OKLAHOMA DEPARTMENT OF TRANSPORTATION

I-244 Arkansas River LRT Track & Bridge Design Criteria Report

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7/20/2009

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 – TRACK ALIGNMENT

1.1 INTRODUCTION

This chapter illustrates and discusses the various elements of track alignment, including different types of alignments, curvature, special trackwork, speed requirements, and clearances. Using currently accepted railroad and transit engineering practices, these criteria provide guidelines for safety, passenger comfort, and economy. Unless otherwise stated in this document, the track safety requirements for the system are not less than those prescribed by the Federal Railroad Administration's "Track Safety Standards" for Class 5 tracks.

Criteria relating to other elements of design, such as transit system drainage, and to work items made necessary by transit system construction, such as miscellaneous utility work, are based on the current specifications and practices of the agencies concerned in the jurisdictions involved.

1.2 SURVEY CONTROL

1.2.1 Horizontal

The horizontal control for all alignments shall be based on survey control points established under the direction of ODOT. Coordinates for control points established for the system shall be located on the Oklahoma Coordinate System of 1983 North Zone, as established by the National Geodetic Survey (NGS). The accuracy of the horizontal ground control and of supporting ground surveys shall as a minimum be second order, class I, as defined by the Federal Geodetic Control Committee and published under the title Classification, Standards of Accuracy and General Specifications of Geodetic Control Stations, prepared by the NGS in February 1974.

1.2.2 Vertical

The vertical control shall be based on the National Geodetic Vertical Datum of 1988 (NGVD), as defined by the NGS descriptions with the most recent adjustments. The accuracy of the vertical ground control and of supporting ground surveys shall as a minimum be second order, class I, as defined above.

1.3 TRACK HORIZONTAL ALIGNMENT

The parameters for the design of track horizontal alignments shall be in accordance with the Design Criteria and recommendations of the current edition of Manual for Railway Engineering published by the American Railway Engineering and Maintenance of Way Association (AREMA). The horizontal alignment of main line tracks shall consist of tangents joined to circular curves by spiral transition curves. Curvature and superelevation shall be related to design speed and the acceleration and deceleration characteristics of the design vehicle. Wherever practical, the track geometrics shall accommodate the maximum operating speed of 65 miles per hour (MPH), where the location of curves, spacing of stations, construction limitations, and the performance characteristics of the design vehicle require an operating speed less than the maximum, the track geometrics shall accommodate the reduced speed.

These criteria are based on standard track gauge of 4 feet 8-1/2 inches measured perpendicular to the rail 5/8 inch below the top of rail.

1.3.1 Speed Requirements

Main Line. Curvature and superelevation shall be related to the characteristics of the vehicle design, the effects of acceleration, deceleration, and speed command levels of the signal system. Wherever the vehicle operational characteristics permit attainment of the highest speed command level, every effort shall be made in the development of the geometric design to accommodate that speed. Wherever restrictions limit the speed to another command level, every attempt shall be made to maintain an alignment to accommodate that speed command level.

1.3.2 Control

The alignment control shall be the centerline of the main line track carrying traffic in the direction of line stationing because it forms the basic control for all other system facilities, each control centerline shall be stationed throughout its length.

The alignments of opposite main line and secondary tracks shall have separately defined geometry with station equalities to the control centerline at spiral tangent points.

1.3.3 Minimum Tangent Length

Tangents shall be joined to circular curves by spiral transition curves. The desired minimum tangent length in feet shall be three times the design speed in miles per hour. Forty feet or 1.5 V, whichever is longer, shall be used as an absolute minimum for main line and yard track. Exceptions shall include the provisions made in section 1.5.3 and for special trackwork.

1.3.4 Track Spacing

Track spacing shall vary, depending upon curvature and upon the type of construction used for the particular section of line. Normal track centers shall be 15 feet 6 inches with center catenary pole structure. Without center poles, track centers shall be a minimum of 14 feet 0 inches on tangent tracks. Track centers of 14 feet 0 inches with center poles of dimension 1 foot or less in width will be allowed upon approval ofODOT. Every attempt should be made to place center catenary poles of larger dimension in areas where track centers are 15 feet 6 inches or greater. Center-to-center dimensions for parallel tracks near stations with center platforms shall depend upon the width of the station platform. Refer to Sections 1.10.2 and 1.10.3 for further guidelines pertaining to track spacing.

1.4 TRACK SUPERELEVATION

Superelevation shall be constant through circular curves, except those lying in acceleration or deceleration zones of direct fixation track. Superelevation shall be achieved by maintaining the top of the inside rail at the top-of-rail profile and raising the outside rail by an amount equal to the track superelevation. Superelevation should not be used in secondary or yard track except where these tracks are parallel to mainline tracks and superelevation is required for clearance purposes. Where topographic conditions permit and when the design speed is constant throughout the curve, the amount of superelevation shown in Table 1.1 should be used for a given design speed and radius of curvature. Where the design speed or the radius falls between the values specified in Table 1.1, the nearest greater amount of superelevation should be used.

Track superelevation is based on the following formula:

$E_t = E_a + E_u = (4\,V^2)/R_c$

Where:

E_t = Total superelevation = $E_a + E_u$
E_a = Actual track superelevation in inches
E_u = Unbalanced superelevation in inches
V = Design speed in miles per hour
R_c = Radius of curvature in feet

The desirable value of E_u shall be between 1-1/4 inches and 1-1/2 inches. Values of E_u greater than 1-1/2 inches to an absolute maximum of 3 inches may be used upon approval of ODOT. The desirable maximum over balance superelevation shall be 1-1/2 inches.

ODOT RAIL PROJECT -- TABLE 1.1
CURVE RADIUS/MINIMUM SPIRAL LENGTH TABLE WITH 1.5 INCHES UNBALANCED SUPERELEVATION
E_a = Actual Superelevation

E_a (inches)	15	20	VELOCITY (mph) 25	30	35	40	45	50	55	60	65	
0.00	600	1,067	1,667	2,400	3,267	4,267	5,400	6,667	8,067	9,600	11,267	Radius (ft.
	23	30	38	45	53	60	68	75	83	90	98	Spiral (ft.
0.50	450	800	1,250	1,800	2,450	3,200	4,050	5,000	6,050	7,200	8,450	Radius (ft.
	23	30	38	45	53	60	68	75	83	90	98	Spiral (ft.
0.75	400	711	1,111	1,600	2,178	2,844	3,600	4,444	5,378	6,400	7,511	Radius (ft.
	25	30	38	45	53	60	68	75	83	90	98	Spiral (ft.
1.00	360	640	1,000	1,440	1,960	2,560	3,240	4,000	4,840	5,760	6,760	Radius (ft.
	33	33	38	45	53	60	68	75	83	90	98	Spiral (ft.
1.25	327	582	909	1,309	1,782	2,327	2,945	3,636	4,400	5,236	6,145	Radius (ft.
	41	41	41	45	63	63	68	75	83	90	98	Spiral (ft.
1.50	300	533	833	1,200	1,633	2,133	2,700	3,333	4,033	4,800	5,633	Radius (ft.
	50	50	50	50	75	75	75	75	90	90	98	Spiral (ft.
1.75	277	492	769	1,108	1,508	1,969	2,492	3,077	3,723	4,431	5,200	Radius (ft.
	58	58	58	58	88	88	88	88	105	105	114	Spiral (ft.
2.00	257	457	714	1,029	1,400	1,829	2,314	2,857	3,457	4,114	4,829	Radius (ft.
	66	66	66	66	100	100	100	100	120	120	130	Spiral (ft.
2.25	240	427	667	960	1,307	1,707	2,160	2,667	3,227	3,840	4,507	Radius (ft.
	74	74	74	74	113	113	113	113	135	135	146	Spiral (ft.
2.50	225	400	625	900	1,225	1,600	2,025	2,500	3,025	3,600	4,225	Radius (ft.
	83	83	83	83	125	125	125	125	150	150	163	Spiral (ft.
2.75	212	376	588	847	1,153	1,506	1,906	2,353	2,847	3,388	3,976	Radius (ft.
	91	91	91	91	138	138	138	138	165	165	179	Spiral (ft.
3.00	200	356	556	800	1,089	1,422	1,800	2,222	2,689	3,200	3,756	Radius (ft.
	99	99	99	99	150	150	150	150	180	180	195	Spiral (ft.
3.25	189	337	526	758	1,032	1,347	1,705	2,105	2,547	3,032	3,558	Radius (ft.
	107	107	107	107	163	163	163	163	195	195	211	Spiral (ft.
3.50	180	320	500	720	980	1,280	1,620	2,000	2,420	2,880	3,380	Radius (ft.
	116	116	116	116	175	175	175	175	210	210	228	Spiral (ft.
3.75	171	305	476	686	933	1,219	1,543	1,905	2,305	2,743	3,219	Radius (ft.
	124	124	124	124	188	188	188	188	225	225	244	Spiral (ft.

ODOT RAIL PROJECT -- TABLE 1.1 (continued)
CURVE RADIUS/MINIMUM SPIRAL LENGTH TABLE WITH 1.5 INCHES UNBALANCED SUPERELEVATION
E_a = Actual Superelevation

E_a (inches)	VELOCITY (mph) 15	20	25	30	35	40	45	50	55	60	65	
4.00	164	291	455	655	891	1,164	1,473	1,818	2,200	2,618	3,073	Radius (ft.
	132	132	132	132	200	200	200	200	240	240	260	Spiral (ft.
4.25	157	278	435	626	852	1,113	1,409	1,739	2,104	2,504	2,939	Radius (ft.
	140	140	140	140	213	213	213	213	255	255	276	Spiral (ft.
4.50	150	267	417	600	817	1,067	1,350	1,667	2,017	2,400	2,817	Radius (ft.
	149	149	149	149	225	225	225	225	270	270	293	Spiral (ft.
4.75	144	256	400	576	784	1,024	1,296	1,600	1,936	2,304	2,704	Radius (ft.
	157	157	157	157	238	238	238	238	285	285	309	Spiral (ft.
5.00	138	246	385	554	754	985	1,246	1,538	1,862	2,215	2,600	Radius (ft.
	165	165	165	165	250	250	250	250	300	300	325	Spiral (ft.
5.25	133	237	370	533	726	948	1,200	1,481	1,793	2,133	2,504	Radius (ft.
	173	173	173	173	263	263	263	263	315	315	341	Spiral (ft.
5.50	129	229	357	514	700	914	1,157	1,429	1,729	2,057	2,414	Radius (ft.
	182	182	182	182	275	275	275	275	330	330	358	Spiral (ft.
5.75	124	221	345	497	676	883	1,117	1,379	1,669	1,986	2,331	Radius (ft.
	190	190	190	190	288	288	288	288	345	345	374	Spiral (ft.
6.00	120	213	333	480	653	853	1,080	1,333	1,613	1,920	2,253	Radius (ft.
(1)	198	198	198	198	300	300	300	300	360	360	390	Spiral (ft.
6.00	100	178	278	400	544	711	900	1,111	1,344	1,600	1,878	Radius (ft.
(2)	198	198	198	198	300	300	300	300	360	360	390	Spiral (ft.

(1) Desirable radii, using 1.5 inches unbalanced superelevation.

(2) Absolute minimum radii, using 3 inches unbalanced superelevation.

The desired maximum actual superelevation (Ea) shall be 4 inches. An absolute maximum of 6 inches superelevation may be used upon approval of ODOT.

Actual superelevation shall be in 1/4-inch increments. All curved track shall have a minimum actual superelevation (Ea) of 1/2 inch. When zero superelevation is used upon approval of ODOT the amount of resulting unbalanced superelevation desired should not exceed 1-1/2 inches. The maximum allowable shall be 3 inches. Refer to Section 1.9 for the condition of variations in train operating speeds within a curve in direct fixation track.

1.5 HORIZONTAL CURVATURE

1.5.1 Circular Curves

Circular curves shall be defined by the arc definition of curvature and specified by their radius (Rc) in feet.

The desired minimum length of circular curve along main line tracks shall be 200 feet. The absolute minimum length of circular curve in feet along main line tracks shall be three times the design speed (V) in miles per hour, or 60 feet, whichever is greater. Turnouts and reverse curves behind turnouts are exempted from these criteria as their curve lengths are dictated by turnout geometry.

For multi-track layouts, where two or more tracks follow the same general alignment, the tracks should be placed on concentric curves. Minimum curve radius shall be dictated by vehicle limitations.

1.5.2 Transition Spiral Curves

The transition spiral is defined as a curve whose radius varies inversely as the distance along the curve from the point of spiral. All transition spirals computed for the control track shall be Talbot (clothoid) spirals, in which the following relationship pertains:

$RL = R_c \ L_s$

Where:

R = Radius of curvature of the spiral at any given point between the TS and SC.
L = Distance along the spiral from the point of spiral, TS, to the given point.
R_c = Radius of curvature of the circular curve R_c equals R at SC.
L_s = Length of spiral from TS to SC.

The elements of the transition spiral curve are shown in Figure 1.1 and Figure 1.2. All horizontal circular curves in main line tracks shall require transition spirals where joining tangent track or where compounded to a curve of a different radius. The track superelevation shall be attained linearly throughout the length of the transition spiral curve. Absolute minimum spiral curve lengths are limited by maximum superelevation runoff rates.

The minimum spiral length shall be the greatest length obtained from the following formulas:

$L_s = VE_a$
$L_s = VE_u$
$L_s = 33\ E_a$ for speeds ≤ 30 mph
$L_s = 50\ E_a$ for speeds > 30 mph and ≤ 50 mph
$L_s = 60\ E_a$ for speeds > 50 mph

Where:

L_s = Length of spiral in feet.
V = Design speed in miles per hour.
E_a = Actual superelevation in inches.
E_u = Unbalanced superelevation in inches.

Table 1.1 shows length of spiral (Ls) for various combinations of design speed (V) and radius of curvature (Rc). Where topographic conditions permit and where the design speed is constant throughout a curve, the minimum design lengths (Ls) of transition spiral curves are listed in Table 1.1 for a given design speed and radius of curvature, in conjunction with the selection of superelevation as described in section 1.4.

Spirals on parallel tracks at concentric circular curves are to be concentric. The spiral length for the inner most curve (curve with the shortest radius) shall be computed and the other spiral length shall be adjusted accordingly. Extremely long spirals shall be avoided by applying compound curves. Spirals will be used in yard and secondary tracks where heavily traveled.

1.5.3 Reverse Curves

If the minimum tangent length specified in section 1.3.3 cannot be accommodated between reverse curves, the transition spiral curves of the two curves shall be extended to meet at the point of reverse curvature. Superelevation transition shall be in accordance with the method shown on Figure 1.5. A maximum separation of 1 foot between the spirals is acceptable in lieu of meeting at a point.

