5.00'
Use	5.0 ft

5. Track spacing with center OCS poles without center walkway:

VDE @ 9.25' above top of rail	5.36x2	10.72'
Track construction tolerance	0.04x2	0.08'
OCS construction tolerance	0.06x2	0.12'
Running clearance	0.50x2	1.00'
OCS operating envelope		1.42'
Total		13.34'
Preferred use		14.0 ft
Minimum use		13.5 ft

6. Track spacing without center OCS poles with a center walkway:

VDE @ 9.25' above top of rail	5.36x2	10.72'
Track construction tolerance	0.04x2	0.08'
Center at-grade evacuation walkway		3.00'
Total		13.80'
Use		14.0 ft

7. Track spacing without center OCS poles and without a center walkway:

VDE @ 9.25' above top of rail	5.36x2	10.72'
Safety space		1.50'
Track construction tolerance	0.04x2	0.08'
Running clearance		0.50'
Total		12.80'
Use		13.0 ft

8. Track spacing without center OCS poles and without a center walkway, per D.3 above:

VDE @ 9.25' above top of rail	5.36x2	10.72'
Track construction tolerance	0.04x2	0.08'
Running clearance		0.50'
Total		11.30'
Use		11.5 ft

4.1.3.4 Vertical Clearances

Vertical clearance for Rail Transit System is defined as a minimum distance, measured vertically from the top of rail to the face (bottom) of obstruction above the track.

A. Vertical clearance shall be 14.0 ft for HRT system and 15.0 ft for LRT system in bored tunnels, cut-and-cover boxes, semi-depressed (in trench), at-grade and aerial guideways.

B. Height of overhead contact wire for LRT system shall not be below 14.0 ft and over 22.5 ft above top of rail.

C. Height of overhead contact wire shall not be below 18 ft above top of rail at pedestrian or road vehicle grade crossings and shall be in compliance with CPUC GO 95 Rules 37 and 43.

4.1.3.5 Circular (Bored) Tunnels

Clearance diagrams, based on above mentioned clearance requirements for both Heavy and Light Rail circular tunnels, are presented on Fig. 4.14 through 17.

For noise and vibration mitigation purposes, space for filling material shall be provided between the bridging beam (per Metro Standard Trackwork Drawing TS-528) and tunnel interior.

Consistent tunnel interior diameter of 18'-10" is presented on clearance diagrams Fig. 14 through 4.17, for both HRT and LRT tunnels. However, different size of the tunnel may be used with proper justification, compliance with clearance requirements of Section 4.1.3 and acceptance by Metro.

4.1.4 At-Grade Guideway

4.1.4.1 General

A. Guideway is defined as a portion of the rail system, which supports the track and its appurtenant structures. Criteria for the design of trackwork are addressed in Section 4.2 Trackwork.

B. This section establishes criteria for the design of at-grade portions of the rail system guideway and defines grading, drainage and other requirements for at-grade guideway cross sections with ballasted track. Guideway in a street with an embedded track is addressed in Section 4.2 Trackwork. Aerial, underground and semi-depressed (U-shape wall) portions of the rail system guideway are addressed in Section 5 Structural

C. At-grade guideway may include trackbed, slopes, benches, retaining walls, open and underground drainage facilities.

D. At-grade guideway, equipped with contact rail traction power system, shall be protected by continuous fencing to prevent unauthorized access.

E. At-grade guideway, equipped with Overhead Contact System, shall be protected by continuous fencing or substantial barriers between the grade crossings to prevent access of unauthorized personnel and street vehicles.

F. At-grade guideway may contain longitudinal and transverse electrical ductbanks and other underground and overhead utilities, including Overhead Contact System for Light Rail traction power.

4.1.4.2 Sub-grade

Minimal 24:1 slope shall be provided on a sub-grade downward the drainage device. Preferable configuration shall have a high point at a single track center or in the middle between two tracks, with drainage devices (ditches or subdrains) on both sides of the trackbed. However, single slope sub-grade may be provided with proper justification for a single track trackbed.

Main Line trackbed for more than one track with single drainage device at one side or in a center of the trackbed will not be accepted by Metro.

Amount of tracks on a sub-grade slope for multiple tracks trackbed off the Main Line shall be limited by reasonable depth of the drainage device, but not to exceed 4 tracks.

4.1.4.3 Slopes and retaining walls

Design of cut and fill slopes shall be based on geotechnical evaluation of existing soil and materials for construction of embankment and geotechnical recommendations for slope stability, including steepness and depth/height of cut and fill slopes, height between tiers, use of filter fabric, required material compaction and other elements of cut and fill guideway.

Surface rainwater (and ground water, if apply) flow shall be prevented from entering the trackbed, therefore other elements of cut and fill guideway may include earth or concrete intercept ditches on a top of a cut, on a face of a slope and between the trackbed and a slope, benches with a maintenance access and berms at the open drainage ditches.

Due to limited space, portion of or the entire slope may be replaced by the retaining wall. Same requirements for preventing the surface rainwater from entering the trackbed apply; therefore retained guideway may include intercepting ditches and benches. Tiered retaining wall guideway may include benches with construction and maintenance access. In retained guideway subgrade rainwater shall be collected by the subdrain.

Permanent erosion control for cut and fill slopes shall be provided after the completion of earthwork. Landscaping design shall comply with requirements of Section 6 Architectural of the Criteria.

Retaining walls shall be designed per Caltrans or local jurisdiction requirements, including among others, requirements for weep holes.

See Fig. 4-18 through 4-20 for cross section design requirements.

4.1.4.4 Drainage

For stability of trackbed, water seeping or flowing toward the track shall be intercepted and diverted before it reaches the trackbed; water, falling upon the track area shall be drained off the trackbed quickly.

On a retained approaches to bridges, provisions shall be made for diverting water away from bridge abutments in the underdrain and off the guideway, independent of abutment weephole drainage.

Open earth or concrete ditches shall be provided alongside the trackbed in cut and fill guideway sections.

Open ditches shall be provided between the toe of the slope and the trackbed in cuts; as intercepting ditches on a top of a cut slope, alongside the top of retaining walls, alongside the toe of fill slopes and along benches.

Drainage from the trackbed in retained sections shall be provided by underdrain (subdrain) system, which consists of perforated pipe, located on a bottom of the trench, filled with permeable material and surrounded with filter fabric. **Minimum size of the perforated pipe at a high point of an underdrain line shall be 6 inches.**

See Fig. 4.19 for underdrain details.

Drainage shall be provided for switch machines, installed in embedded or paved track structures: drainage opening in an earth case shall be connected to a storm drain system.

Design of open ditches and underdrain shall comply with requirements for drainage design in Section 3 Civil.

4.1.4.5 Undertrack Structures

Underground utilities and other undertrack structures may run alongside or cross the at-grade guideway.

Underground utilities may include pipelines and electrical ductbanks, proposed or existing, owned and operated by Metro or another Party.

Preferable alignment for an underground utility or another structure, running alongside the track, is outside of track load influence. If the utility shall be located under the trackbed, it shall be placed between the tracks to provide access to manholes, pullboxes, etc. Depth of the utility under the track shall not be less than 48 inches under the top of rail, and a minimum 6 inches below bottom of subballast (top of subgrade).

Protection of the pipeline, crossing the guideway, shall extend between Metro Right-of-Way lines to protect the pipeline and Metro Rail Operations.

4.1.4.6 Wayside Access

Access to the guideway at track level must be provided for maintenance and emergency work. This requires provision for highway vehicles carrying men, tools, and material to drive to and along the guideway to the fullest extent possible, and for vehicles equipped with flanged as well as highway wheels (Hi-Rail Equipment) to drive onto the track at strategic locations. Consideration shall be given to accessibility when locating entry points to the Metro right-of-way from public streets and highways.

A. Service Roads

Where practicable, a 10 ft wide unpaved service road on the right-of-way and paralleling the at-grade guideway shall be provided. It may be on either side of the track and need not be continuous, but access and turnaround facilities shall be considered for each section of the guideway. The feasibility of providing service roads shall be considered for each section of at-grade track.

B. Highway Vehicle Access Points

Access by highway vehicles shall be provided to the at-grade guideway near subway portals, crossovers, rail line junctions, and any other at-grade points where heavy maintenance requirements are anticipated. Where service roads are not provided, access shall be provided at intervals not exceeding 2 miles, preferably at 1-mile intervals. Consideration shall be given at these access points to vehicle turning requirements and to limited parking space for the transit systems highway equipment.

C. Hi-Rail Vehicle Access Points

Hi-Rail vehicles may access the track at grade crossings and paved areas of the Yards. However, some areas of the guideway, such as approaches to aerial structures and tunnel portals, or other areas, as defined by Metro, require access points for maintenance and rescue operations. These access points shall be located in close proximity to the pointed areas and shall accommodate large Hi-Rail vehicle, such as 3-axle truck.

4.1.5 Right-Of-Way and Fencing Requirements

4.1.5.1 Right-of-Way

Objective of this section of the Criteria is to provide the designer with directions for defining the width and depth of the ROW, necessary to fit the entire transit guideway, including all its elements.

Minimal required lateral distances from different points of the guideway to Metro ROW line are:

- Outer edge of an open earth or concrete ditch on a top of cut slope 5 ft
- Outer edge of an open earth or concrete ditch on a top of retaining wall without a bench 10 ft

- Outer edge of an open earth or concrete ditch alongside the fill without a berm/service road 10 ft
- Top of the cut slope without intercepting ditch 10 ft
- Toe of a fill slope without an intercepting ditch 10 ft
- Foundation of retaining wall 2 ft
- Underground box , tunnel or U-shape wall 5 ft
- Aerial structure 5 ft

See Fig. 4-18 through 4-22 for ROW requirements.

For underground guideways the upper ROW limit shall be established at 10 ft above the high point of the structure, and the lower limit at 10 ft under the low point of the structure.

Vent and fan shafts, if not located on Metro property, shall be provided with minimum of 4 ft ROW space from exterior face of the structure. Access to the shaft is required.

4.1.5.2 Fencing

Fences, walls and barriers shall be provided to protect the at-grade guideway from unauthorized access (intrusion) by people and road vehicles; for protection of Metro patrons at aerial stations and stations, adjacent to other rail facilities:

1. At-grade guideway without contact rail shall be protected by 8 ft high fence, with proper warning signs on it, between grade crossings. However, 3’-7” height fence is required on approach to grade crossings for train operator’s full vision field. At-grade guideway, equipped with contact rail for traction power, shall be protected by the continuous 8 ft high fence with proper warning signs on it.
2. Guideway, located alongside the roadway (street) with vehicular traffic, within less than 10 ft from the traffic lane, shall be protected by the fence and the barrier (Caltrans K-Rail or similar).
3. No vegetation shall be provided within the fenced at-grade guideway with ballasted track.
4. Protection fence or barrier shall be provided at the edge of a public sidewalk, adjacent to guideway with embedded track.
5. Guideway with embedded track, located in a street, may be equipped with a fence or barrier, installed between the tracks, to prevent unauthorized crossing of the street and the guideway by the people and road vehicles. Fence or barrier may be installed between the tracks in at-grade guideway with ballasted track at passenger stations to prevent unauthorized track crossing by people. Fence or barrier between the tracks shall be provided only by request from Metro Fire/Life Safety or Rail Operations.
6. Protective fence shall be provided on passenger stations between Metro guideway and adjacent tracks, operated by another Party, such as Metrolink, Amtrak, UPRR or BNSF.
7. Protective fence shall be provided at aerial passenger stations on a field side of a track, across from center passenger platform.

8. Clearance requirements per Section 4.1.3 apply to all fences and barriers, addressed in this section.
9. Protective fence shall be provided on aerial structures, overcrossing Metro transit guideway with an OCS.
10. Protective rail or barrier shall be provided on approaches to street or highway aerial structures, overcrossing Metro transit guideway, both sides from both directions.

4.1.6 Track Horizontal and Vertical Geometry

4.1.6.1 General

A. The requirements for horizontal and vertical alignment - track geometry - are based on recommendations of American Railway Engineering and Maintenance Association (AREMA).

B. Track horizontal and vertical alignment consists of two geometry elements: tangents and curves. Tangents shall be connected by circular (horizontal alignment) or parabolic (vertical alignment) curves.

C. Special trackwork and passenger platforms shall be located on horizontal and vertical tangents.

D. Transition curves shall be provided between the horizontal tangent and a circular curve, where it is required. The Criteria requirements for length and curvature of the geometrical elements of alignment are based on train Operating Speed.

E. Main Line alignment shall be designed for the established maximum Operating Speed. Metro approval is required for alignment, designed for speed below maximum Operating Speed.

F. Maximum Operating Speed for LRT systems is set to 65 MPH for exclusive and semi-exclusive alignments, and shall be reduced as necessary under the requirements of CPUC GO 143 Table1.

G. Maximum Operating Speed for HRT systems is set to 75 MPH.

H. Horizontal and vertical curves are main speed constraining elements in alignment, therefore the curve data, including the design speed (speed, allowed by geometry, also called civil speed), shall be clearly presented on a track Plan and Profile drawings. To optimize the geometry, design speed shall match the speed limits breakout (speed codes), established by Metro Rail Operations.

I. Horizontal and vertical geometry shall be produced; using industry accepted Civil Engineering Geometry Software (i.e. InRoads by Bentley) for every track, including crossovers. Centerline of the right Main Track shall be used as a guideway baseline to establish controls for other systems elements. Stationing of the left track (mismatched due to curvatures) shall be equated with right track stationing at the beginning of every parallel track segment of the alignment.

4.1.6.2 Horizontal Alignment - Tangent

A. Main line

1. Length of a tangent shall be defined as
   L=3V,
   Where L is length in ft,
   V is design speed in MPH
2. Minimum length shall be 100 ft for LRT systems, 75 ft for HRT

B. Passenger stations

Passenger station platform shall be located on a tangent.

Minimum length tangent shall extend 50 ft beyond each end of the passenger platform for LRT systems and 75 ft for HRT.

4.1.6.3 Horizontal Alignment - Curves

A. Curvature and Length

1. Circular curves shall be defined by arc definition and specified by their radii.
2. Minimum radius for LRT alignment shall be 100 ft, for HRT 250 ft.
3. Minimum radius for both LRT and HRT alignment in bored tunnels shall be 1,000 ft; sharper curvature shall be justified per boring machine specifications and approved by Metro.
4. Length shall be defined by the formula L=3V, where L is length of circular curve in feet, V is the train speed in MPH.
5. Minimum length shall be 100 ft for LRT and 75 ft for HRT alignments.

B. Superelevation

1. Superelevation shall be used on curved track to reduce the lateral centrifugal force, applied to the car and the passenger, by rotating the car around track centerline toward the center of the curve.
2. State of equilibrium is reached, when the resulting force, which is the function of speed, curvature and superelevation, is perpendicular to the plane of superelevated track. In state of the equilibrium both of the car axle wheels bear equally on the rails, which provides for vehicle stability in a movement through the curve and the passenger's body is firmly pressed to the seat, which provides for passenger comfort.
3. Equilibrium superelevation shall be divided in two elements:

   E=Ea+Eu, where

   Ea – actual superelevation, defined as a height difference between inner (low) and outer (high) top of rail of the superelevated track,

   Eu – unbalanced superelevation, equivalent to the part of centrifugal force, not balanced by actual superelevation
4. Actual superelevation limit is 4 inches, unbalanced – 3 inches. Metro prior approval is required for increase of unbalanced superelevation to 4.5 inches. Rail vehicle suspensions characteristics shall be

considered by designer to justify superelevation increase for Metro approval.

5. Equilibrium (total) superelevation shall be defined by formulas:

   $E= 3.839V^2/R$ for LRT systems
   $E= 4.011V^2/R$ for HRT systems,

   Where E is the total superelevation in inches, V is design speed through the curve in MPH, R is curve radius in feet.

6. Values for superelevation shall be rounded to 0.25 inches in contract documents. For calculated total superelevation of 0.5 inches or less, no actual superelevation is required.

C. Transition Curves and Superelevation Run-Off

1. Transition curves are ones with variable curvature, where radius is changing from infinity at a tangent point to the radius of the adjacent circular curve at curve point. Barnett spiral shall be used for transition curve.

2. Transition curves (spirals) may be used to connect tangents to non-superelevated circular curves on main tracks to reduce the flange/rail impact at the beginning of the curve.

3. Spirals shall be used to connect tangents to superelevated circular curves on main tracks to provide the superelevation run-off and reduce the flange/rail impact at the beginning of the curve. The length of the spiral shall be sufficient to accommodate full superelevation run-off.

4. Superelevation run-off is a portion of the track outside of superelevated curve, where the track plane is changing from horizontal at the tangent point to fully rotated one at the circular curve point.

5. The length of the superelevation run-off and accordingly of the spiral shall be defined by the 3 parameters below:

   Roll – controls the speed of car rotation around track centerline

   $L_{Roll}=1.17 \times Ea \times V$

   Lateral jerk – controls the acceleration, caused by centrifugal force, not balanced by the actual superelevation Ea

   $L_{Lateral\ jerk}=1.22 \times Eu \times V$

   Twist (racking) – controls the plane, created by four corners (four wheels) on a bottom of the car

   $L_{Twist}=31 \times Ea$

   The highest value from the above three formulas shall be used as a length of the spiral

6. Minimum length of the spiral shall be 100 ft for LRT and 75 ft for HRT alignments.

7. To achieve the highest level of vehicle stability and passenger comfort, the unbalanced superelevation (Eu) shall be minimized, by using maximum allowed actual superelevation (Ea) in equation E=Ea+Eu.

8. Requirements in this section apply to spirals/superelevation run-off between compound curves.

4.1.6.4 Vertical Alignment - Tangents

A. Main Line

1. Maximum (ruling) grades for LRT systems shall be:

   G_{Ruling} =5% - for grade length from 500 to 1000 ft between vertical points of intersection

   G_{Ruling} =6% - for grade length less than 500 ft between vertical points of intersection

2. Maximum (ruling) grade for HRT systems shall be

   G_{Ruling} =4%

3. Maximum (ruling) grade shall be reduced through horizontal curves, using compensated grade, per formula

   $G=G_{Ruling} – 229.2/R$

   Where G is total grade in percent, allowed through the horizontal curve, G_{Ruling} is the maximum allowed grade in percent, R is the radius of the horizontal curve in feet

4. Minimum length of vertical tangent shall be defined as

   $L=3V$,

   Where L is tangent length in feet, V is design speed in MPH.

5. Minimum length of vertical tangent shall be 100 ft for LRT and 75 ft for HRT alignments

B. Passenger and service platforms

Maximum track grade at the platform shall be 1%

Vertical tangent shall extend 50 ft beyond ends of platform for LRT and 75 ft for HRT systems

C. Service and Yard Tracks

1. Connecting tracks shall to be graded down away from the Main Tracks. If grading down toward Main Tracks is necessary, Main Track protection, like derail, shall be provided to prevent run away car from reaching the Main Track.

2. Stub end tracks shall be graded down toward the bumping post; otherwise grade shall not exceed 0.2%.

3. Storage tracks shall be level or the dish profile (a sag in middle) shall be provided. Dish profile grades shall not exceed 0.2%.

4.1.6.5 Vertical Alignment - Curves

1. Parabolic curves shall be used to connect vertical tangents with different grades
2. Vertical curves shall be used for grade differences in excess of 0.1%
3. Equivalent radius shall be used to specify the curvature of parabolic vertical curve:

   $R=3.583V^2$,

   Where R is equivalent radius of vertical curve in feet, V is design speed in MPH
4. Minimum equivalent radius of vertical curve shall be 1650 ft for LRT and 2000 ft for HRT alignments
5. Conversion from equivalent radius (R) to rate of change (r), if necessary, shall be defined as:

   $r = 10{,}000/R$,

   Where “r” is rate of change in percent per 100 ft stations, R is equivalent radius of vertical curve in feet.
6. Length of vertical curve shall be defined as:

   $L=R \times (G_1 + G_2)$,

   Where L is length of vertical curve in feet, R is equivalent radius of vertical curve in feet, G_1 and G_2 are two adjacent grades in decimal fractions.
7. Minimum length of vertical curve shall be 100 ft for LRT and 150 ft for HRT alignments.
8. Vertical curve shall not be closer, than in 50 ft to the end of passenger or service platform for LRT and 75 ft for HRT systems.

4.2 TRACKWORK

4.2.1 Introduction

This section provides requirements for design of track structure, which includes:

- Subballast
- Ballast
- Ties
- Rails
- Special trackwork
- Track appurtenances and other track materials

4.2.2 General

- Trackwork shall conform to recommendations set forth in the most current American Railway Engineering and Maintenance-of-Way Association (AREMA) Manuals for

Railway Engineering and the Portfolio of Trackwork Plans, except where modified to reflect the physical and operating characteristics of the system.

- Track structure shall be designed to reduce levels of stray currents resulting from the use of the running rails as the negative return circuit for the traction current.
- Track structure shall be designed to reduce the noise and vibration transmission due to the passage of the transit vehicles to levels that are not intrusive in adjacent properties and not uncomfortable for transit patrons.
- Track structure shall be designed for the maximum degree of constructability and maintainability. Maximum accessibility should be provided to track structure components requiring frequent maintenance (i.e. special trackwork, grade crossings, direct fixation fasteners, etc.)
- Track components design shall be standardized to facilitate maintenance and minimize the inventory of materials.

4.2.3 Categories of Tracks and Types of Track Structures

There are two main categories of tracks in Metro rail transit system:

- Mainline Tracks – Tracks that carry revenue passengers.
- Yard and Secondary Tracks - Tracks that do not carry revenue passengers, such as service tracks, provided for storage, maintenance or non-revenue connections.

Trackwork may include the following types of track structure:

- Ballasted track
- Direct fixation track
- Slab track
- Embedded track
- Paved track

4.2.3.1 Ballasted Track

Ballasted track structure in Metro rail systems consists of rails, seated on tie plates/pads fastened to ties; and ties embedded in ballast layer. There shall be a layer of subballast between the ballast and compacted subgrade.

Ballasted track shall be used for trackwork in at-grade guideway, yards and other secondary tracks.

The minimum depth of subballast measured from the bottom of the ballast at the centerline of the rail to the top of subgrade shall be 8" for mainline track and 6" for yard and secondary tracks.

The minimum depth of ballast from the bottom of the tie at the centerline of the rail to the top of subballast shall be 12" for mainline tracks and 8" for yard and secondary tracks.

The ballast shoulders shall be at least 12" wide. If safety walk is required on ballast shoulders, they shall be at least 30 inches wide.

The final top of ballast elevation shall be level to the top of tie except in the area six inches on either side of the rail where the ballast must be cribbed to maintain one inch of clearance between the bottom of the rail and the top of ballast.

AREMA Size No. 4 ballast shall be used, except at grade crossings and embedded tracks where AREMA Size No. 5 ballast shall be used to reduce settlement.

Subballast shall conform to AREMA specifications

Approach slabs shall be used to provide smooth transition from ballasted track to direct-fixation track and vise versa. Approach slabs shall be installed so that the minimum depth of ballast under the ties is 12 inches.

4.2.3.2 Direct Fixation Track

Direct fixation track structure in Metro rail systems consist of rail, seated on plates/pads, fastened to second pour concrete plinths; plinths are connected to bridge, tunnel or another supporting structure.

Direct fixation track structure shall be used for aerial, underground and semi-depressed guideways.

4.2.3.3 Slab Track

Concrete slab track structure consists of rail, seated on plates/pads, fastened to continuously reinforced concrete slab supported by a stabilized subbase on compacted subgrade.

Slab track structure may be used in some segments of the at-grade guideway if directed by Metro.

4.2.3.4 Embedded Track

Embedded track structure in Metro rail systems consist of rail encased in 4000 psi concrete up to top of rail level. Track structure shall have provisions for gage, alignment and cross level track adjustment prior to encasement to meet Metro construction tolerance requirements. Flangeway shall be provided as necessary; widening of the flangeway is needed in horizontal curves with radii 500 ft or less. However, at pedestrian crossings width of the flangeway shall not exceed 2.5 inches.

Electrical insulation shall be provided with track-to-earth resistance level 300 Ohms-1,000 ft.-2 rails.

The electrical resistance from rail to rail minimum value is 3 ohms per 1000 feet for existing construction and minimum 5 ohms per 1000 feet for new construction.

Embedded track structure shall be used in at-grade guideway located on a public street, where emergency or other road vehicles are allowed to ride over the Metro tracks.

4.2.3.5 Paved Track

Paved track structure in Metro rail systems consists of ballasted track, covered at a top of rail level by concrete or elastomeric plates, or asphalt concrete pavement with flangeways, drainage and electrical insulation (see 4.2.3.4 above).

Paved track shall be used at grade crossings in a ballasted track at-grade guideway and yards. If directed by Metro it may be used in a public street as a substitute for embedded track.

4.2.4 Track Gauge

The standard track gauge shall be 4'-8 1/2". Track gauge shall be measured between the gauge sides of the heads of rails at a distance of 5/8" below the top of rails. Wider gauges shall be used in some curves, depending upon the degree of curvature.

Gauges for special trackwork shall be as recommended in the AREMA Portfolio of Trackwork Plans except as modified to reflect the physical and operation characteristics of the system.

Track gauges shall be as follows:

4.2.4.1 Light Rail Transit System

These gauges are based on the use of a standard American Association of Railroads multiple wear wheel profile with gauge of 4'-7 11/16" and axle spacing between 6 feet and 7 feet.

- Tangent track and curves with radius equal to or larger than 500'-gauge: 4'-8 1/2"
- Curves with radius from 250' to 500' - gauge: 4'-8 3/4".
- Curves with radius larger than 82' but less than 250' - gauge: 4'-9".

4.2.4.2 Heavy Rail Transit System

These gauges are based on the use of standard American Association of Railroads multiple wear wheel profile with a gauge of 4'-7 11/16" and an axle spacing between 7 feet and 8 feet 6 inches.

- Tangent track and curves with radius equal to or larger than 1000'-guage: 4'-8 ½.
- Curves with radius smaller than 1000' but equal to or larger than 780'-gauge: 4'-8 ⅝.
- Curves with radius smaller than 780' but equal to or larger than 500'-gauge: 4'-8 ¾.
- Curves with radius smaller thank 500'-gauge: 4'-9".

Incremental gauge widening of 1/16" shall be accomplished in a transition distance of 31'. Gauge widening shall be distributed through the spiral curve for a spiral-circular-spiral type curve. For circular curves without spirals, the gauge widening distance shall be distributed by placing half the distance on the tangent and half on the circular curve.

~~Gauges for special trackwork shall be as recommended in the AREMA Portfolio of Trackwork Plans except as modified to reflect the physical and operation characteristics of the system.~~

4.2.5 Alignment and Superelevation

For horizontal and vertical alignment and superelevation, refer to Section 4.1 Guideway.

4.2.6 Construction Tolerances

Track construction tolerances are determined by taking into consideration safety, speed of operation, and type of service to be provided shall be pursuant to FRA Class 6 Track Safety Requirements. Recommended construction tolerances are shown in Table 4.1.

TABLE 4.1
TRACK CONSTRUCTION TOLERANCES

			Vertical Track Alignment		Horizontal Track Alignment	
Type of Track	Gauge Variation	Cross Level and Superelevation Variation	Total Deviation	Middle Ordinate in 62' Chord	Total Deviation	Middle Ordinate in 62' Chord
Mainline Direct Fixation and Embedded Track	± 1/16"	± 1/16" Ea 1/8" Max Total	± 1/8"	± 1/8"	± 1/8"	± 1/16" Tangent 1/8" Curve
Main Line Ballasted Track	± 1/16"	± 1/16" Ea 1/8" Max Total	± 1/8"	± 1/8"	± 1/8"	± 1/16" Tangent 1/8" Curve
Yard Track	± 1/16"	± 1/16" Ea 1/8" Max Total	± 1/8"	± 1/8"	± 1/8"	± 1/16" Tangent 1/8" Curve

Notes:

(1) Variations of gauge, cross level, and superelevation shall not exceed 1/16" per 31' of track.
(2) Total deviation is measured between the theoretical and actual alignment at any point in the track.
(3) Total horizontal deviation in passenger platform areas shall be zero inches toward the platform and 1/8 inch away from the platform

4.2.7 Rail

The standard rail section shall be 115 RE as shown in Figure 4.23. Rails shall be either control-cooled carbon steel or special alloy rails manufactured in accordance with the requirements of AREMA.

- Standard strength rails shall be used where excessive rail wear is not anticipated. These rails shall be control-cooled carbon steel rail.
- Where excessive rail wear is anticipated, high strength rails shall be used. These rails shall be control-cooled or special alloy rails and either fully heat-treated or head hardened.

High Strength rails shall be used only:

- On curves in LRT mainline track with a radius of 500' or less and in HRT mainline traffic with radius of 2000' or less. The high strength rail shall extend into the tangent track a minimum of 35 feet beyond the point of tangency.
- On grades greater than 3 percent.
- In areas of repeated acceleration and/or decelerations such as passenger stations. High strength rail shall extend at least 100' beyond the ends of the platform.
- Within special trackwork units.

High-strength rail may be used in other areas where excessive rail wear is anticipated but only with prior written approval from Metro.

High strength rails shall not be used on secondary, emergency, or storage tracks unless excessive rail wear is anticipated and only upon approval by the Metro.

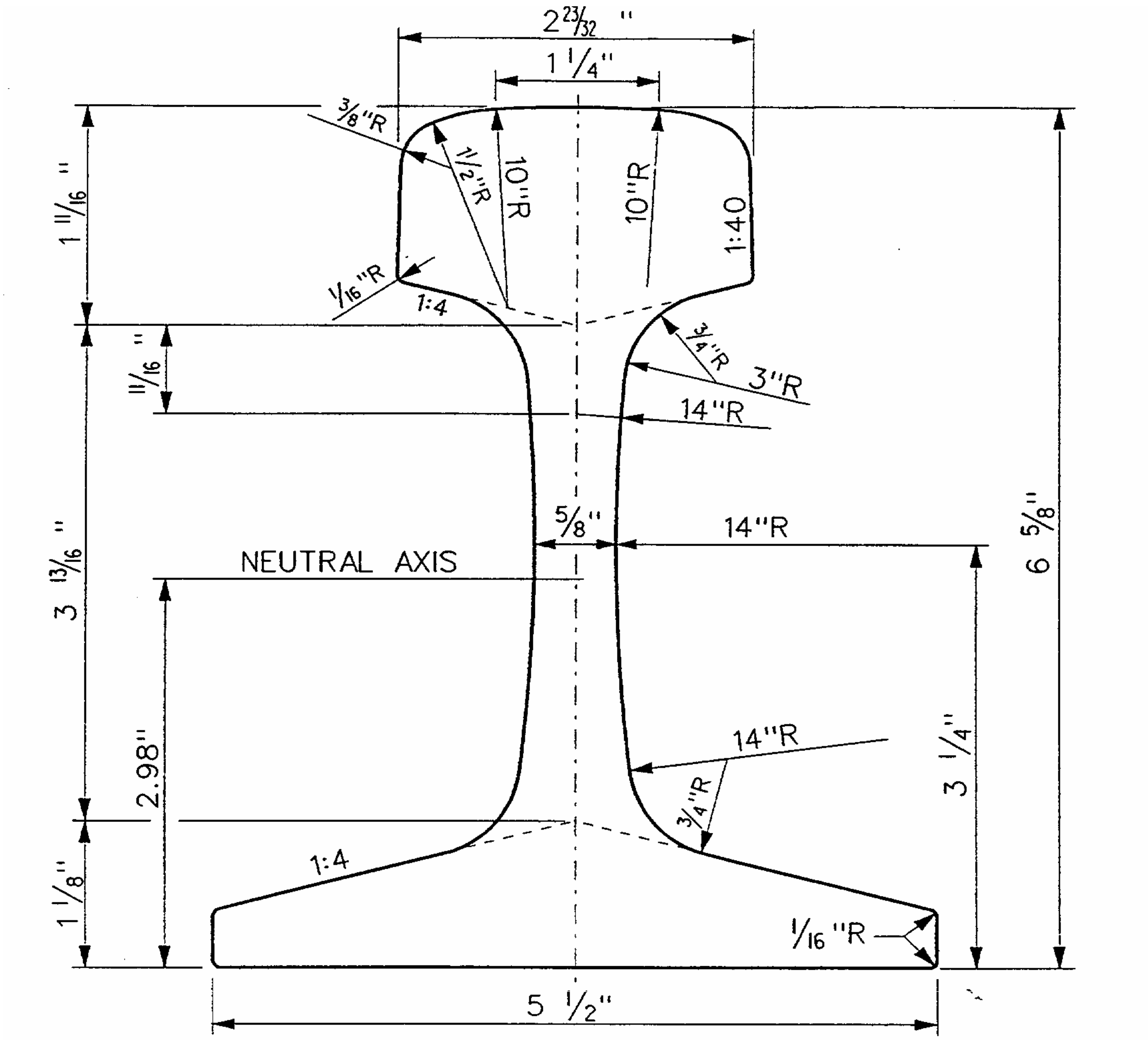
Rails in curves with radii of 300' or less shall be precurved using standard shop practices.