Double Reverse Curves. Double reverse curves shall not be used in the system unless the distance between the point of change from the first curve to the second curve and the point of change from the second curve to the third curve is at least 450 feet.

1.5.4 Compound Curves

Compound circular curves may be used provided they are connected by an adequate transition spiral curve or superelevation transition length. Lengths of transition spiral curves or superelevation transitions shall be determined from the formulas cited in section 1.5.2, with E_a (the difference between superelevations of the two circular curves) substituted for E_a and E_u (the difference between the unbalanced superelevation of the two curves) substituted for E_u. For combining spiral formulas, refer to Appendix E of Route Location and Design, T.F. Hickerson - McGraw Hill, 1964. Combining spirals may be omitted if the "p" distance as described by Hickerson would be less than 0.03 ft. Compound curves should replace short tangent track between curves in the same direction.

1.6 VERTICAL ALIGNMENT

The profile grade shall be defined as the top of the low rail. Changes in profile gradients shall be joined by vertical curves at crests and sags. In areas of curved alignment where the profile is given for one track only, the grade of the second track shall be adjusted uniformly to accommodate the differences in lengths throughout the curves.

1.6.1 Maximum and Minimum Gradient, Main Line

The maximum desirable gradient for main line track on tangent sections of track shall be ±4.0 percent. Where feasible, the lowest gradient possible shall be used.

The absolute maximum gradient for main line track on tangent sections of track shall be ± 6.0 percent.

The absolute maximum gradient for main line track on curved sections of track shall be determined from the formula:

$G_m = 6 - 230/R$

Where: G_m is the absolute maximum grade in percent and R is the horizontal curve radius in feet.

To facilitate drainage, a minimum gradient of ±0.15 percent shall be maintained on direct fixation track. A 0.0 percent gradient for ballasted track construction is acceptable if drainage can be accommodated. Refer also to Sections 1.6.2 and 1.8.

1.7 VERTICAL CURVATURE

Vertical tangents along main line track shall be connected by parabolic vertical curves having a constant rate of change of grade. Elements of a vertical curve are shown in Figure 1.6. For elevations along the vertical curve, use the following formula:

$E_x = E_a + g_1 x + 1/_2\, r\; x^2$

Where:

E_x = elevation of a point on the vertical curve, in feet.

E_a = elevation of the PVC, in feet.

g_1 = grade into the vertical curve, in %.

g_2 = grade out of the vertical curve, in %.

x = distance from PVC to point on vertical curve, in stations.

r = rate of change of grade, in % per station.

r = $(g_2 - g_1)$ /LVC, where LVC is specified in stations.

Station = 100 feet

PVC = Point of vertical curve

LVC = Length of Vertical Curve

1.7.1 Desirable Length of Vertical Curve

The desirable length of vertical curve (LVC) in main line track shall be determined by the following formulas:

LVC = $(AV^2)/25$ (crest) for speeds $\geq$ 42 mph

LVC = $(AV^2)/45$ (sag) for speeds $\geq$ 56 mph

Where:

LVC = Length of vertical curve in feet.
V = Design speed in miles per hour.
A = The algebraic difference in the grades (in percent) approaching and leaving the curve.

For lower speeds, use the minimum lengths indicated in section 1.7.2.

1.7.2 Minimum Length of Vertical Curve

Except in paved track, the absolute minimum length of vertical curve in main line track shall be the greatest of the lengths determined by the following formulas:

LVC = 100A (crest) for speeds $\geq$ 55 mph

LVC = $(AV^2)/30$ (crest) for speeds $\geq$ 46 mph and $<$ 55 mph

LVC = 70A (crest) for speeds < 46 mph

LVC = $(AV^2)/60$ (sag) for speeds $\geq$ 65 mph

LVC = 70A (sag) for speeds < 65 mph

LVC = 3V

LVC = 100

In paved track, minimum length of vertical curve shall be determined by the formula LVC = 3V for both sag and crest.

1.7.3 Reverse Vertical Curves

Reverse vertical curves may be used provided each vertical curve meets the requirements of section 1.7.1 or section 1.7.2.

1.7.4 Compound Vertical Curves

Compound or asymmetrical vertical curves may be used with prior approval of ODOT, provided that all points of the curve meet the requirements of section 1.7.1 or 1.7.2.

1.7.5 Combined Horizontal and Vertical Curves

Where possible, combined horizontal and vertical curves shall be avoided. Where a vertical curve occurs within a horizontal curve, the length of the vertical curve shall be increased to 1.5 times the minimum required length.

1.8 STATIONS AND SPECIAL TRACKWORK

Special trackwork is any type of turnout and rail crossing. Stations and special trackwork shall be located on horizontal and vertical tangents. Horizontal and vertical tangents shall extend 50 feet beyond the future limits of the station platforms unless otherwise approved in advance by ODOT. Curved horizontal alignments through stations may be allowed upon approval by ODOT.

The maximum gradient shall be ±1.5 percent through those stations at which the tracks are not to be used for storage. If the station tracks are to be used for storage, the maximum gradient shall be ±0.15 percent. The maximum desirable gradient through special trackwork shall be ±1.0 percent; the absolute maximum gradient through special trackwork shall be ±4.5 percent. Any gradients in excess of these will require approval by ODOT.

1.9 VARIATIONS IN TRAIN OPERATING SPEEDS

Variation in train operating speed through a curve will result where ever that curve lies in an acceleration or deceleration zone. Such zones will exist adjacent to stations and elsewhere throughout the system. These zones will be established by the train simulation program.

The track superelevation, E_a, for such a curve in direct fixation track shall be varied along the curve so that a more or less uniform unbalanced superelevation, E_u, will be maintained for cars at the middle of a 300-foot- long train. If uniform unbalanced superelevation cannot be obtained, consideration shall be given to using a compound curve or an extra long transition spiral. The absolute maximum unbalanced superelevation experienced by cars at the head and tail ends of the train shall be between the limits of ±3 inches. The desirable value of unbalanced superelevation shall be between 1-1/4 inches and 1-1/2 inches.

1.10 CLEARANCES

1.10.1 Static, Dynamic and Car Dynamic Envelope

Figure 1.3 identifies the exterior extent or envelope of a vehicle on tangent track in the static and dynamic states. The solid line in Figure 1.3 identified as the Static Envelope represents the shape of a vehicle at rest with all mechanical features in perfect condition. The dashed line, or the Dynamic Envelope, indicates the lateral limits that a vehicle may reach in motion taking into consideration such factors as vehicle roll, track tolerance, and skew. This dashed line can be thought of as the physical dimensions of the vehicle for design purposes, but with no clearances or construction tolerances added. Track tolerances utilized in development of the dynamic envelope are a maximum of 2" for direct fixation and 4" for ballasted construction applied at the mirror of the car. Since ballasted track is more easily displaced than direct fixation track, the outline for ballasted track conditions is shown.

Offset dimensions from centerline of track to the Clearance Envelope are shown at three points along the side of the car. These points are designated on Figure 1.3 and appear at the bottom of the car, at the mirror and the top of the car body. The horizontal dimension to the mirror from centerline of track may be disregarded if approval has been given by ODOT for 14 foot track centers with center catenary poles in accordance with Section 1.3.4.

1.10.2 Variations of the Clearance Envelope due to Curvature and Superelevation

In horizontal curves, side clearances shall be increased to account for increased vehicle end overhang and middle ordinate. Furthermore, track superelevation must also be taken into consideration.

The additional clearances required on curves due to end overhang outside of curve is equal to $(R^2+ 747.65)^{1/2}-R$ and due to middle ordinate inside of curve is $R-(R^2-15.88^2)^{1/2}$. Additional clearances at turnouts due to car overhang are shown on Figures 1.4 through 1.9.

Clearances on the inside of curves shall be increased 2 inches for every 1 inch of actual superelevation. Transition in clearance requirements for curves shall be provided over that part of the transition spiral and adjacent tangent as required. Widening to the outside and the inside of the curve shall begin at a point 50 feet into the tangent and be completed at a point 50 feet in advance of the tangent.

The minimum distance between center line of tracks on curves, as shown on Figure 2-6 (KX6-0007), shall be the greater of 12.917 feet + e + m or 14 feet, where e = end overhang which is $(R^2 + 747.65)^{1/2} - R$ and m, midordinate which is $R - (R^2 - 15.88^2)^{1/2}$.

Minimum distance to poles shall be distance C_2 and C_3 as shown on Figure 2.8 (KX6-0046) and on Figure 2-9 (KX6-0047). $C_2 = 7.750 - e + 0.165\ E_a$ or $C_2 = 7.10 + m + 0.176\ E_a$, whichever is greater; $C_3 = 7.750 + e - 0.165\ E_a$. Selection depends on the direction of curvature. If approval has been given by ODOT for 14 foot 0 inch track centers with 1 foot maximum width center catenary poles, the constant 7.000 shall be substituted for 7.750 in the above equations for C_2 and C_3.

Minimum distances C_1 and C_4 to outside walls as shown on Figure 2.9 (KX6 - 0047) shall be as follows: $C_1 = 7.58 + e - 0.011\ E_a$, or $C_1 = 7.93 + e - 0.112\ E_a$, or $C_1 = 8.00$ feet, whichever is greater; $C_4 = 7.93 + m + 0.112\ E_a$, or $C_4 = 8.00$ feet, whichever is greater.

1.10.3 Horizontal and Vertical Clearances and Tolerances

Any structure and emergency walkway alongside ODOT rail lines shall be clear of the Clearance Envelope by a distance equal to the sum of the applicable clearances and tolerances outlined below:

Construction Tolerances:

Aerial Structures	1"
Catenary Poles	2"
Catenary Pole Deflection	1"
All other Structures	3"
Running Clearance Along All Structures	5/8"
Acoustical Treatment Where Required	3"

The above dimensions are design values, the applicability of which depends on the type of track construction, as well as on the type of structure which the vehicle Clearance Envelope must clear. When the applicable clearances and tolerances are added to the Clearance Envelope dimensions, the resulting envelope shall be referred to as the Design Envelope. With the exception of passenger station platforms, all structures installed above the top of the nearest rail must be set either at or beyond this Design Envelope.

The distance from the edge of the special use (high block) platform to the car body shall be 3 inches from the Static Car Outline.

A clear space for a service walkway shall be provided on one side of each track for emergency egress and maintenance access. The space shall be adjacent to the vehicle (with no obstructions between the space and the vehicle). The space shall have a minimum width of 22 inches (24 inches desirable) and a minimum height of 84 inches. The upper corners of the space may be clipped 3 inches horizontally and 12 inches vertically. The space shall be measured from the top of the low rail, except in tunnels and on structures with walkways. The space may be raised 8 inches. The clear space must be outside of the vehicle dynamic envelope (including track and maintenance and construction tolerances).

The following clearances shall be provided in the design and construction of the ODOT system. All vertical and horizontal clearances shall be verified with the appropriate authorities by the section designer at the time of final design.

The following horizontal clearances shall be applicable for tangent alignment on ballasted track except as noted. These clearances shall be compensated for curvature and superelevation when required. Clearance compensation factors shall be as shown on clearance diagrams and directive drawings. For clearances of special trackwork, see Figures 1.4 through 1.9.

<u>Horizontal Clearances - Tangent Alignment</u>.

- Between adjacent main line parallel tracks, center-to-center, 15 feet 6 inches minimum with an 18 inch maximum diameter center catenary pole, and 14 feet 0 inches without center catenary pole. Track centers of 14 feet 0 inches with center catenary pole width of 1 foot 0 inches or less allowable upon approval by ODOT.

- Fixed structure, measured from centerline of track and nearest point of fixed structure except as otherwise noted below:

	Minimum	Desirable
-Fixed structure equal to or less than six (6) feet in length:		
Direct Fixation	7'-0"	8'-6"
Ballasted	7'-0"	8'-8"
- Fixed structure greater than six (6) feet in length:		
Direct Fixation	8'-6"	12'-0"
Ballasted	8'-6"	12'-0"

- Between acoustical barrier or handrail and centerline of nearest track provided walkway is available elsewhere on the right-of-way.	6'-7 1/2"	8'-0"
- Fences parallel to track measured from centerline of track on retained fill or embankment:	8'-6"	12'-0"
Between centerline of a catenary pole and centerline of nearest track:		
Direct Fixation	7'-2 1/2"	8'-0"
Ballasted	7'-4 1/2"	8'-0"

<u>Vertical</u>. Vertical clearance, guideway structure over public highways and local public roads and streets shall be as required by the Authority having jurisdiction over the roads. Minimum vertical clearance shall be 16'- 6".

The vertical clearance over a guideway structure to a fixed structure, measured from top of rail to the nearest point of obstruction, shall be as follows:

Exclusive LRT Right-of-Way 22'-0"

Lower clearances under existing structures may be considered with approval of ODOT and coordination with the overhead catenary system design.

Under the rail vehicle, between rails, structures will be allowed to intrude on the clearance envelope a maximum of 3/4 inch above top of rail on a tangent track.

<u>Streets</u>. The minimum lateral clearance for streets and highways shall normally be two feet, measured from the face of the curb to the ODOT right-of-way line. This distance must be increased where signs, hydrants, utilities, sidewalks, or traffic signals must be accommodated in this space. Clearances of guideway structure adjacent to streets or expressways shall be in accordance with the current <u>ODOT Design Standards</u> and standards of local agencies having jurisdiction over the roadway affected.

<u>Railroads</u>. All railroad clearances and trackwork shall comply with current plans and specifications of the respective railroad or ODOT, whichever is greater. All railroad clearances, joint-use drainage structures, common support structures, and right-of-way lines are subject to verification by the individual railroad company. In the absence of such plans and specifications, trackwork shall comply with the current AREMA <u>Manual for Railway Engineering</u> and <u>Portfolio of Trackwork Plans</u> and shall be approved by a responsible officer of the affected company.

<u>Clearance Envelope for Structures</u>. Clearances for wayside structures located below top-of-rail in ballasted track construction shall comply with Figure 1.7.

NOTES ON TABLE 1.1: CURVE/RADIUS/MINIMUM SPIRAL LENGTH

1. The table shall be used as a design aid to apply the project design criteria.

2. The applicable design criteria are:

   a. Track superelevation shall be based upon the following formula:

      $E_a + E_u = (4V^2)/R$

      Where:

      E_a = Actual superelevation, in inches.
      E_u = Unbalanced superelevation, in inches.
      V = Design speed, in miles per hour.
      R = Curve radius, in feet.

   b. The desired maximum actual superelevation, E_a shall be 4 inches. The absolute maximum shall be 6 inches.

   c. The desired unbalanced superelevation, E_u shall be between 1-1/4 inches and 1-1/2 inches. The absolute maximum shall be 3 inches.

   d. Actual superelevation, E_a shall be applied in 1/4 inch increments. Actual superelevation of less than 1/2 inch shall not be used.

   e. Minimum spiral length, L_s shall be the greatest value determined from the following formulas:

      $L_s = VE_2$
      $L_s = VE_u$
      $L_s = 33\ E_a$ for $V \leq 30$ mph
      $L_s = 50\ E_a$ for $V > 30$ mph and $V \leq 50$ mph
      $L_s = 60\ E_a$ for $V > 50$ mph

3. Because the relationship between E_a, V and R is absolute, given values for two of these variables the value of the third, as derived from the table, is correct. It is not a maximum or minimum allowable value. In general, values should not be interpolated, and the tables should be used according to note 5.