4.2.7.1 Continuously Welded Rail

All rail shall be installed as continuously welded rail (CWR) except where noted below.

1. Special trackwork.
2. Curves where rail handling may be a problem

Structural joints: Certain structural design features of tunnels, subways, aerial structures, or bridges may require that the rail be jointed and/or provided with expansion joints.



RAIL	AREA (Sq. In.)
Head	4.03
Web	2.80
Base	4.42
Total	11.25

Rail weight	114.7 Lbs./Yd.
Moment of inertia	65.9 $In.^4$
Section modulus, head	18.1 $In.^3$
Section modulus, base	22.0 $In.^3$
Moment of Inertia Vert Axis	10.8 $In.^4$

FIGURE 4.23 115RE RAIL SECTION

4.2.7.2 Rail Anchoring

Anchorage for CWR shall be provided by the rail fastening system of the direct fixation fasteners or concrete ties to deter expansion and contraction of rail ends, and to prevent rail creep. At critical locations, it may be necessary to relieve expansion and contraction of the rail to prevent damage to the track or to the supporting structure. When the anticipated stresses or movement of the rail cannot be relieved, expansion joints or low restraint rail clips shall be considered.

In the conventional ballasted track construction where timber ties and track spikes are used, rail anchors shall be installed. Box anchoring of ties shall be in accordance with the AREMA recommendations.

4.2.7.3 Rail Welding

Welding of rails into CWR strings shall be either by electric flash butt process or thermit process. Electric flash butt welding shall be used wherever feasible. Thermit welding or mobile electric flush butt welding shall be used to join strips of CWR; where required for rail handling; or where rail requires precurving.

Rail welding shall be in accordance with the AREMA recommendations and as modified in the Technical Specifications.

4.2.7.4 Rail Joints

Rail joints shall be used where rail welding is not practical or where required by signal track circuits.

Thirty-six inch long, six hole joint bars shall be used at rail joints. Drillings, punching and track bolts shall be as recommended by the AREMA "Manual for Railway Engineering," Chapter 4, Part 1.

Where required by the signal track circuits, insulated rail joints shall be installed. These insulated rail joints shall meet the following track requirements:

- They shall conform with the requirements for rail joints specified by AREMA for 36-inch joint bars.
- They shall be compatible with the requirements for the CWR, and be able to transfer the longitudinal rail loads, due to thermal expansion and contraction of the rail.
- They shall not interfere with the rail fasteners or restraining rail design.
- Their design shall prevent excessive wear and damage to component parts.

4.2.8 Guardrails

4.2.8.1 Restraining Rails

Tracks with sharp curvatures shall have the inside running rail guarded with restraining rail to prevent derailments due to wheels climbing and to reduce rail wear. Restraining rail shall be installed in the following tracks:

All mainline tracks with a radius less than 500' for LRT Systems and less than 780’ for HRT System.

All yard and non-revenue secondary track with a radius of 100' or less, for LRT System and 370’ or less for HRT System.

These requirements do not apply to special trackwork.

Restraining rail shall extend beyond the curve onto tangent track on each end of the curve a minimum distance of 35 feet on each end of the curve.

Restraining rail shall be in accordance with the Standard Drawings and the Technical Specifications.

4.2.8.2 Emergency Guardrails

Emergency guardrails or check rails may be provided on ballasted or direct fixation bridges subject to the approval by Metro.

Guardrails may be made of either new or used tee rails, or standard structural shape and shall be installed near the gauge side of the inner rail at a distance of approximately 12" from the running rail.

Guardrails shall extend 60 feet ahead of the abutment face on the approach end and 30 feet beyond the abutment on the departure end of each structure. The above lengths do not include the end approaches of the inner guardrails, which shall be 16 feet long at each end and tapered to the center of the track.

If the guardrails are continuously welded, the longitudinal forces they generate shall be considered in the design of the structures and the track.

As the restraining rails and emergency guardrails are made of steel, the effects of induced electrical currents in these rails shall be considered because of their proximity to the running rails that are carrying electrical return currents.

4.2.9 Ties

All ballasted mainline and yard tracks shall use concrete ties. Timber ties may be used in special circumstances as approved by the Metro.

Concrete ties shall be spaced 30" center to center on tangent, and curved track of a radius greater than or equal to 500'. On curves of radii less than 500', concrete ties shall be spaced 24" center to center.

Timber ties shall be spaced 24" center to center on tangent and curved tracks with radii greater than or equal to 300'. On curves of radius less than 300', timber ties shall be spaced 20" center to center.

For ballasted embedded track and road crossings, the tie spacing shall be 24" center to center, for both concrete ties and timber ties.

Concrete crossties shall be 8'-0" or 8'-3" in length conforming to the current Metro-furnished material specifications. Timber crossties shall be 8'-6" in length, conforming to AREMA 7-inch grade crossties.

Switch ties for special trackwork shall be made of concrete. Timber may be used subject to approval by Metro. Switch ties for special trackwork shall be spaced as established by AREMA and the trackwork standard drawings. Dimensions of concrete switch ties shall be as recommended by the manufacturer and as approved by Metro. Timber switch ties dimensions when used shall be 7" x 9" and of various lengths as required.

Concrete ties and timber ties shall conform to the AREMA specifications.

4.2.10 Rail Fastenings

Ballasted, direct fixation, and embedded tracks shall use a fastening system which shall electrically isolate the rail from the tie and the ballast or track concrete. It shall also dampen the noise and the vibration due to the passing of the vehicle.

Ballasted track with concrete ties shall use a fastening system consisting of an embedded rail clip shoulder, elastic rail clips, rail insulators and elastomer pads.

Direct fixation and embedded track shall use a fastening system consisting of elastic rail clips, elastomer pad, and anchor bolts. Direct-fixation fasteners shall be spaced 30" center to center on the mainline and 33" center to center in the yard shall be placed opposite each other.

Ballasted track with timber ties shall use a fastening system similar to that for direct-fixation track, except that screw spikes shall be used in lieu of anchor bolts.

Special trackwork shall use a fastening system similar to either the direct fixation track, or ballasted track depending on the type of track construction of the adjacent area. The spacing of the fasteners shall be as shown on the Directive or Standard Drawings.

The longitudinal rail restraint capability of the rail fastening assembly (two clips) shall be between 1,600 pounds to 2,200 pounds before rail slips.

4.2.11 Special Trackwork

Special trackwork includes turnouts and crossovers. Special trackwork shall be manufactured and installed as recommended in the AREMA specifications and standards, except where modified to meet the special conditions of the Metro Rail System.

All the parts of turnouts and crossovers in embedded or paved track structures shall be provided with electrical insulation, sufficient to comply with requirements for electrical resistance per 4.2.3.4 above. Switch machines, installed in embedded or paved track structures shall have protection rating of NEMA 6P and drainage provisions per 4.1.4.4 above, to prevent flooding damage.

All special trackwork shall be located only on horizontal and vertical tangents. They shall not be located on vertical curves. Special trackwork in areas designated as pedestrian or vehicular crossings shall be avoided. Alignment geometrics shall be arranged in such a manner as to utilize standard frogs and crossing angles. Crossing angles shall be equal to or greater than that of No. 6 ½ frog to avoid the use of complicated design and heavy maintenance frogs such as the movable point frogs.

Turnouts and crossovers shall be selected in accordance with the following criteria:

- No. 20, No. 15, and No. 10 turnouts shall be used where higher speeds are required through the curved portion of the turnouts. These turnouts shall be used for permanent turnback crossovers on terminal and intermediate stations and mainline junctions of routes. No. 10 turnouts shall be used on mainline tracks except if higher speed is required but must be approved by Metro.

- Turnouts at terminal stations shall be minimum No. 15.
- No 8 turnouts shall be used in HRT yards. This turnout may be used for yard access track connections to LRT mainline.
- 190-Foot Radius Lateral turnouts shall be used for turnouts and crossovers in LRT yards and in areas where there are ~~no~~ space limitations.
- 410-Foot Radius or No. 5 Equilateral turnouts shall be used in the LRT mainline pocket tracks.

All turnouts shall use curved split switches in accordance with AREMA Plan No. 221, Point Detail 5100. All frogs shall be of railbound manganese type with wear-resistant guardrails. Metro trackwork standard drawings shall be used as a reference for design of special trackwork.

All Main Line turnouts shall be equipped with integrated roller slide plates (Schwihag or equivalent)

Special trackwork shall not be located within 200 feet of transition between direct-fixation and ballasted track.

4.2.11.1 Allowable Civil Speeds

TABLE 4.2

MAXIMUM ALLOWABLE CIVIL SPEED THROUGH TURNOUT

TURNOUT	CIVIL SPEED (MPH)
190-Foot Radius Lateral Turnout	12
No. 5 Equilateral Turnout	16
No. 8 Lateral Turnout	19
No. 8 Equilateral Turnout	27
No. 10 Lateral Turnout	25
No. 10 Equilateral Turnout	35
No. 12 Equilateral Turnout	43
No. 15 Lateral Turnout	35
No. 20 Lateral Turnout	50

The data shown above are speeds through level turnouts giving ride conditions equivalent to those obtained in traversing a curve elevated 3 inches less than that required for equilibrium – 3 inches of unbalanced superelevation without run-off. (Source: AREMA Chapter 5, Part 3, "Speeds of Trains Through Level Turnouts.")

Speeds through turnouts are calculated based on the AREMA formula $E = 0.007\ V^2D-3$, where D equals the degree of curvature of the closure curve or the switch curve, which ever is sharper.

4.2.11.2 Limiting Dimensions

The minimum distance between a turnout's point of switch and TS (or TC) or PVC shall conform to the distances shown in Table 4.3.

The required distances between P.I.T.O's of various combinations and directions of turnouts for HRT shall be not less than those shown in Table 4.4 through Table 4.9, and Table 4.10 through 4.15 for LRT.

The minimum length of tangent between any point of switch and a station platform shall be 50 feet. The minimum tangent distance proceeding a point of switch shall be 10 feet.

4.2.12 Miscellaneous Track Appurtenances

4.2.12.1 Bumping Posts

Bumping Posts shall be designed to engage the anticlimber of the transit vehicle. They shall be installed at the ends of all stub-end tracks

4.2.12.2 Derails

Derails shall be used only at those locations specified by Metro. These devices are normally used on tracks used for storage of unattended vehicles, when directly connected to the mainline track and with a grade descending toward the mainline track.

4.2.12.3 Rail Lubricators

Rail Lubricators shall be installed in areas where excessive rail wear or wheel squeal near noise-sensitive areas is anticipated. Location shall be coordinated with Metro.

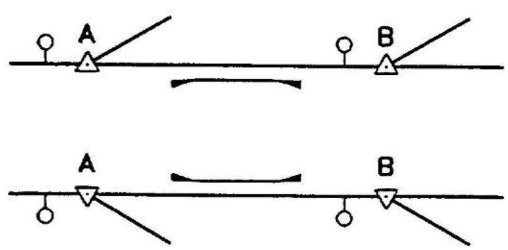
TURNOUT NO	TYPE OF TRACK CONSTRUCTION	MINIMUM DISTANCE FROM POINT OF SWITCH THRU TURNOUT TO:	
		T.S. OR T.C.	P.V.C.
190'R	DIRECT FIXATION	49.00'	49.00'
190'R	BALLASTED	53.00'	53.00'
5Y	DIRECT FIXATION	52.00'	52.00'
5Y	BALLASTED	59.00'	59.00'
410R-Y	DIRECT FIXATION	52.00'	52.00'
410R-Y	BALLASTED	59.00'	59.00'
6	DIRECT FIXATION	59.00'	59.00'
6	BALLASTED	71.00'	71.00'
8	DIRECT FIXATION	86.00'	86.00'
8	BALLASTED	98.00'	98.00'
8-Y	DIRECT FIXATION	80.00'	80.00'
8-Y	BALLASTED	95.00'	95.00'
645'R	DIRECT FIXATION	86.00'	86.00'
645'R	BALLASTED	98.00'	98.00'
10	DIRECT FIXATION	94.00'	94.00'
10	BALLASTED	112.00'	112.00'
15	DIRECT FIXATION	137.00'	137.00'
15	BALLASTED	163.00'	163.00'
20	DIRECT FIXATION	184.00'	184.00'
20	BALLASTED	220.00'	220.00'

LIMITING DIMENSIONS FOR SPECIAL TRACKWORK
TABLE 4.3

BACK-TO-POINT TURNOUTS OF SAME HAND

TURNOUT & HAND		A - B DISTANCE	
A	B	8'-0" END APPROACH	4'-0" END APPROACH
6R	6R	84.58	84.58
6L	6L	84.58	84.58
8R	8R	112.44	112.44
8L	8L	112.44	112.44
8R	10R	112.44	112.44
8L	10L	112.44	112.44
8R	15R	112.44	112.44
8L	15L	112.44	112.44
10R	10R	140.35	140.35
10L	10L	140.35	140.35
10R	15R	140.35	140.35
10L	15L	140.35	140.35
10R	20R	140.35	140.35
10L	20L	140.35	140.35
15R	15R	210.23	210.23
15L	15L	210.23	210.23
15R	20R	210.23	210.23
15L	20L	210.23	210.23

Note: Limiting dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.

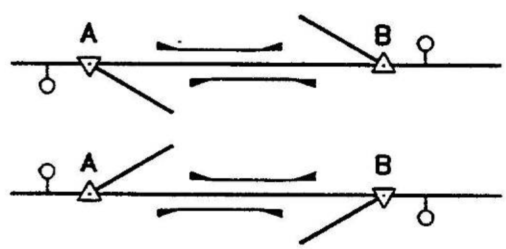


LIMITING DIMENSIONS FOR SPECIAL TRACKWORK (FOR HEAVY RAIL TRANSIT SYSTEM) TABLE 4.4

BACK-TO-TURNOUT OF SAME HAND

TURNOUT & HAND		A - B DISTANCE	
A	B	8'-0" END APPROACH	4'-0" END APPROACH
8R	8R	134.417'	134.417'
8L	8L	134.417'	134.417'
8R	10R	151.605'	151.605'
8L	10L	151.605'	151.605'
8R	15R	189.021'	189.021'
8L	15L	189.021'	189.021'
10R	10R	168.792'	168.792'
10L	10L	168.792'	168.792'
10R	15R	206.209'	206.209'
10L	15L	206.209'	206.209'
10R	20R	244.730'	244.730'
10L	20L	244.730'	244.730'
15R	15R	243.625'	243.625'
15L	15L	243.625'	243.625'

Note: **Limiting Dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.**

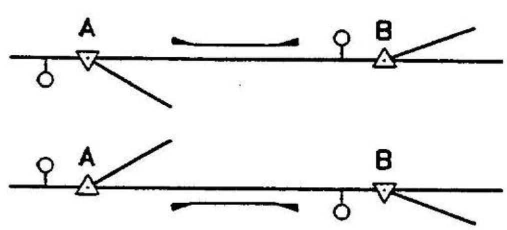


REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR HEAVY RAIL TRANSIT SYSTEM)
TABLE 4.5

BACK-TO-POINT TURNOUTS OF OPPOSITE HAND
(LARGE FROG ANGLE LEADING)

TURNOUT & HAND		A - B DISTANCE	
A	B	8'-0" END APPROACH	4'-0" END APPROACH
8R	8L	105.042'	105.042'
8L	8R	105.042'	105.042'
8R	10L	106.458'	106.458'
8L	10R	106.458'	106.458'
8R	15L	115.021'	115.021'
8L	15R	115.021'	115.021'
10R	10L	123.604'	123.604'
10L	10R	123.604'	123.604'
10R	15L	132.167'	132.167'
10L	15R	132.167'	132.167'
10R	20L	151.730'	151.730'
10L	20R	151.730'	151.730'
15R	15L	169.625'	169.625'
15L	15R	169.625'	169.625'
15R	20L	189.188'	189.188'
15L	20R	189.188'	189.188'

Note: Limiting dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.

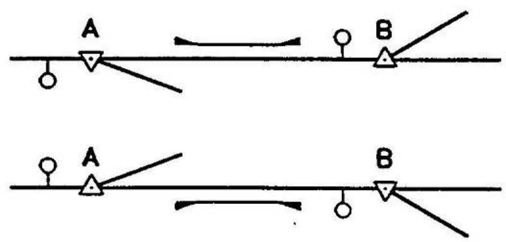


BACK-TO-POINT TURNOUTS OF OPPOSITE HAND
(LARGE FROG ANGLE LEADING)
TABLE 4.6

BACK-TO-POINT TURNOUTS OF OPPOSITE HAND
(SMALLER FROG ANGLE LEADING)

TURNOUT & HAND		A - B DISTANCE	
A	B	8'-0" END APPROACH	4'-0" END APPROACH
10R	8L	122.188'	122.188'
10L	8R	122.188'	122.188'
15R	8L	159.646'	159.646'
15L	8R	159.646'	159.646'
15R	10L	161.062'	161.062'
15L	10R	161.062'	161.062'
20R	10L	201.083'	201.083'
20L	10R	201.083'	201.083'

Note: Limiting dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.

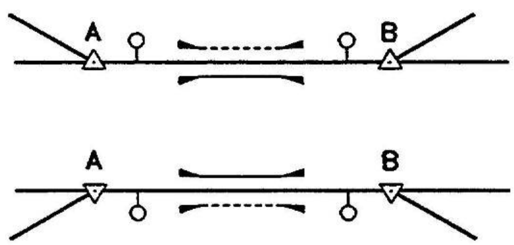


REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR HEAVY RAIL TRANSIT SYSTEM)
TABLE 4.7

POINT-TO-POINT TURNOUTS OF OPPOSITE HAND

TURNOUT		REQUIRED DIST W/O CONTACT RAIL	A - B DISTANCE	
A	B		8'-0" APPROACH	4'-0" APPROACH
6 R L	6 R L	48.792'		
6 R L	8 R L	59.792'		
8 R L	8 R L	76.031'	122.500'	117.500'
8 R L	10 R L	77.448'	123.916'	118.916'
10 R L	10 R L	78.864'	125.333'	120.333'
10 R L	15 R L	83.177'	133.896'	128.896'
10 R L	20 R L	106.990'	153.458'	148.458'
15 R L	15 R L	90.656'	142.458'	137.458'

Note: **Limiting dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.**

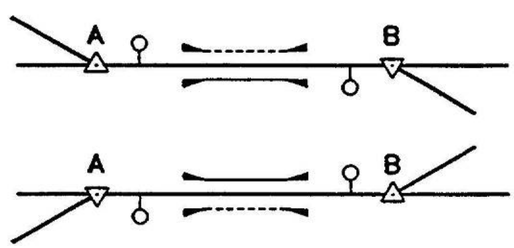


REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR HEAVY RAIL TRANSIT SYSTEM)
TABLE 4.8

POINT-TO-POINT TURNOUTS OF SAME HAND

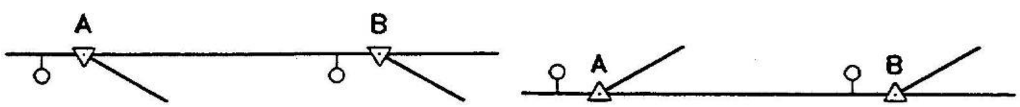
TURNOUT		REQUIRED DIST W/O CONTACT RAIL	A - B DISTANCE	
A	B		8'-0" APPROACH	4'-0" APPROACH
6 R L	6 R L	48.792'		
6 R L	8 R L	59.792'		
8 R L	8 R L	76.031'	122.500'	117.500'
8 R L	10 R L	77.448'	123.916'	118.916'
10 R L	10 R L	78.864'	125.333'	120.333'
10 R L	15 R L	83.177'	133.896'	128.896'
10 R L	20 R L	106.990'	153.458'	148.458'
15 R L	15 R L	90.656'	142.458'	137.458'

Note: Limiting dimensions are based on the use of contact rails between turnouts to avoid unbridgeable gaps.



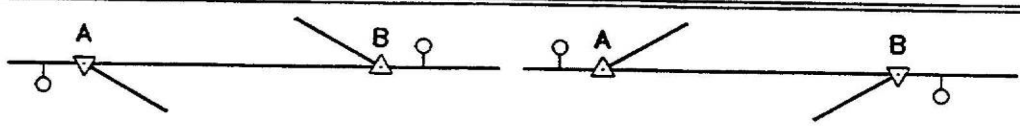
REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR HEAVY RAIL TRANSIT SYSTEM)
TABLE 4.9

TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
190'R -R	190'R -R	60.00	56.88
190'R -L	190'R -L	60.00	56.88
190'R -R	6R	62.92	56.88
190'R -L	6L	62.92	56.88
190'R -R	8R	75.59	56.88
190'R -L	8L	75.59	56.88
6R	6R	84.58	84.58
6L	6L	84.58	84.58
6R	8R	84.58	84.58
6L	8L	84.58	84.58
8R	8R	112.44	112.44
8L	8L	112.44	112.44
8R	10R	112.44	112.44
8L	10L	112.44	112.44
8R	15R	119.50	112.44
8L	15L	119.50	112.44
8R	20R	138.38	122.29
8L	20L	138.38	122.29
10R	10R	140.35	140.35
10L	10L	140.35	140.35
10R	15R	140.35	140.35
10L	15L	140.35	140.35
10R	20R	153.50	140.35
10L	20L	153.50	140.35
15R	15R	210.23	210.23
15L	15L	210.23	210.23
15R	20R	210.23	210.23
15L	20L	210.23	210.23
20R	20R	280.18	280.18
20L	20L	280.18	280.18



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR LIGHT RAIL TRANSIT SYSTEM)
TABLE 4.10

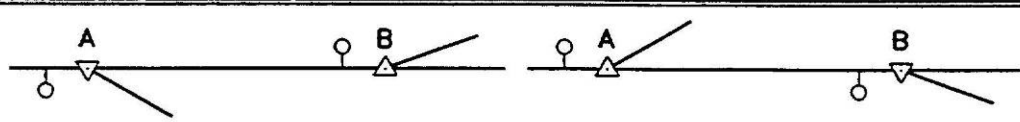
TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
190'R -R	190'R -R	96.78	71.78
190'R -L	190'R -L	96.78	71.78
190'R -R	6R	84.58	84.58
190'R -L	6L	84.58	84.58
190'R -R	8R	112.44	104.41
190'R -L	8L	112.44	104.41
6R	6R	106.33	84.58
6L	6L	106.33	84.58
6R	8R	119.21	112.44
6L	8L	119.21	112.44
8R	8R	132.09	112.44
8L	8L	132.09	112.44
8R	10R	146.22	130.33
8L	10L	146.22	130.33
8R	15R	210.23	195.22
8L	15L	210.23	195.22
8R	20R	280.18	260.17
8L	20L	280.18	260.17
10R	10R	160.35	140.35
10L	10L	160.35	140.35
10R	15R	210.23	195.22
10L	15L	210.23	195.22
10R	20R	280.18	260.17
10L	20L	280.18	260.17
15R	15R	241.01	195.22
15L	15L	241.01	195.22
15R	20R	281.04	260.17
15L	20L	281.04	260.17
20R	20R	321.08	260.17
20L	20L	321.08	260.17



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR LIGHT RAIL TRANSIT SYSTEM)
TABLE 4.11

BACK-TO-POINT TURNOUTS OF OPPOSITE HAND
(LARGER FROG ANGLE LEADING)

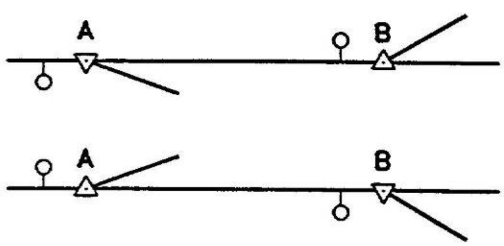
TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
190'R -R	190'R -L	74.00	63.50
190'R -L	190'R -R	74.00	63.50
190'R -R	6L	73.25	62.75
190'R -L	6R	73.25	62.75
190'R -R	8L	85.92	75.42
190'R -L	8R	85.92	75.42
6R	6L	79.00	79.00
6L	6R	79.00	79.00
8R	8L	109.00	101.00
8L	8R	109.00	101.00
8R	10L	108.75	100.67
8L	10R	108.75	100.67
8R	15L	119.50	111.50
8L	15R	119.50	111.50
10R	10L	123.00	113.00
10L	10R	123.00	113.00
10R	15L	133.75	123.75
10L	15R	133.75	123.75
10R	20L	152.63	142.62
10L	20R	152.63	142.62
15R	15L	174.00	154.00
15L	15R	174.00	154.00
15R	20L	192.88	172.88
15L	20R	192.88	172.88



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR LIGHT RAIL TRANSIT SYSTEM)
TABLE 4.12

BACK-TO-POINT TURNOUTS OF OPPOSITE HAND (SMALLER FROG ANGLE LEADING)

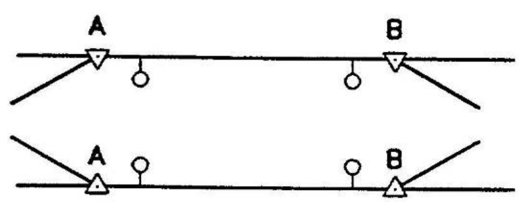
TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
10R	8L	123.25	113.25
10L	8R	123.25	113.25
15R	8L	163.50	143.51
15L	8R	163.50	143.51
15R	10L	163.25	143.26
15L	10R	163.25	143.26
20R	10L	203.42	164.33
20L	10R	203.42	164.33



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS (FOR LIGHT RAIL TRANSIT SYSTEM) TABLE 4.13

POINT-TO-POINT TURNOUTS OF OPPOSITE HAND

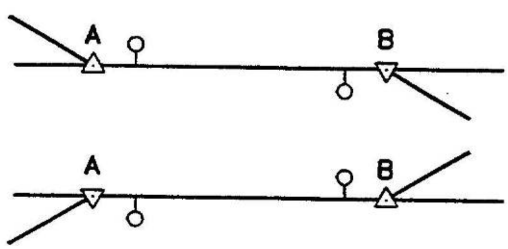
TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
190'R R L	190'R R L	66.32	52.32
190'R R L	6 R L	65.58	51.58
190'R R L	8 R L	78.24	64.24
6 R L	6 R L	64.83	50.83
6 R L	8 R L	77.50	63.50
8 R L	8 R L	90.17	76.17
8 R L	10 R L	89.92	75.92
8 R L	15 R L	100.67	86.67
8 R L	20 R L	119.54	105.54
10 R L	10 R L	89.67	75.67
10 R L	15 R L	100.42	86.42
10 R L	20 R L	119.29	105.29
15 R L	15 R L	111.17	97.17
15 R L	20 R L	130.04	116.04
20 R L	20 R L	148.92	134.92



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR LIGHT RAIL TRANSIT SYSTEM)
TABLE 4.14

POINT-TO-POINT TURNOUTS OF SAME HAND

TURNOUT & HAND		A - B DISTANCE	
A	B	DESIRED	MINIMUM
190'R R/L	190'R R/L	66.32	52.32
190'R R/L	6 R/L	65.58	51.58
190'R R/L	8 R/L	78.24	64.24
6 R/L	6 R/L	64.83	50.83
6 R/L	8 R/L	77.50	63.50
8 R/L	8 R/L	90.17	76.17
8 R/L	10 R/L	89.92	75.92
8 R/L	15 R/L	100.67	86.67
8 R/L	20 R/L	119.54	105.54
10 R/L	10 R/L	89.67	75.67
10 R/L	15 R/L	100.42	86.42
10 R/L	20 R/L	119.29	105.29
15 R/L	15 R/L	111.17	97.17
15 R/L	20 R/L	130.04	116.04
20 R/L	20 R/L	148.92	134.92



REQUIRED DISTANCES BETWEEN P.I.s OF TURNOUTS
(FOR LIGHT RAIL TRANSIT SYSTEM)
TABLE 4.15

CIRCULAR CURVES

I = TOTAL INTERSECTION ANGLE

Δ = CENTRAL ANGLE OF CIRCULAR CURVE $= I - 2\theta S$ (EQUAL SPIRAL LENGTHS)

Δ = CENTRAL ANGLE OF CIRCULAR CURVE $= I - (\theta S1 + \theta S2)$ (UNEQUAL SPIRAL LENGTHS)

DC = DEGREE OF CURVE (ARC DEFINITION) $= \frac{5729.58}{R} = \frac{18{,}000}{\pi R}$

R = RADIUS OF CIRCULAR CURVE

T = TANGENT LENGTH OF CIRCULAR CURVE $= R\tan\frac{\Delta}{2}$

TI = TANGENT LENGTH FROM P.C. TO P.I. TI $= R\tan\frac{I}{2}$

LC = LENGTH OF CIRCULAR CURVE $= \frac{\Delta R}{57.2959} = \frac{\Delta \pi R}{180}$

E = EXTERNAL DISTANCE = R (EXSEC $\frac{\Delta}{2}$)

PC = POINT OF CURVE

PT = POINT OF TANGENCY

TS = TANGENT TO SPIRAL

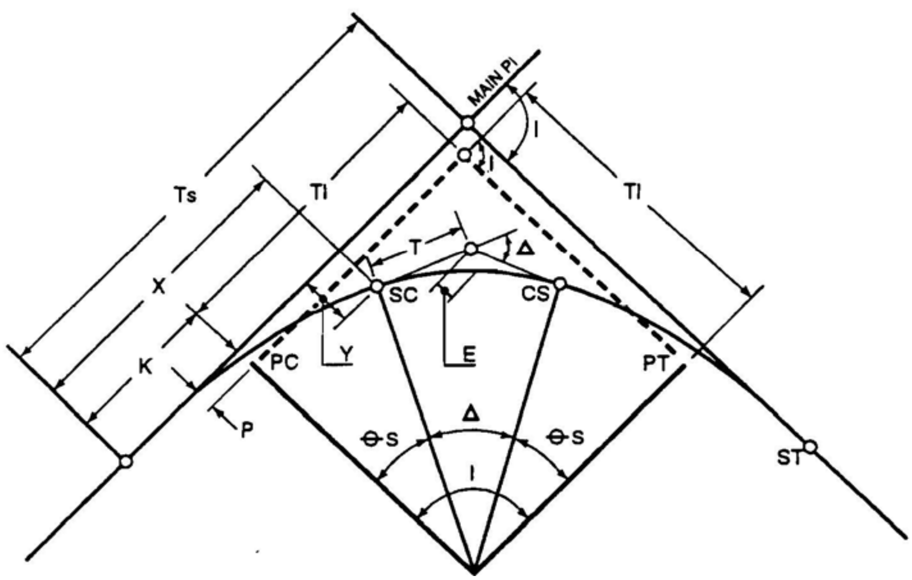
SC = SPIRAL TO CURVE

CS = CURVE TO SPIRAL

ST = SPIRAL TO TANGENT

PI = POINT OF INTERSECTION

NOTE:
SEE FIGURE 4-2 FOR SPIRAL FUNCTIONS AND ABBREVIATIONS.