4. The values of L_s, as derived from the table, are minimum allowable values. For any combination of E_a and V, the spiral length shall equal or exceed the tabulated value of L_s.

5. The table shall be used as follows:

   a. <u>If speed, V, and radius, R, are known</u> - Find the appropriate V column. Scan down the column to find the first value of radius $\leq$ R. Use actual superelevation = E_a. Use spiral length $\geq L_s$. If there is no value of radius $\leq$ R, this combination of V and R is not permissible.

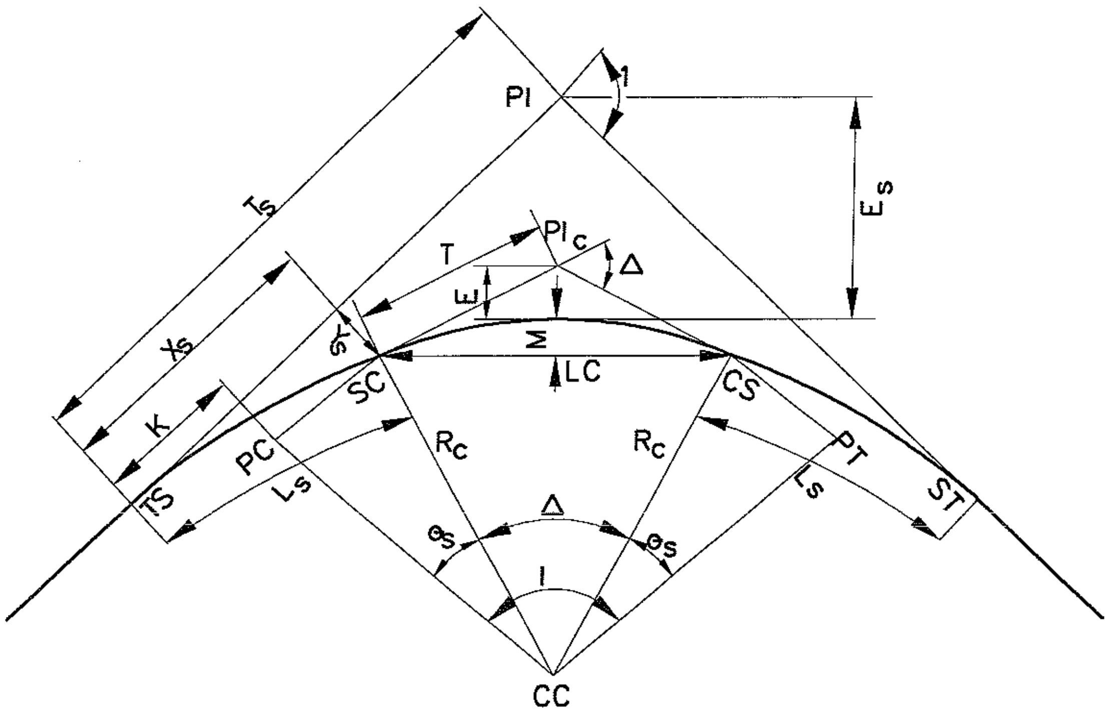
   b. <u>If actual superelevation, E_a, and radius, R, are known</u> - Find the appropriate E_a row. Scan right along the row to find the first value of radius > R. Move left one column. Use speed = V. Use spiral length $\geq L_s$. If there is no value of radius > R, this combination of E_a and R is not permissible.

   c. <u>If actual superelevation, E_a, and speed, V, are known</u> - Find the appropriate E_a row and V column. Let the radius at the intercept of E_a and V = R. Move up one row. Let this radius = R_z. Use a value of radius, R, such that R_z > R $\geq$ R. Use spiral length $\geq L_s$, where L corresponds to R.

   d. <u>If speed, V, and spiral length, L_s, are known</u> - Find the appropriate V column. Scan down the column to find the first value of spiral length > L_s. Move up one row. This is the minimum allowable radius. Use this R and E_a combination or any other R and E_a combination above it in the column. If there is no value of spiral length > L_s, this combination of V and L_sd is not permissible.

   e. <u>If actual superelevation, E_a, and spiral length, L_s, are known</u> - Find the appropriate E_a row. Scan right along the row to find the first value of spiral length > L_s. Move left one column. This is the minimum allowable radius. Use this R and V combination or any other R and V combination left of it in the row. If there is no value of spiral length > L_s, this combination of E_a and L_s is not permissible.

   f. <u>If radius, R, and spiral length, L_s, are known</u> - Scan down all columns to find the first values of radius $\leq$ R. Scan the first values of radius $\leq$ R to determine those for which spiral length $\leq L_s$. Use any E_a and V combination for first value of radius $\leq$ R and spiral length $\leq L_s$. If there are no values of radius $\leq$ R or spiral length $\leq L_s$, this combination of R and L_s is not permissible.



CIRCULAR CURVE DEFINITIONS

- CC — CENTER OF CIRCULAR CURVE
- CS — POINT OF CHANGE FROM CIRCULAR CURVE TO SPIRAL
- D_C — DEGREE OF CIRCULAR CURVE (ARC DEFINITION)
- E — EXTERNAL DISTANCE FROM PIc
- E_S — EXTERNAL DISTANCE FROM PI
- I — TOTAL CENTRAL ANGLE
- K — DISTANCE FROM TS/ST TO PC/PT OF CIRCULAR CURVE MEASURED ALONG MAIN TANGENT
- L — LENGTH OF SPIRAL ARC FROM TS TO ANY POINT ON SPIRAL
- L_S — LENGTH OF SPIRAL ARC FROM TS/ST TO SC/CS
- LC — LONG CHORD OF CIRCULAR CURVE
- Lc — LENGTH OF CIRCULAR CURVE
- LT_S — LONG TANGENT LENGTH OF SPIRAL
- M — MID ORDINATE DISTANCE OF CIRCULAR CURVE
- P — OFFSET OF PC/PT OF CIRCULAR CURVE MEASURED FROM MAIN TANGENT
- PC — POINT OF CIRCULAR CURVE
- PI — POINT OF INTERSECTION OF MAIN TANGENTS
- PI_C — POINT OF INTERSECTION OF CIRCULAR CURVE TANGENTS
- PT — POINT OF TANGENT OF CIRCULAR CURVE
- R_C — RADIUS OF CIRCULAR CURVE
- SC — POINT OF CHANGE FROM SPIRAL TO CIRCULAR CURVE
- SI — POINT OF INTERSECTION OF SPIRAL
- ST — POINT OF CHANGE FROM SPIRAL TO TANGENT
- ST_S — SHORT TANGENT LENGTH OF SPIRAL
- T — TANGENT LENGTH OF CIRCULAR CURVE
- TS — POINT OF CHANGE FROM TANGENT TO SPIRAL
- T_S — TANGENT LENGTH FROM TS/ST TO PI
- X — DISTANCE FROM TS/ST OF ANY POINT ON SPIRAL PROJECTED TO MAIN TANGENT
- X_S — DISTANCE FROM TS/ST TO SC/CS PROJECTED TO MAIN TANGENT
- Y — OFFSET OF ANY POINT ON SPIRAL MEASURED FROM MAIN TANGENT
- Y_S — OFFSET OF SC/CS MEASURED FROM MAIN TANGENT
- θ — CENTRAL ANGLE OF SPIRAL ARC L
- θ_S — CENTRAL ANGLE OF SPIRAL ARC Ls
- ϕ — DEFLECTION ANGLE OF A CHORD BETWEEN TS/SC AND ANY POINT ON SPIRAL
- Δ — CENTRAL ANGLE OF CIRCULAR CURVE

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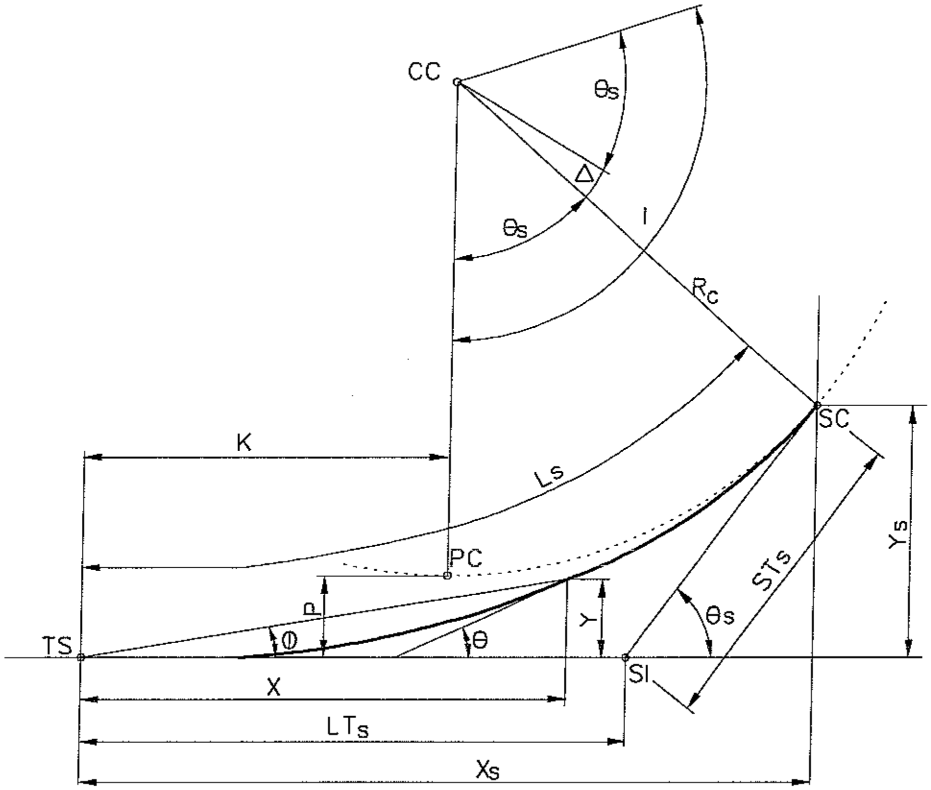

SPIRAL TRANSITION CURVE

EQUATIONS

$X = \frac{L}{100}(100-0.3046174198\theta^{2}(10)^{-2}-0.429591539\theta^{4}(10)^{-7}-0.301987076\theta^{6}(10)^{-12})$ - Xs AT THE SC/CS

$Y = \frac{L}{100}(0.5817764173-0.12658516\theta^{3}(10)^{-4}-0.122691057\theta^{5}(10)^{-9})$ -Ys AT THE SC/CS

$\Delta = I-2\theta s$

$\theta s = \frac{LsDc}{200}$

$\theta = (\frac{L}{Ls})^2 \theta s$

$\Phi = \text{ARC TAN } \frac{Y}{X}$

$Dc = \frac{100(360)}{2\pi Rc}$

$E = Rc(\frac{1}{\cos\frac{\Delta}{2}} - 1)$

$Es = \frac{(Rc-P)}{\cos(I/2)} - Rc$

$K = Xs - Rc \sin \theta s$

$LC = 2Rc\sin\frac{\Delta}{2}$

$Lc = \frac{100\ \Delta}{Dc}$

$LTs = Xs - \frac{Ys}{\tan\theta s}$

$M = Rc(1-\cos\frac{\Delta}{2})$

$P = Ys - Rc(1-\cos\theta s)$

$STs = \frac{Ys}{\sin\theta s}$

$T = Rc\tan\frac{\Delta}{2}$

$Ts = (Rc+P)\tan\frac{I}{2} + K$

APPROXIMATE FORMULAS

$X = Ls$

$K = \frac{Ls}{2}$

$Y = \frac{Ls^2}{6R}$

$P = \frac{Ls^2}{24R}$

L.T. $\frac{2}{3}Ls$

S.T. $\frac{1}{3}Ls$

NOTES:

1. I,Δ,θ,Φ AND Dc IN DEGREES, ALL OTHER DIMENSIONS IN FEET.
2. REFERENCE T. HICKERSON, ROUTE LOCATION AND DESIGN MCGRAW-HILL,INC. 1967.

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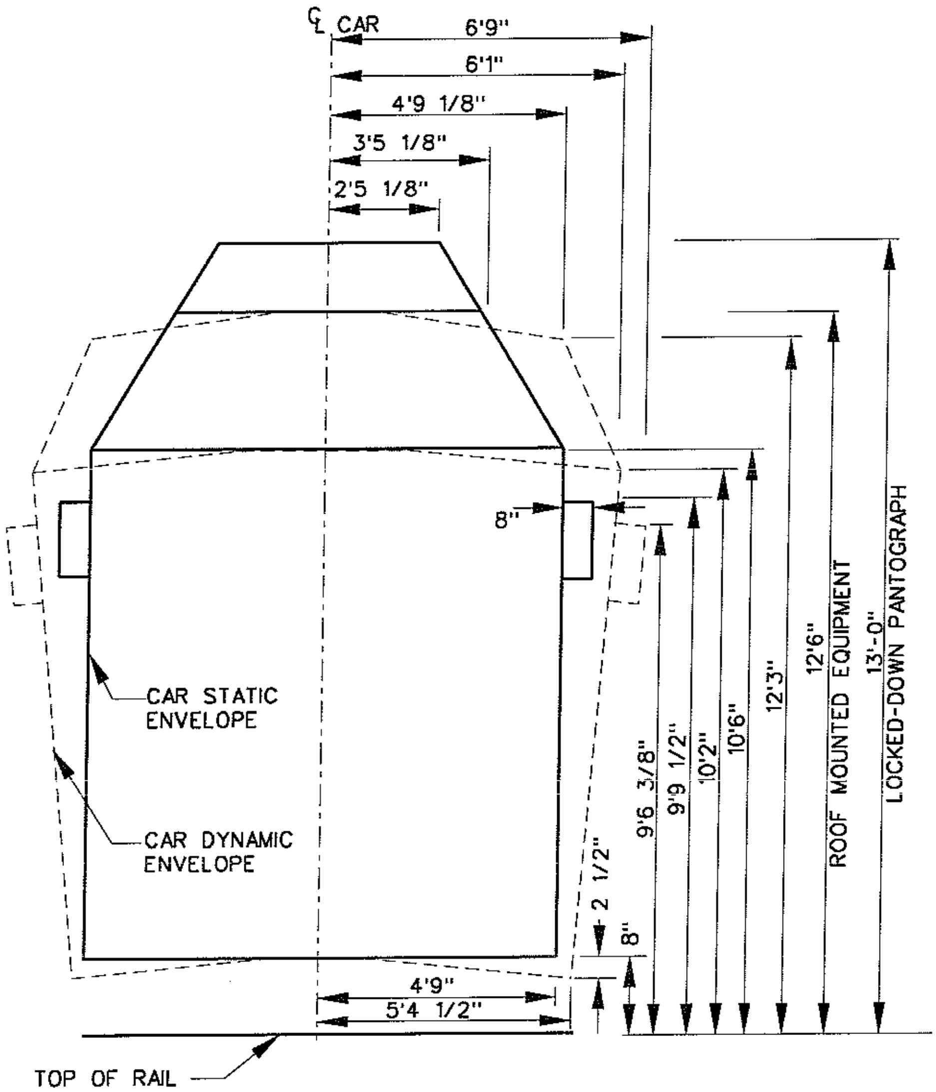

INCLUDES:

VEHICLE DYNAMIC ENVELOPE (SEE SYSTEM DESIGN CRITERIA CHAPTER 2 FOR EXACT VALUES)
TRACK TOLERANCE-4 INCHES HORIZONTALLY AT THE MIRROR FOR BALLASTED TRACK. (SEE 1.10.1) -SUBTRACT 2 INCHES HORIZONTALLY AT THE MIRROR FOR DIRECT FIXATION TRACK.

EXCLUDES:

CONSTRUCTION TOLERANCE (SEE (1.10.3))
CURVATURE-SUPERELEVATION, MIDORDINATE AND OVERHANG(SEE 1.10.2)

——— STATIC OUTLINE
- - - - DYNAMIC OUTLINE

TANGENT SECTION

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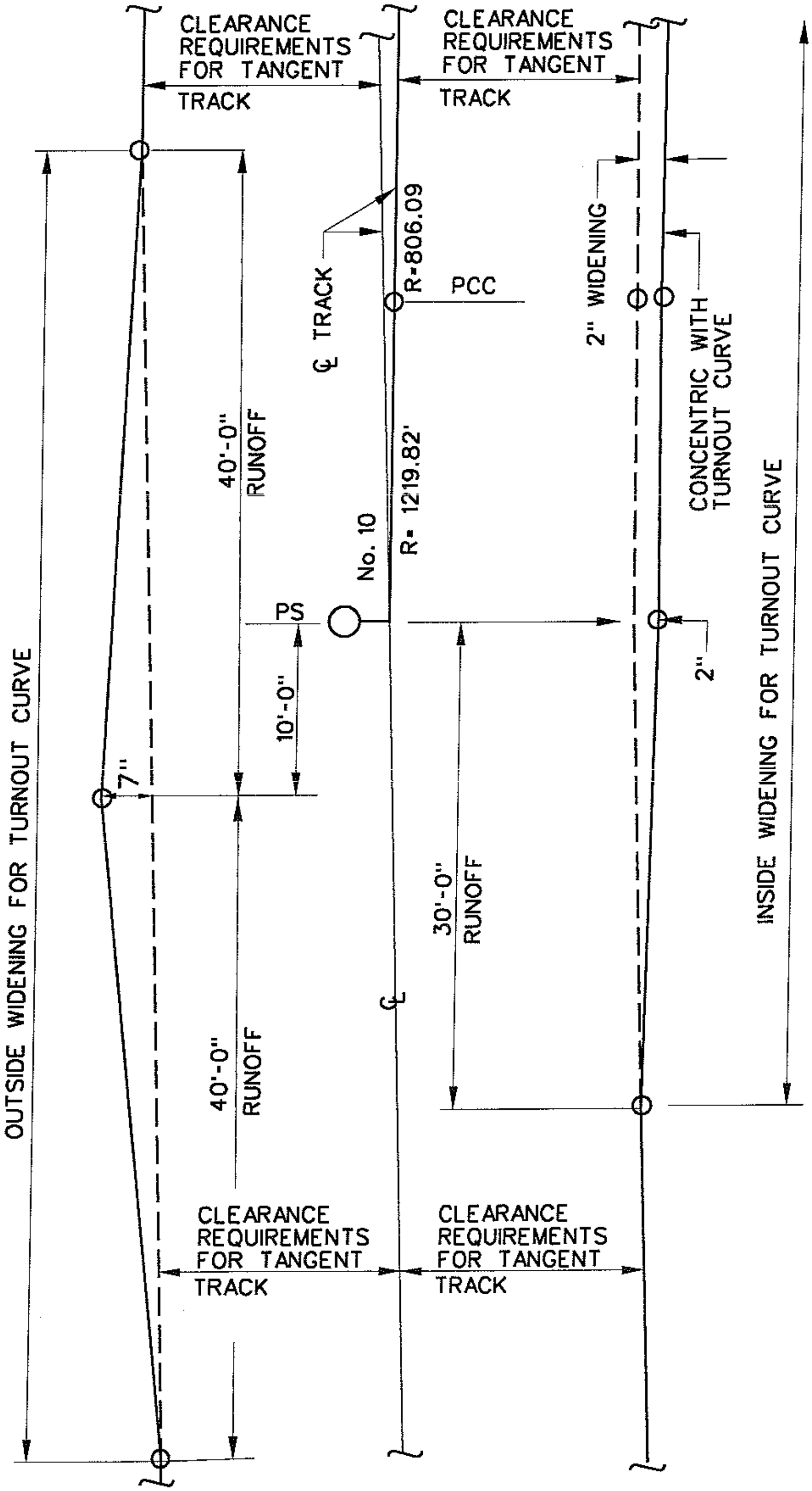

NOTES:

1. SEE REQUIRED CLEARANCE FOR TANGENT TRACK.
2. CLEARANCE WIDENING COMPUTED BASE ON THE UPPER AND OUTER POINT ON THE MIRROR OF A SKEWED CAR WHICH IS 5.415 FEET FROM THE CENTERLINE OF TANGENT TRACK.

L:•150-10146-000•4-0-PRODUCTION•4-06-REF-STUDIES-REPORTS•BY•LAN•4-06-03 REPORT EXHIBITS•FIGURE1•4.006

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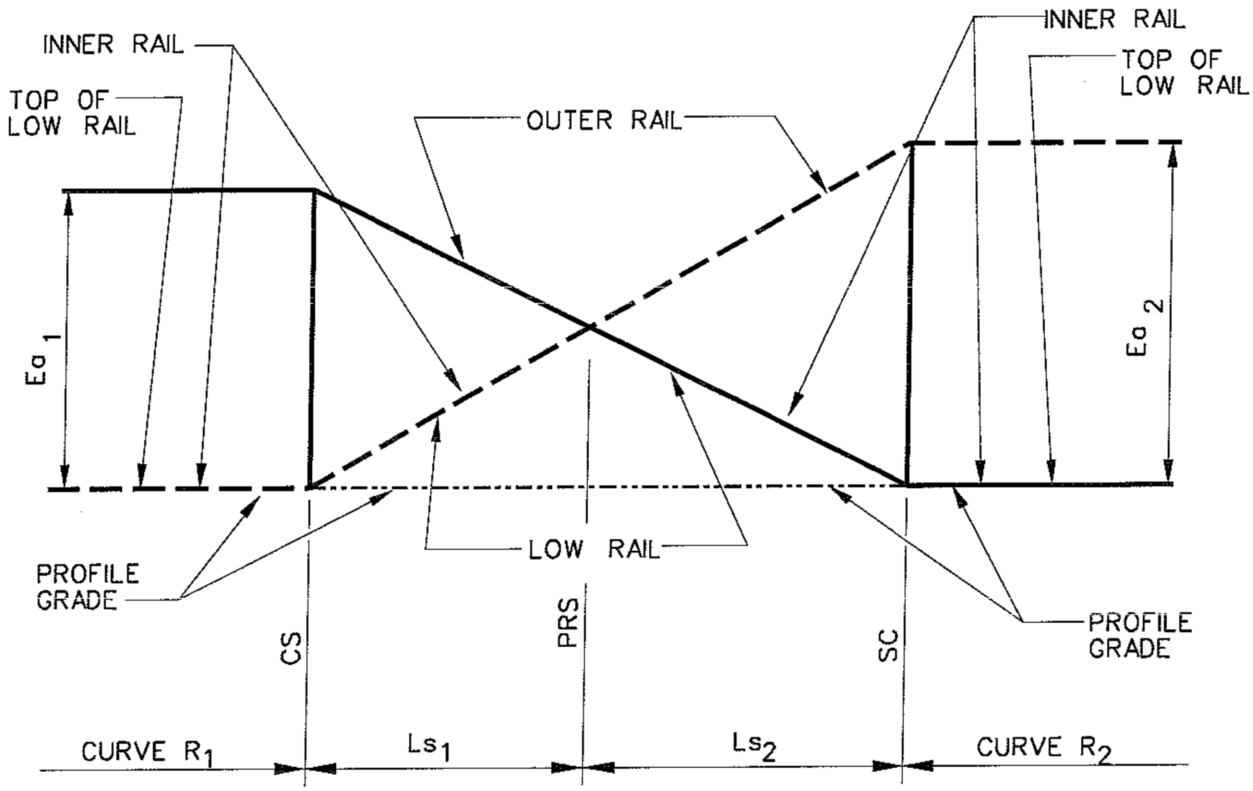
CLEARANCE WIDENING
NO. 10 TURNOUT

SCALE: NONE

FIGURE: 1.4



NOTE:

ON SUPERELEVATED CURVE, TOP OF RAIL ELEVATIONS SHOWN ON PROFILE ARE FOR THE LOWER RAIL.
PROFILE GRADE FOR REVERSE CURVES WILL BE AN IMAGINARY LINE CONNECTING LOW RAIL PROFILES AS SHOWN ABOVE.

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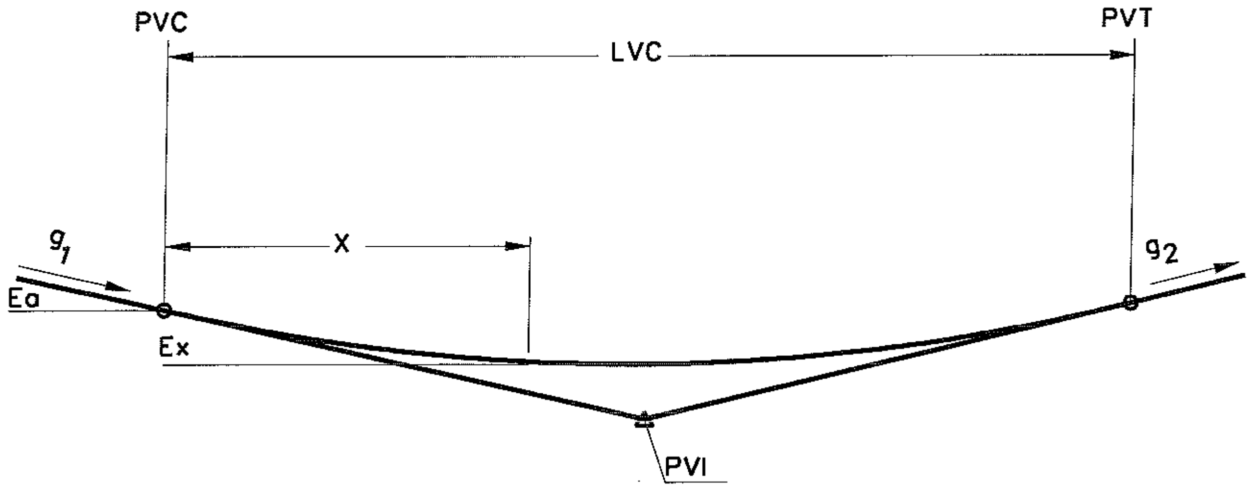
SUPERELEVATION TRANSITION

SCALE: NONE

FIGURE: 1.5



$$Ex = Ea + g_1 X + 1/2r\,(X)^2$$

Where :

Ex = ELEVATION OF A POINT ON THE VERTICAL CURVE, IN FEET.

Ea = ELEVATION OF THE PVC, IN FEET.

g_1 = GRADE INTO THE VERTICAL CURVE, IN%.

g_2 = GRADE OUT OF THE VERTICAL CURVE, IN %.

X = DISTANCE FROM PVC TO POINT ON VERTICAL CURVE, IN STATIONS.

r = RATE OF CHANGE OF GRADE, IN % PER STATIONS.

$r = \frac{g_2 - g_1}{LVC}$ WHERE LVC IS SPECIFIED IN STATIONS.

STATION = 100 FEET

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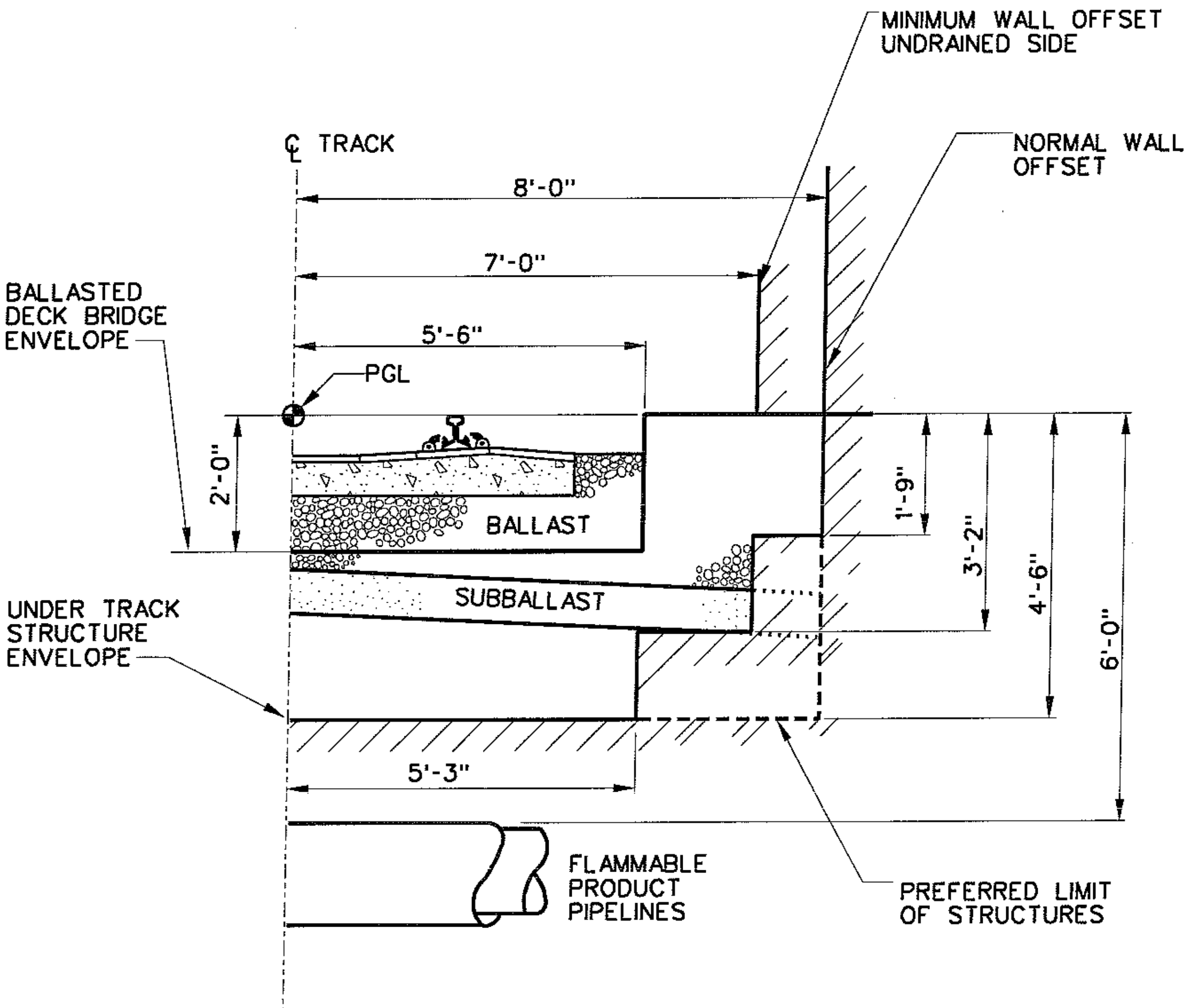
VERTICAL CURVE EQUATION

SCALE: NONE FIGURE: 1.6



UNDERTRACK STRUCTURES SHALL BE OUTSIDE THIS STRUCTURAL ENVELOPE EXCEPT:

1. NECESSARY TRACK RELATED CONDUIT AND CABLE STUB-UPS.
2. DRAINAGE INLETS.
3. DIRECT BURIED CABLES, MUST BE BELOW SUBBALLAST.