CIRCULAR CURVES FUNCTIONS AND ABBREVIATIONS
FIGURE 4.1

SPIRAL TRANSITION CURVE

Ls = LENGTH OF SPIRAL

Os = SPIRAL ANGLE = $\frac{5OLs}{TLR}$, $\delta S = \frac{Ls}{2R}$

$X = Ls \left(1 - \frac{5s^2}{10} + \frac{5s^4}{216} - \frac{5s^6}{9360} + \frac{5s^8}{685,440}\right)$

$Y = Ls \left(\frac{5s}{3} - \frac{5s^3}{42} + \frac{5s^5}{1320} - \frac{5s^7}{75,600} + \frac{5s^9}{6,894,720}\right)$

P = Y - R (1 - COS Os)

K = X - R SIN Os

Ts = TANGENT LENGTH FROM T S TO MAIN P 1 (EQUAL SPIRAL LENGTHS) = (R + P) TAN $\frac{I}{2}$ + K

$Ts1 = T_I + K + \frac{P2 - P1 \cos I}{\sin I}$ (UNEQUAL SPIRAL LENGTHS)

$Ts2 = T_I + K + \frac{P1 - P2 \cos I}{\sin I}$

$ST = \frac{Y}{\sin Os}$

$LT = X - \frac{Y}{\tan Os}$

$LC = \sqrt{X^2 + Y^2}$

Δ = CENTRAL ANGLE OF CIRCULAR CURVE

5s = Os EXPRESSED IN RADIANS

Oc, Os, Δ 5 I ARE IN DEGREES

Ea = ACTUAL SUPERELEVATION IN INCHES

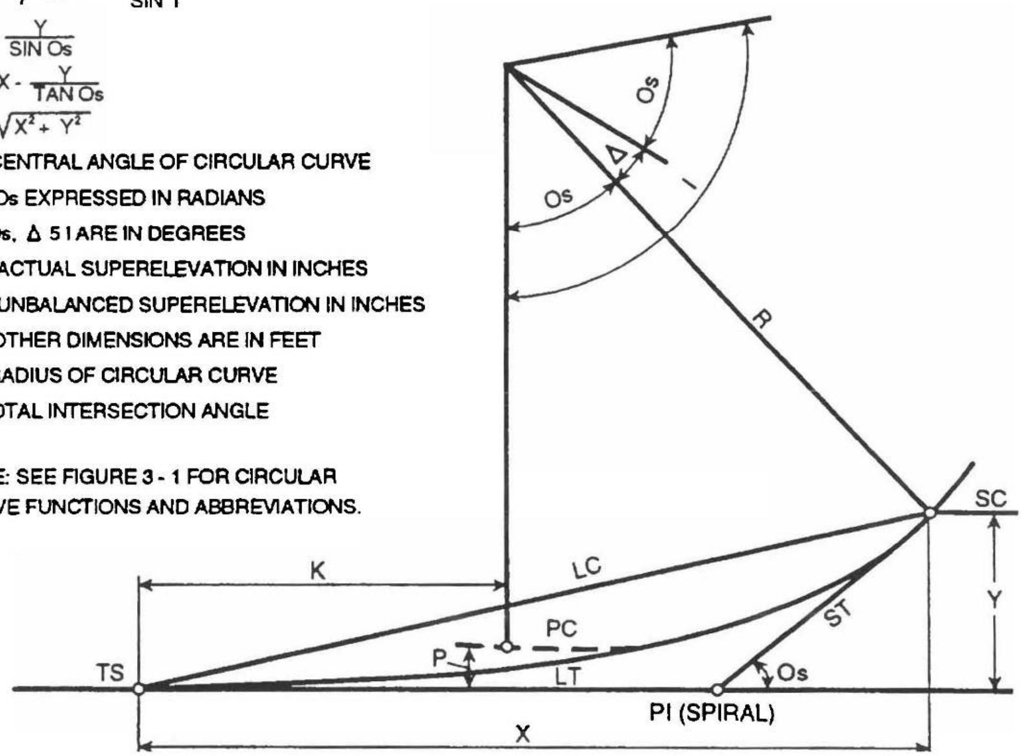
Eu = UNBALANCED SUPERELEVATION IN INCHES

ALL OTHER DIMENSIONS ARE IN FEET

R = RADIUS OF CIRCULAR CURVE

I = TOTAL INTERSECTION ANGLE

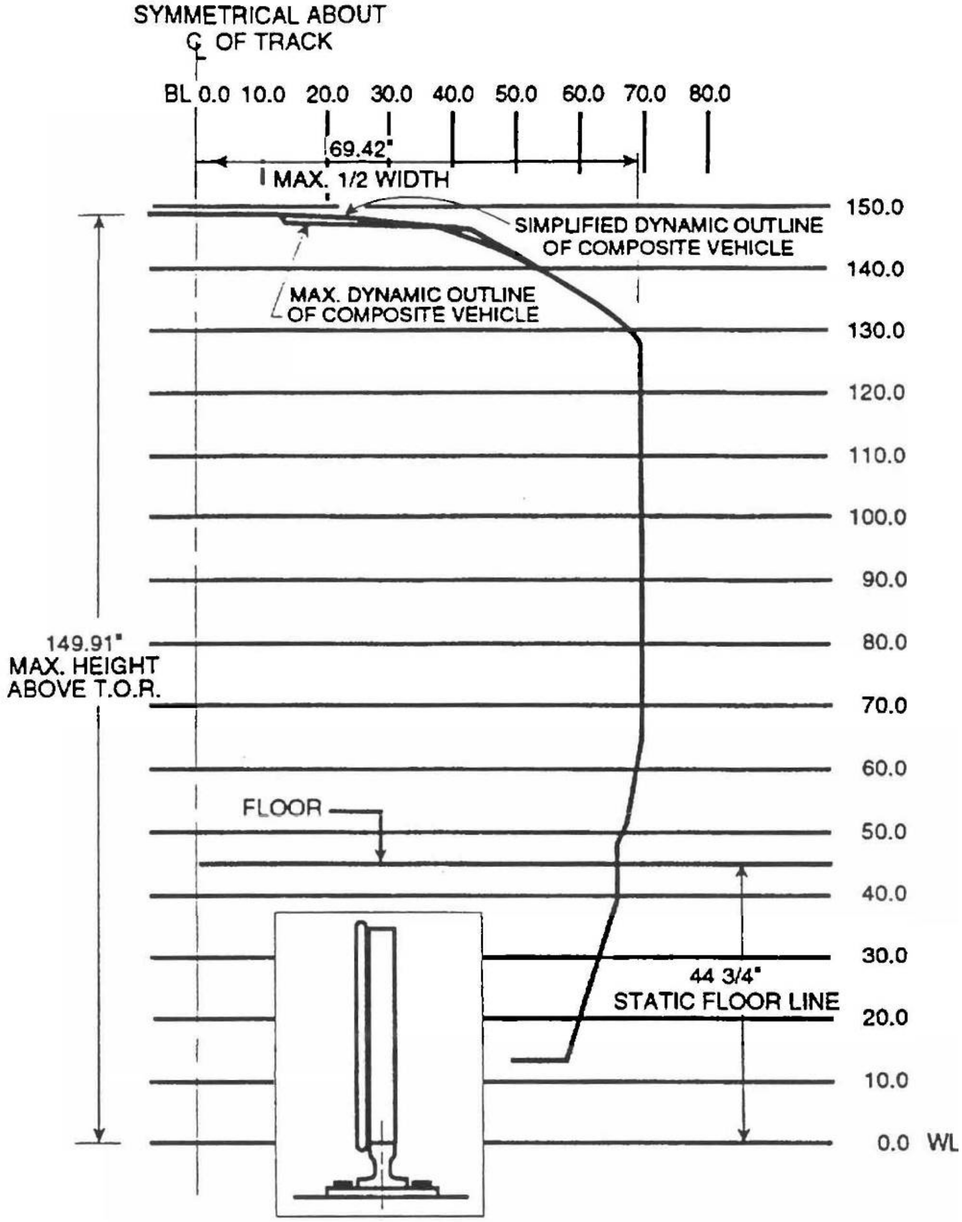
NOTE: SEE FIGURE 3 - 1 FOR CIRCULAR CURVE FUNCTIONS AND ABBREVIATIONS.



SUPERELEVATION

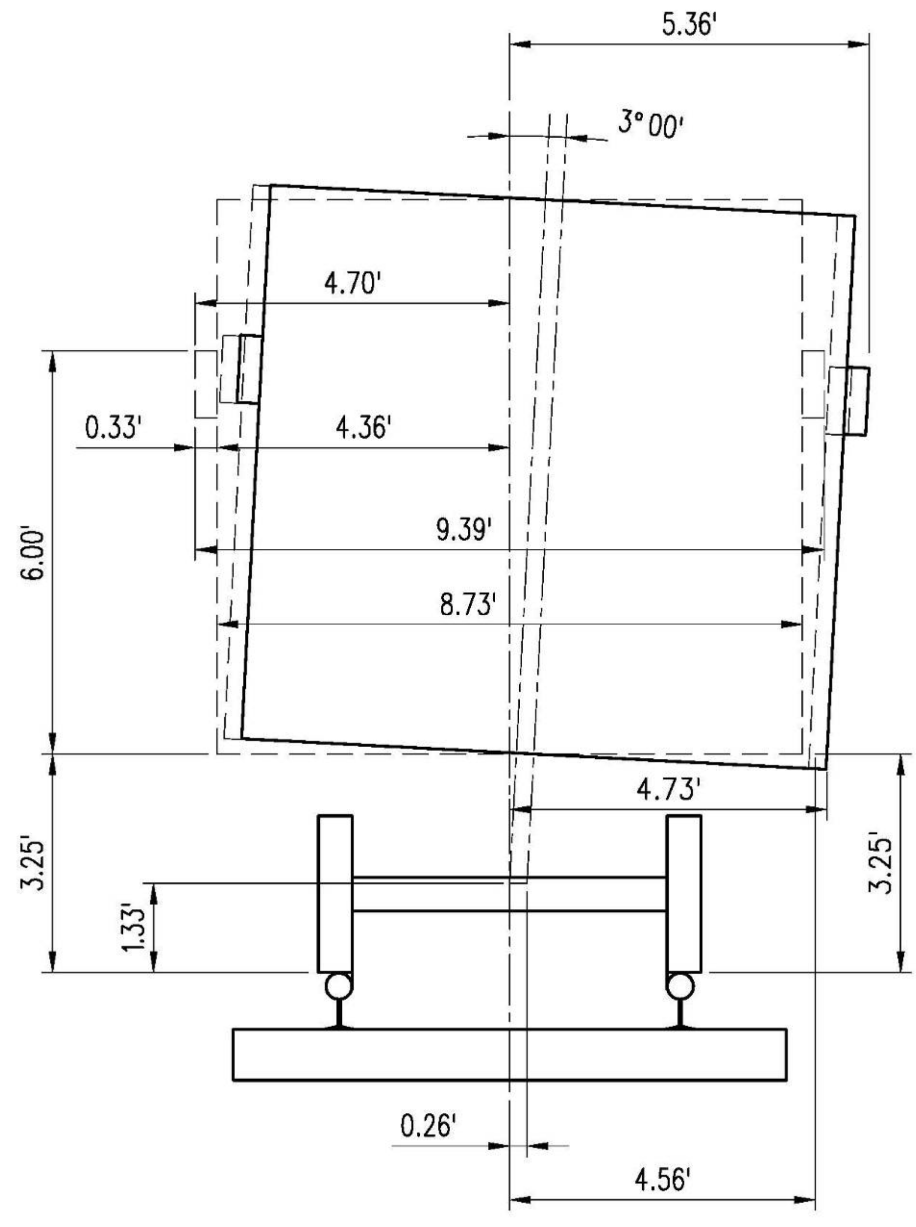
ACTUAL SUPERELEVATION (Ea) WILL BE ATTAINED AND REMOVED LINEARLY THROUGHOUT THE FULL LENGTH OF THE SPIRAL TRANSITION CURVE

SPIRAL CURVES FUNCTIONS AND ABBREVIATIONS
FIGURE 4.2



MAXIMUM DYNAMIC OUTLINE

HEAVY RAIL VEHICLE DYNAMIC ENVELOPE, TANGENT TRACK
FIGURE 4.3



LIGHT RAIL VEHICLE DYNAMIC ENVELOPE
FIGURE 4.4

VEHICLE WIDTH		9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL						
VEHICLE LENGTH		87 FT (EXCLUSIVE OF COUPLERS)						
TRUCK CENTERS		32 FT						
ROLL ANGLE		3 DEGREES						
SUPERELEVATION		0						
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.00	0.40	0.13	0.13	6.93	8.11
100	5.98	7.00	0.00	0.40	0.13	0.13	6.64	7.66
200	5.34	5.90	0.00	0.40	0.13	0.13	6.00	6.56
300	5.12	5.51	0.00	0.40	0.13	0.13	5.78	6.17
400	5.02	5.31	0.00	0.40	0.13	0.13	5.68	5.97
500	4.95	5.19	0.00	0.40	0.13	0.13	5.61	5.85
600	4.91	5.11	0.00	0.40	0.13	0.13	5.57	5.77
700	4.88	5.05	0.00	0.40	0.13	0.13	5.54	5.71
800	4.86	5.00	0.00	0.40	0.13	0.13	5.52	5.66
900	4.84	4.97	0.00	0.40	0.13	0.13	5.50	5.63
1000	4.81	4.92	0.00	0.40	0.13	0.13	5.47	5.58
1500	4.78	4.86	0.00	0.40	0.13	0.13	5.44	5.52
2000	4.76	4.82	0.00	0.40	0.13	0.13	5.42	5.48
8000	4.71	4.73	0.00	0.40	0.13	0.13	5.37	5.39
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 0
FIGURE 4.5

VEHICLE WIDTH		9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL						
VEHICLE LENGTH		87 FT (EXCLUSIVE OF COUPLERS)						
TRUCK CENTERS		32 FT						
ROLL ANGLE		3 DEGREES						
SUPERELEVATION		1 INCH						
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.16	0.40	0.13	0.13	7.09	7.95
100	5.98	7.00	0.16	0.40	0.13	0.13	6.80	7.50
200	5.34	5.90	0.16	0.40	0.13	0.13	6.16	6.40
300	5.12	5.51	0.16	0.40	0.13	0.13	5.94	6.01
400	5.02	5.31	0.16	0.40	0.13	0.13	5.84	5.81
500	4.95	5.19	0.16	0.40	0.13	0.13	5.77	5.69
600	4.91	5.11	0.16	0.40	0.13	0.13	5.73	5.61
700	4.88	5.05	0.16	0.40	0.13	0.13	5.70	5.55
800	4.86	5.00	0.16	0.40	0.13	0.13	5.68	5.50
900	4.84	4.97	0.16	0.40	0.13	0.13	5.66	5.47
1000	4.81	4.92	0.16	0.40	0.13	0.13	5.63	5.42
1500	4.78	4.86	0.16	0.40	0.13	0.13	5.60	5.36
2000	4.76	4.82	0.16	0.40	0.13	0.13	5.58	5.32
8000	4.71	4.73	0.16	0.40	0.13	0.13	5.53	5.23
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 1
FIGURE 4.6

VEHICLE WIDTH		9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL						
VEHICLE LENGTH		87 FT (EXCLUSIVE OF COUPLERS)						
TRUCK CENTERS		32 FT						
ROLL ANGLE		3 DEGREES						
SUPERELEVATION		2 INCHES						
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.33	0.40	0.13	0.13	7.26	7.78
100	5.98	7.00	0.33	0.40	0.13	0.13	6.97	7.33
200	5.34	5.90	0.33	0.40	0.13	0.13	6.33	6.23
300	5.12	5.51	0.33	0.40	0.13	0.13	6.11	5.84
400	5.02	5.31	0.33	0.40	0.13	0.13	6.01	5.64
500	4.95	5.19	0.33	0.40	0.13	0.13	5.94	5.52
600	4.91	5.11	0.33	0.40	0.13	0.13	5.90	5.44
700	4.88	5.05	0.33	0.40	0.13	0.13	5.87	5.38
800	4.86	5.00	0.33	0.40	0.13	0.13	5.85	5.33
900	4.84	4.97	0.33	0.40	0.13	0.13	5.83	5.30
1000	4.81	4.92	0.33	0.40	0.13	0.13	5.80	5.25
1500	4.78	4.86	0.33	0.40	0.13	0.13	5.77	5.19
2000	4.76	4.82	0.33	0.40	0.13	0.13	5.75	5.15
8000	4.71	4.73	0.33	0.40	0.13	0.13	5.70	5.06
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 2
FIGURE 4.7