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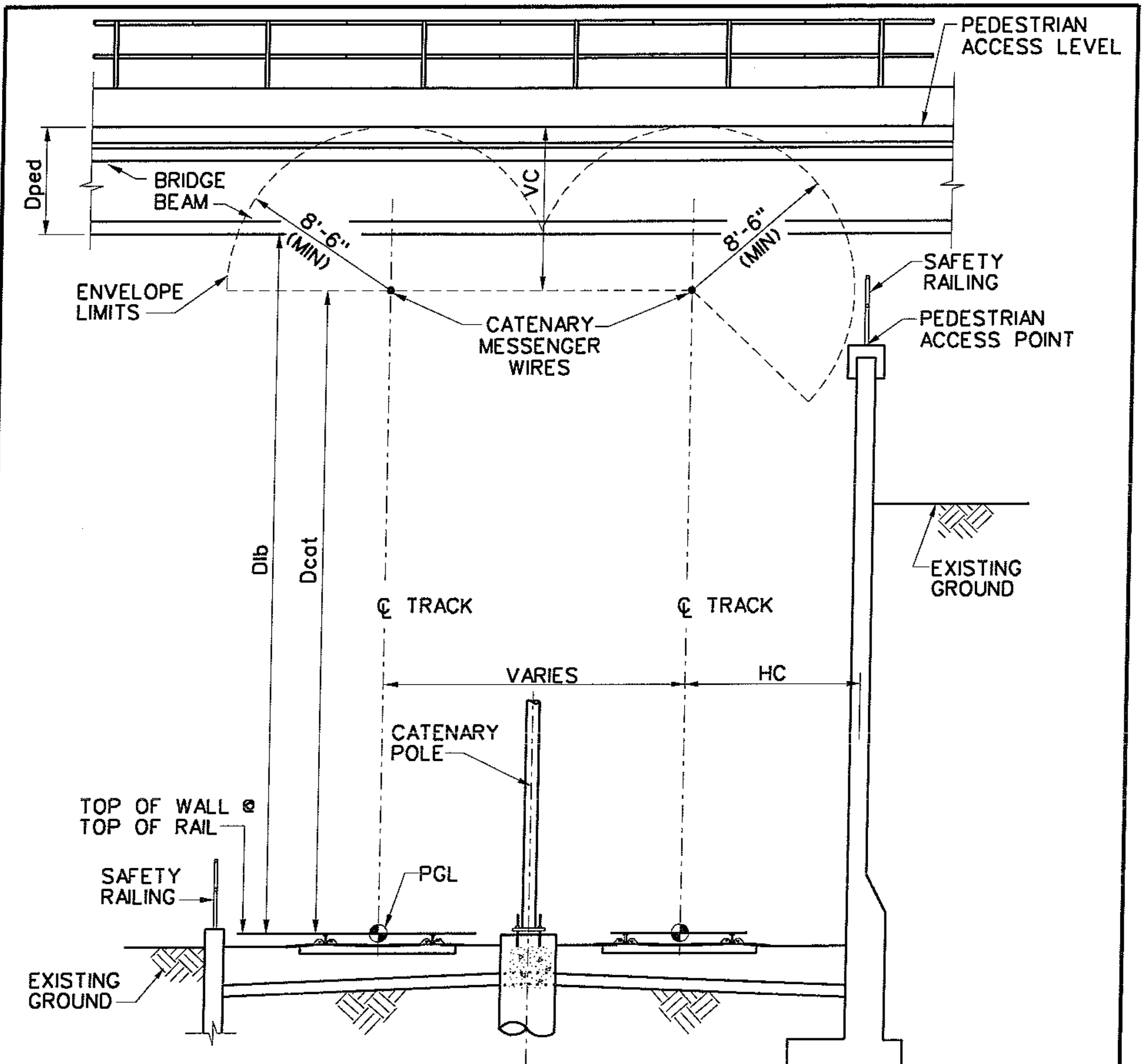
BELOW TRACK CLEARANCES
BALLASTED TRACK

SCALE: NONE

FIGURE: 1.7



NOTES:

1. TOP OF WALL ELEVATION WILL VARY DEPENDING OF ADJACENT FACILITY.
2. ENVELOPE FIGURED FROM THEORETICAL CENTERLINE OF CATENARY MESSENGER WIRE.
3. MEETS CLEARANCE CRITERIA

VC OR HC > 12'-0"; DESIRABLE
> 8'-6"; MINIMUM

SAFETY DEVICES REQUIRED

VC OR HC < 12'-0"; UNLESS MIN ALLOWED
VC OR HC < 8'-6"

VERTICAL

VC= (Dlb + Dped) - Dcat

WHERE; VC=VERTICAL CLEARANCE
Dlb = DIST, TOP TO RAIL TO LOW BEAM
Dped = LOW BEAM TO PEDESTRIAN ACCESS LEVEL
Dcat = TOP OF RAIL TO CATENARY WIRE

HORIZONTAL

HC = HORIZONTAL CLEARANCE; CANTENARY WIRE TO WALL/RAILING CENTERLINE DIST.

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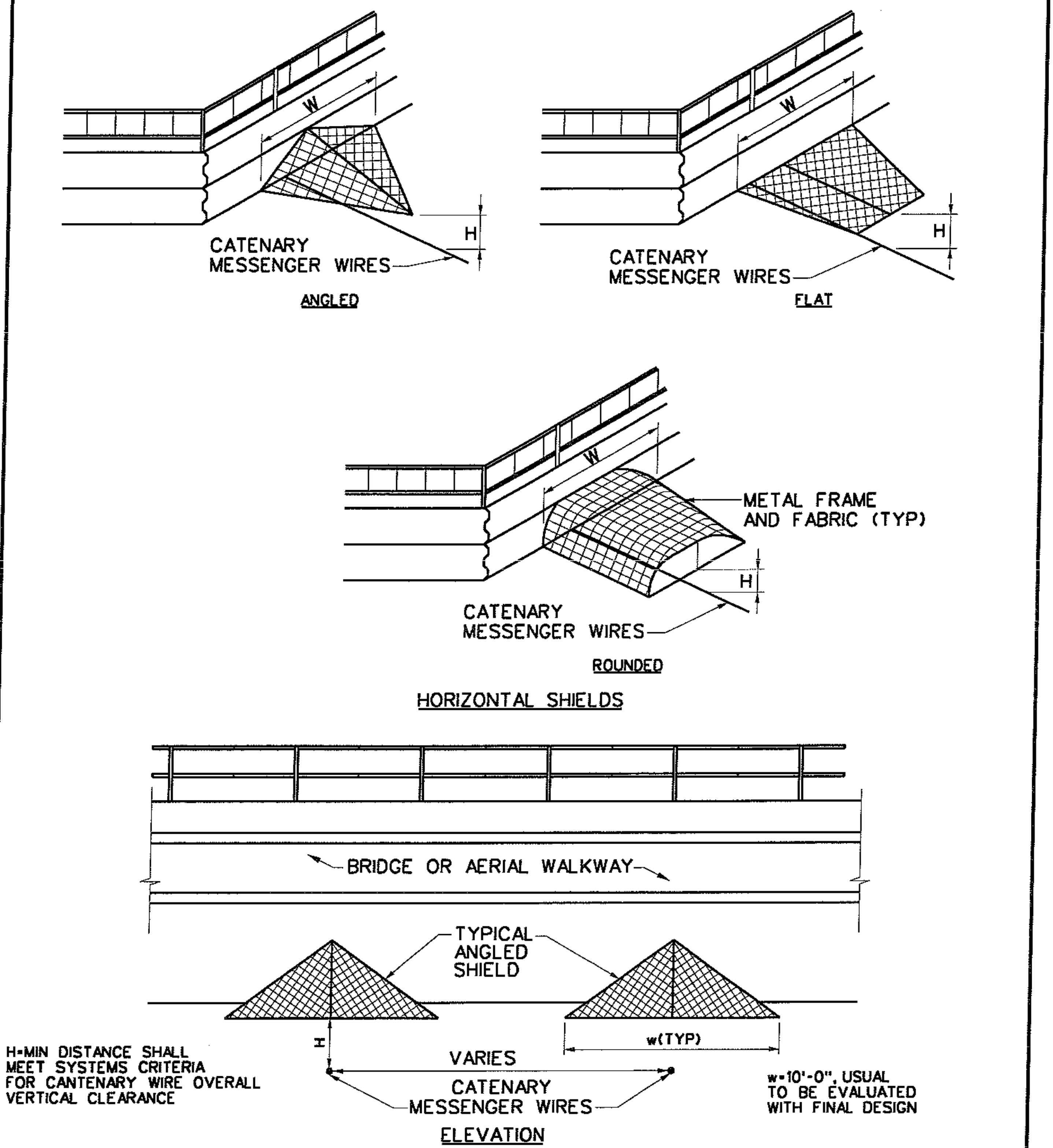
I-244 LRT BRIDGE OVER ARKANSAS RIVER

CATENARY SAFETY ENVELOPE

SCALE: NOT TO SCALE

FIGURE: 1.8



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CATENARY WIRE SAFETY SHIELD

SCALE: NOT TO SCALE

FIGURE: 1.9

CHAPTER 2 – TRACKWORK

2.1 INTRODUCTION

This chapter presents the various types of trackwork that may be used on the ODOT system. Related subjects covered include trackwork locations, use of derails, requirements for ballast, information about ties, rail fasteners and joints, and considerations for grade crossings.

Track materials and special trackwork shall comply with design criteria, directive drawings, and standard drawings for the ODOT rail system. These criteria and drawings are based on the current edition of the American Railway Engineering Association (AREMA) Manual for Railway Engineering and Portfolio of Trackwork Plans. They have been modified as necessary to reflect the physical requirements and operating characteristics of the ODOT rail system.

2.2 CLASSIFICATION OF TRACK

Track shall be classified as follows:

- Main line track. Main line track shall consist of all track constructed for the purpose of carrying revenue passengers.

- Yard track. Yard track shall consist of all other track constructed for the purpose of switching, storing, or maintaining transit vehicles. Pocket, interline connector, transfer zone, or yard lead tracks shall be constructed to main line track standards.

2.3 TRACK CONSTRUCTION TYPE

Trackwork shall be divided into three types of construction. Sections 2.3.1 through 2.3.3 provide an overview of the track construction types.

2.3.1 Tie-and-Ballast Construction

Construction shall conform to the following:

- Main line track. At-grade track shall consist of concrete ties, resilient track fastenings, ballast, and subballast upon a prepared subgrade. Bridges less than or equal to 500 feet in length shall have ballasted decks. Bridges over 500 feet in length shall have Direct Fixation tracks subject to approval of ODOT.

- Yard track. Yard track shall consist of timber ties, joint bars, tie plates, cut spikes, ballast, and subballast upon a prepared subgrade.

- Special trackwork. Special trackwork shall consist of timber ties, tie plates, ballast, and subballast upon a prepared subgrade. Fastenings for yard special trackwork shall be cut spikes, while main line special trackwork shall be a resilient type.

Refer to Figures 2.1 through 2.9 for sections of various tie-and-ballast track construction. These sections will be used where sufficient right-of-way is available and must be modified to accommodate available widths.

2.3.2 Direct-Fixation Construction

Direct-fixation construction shall be used for main line track on non-ballasted aerial structures and in subway structures. When bounded by aerial, subway, or U-wall sections of track, direct-fixation construction also shall be used on track slab at grade for sections less than 350 feet in length. Revenue track and special trackwork shall be fastened directly to the track concrete using direct fixation (standard or special) trackwork fasteners.

Resilient direct fixation rail fasteners shall be used to secure track to concrete. (Refer to the trackwork standard drawings for direct fixation details.) Consideration shall be given during the design of adjacent facilities for the clearance required to install the fasteners (see Figure 2.10).

The direct fixation rail fastener shall consist of two resilient rail clips, a bonded elastomeric plate with two female anchorage assemblies, and associated hardware. The fastener shall restrain movement of rail in the vertical, lateral, and longitudinal directions to a degree sufficient to support the rail in the anticipated operating and maintenance conditions. The fastener shall also be designed to minimize stray currents from running rail to ground, and to abate vibration and noise.

The rail hold-down assembly required in direct fixation special trackwork units shall be the same basic rail hold-down assembly used in main line track direct fixation construction. The reinforcing steel of the concrete track structure shall be designed to provide for the resilient direct fixation fastener securing devices.

2.3.3 Dual Block Concrete Tie Construction

In lieu of direct fixation construction, dual block concrete tie construction can be used. The dual block system consist of precast, reinforced concrete block and resilient rail fasteners. The base of each block is placed upon a resilient pad encased in a rubber boot which provides resilient separation between the rail support and the surrounding concrete. Due to the damping provided by the rubber boot, the dual block construction may be required in noise and/or vibration sensitive areas. The surrounding concrete is a second pour made after the dual blocks are placed, aligned and supported on an invert or deck slab.