VEHICLE WIDTH			9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL					
VEHICLE LENGTH			87 FT (EXCLUSIVE OF COUPLERS)					
TRUCK CENTERS			32 FT					
ROLL ANGLE			3 DEGREES					
SUPERELEVATION			3 INCHES					
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.49	0.40	0.13	0.13	7.42	7.62
100	5.98	7.00	0.49	0.40	0.13	0.13	7.13	7.17
200	5.34	5.90	0.49	0.40	0.13	0.13	6.49	6.07
300	5.12	5.51	0.49	0.40	0.13	0.13	6.27	5.68
400	5.02	5.31	0.49	0.40	0.13	0.13	6.17	5.48
500	4.95	5.19	0.49	0.40	0.13	0.13	6.10	5.36
600	4.91	5.11	0.49	0.40	0.13	0.13	6.06	5.28
700	4.88	5.05	0.49	0.40	0.13	0.13	6.03	5.22
800	4.86	5.00	0.49	0.40	0.13	0.13	6.01	5.17
900	4.84	4.97	0.49	0.40	0.13	0.13	5.99	5.14
1000	4.81	4.92	0.49	0.40	0.13	0.13	5.96	5.09
1500	4.78	4.86	0.49	0.40	0.13	0.13	5.93	5.03
2000	4.76	4.82	0.49	0.40	0.13	0.13	5.91	4.99
8000	4.71	4.73	0.49	0.40	0.13	0.13	5.86	4.90
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 3
FIGURE 4.8

VEHICLE WIDTH			9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL					
VEHICLE LENGTH			87 FT (EXCLUSIVE OF COUPLERS)					
TRUCK CENTERS			32 FT					
ROLL ANGLE			3 DEGREES					
SUPERELEVATION			4 INCHES					
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.65	0.40	0.13	0.13	7.58	7.46
100	5.98	7.00	0.65	0.40	0.13	0.13	7.29	7.01
200	5.34	5.90	0.65	0.40	0.13	0.13	6.65	5.91
300	5.12	5.51	0.65	0.40	0.13	0.13	6.43	5.52
400	5.02	5.31	0.65	0.40	0.13	0.13	6.33	5.32
500	4.95	5.19	0.65	0.40	0.13	0.13	6.26	5.20
600	4.91	5.11	0.65	0.40	0.13	0.13	6.22	5.12
700	4.88	5.05	0.65	0.40	0.13	0.13	6.19	5.06
800	4.86	5.00	0.65	0.40	0.13	0.13	6.17	5.01
900	4.84	4.97	0.65	0.40	0.13	0.13	6.15	4.98
1000	4.81	4.92	0.65	0.40	0.13	0.13	6.12	4.93
1500	4.78	4.86	0.65	0.40	0.13	0.13	6.09	4.87
2000	4.76	4.82	0.65	0.40	0.13	0.13	6.07	4.83
8000	4.71	4.73	0.65	0.40	0.13	0.13	6.02	4.74
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

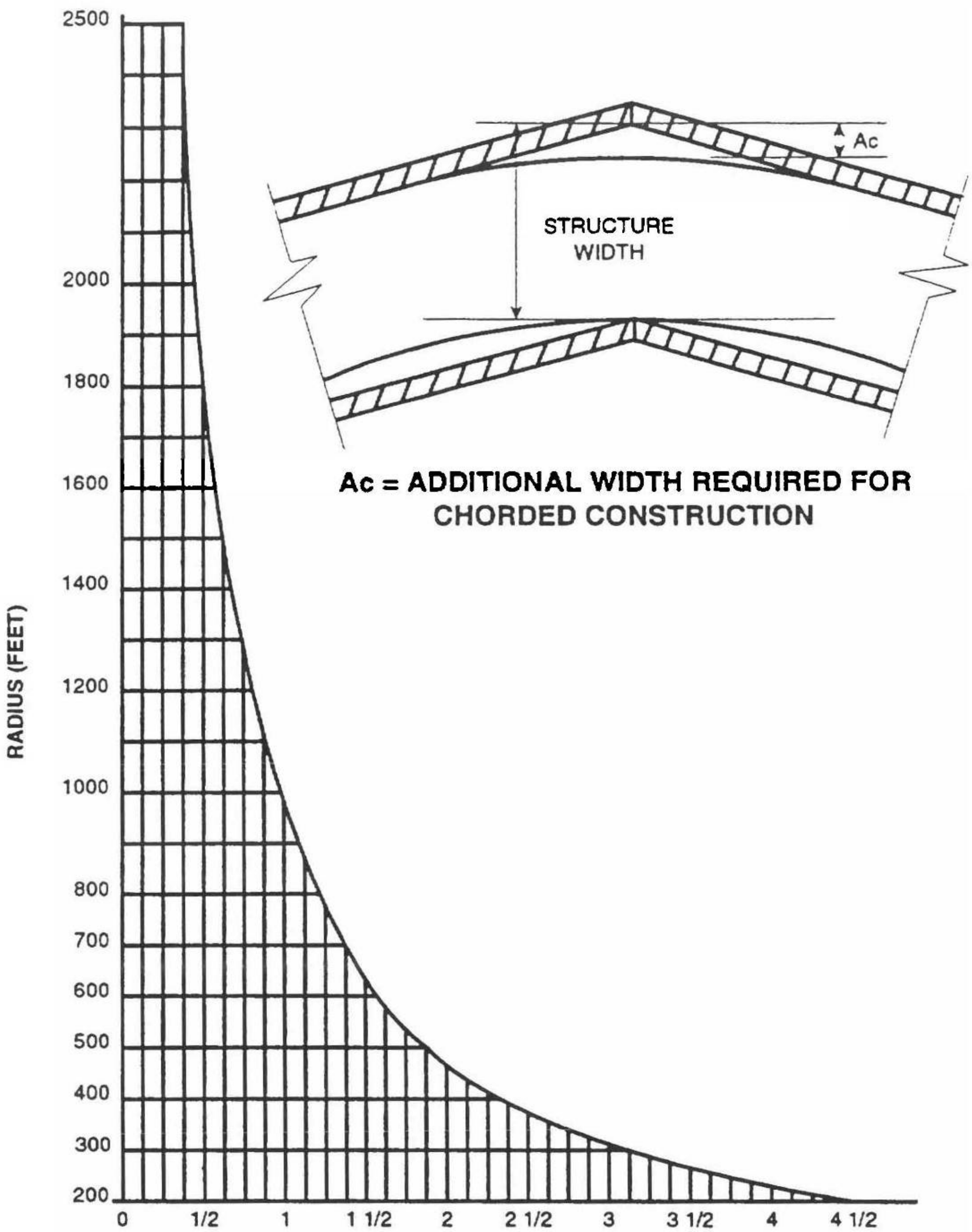
LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 4
FIGURE 4.9

VEHICLE WIDTH		9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL						
VEHICLE LENGTH		87 FT (EXCLUSIVE OF COUPLERS)						
TRUCK CENTERS		32 FT						
ROLL ANGLE		3 DEGREES						
SUPERELEVATION		5 INCHES						
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.82	0.40	0.13	0.13	7.75	7.45
100	5.98	7.00	0.82	0.40	0.13	0.13	7.46	7.00
200	5.34	5.90	0.82	0.40	0.13	0.13	6.82	5.90
300	5.12	5.51	0.82	0.40	0.13	0.13	6.60	5.51
400	5.02	5.31	0.82	0.40	0.13	0.13	6.50	5.31
500	4.95	5.19	0.82	0.40	0.13	0.13	6.43	5.19
600	4.91	5.11	0.82	0.40	0.13	0.13	6.39	5.11
700	4.88	5.05	0.82	0.40	0.13	0.13	6.36	5.05
800	4.86	5.00	0.82	0.40	0.13	0.13	6.34	5.00
900	4.84	4.97	0.82	0.40	0.13	0.13	6.32	4.97
1000	4.81	4.92	0.82	0.40	0.13	0.13	6.29	4.92
1500	4.78	4.86	0.82	0.40	0.13	0.13	6.26	4.86
2000	4.76	4.82	0.82	0.40	0.13	0.13	6.24	4.82
8000	4.71	4.73	0.82	0.40	0.13	0.13	6.19	4.73
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

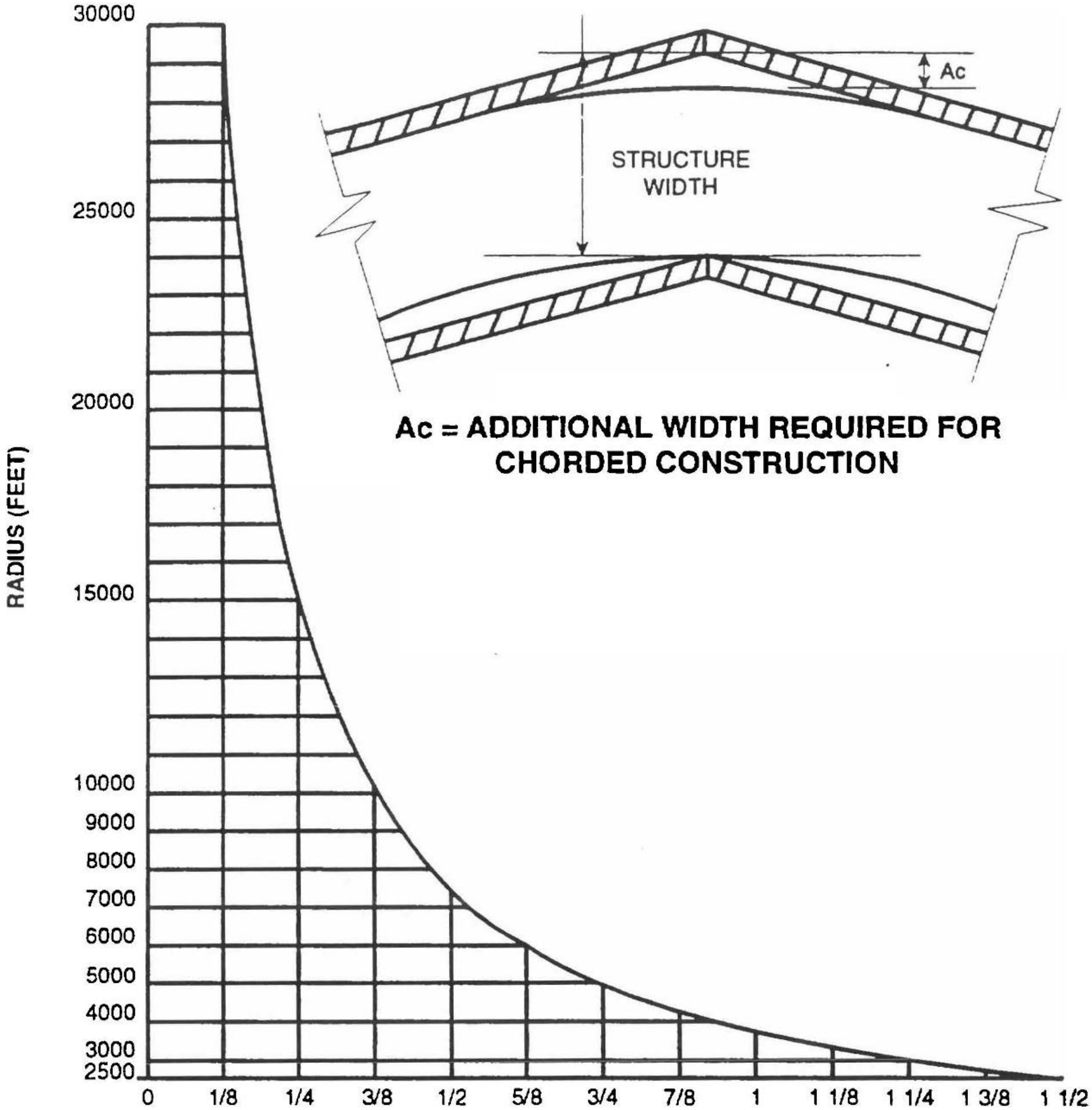
LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 5
FIGURE 4.10

VEHICLE WIDTH			9.39 FT WITH OUTSIDE MIRRORS @ 9.25 FT ABOVE TOP OF RAIL					
VEHICLE LENGTH			87 FT (EXCLUSIVE OF COUPLERS)					
TRUCK CENTERS			32 FT					
ROLL ANGLE			3 DEGREES					
SUPERELEVATION			6 INCHES					
DIMENSIONS IN FEET								
CURVE RADIUS	MID-ORDINATE HALF WIDTH	OVERHANG HALF WIDTH	SUPER EXCURSION	ROLL EXCURSION	SIDE PLAY	FISH TAIL	TOTAL INSIDE CURVE HALF OF VDE	TOTAL OUTSIDE CURVE HALF OF VDE
82	6.27	7.45	0.98	0.40	0.13	0.13	7.91	7.45
100	5.98	7.00	0.98	0.40	0.13	0.13	7.62	7.00
200	5.34	5.90	0.98	0.40	0.13	0.13	6.98	5.90
300	5.12	5.51	0.98	0.40	0.13	0.13	6.76	5.51
400	5.02	5.31	0.98	0.40	0.13	0.13	6.66	5.31
500	4.95	5.19	0.98	0.40	0.13	0.13	6.59	5.19
600	4.91	5.11	0.98	0.40	0.13	0.13	6.55	5.11
700	4.88	5.05	0.98	0.40	0.13	0.13	6.52	5.05
800	4.86	5.00	0.98	0.40	0.13	0.13	6.50	5.00
900	4.84	4.97	0.98	0.40	0.13	0.13	6.48	4.97
1000	4.81	4.92	0.98	0.40	0.13	0.13	6.45	4.92
1500	4.78	4.86	0.98	0.40	0.13	0.13	6.42	4.86
2000	4.76	4.82	0.98	0.40	0.13	0.13	6.40	4.82
8000	4.71	4.73	0.98	0.40	0.13	0.13	6.35	4.73
TANGENT	4.70	4.70	0.00	0.40	0.13	0.13	5.36	5.36