2.4 TRACK GAUGE

Standard track gauge throughout the system shall be 4 feet 8-1/2 inches, as measured perpendicular between inside faces of running rail at a point 5/8-inch below the top of rail. Track gauge shall be widened as necessary on short radius curves of 500 foot radius or less.

2.5 TRACK CONSTRUCTION TOLERANCES

Track construction tolerances shall comply with the criteria shown in Table 2-1.

TABLE 2-1
TRACK CONSTRUCTION TOLERANCES

Class and Type of Track	Gauge Variation	Cross Level and Superelevation Variation	Vertical Track Alignment		Horizontal Track Alignment	
			Total Deviation	Middle Ordinate In 62' Chord	Total Deviation	Middle Ordinate In 62' Chord
Direct Fixation and Paved Track	± 1/8"	± 1.8"	± 1/4"	± 1/8"	± 1/4"	± 1/8"
Mainline Ballasted Track	± 1/8"	± 1/8"	± 1/2"	± 1/8"	± 1/2"	± 1/8"

Notes:

(1) Total deviation is measured between the theoretical and actual alignment centerline at any point in the track.

(2) Total horizontal and vertical deviation in road crossing and station areas ± 1/4".

2.6 RAIL

Except as specified below, standard running rails shall be 115RE section, manufactured in accordance with current AREMA "Specifications for Steel Rail." Specially treated, control- cooled rail shall be used as follows:

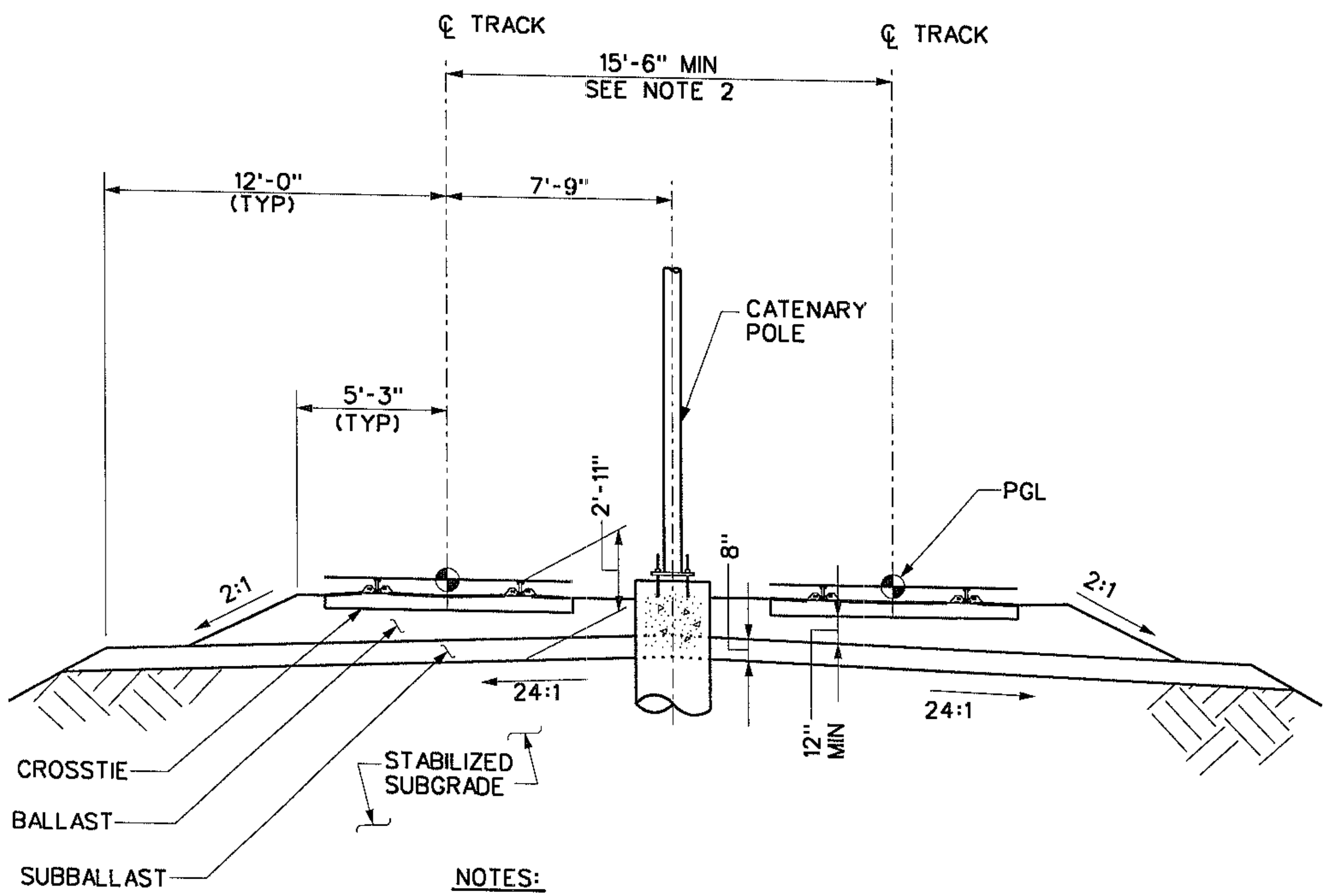
- End-Hardened Rail. End-hardened rail shall be used for all bolted joints except where premium rails are used.

- Premium Rail. Fully heat-treated rail, premium alloy, or head-hardened rail shall be used for all special trackwork.

"A" rails shall not be used as running rails in main line track and special trackwork, but may be used for yard track and secondary track, except for shop track running through pit areas. Rails to be used for welded rail shall be furnished with blank ends. Rail ends to be used in bolted joints shall be drilled in accordance with the most current AREMA requirements and beveled in accordance with the most current version of AREMA Plan No. 1005.

Premium rail is used in curves of 500 feet radius or less, and shall extend a minimum of 5 feet into the tangent track on the approach and departure ends of the curve. Minimum rail length shall be 15 feet 8 inches, except as necessary in special work and turnouts. Rails to be used in curves with a centerline radius of less than 450 feet shall be pre-curved. The pre-curving of the rail shall be accomplished through standard shop methods.

Girder rail used in paved track shall be of an appropriate section, control-cooled and manufactured in accordance with current AREMA "Specifications for Steel Rail". Premium girder rail shall be used for the same applications as 115 RE rail.



NOTES:

1. SEE OTHER TYPICAL DRAWINGS FOR SLOPES, R/W, AND RELATIONSHIPS TO OTHER FEATURES.
2. TRACK CENTERS MAY BE REDUCED TO 14'-0" IN AREAS WHERE A CENTER POLE IS NOT REQUIRED OR WITH A CENTER POLE OF WIDTH EQUAL TO OR LESS THAN 1 FOOT UPON ODOT APPROVAL.

TANGENT AT GRADE

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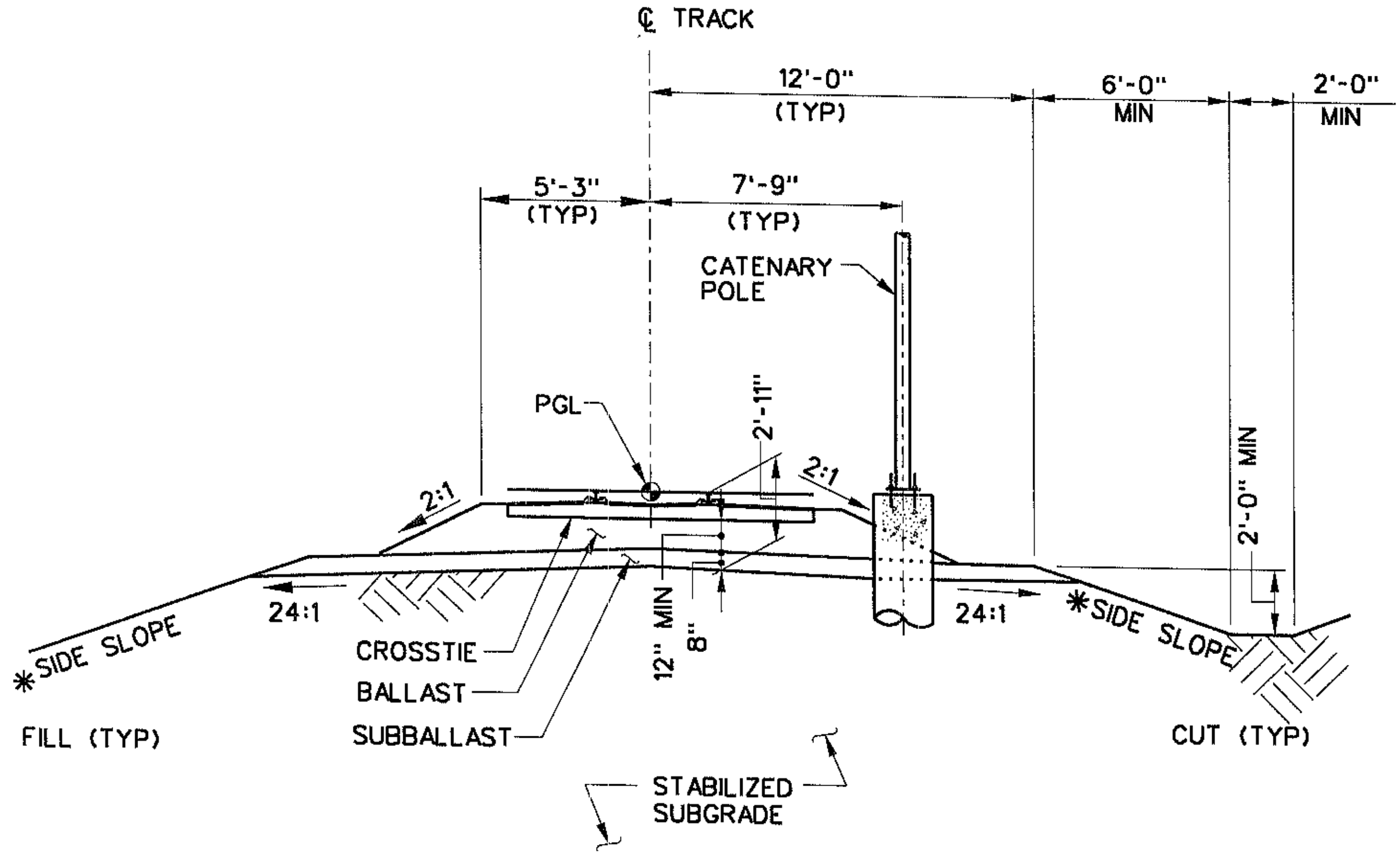
TANGENT AT GRADE

SCALE: 1"=6'-0" FIGURE: 2.1



NOTE:

* SIDE SLOPES TO BE 3:1 UNLESS OTHERWISE DETERMINED BY GEOTECHNICAL REQUIREMENTS.

TANGENT SINGLE TRACK-AT GRADE

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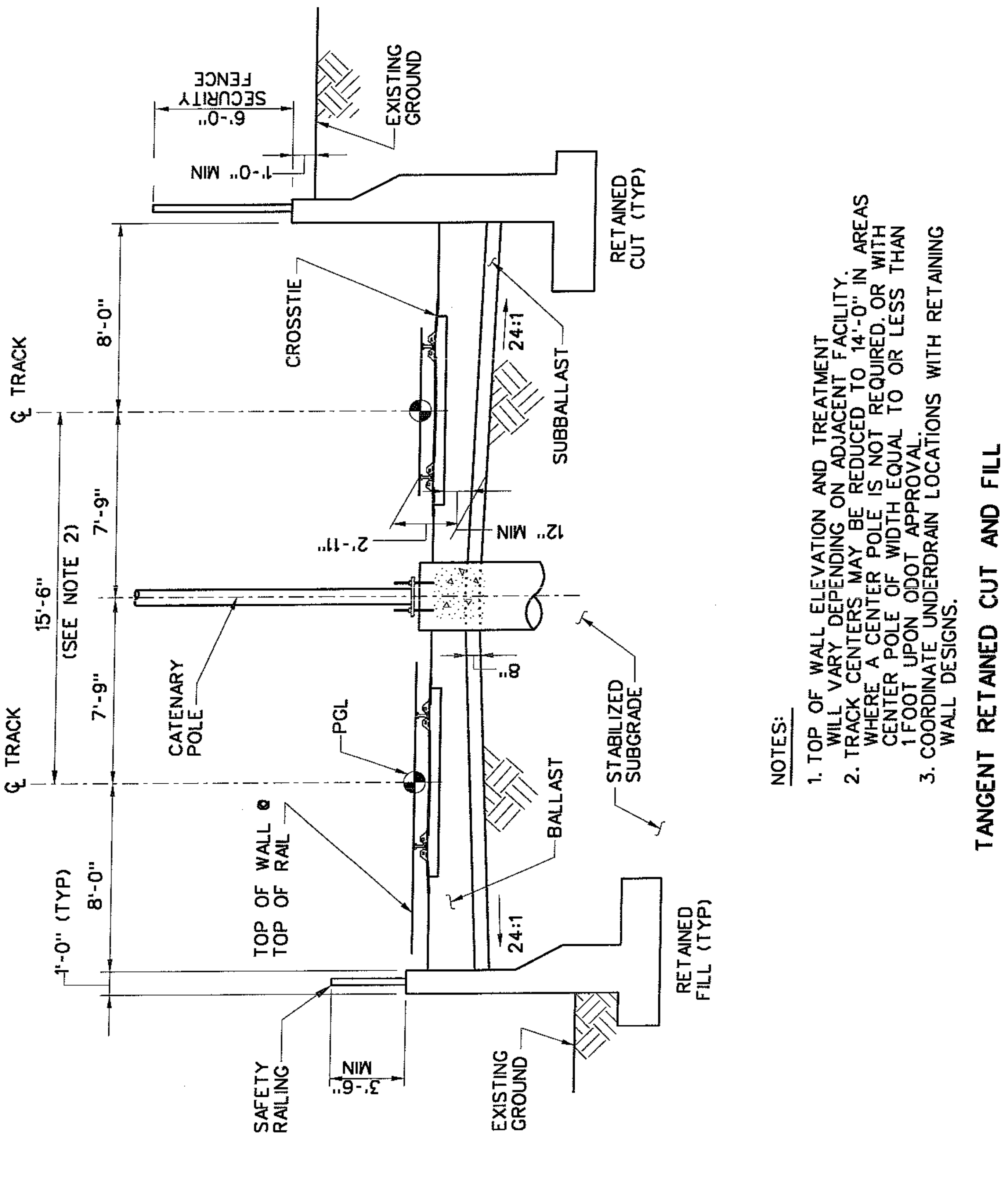
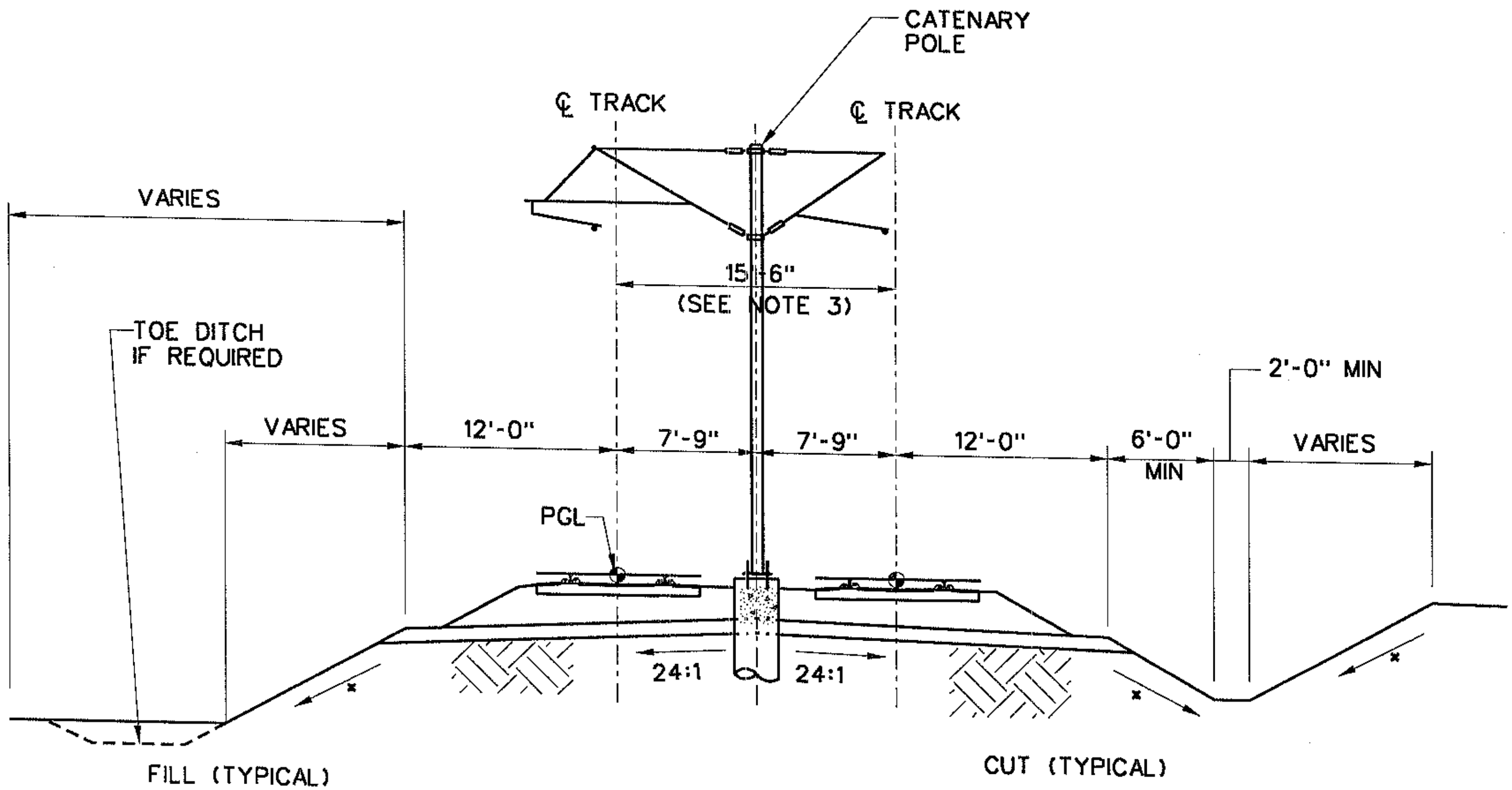


L:\150-10146-000\4-0-PRODUCTION\4-06-REF-STUDIES-REPORTS\BY\LAN\4-06-03 REPORT EXHIBITS\FIGURE2-3.006

LAN Lockwood, Andrews & Newnam, Inc. A LEO A. DALY COMPANY	8350 NORTH CENTRAL EXPWY SUITE 1400 DALLAS, TX 75206 214.522.8778 www.lan-inc.com	I-244 LRT BRIDGE OVER ARKANSAS RIVER TANGENT RETAINED CUT AND FILL SCALE: 1"=6'-0" FIGURE: 2.3

L:*150-10146-000*4-0-PRODUCTION*4-06-REF-STUDIES-REPORTS*BY*LAN*4-06-03 REPORT EXHIBITS*FIGURE2*4.010



NOTES:

1. SEE FIG NO. 2.1 AND FIG NO. 2.5 FOR CURVES, SLOPES AND DIMENSIONS NOT SHOWN HERE.
2. * SIDE SLOPES TO BE 3:1 UNLESS OTHERWISE DETERMINED BY GEOTECHNICAL REQUIREMENTS.
3. TRACK CENTER MAY BE REDUCED TO 14'-0" IN AREAS WHERE A CENTER POLE IS NOT REQUIRED. OR WITH A CENTER POLE OF WIDTH EQUAL TO OR LESS THAN 1 FOOT UPON ODOT APPROVAL.

AT GRADE-CUT AND FILL

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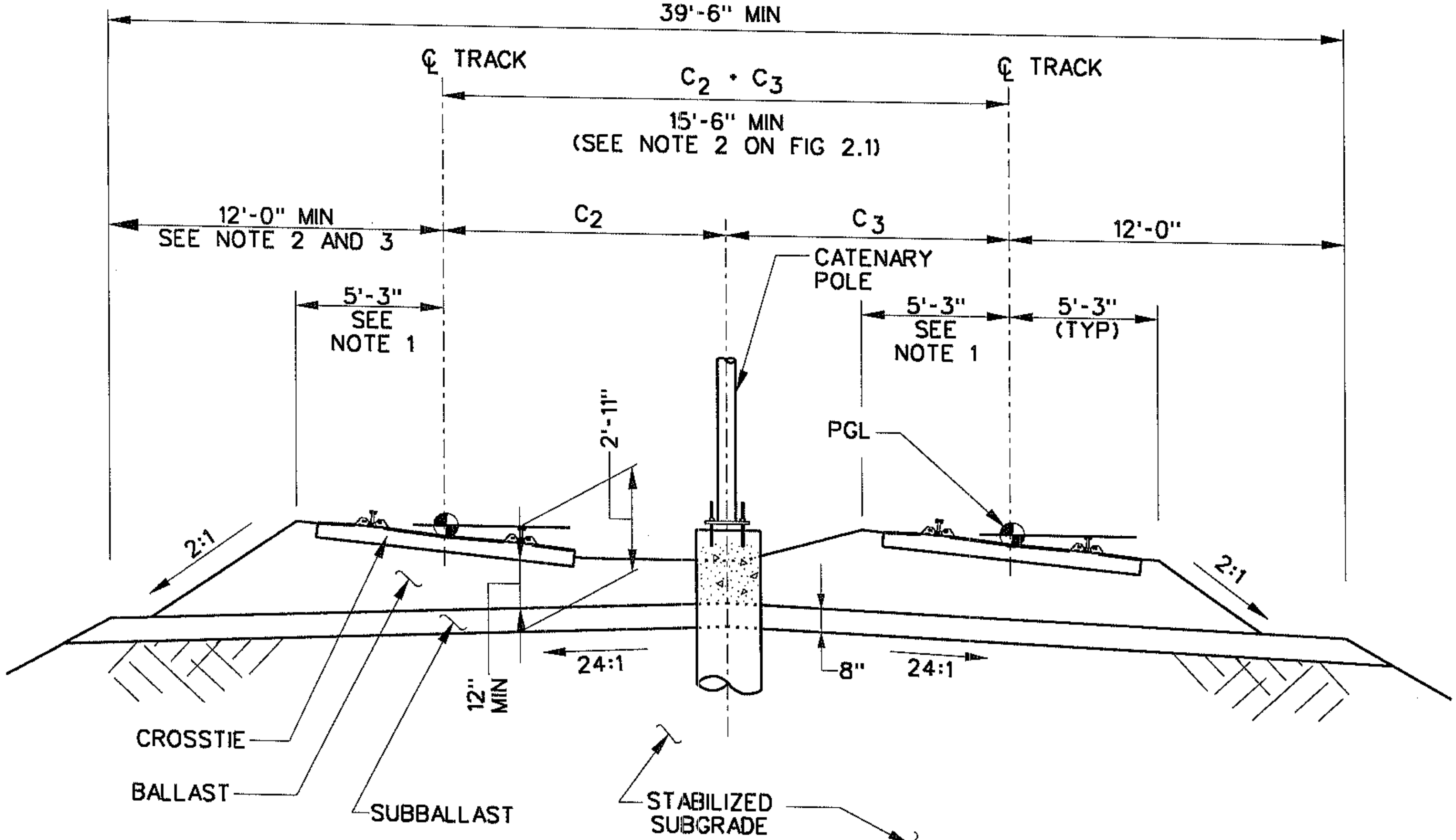
I-244 LRT BRIDGE OVER ARKANSAS RIVER

AT GRADE-CUT AND FILL

SCALE: 1"=10'-0"

FIGURE: 2.4

L:*150-10146-000*4-0-PRODUCTION*4-06-REF-STUDIES-REPORTS*BY*LAN*4-06-03 REPORT EXHIBITS*FIGURE2*5.006



NOTES:

1. FOR RAIDUS LESS THAN 1000'; INCREASE TO 5'-9".
2. FOR SUPERELEVATED CURVES WHERE EACH IS GREATER THAN 2", INCREASE SHOULDER TO 13'-6".
3. ADD ONE FOOT TO REQUIRED SHOULDER WHERE R ≤ 1000'.
4. C_2 , C_3 : SEE SECTION 1.10.2.

CURVED AT GRADE WITH CENTER POLE

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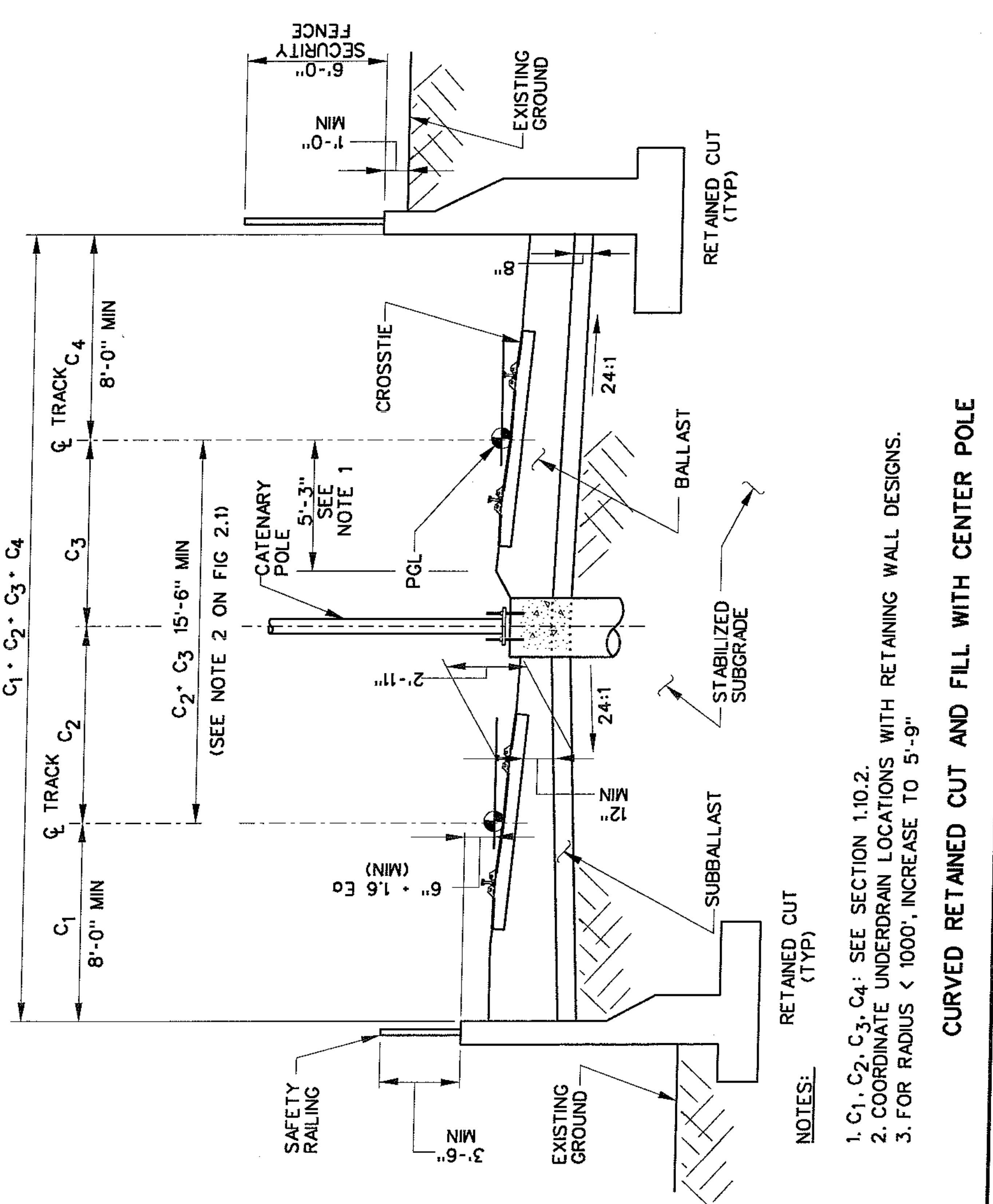
CURVED AT GRADE

SCALE: 1"=6'–0"

FIGURE: 2.5



NOTES:

1. C_1, C_2, C_3, C_4: SEE SECTION 1.10.2.
2. COORDINATE UNDERDRAIN LOCATIONS WITH RETAINING WALL DESIGNS.
3. FOR RADIUS < 1000', INCREASE TO 5'-9"

CURVED RETAINED CUT AND FILL WITH CENTER POLE

L:\150-10146-000\4.0-PRODUCTION\4-06-REF-STUDIES-REPORTS-BY-LAN\4-06-03 REPORT EXHIBITS\FIGURE2-6.006

lan Lockwood, Andrews & Newnam, Inc. A LEO A. DALY COMPANY	8350 NORTH CENTRAL EXPWY SUITE 1400 DALLAS, TX 75206 214.522.8778 www.lan-inc.com	I-244 LRT BRIDGE OVER ARKANSAS RIVER CURVED RETAINED CUT AND FILL SCALE: 1"=6'-0" FIGURE: 2.6

2.7 RAIL LUBRICATION

Lubrication shall be by car-mounted applicator in accordance with systems criteria, except that the bearing face of all restraining rail shall be lubricated to reduce rail and wheel wear. The track lubricating mechanisms shall be automatic, adjustable, and shall not dispense lubricant on the top of the rail, invert, or ground. The lubricant shall have low electrical conductivity. Other locations shall require lubrication as determined by ODOT.