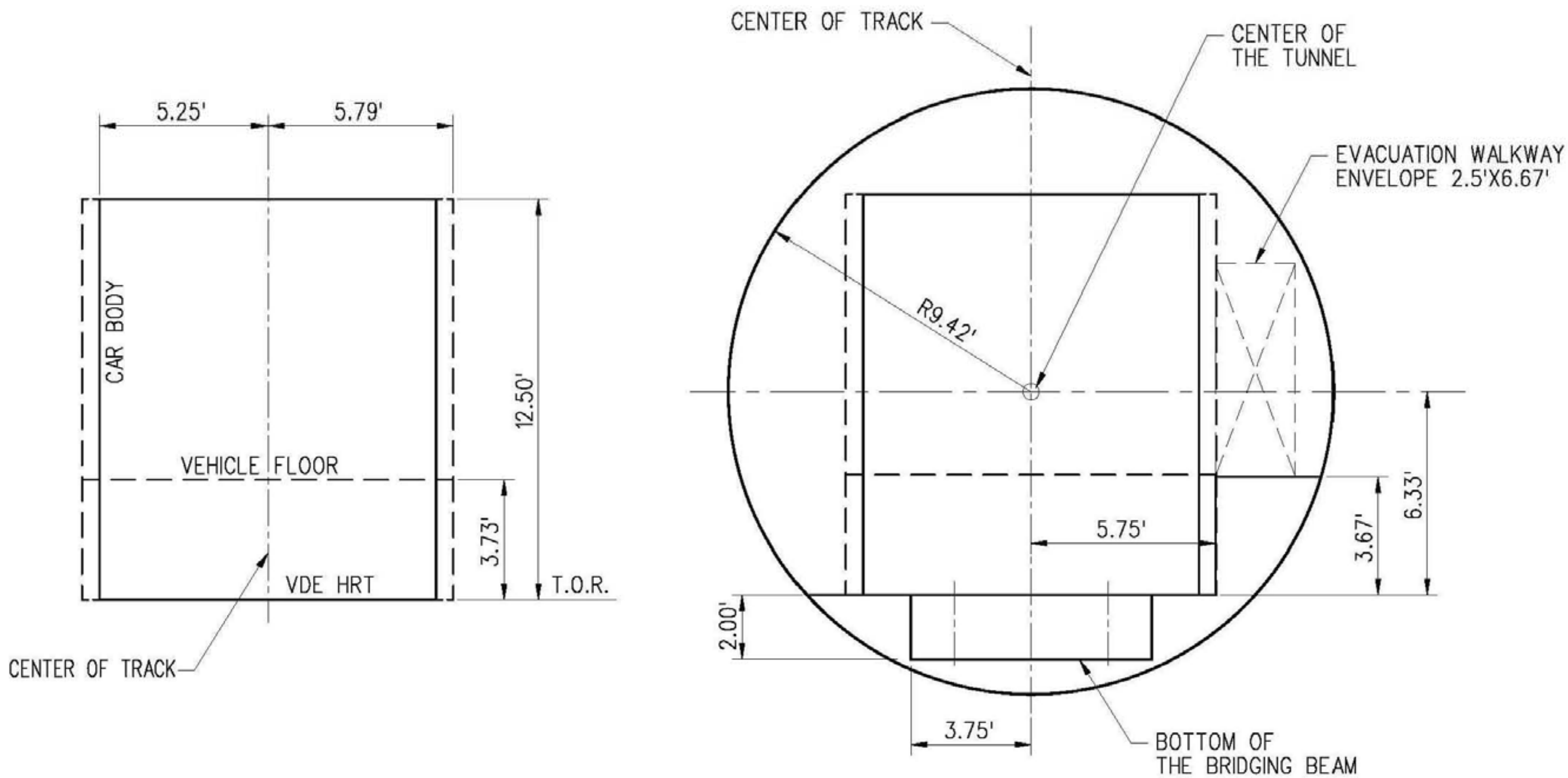
LIGHT RAIL VEHICLE DYNAMIC ENVELOPE – SUPERELEVATION 6
FIGURE 4.11



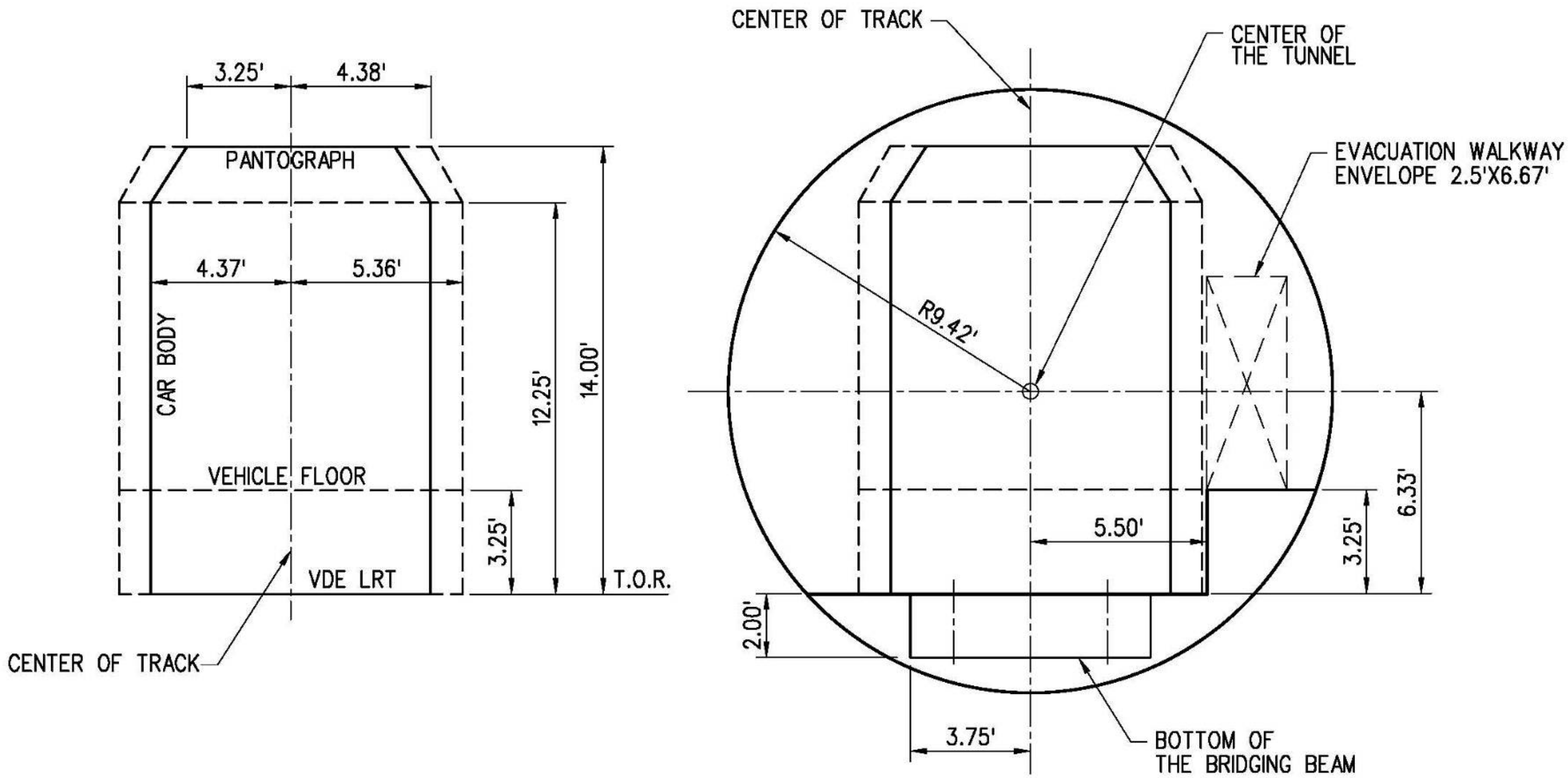
ADDITIONAL WIDTH FOR CHORDED CONSTRUCTION (in inches)
CURVE RADII 200' TO 2,500'
FIGURE 4.12



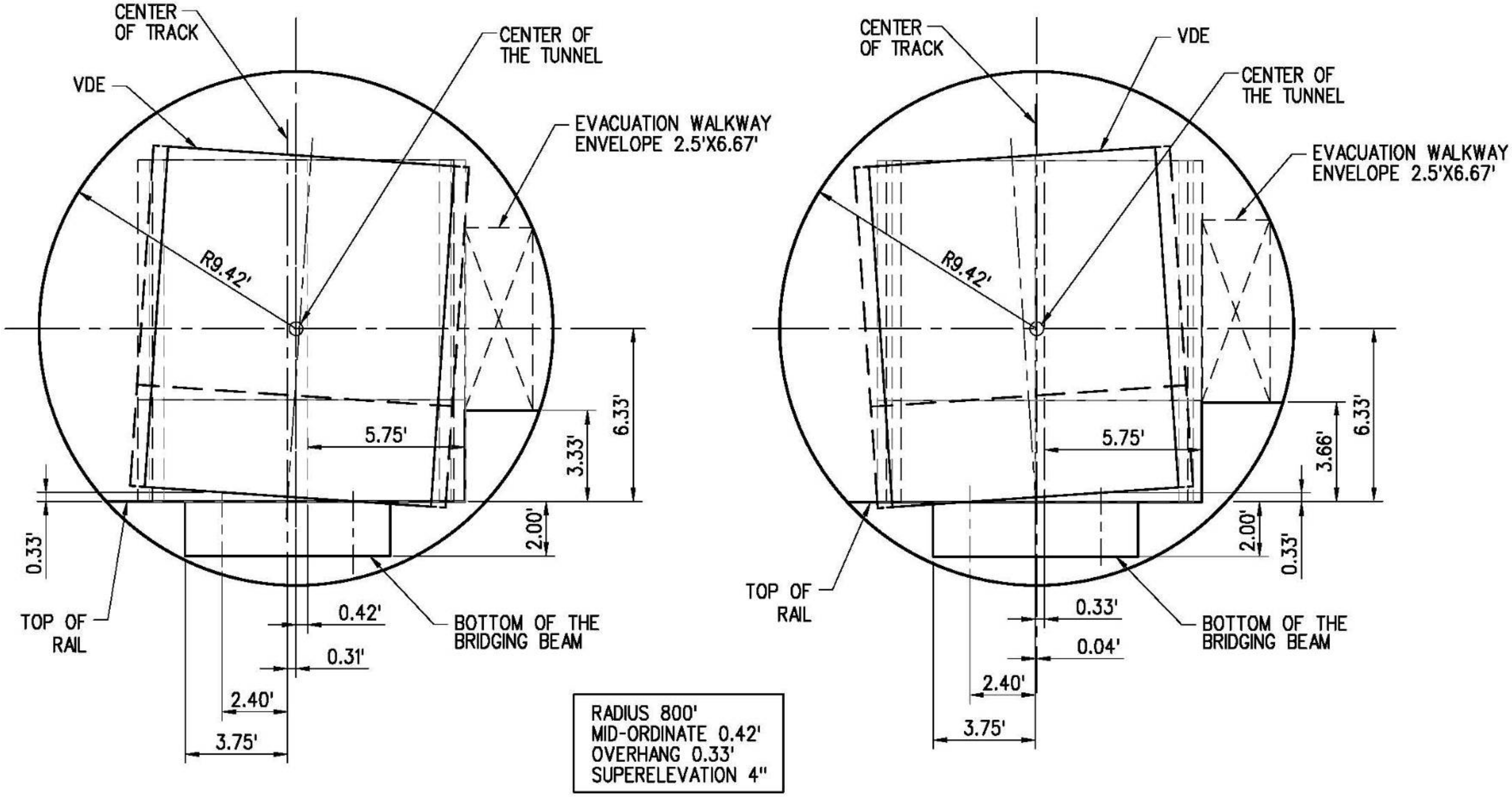
ADDITIONAL WIDTH FOR CHORDED CONSTRUCTION
CURVE RADII 2,500' TO 3,000'
FIGURE 4.13



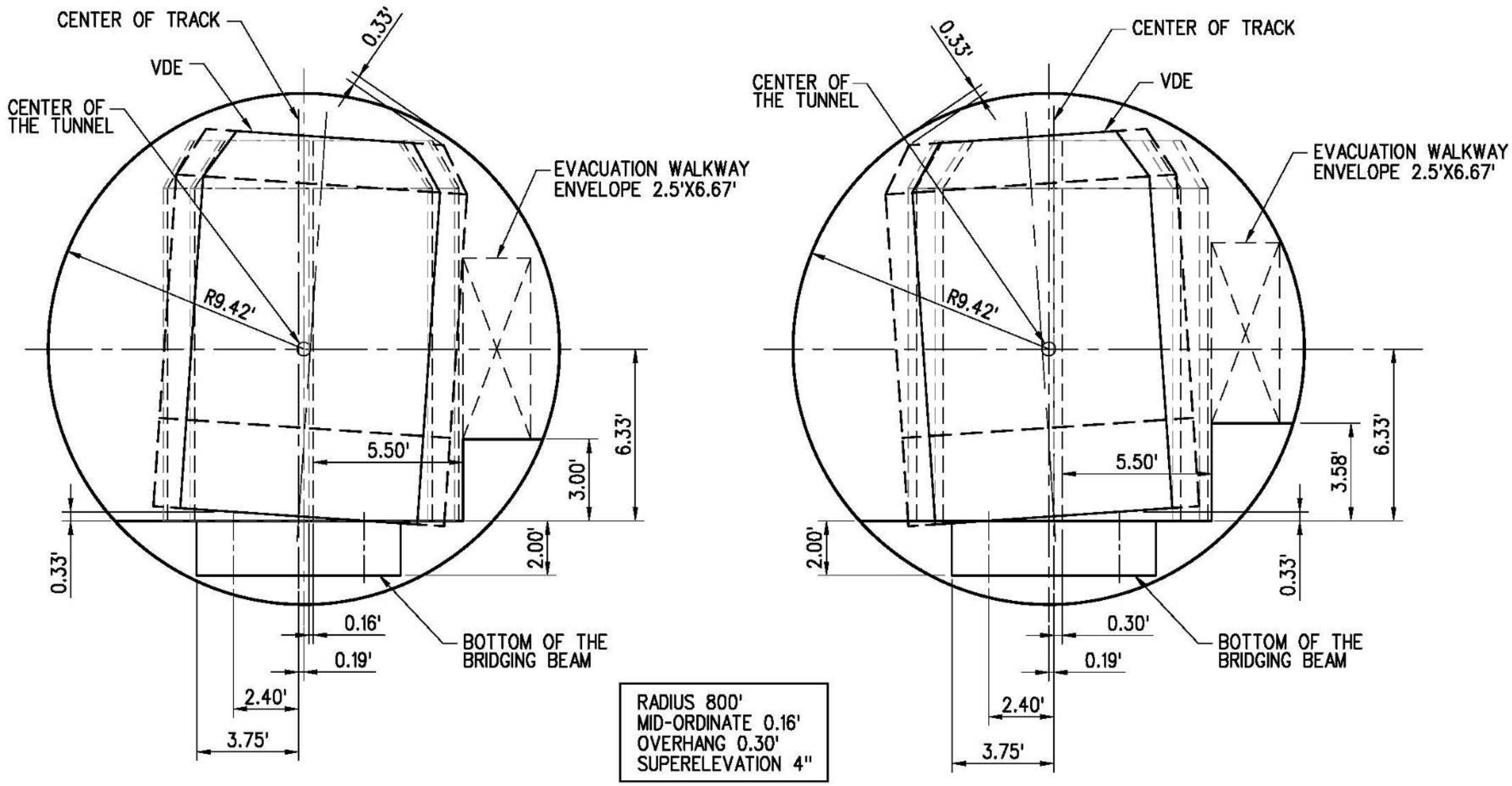
HRT SIMPLIFIED VDE TUNNEL ON TANGENT
FIGURE 4.14



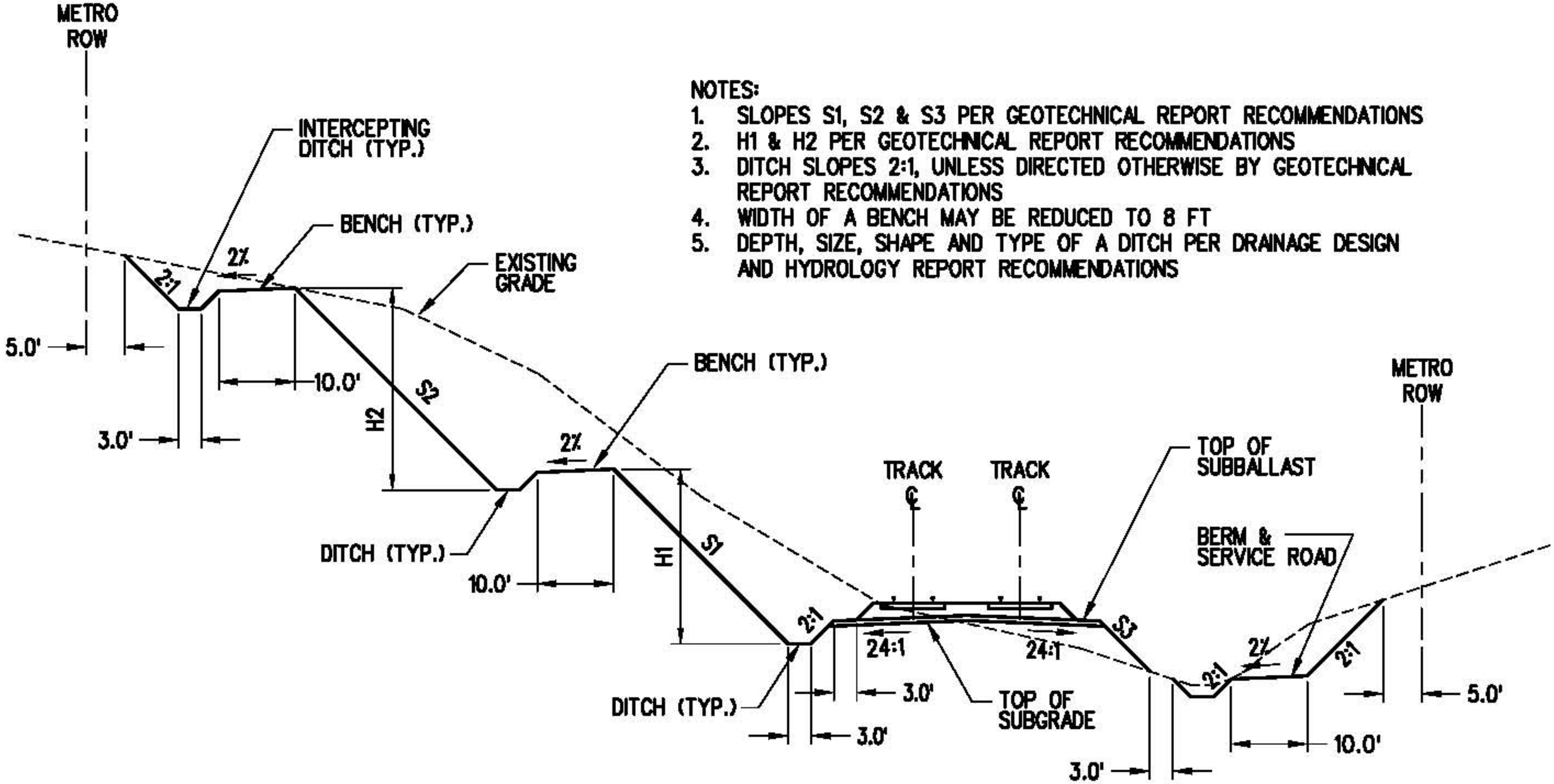
LRT SIMPLIFIED VDE TUNNEL ON TANGENT
FIGURE 4.15



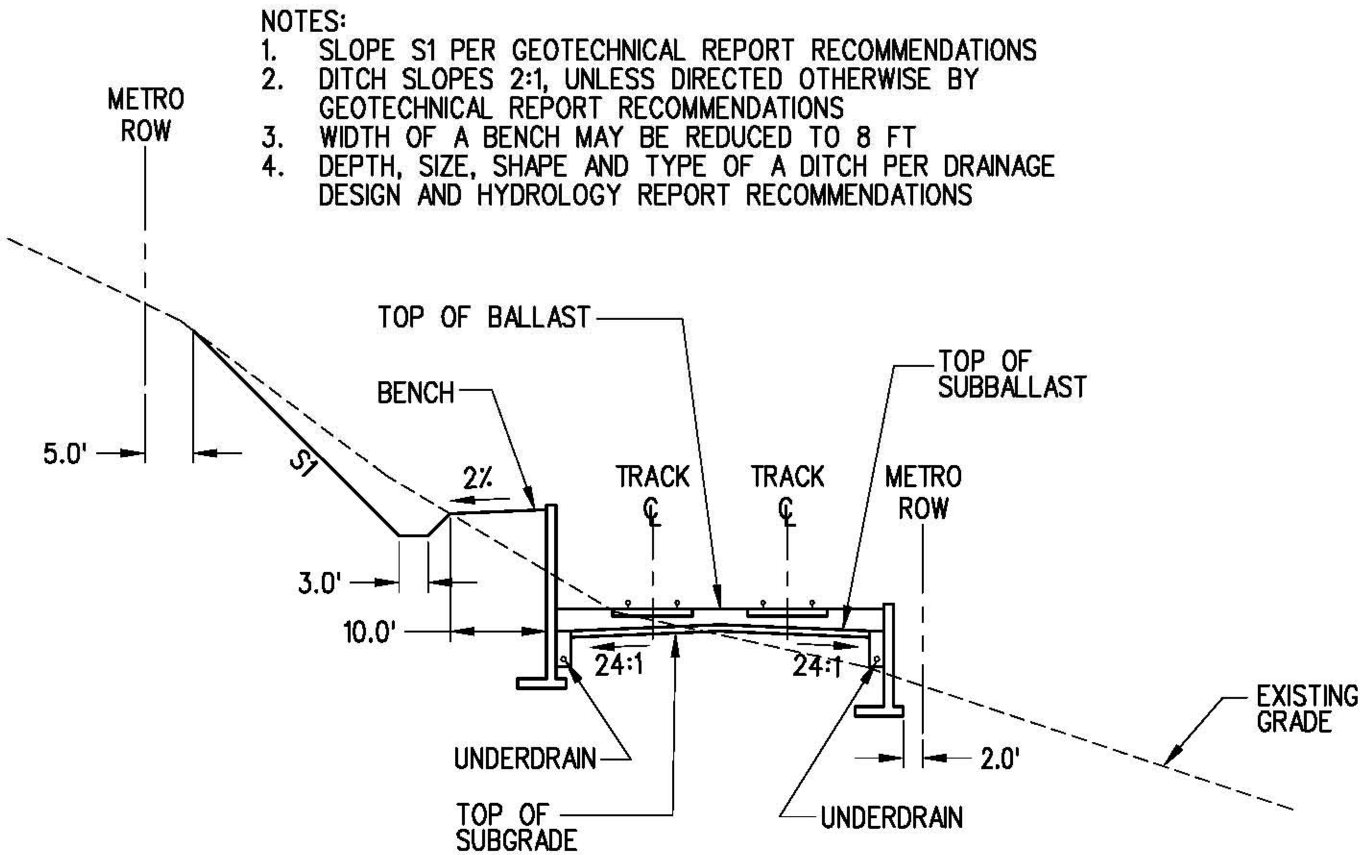
HRT TUNNEL ON SUPERELEVATED CURVE
FIGURE 4.16



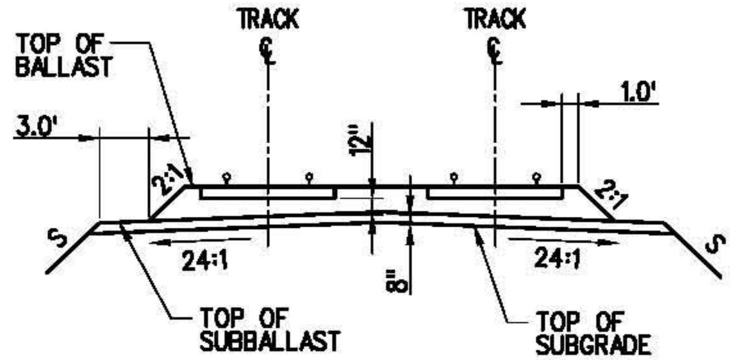
LRT TUNNEL ON SUPERELEVATED TRACK
FIGURE 4.17

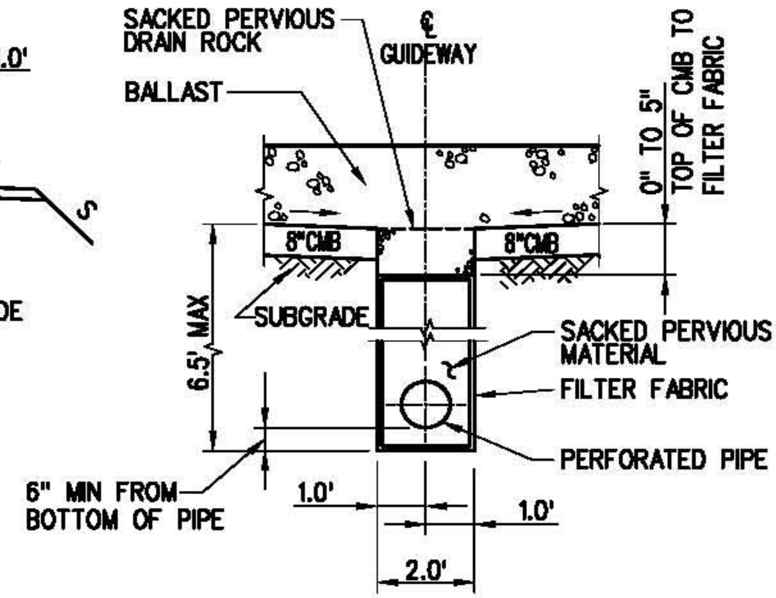


AT GRADE GUIDEWAY CUT AND FILL TYPICAL SECTION
FIGURE 4.18



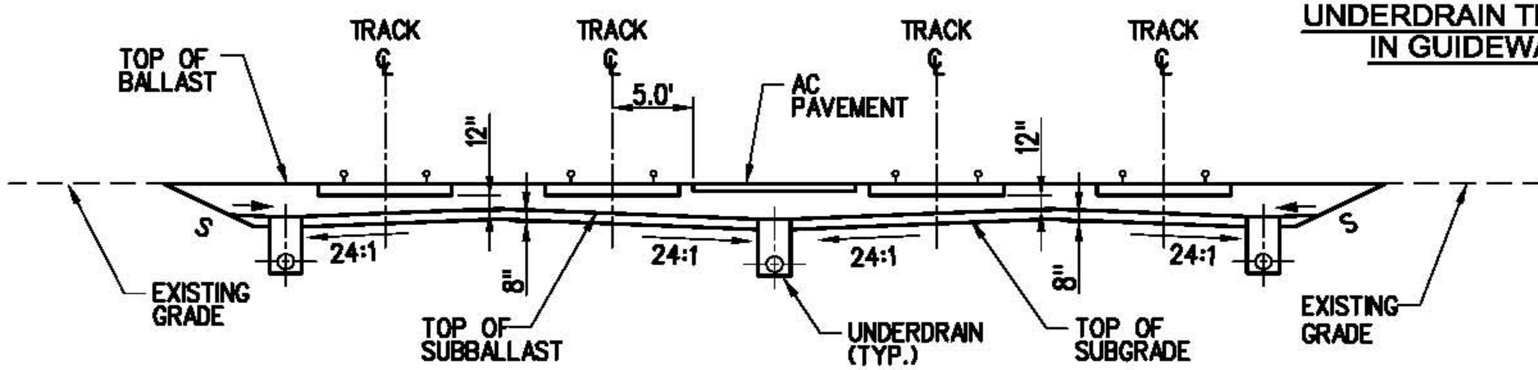
AT GRADE GUIDEWAY RETAINED TYPICAL SECTION
FIGURE 4.19



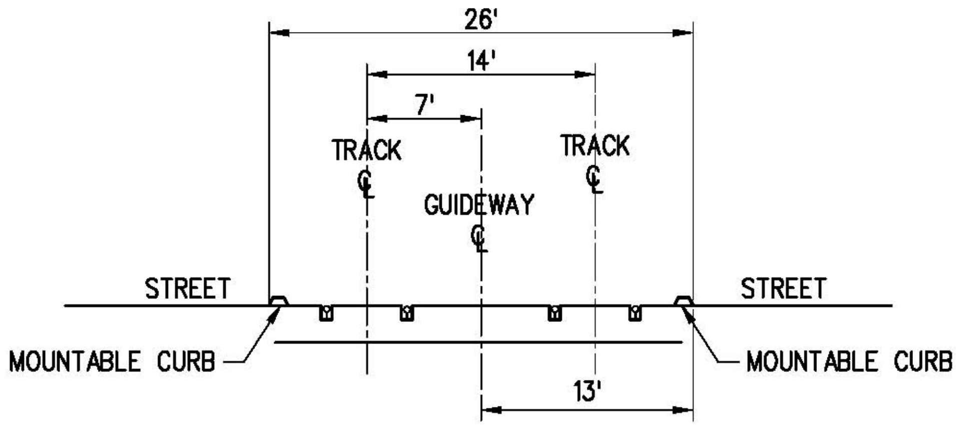


UNDERDRAIN TRENCH IN GUIDEWAY

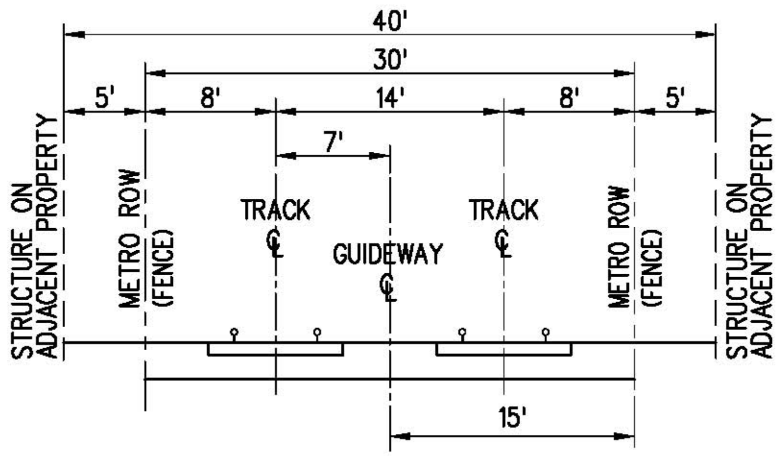
NOTES:
1. SLOPES (S) PER GEOTECHNICAL RECOMMENDATIONS.
2. DEPTH OF BALLAST 12" MIN FOR MAIN LINE, 8" FOR OTHER TRACKS, MEASURED UNDER THE RAIL.
3. DEPTH OF SUBBALLAST 8" MIN FOR MAIN LINE, 6" FOR OTHER TRACKS, MEASURED UNDER THE RAIL.



BALLASTED TRACK TYPICAL SECTIONS
FIGURE 4.20

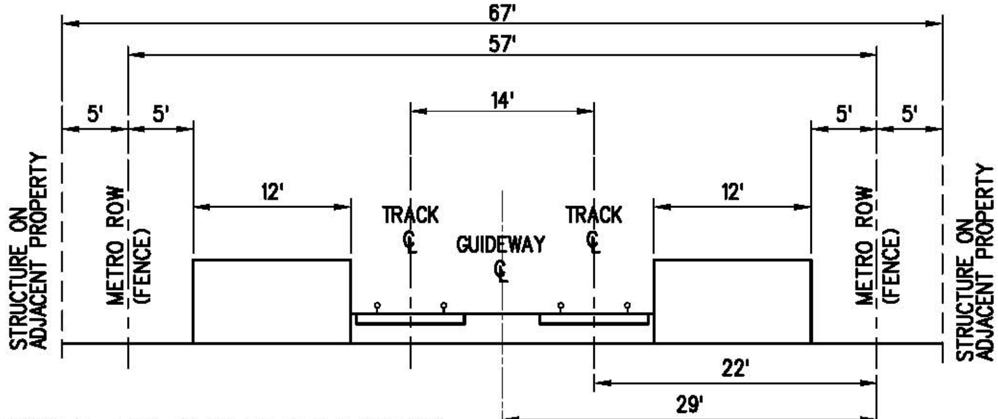


SECTION A - ROW BETWEEN STATIONS STREET ROW

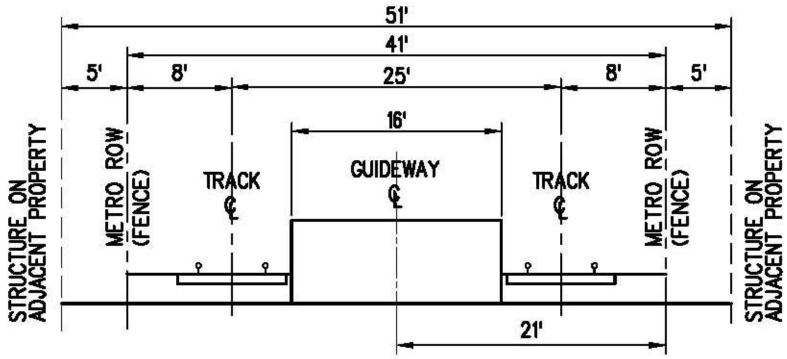


SECTION B - ROW BETWEEN STATIONS EXCLUSIVE OR SEMI-EXCLUSIVE ROW

LRT RIGHT-OF-WAY TYPICAL SECTIONS A AND B
FIGURE 4.21



SECTION C - ROW AT SIDE PLATFORM STATION



SECTION D - ROW AT CENTER PLATFORM STATION

LRT RIGHT-OF-WAY TYPICAL SECTIONS C AND D
FIGURE 4.22