2.8 SPECIAL TRACKWORK

This section defines special trackwork configurations, outlines location procedures, describes component features, and lists operating constraints. Special trackwork consists of turnouts and rail crossings. Maximum operating speeds through the diverging moves on turnouts shall be as indicated in Table 2-2.

Table 2-2
MAXIMUM OPERATING SPEEDS THROUGH DIVERGING MOVES OF TURNOUTS

TURNOUT NO.	MAXIMUM SPEED LIMIT (MPH)
10 - Lateral	20
10 - Equilateral	25

2.8.1 Configurations

The units and their criteria to be used on the system include:

- No. 10 turnouts, at minimum, at junctions between routes (19-foot-6-inch curved split switch).
- No. 10 turnouts (19-foot-6-inch curved split switch) for main line track crossovers, turnouts to the yard, pocket tracks, and end-of-line storage.
- No. 10 equilateral turnouts (26 foot curved split switch) for pocket tracks, for aerial tracks and subway track installations. No. 10 lateral turnouts (19- foot-6-inch curved split switch) for at-grade locations.

Combinations of these units to be used on the system shall include the following arrangements:

- <u>Universal</u>. This configuration employs two single back-to-back crossovers connecting main line tracks.
- <u>Double Crossover</u>. This trackwork consists of four lateral turnouts connected together by a rail crossing composed of two end frogs and two center frogs. It shall be used in all direct-fixation locations.

Details of these units and configurations are shown on the trackwork standard and directive drawings.

2.8.2 Location Criteria

Crossovers and turnouts shall be located on tangent track and on constant profile grades with a desired maximum grade of ±1 percent and an absolute maximum grade of ±4.5 percent. The installation of special trackwork on a horizontal or vertical curve may be considered, but will require prior approval by ODOT.

Special trackwork is a source of noise and vibration. Those factors will be considered, as will the recommendations of the acoustical consultant when selecting locations and alternative designs for special trackwork.

Special trackwork shall not be located within 250 feet of a transition between ballasted track and direct fixation track. The desirable and minimum length of tangent track between any point of switch and a future end of a station platform shall be 50 feet. The desirable horizontal and vertical tangent distance preceding a point of switch shall be 50 feet, and the absolute minimum shall be 10 feet. The minimum distance measured from a point of switch through a turnout to a horizontal or vertical curve point shall be as shown in Table 2-3.

2.8.3 Switch Machine Locations

Switch machine locations shall be positioned as follows:

- Subway and aerial structures. On turnout side, in tension.
- Emergency crossovers. On turnout side, in tension.
- At-Grade junctions. On turnout side, in tension.

2.8.4 Component Features

The basis of design for all special trackwork components is the AREMA "Portfolio of Trackwork Plans"; however, certain features of the special trackwork components may vary from AREMA design. Any deviation from the trackwork standard drawings shall require approval by ODOT.

Possible variations include:

- Special trackwork will be welded.
- Frogs with extended arms to provide adequate clearance for rail welds and suspended joints.

- Main line switches utilizing extended switch points with a floating heel block and tie spacing increased in the closure area and after the frog.
- Gauge plates beneath the switch and frog.

- Rail crossings in conformance with the standards indicated on AREMA Plan No. 820-68.

- All turnouts with Samson switch points with undercut stock rails according to AREMA Plan No. 221-62, point detail 5100.

- Direct fixation turnouts supported by special direct fixation fastenings.

- Curved switch points and stock rails pre-curved, using standard shop methods.

- Closure rails with radii less than 450 feet pre-curved, using standard shop methods.

TABLE 2-3
LIMITING DIMENSIONS FOR SPECIAL TRACKWORK

Turnout No.	Type of Track Construction	Minimum Distance From Point of Switch Through Turnout To Point of Curve (Vertical or Horizontal	
		Desirable	Minimum*
10	Ballasted	120'	100'
10 Equil.	Ballasted	120'	100'

*May require change in long tie layout.

Note:

(1) For curves of opposite direction than the turnout curve the section 1.3.4, Minimum Tangent Length applies.

(2) There are no restrictions at non-ballasted track structure for long ties adjustment or shimming when minimum distances are applied.

2.9 DERAILS

Derails shall be installed on access tracks to railroad sidings and on any yard or secondary track normally used for the storage of unattended vehicles if:

- Any of those tracks are directly connected to the main line track.
- Their prevailing grade descends to the main line track.

Descending grades to the main track should be avoided whenever possible. The location and direction of derails, which will be electrically operated and interlocked with wayside signals, shall be approved by ODOT. (See Systems Design Criteria Chapter 4 - Signals System for more information.)

2.10 APPROACH SLABS

A transitional approach slab shall be provided at all transitions between ballasted track, direct fixation track, and paved track. (See the trackwork standard drawings for details.)

2.11 END OF TRACK RESTRAINING DEVICE

A rail-mounted retarding device shall be used on stub-end tracks located in yards, on main lines, or on sidings. This device shall limit movement by absorbing vehicle energy and it shall include an anti-climbing feature. Should conditions warrant, an additional hydraulic car-retarder shall be considered. (Refer to the trackwork standards and directives for details.)

2.12 CORROSION PROTECTION

Not Required.

2.13 SUBBALLAST AND BALLAST

A flexible-base material shall be used for subballast. Asphalt base may be considered where soil conditions warrant and where use is economical and technically adequate. Ballast shall be crushed stone conforming to the current AREMA specifications of ballast.

2.13.1 Subballast

Subballast or an accepted alternate material shall be used for all ballasted track. Subballast shall not be used on ballasted deck bridges or U-wall construction. The subballast for all tracks shall consist of a uniform layer placed and compacted over the entire width of the roadbed following the profile and cross section. The depth of subballast measured from the bottom of the ballast to the top of the subgrade shall be a minimum of 8 inches. Subsurface conditions shall be determined in accordance with

Chapter 10 - Geotechnical Information. All subballast material shall conform to current ODOT Type A Aggregate Base.

2.13.2 Ballast

The minimum depth of ballast from the bottom of the tie to the top of the subballast (beneath the lowest running rail) shall be 12 inches. Cribs and shoulders shall be filled with ballast to the top of the tie. If not direct-fixation construction, the minimum depth of ballast beneath the bottom of ties on ballasted-deck bridges and U-wall construction shall be 8 inches.

Shoulder ballast shall extend 12 inches beyond the end of ties parallel to the plane formed by the top of the tie. The high outside shoulder shall be increased to 18 inches for curves where the radius (R) equals 1,000 feet or less. In at-grade sections, shoulder ballast shall then slope at 2:1 to the subballast. For additional details refer to the trackwork standard drawings. All ballast shall conform to the current AREMA specification for ballast. No. 4 size ballast shall be for main line tracks and No. 5 size ballast shall be for yard. Crushed cementitious rock such as limestone or dolomite shall not be used for mainline ballast. Crushed cementitious rock may be used for yard tracks. Slag shall not be used for either mainline or yard track ballast.

2.14 TIES

Cross ties for main line ballasted track segments shall be concrete. Timber ties shall be used for ballasted special trackwork.

2.14.1 Concrete Ties

Concrete cross ties shall be used in main line ballasted track and shall be spaced a maximum of 30 inches center-to-center. They shall include a cant (1:40) on the rail bearing area. Tie spacing at approach slabs shall be as shown in the trackwork standard drawings. Concrete crossties used in main line ballasted track at-grade crossing shall be spaced at 18 inches center-to-center.

2.14.2 Dual Block Concrete Ties

Dual block concrete ties may be used in main line track construction in lieu of direct fixation track. The ties shall be spaced a maximum of 30 inches center to center. The individual blocks shall be encased in a rubber boot. The tie assembly shall be held in place with a second pour of concrete. Ductile iron shoulders shall be deeply embedded in the concrete block to form an integral part of the rail support system.

2.14.3 Timber Ties

All timber ties shall be treated mixed hardwoods with anti-splitting devices installed in accordance with current AREMA specifications. All timber ties shall be air seasoned and treated with an appropriate preservative in accordance with the current AREMA "Specifications for Ties."

Timber Cross Ties. Timber cross ties shall be used in yard ballasted track. All timber cross ties shall be new, pre-bored, 7" grade treated tie, 8 feet 6 inches in length. They shall conform to current AREMA "Specifications For Timber Cross Ties." Timber cross ties shall be spaced a maximum of 24 inches center- to-center.

Timber Switch Ties. All timber switch ties shall be new, treated 7 inch by 9 inch ties, in lengths specified in the trackwork standard drawings. They shall conform to the current AREMA "Specifications for Timber Switch Ties." Timber switch ties shall be field bored, and holes shall be treated with an appropriate preservative.

2.15 RAIL FASTENERS

Concrete ties shall use resilient clip track fasteners suitable for the loading and operating conditions of the system. The fastener assembly shall also have an insulating tie pad and clip insulators. Main line timber cross ties shall also use a resilient clip track fastener, where applicable, complete with double-shoulder canted (1:40) tie plates, spring clips, rubber pad, insulated anchorage bushing, and timber screw spikes (plate hold-down). The same resilient clip track fastener shall be used on main line timber switch ties wherever possible. Cut spikes or another rail hold-down shall be used as required. Special plates shall be used to support switch and frog components, and the use of these plates may require the use of specially modified rail fastening devices in lieu of the resilient clip track fastener. Yard track and yard special trackwork shall utilize cut spikes, hooked twin plates, and tie plates.

2.16 GUARDED TRACK

All main line ballasted and direct-fixation track having a centerline radius less than or equal to 500 feet shall have the inside running rail guarded with a restraining rail. This type of guarding protection shall be achieved by using a fabricated assembly with an adjustable and replaceable wear bar. The guard shall protrude 1 inch above the top of the low rail and shall be electrically isolated from the running rail. The guard rail shall extend 32 feet into tangent track. Alternative designs employing other methods of guarding will be considered. The operating speed on track with restraining rail shall not exceed 25 miles per hour in any application. Special trackwork shall be guarded in the frog and crossing areas. Guarding for main line and yard track frogs and crossings shall consist of an AREMA type design using a spacer block bolted to the running rail.

2.17 JOINING RAIL

2.17.1 Welding

Unless otherwise specified, girder and tee rails shall be joined by pressure-weld methods into continuously welded rail (CWR) strings. Contiguous strings of CWR shall be joined together with thermite or electric flash butt welds. String lengths shall be determined during final trackwork design. Girder rail shall be welded to tee rail by use of a specially designed rail plug. This plug will facilitate a change in cross section from girder rail to tee rail. Rails to be welded shall not be drilled for joint bars.

Any rail to be welded which contains bolt holes shall first be cropped a minimum distance of 3 inches from the center of the last hole. All pressure welds shall be checked by a brush recorder that monitors the flashing process. These pressure welds also shall be magnetic-particle tested. All welds shall be ultrasonically tested as outlined by the AREMA Manual for Railway Engineering by an individual qualified in the ultrasonic testing of rail weldments. Additionally, a selected number of welds will be radiographed. An acceptance criteria for allowable size and number of weld defects will be determined during final trackwork design.

2.17.2 Bolted Joints

Except where specified below, the use of bolted joints shall be minimized. The standard bar for use with 115RE rail shall be 36 inches in length, with 6 holes conforming to the current AREMA specifications for Rail Drillings, Bar Punchings and Track Bolts. As may be necessary according to these criteria, joint bars shall be located in special trackwork and in other locations. Special provisions shall be made to allow for the electrical bonding of rail joints for traction power and signaling requirements.

2.17.3 Epoxy Bonded Joints

Epoxy bonded joints shall be electrically bonded to provide a continuous path for traction power negative return current and signal circuits. Epoxy bonded joints shall comply with the following parameters:

- They shall employ an identical drilling pattern as standard joint bars.
- They shall be compatible with the standard direct fixation rail fasteners used on the ODOT system.
- They shall comply with the general requirements of a rail joint as defined by Chapter 4 of the current AREMA Manual for Railway Engineering.

2.17.4 Insulated Joints

Insulated joints of the epoxy-bonded type shall be used wherever it is necessary to electrically isolate contiguous rails from each other to comply with track signaling criteria. Track bolts shall be the high-strength type. Insulated joint bars shown in Figure 2.11 shall also comply with the physical parameters listed in Section 2.17.3 of these criteria. (The Systems Designer will define insulated joint locations.)

2.18 GRADE CROSSINGS

2.18.1 Highway

Main line track grade crossings shall be prefabricated from concrete or a concrete and steel composite. They shall be designed for ease of replacement, electrical isolation, and use of running rail in track circuits. Rail joints and thermite welds shall not be located within grade crossing limits. Track underdrains shall be used at all grade crossing sites in conjunction with suitable geotextile filter fabrics.

Grade crossings shall be located on tangent tracks wherever possible. Grade crossings located in curved track and special trackwork shall be avoided wherever possible. Cross ties shall be spaced in accordance with the grade crossing panel manufacturer's recommendations and as addressed in section 2.14 of this chapter. Mainline track grade crossing will incorporate pedestrian crossings as required. Pedestrian crossings in Stations shall be concrete and shall be located as needed.

2.18.2 Railroad

Railroad at-grade crossings of ODOT main line tracks shall be restricted to those railroad tracks that serve industrial sidings. Such crossings will be a rigid design in accordance with AREMA Plan 820.

2.19 RAIL ANCHORS

Rail anchors shall be applied to all tracks constructed with timber tie. Application of rail anchors shall conform to the AREMA manual Specification for Rail Anchors, Chapter 5.

CHAPTER 3 – TRACKWAY

3.1 INTRODUCTION

This chapter establishes criteria for the design of at-grade sections of the trackway and provides, together with other system requirements, a determination of right-of-way requirements for line sections of the ODOT rail system. Trackway is defined as that portion of the ODOT rail system rail line that has been prepared to support the track and its associated structures. At-grade trackway is that trackway that is neither on aerial structures, in subways, in U-wall sections, nor paved track. At-grade trackway generally includes the entire right-of-way exclusive of stations, and includes the subgrade, slopes of cuts and fills, the drainage systems for diverting or carrying water away from the track area, and the catenary pole foundations. The trackway may contain longitudinal and transverse direct-burial cable, ductbanks, electrical conduits, utilities structures, or acoustical barriers. These criteria are to be used in conjunction with all appropriate chapters of the Civil Design Criteria, as well as the Structural Design Criteria chapters. Some dimensions indicated in these criteria are also shown on the trackwork standard and directive drawings, and the at-grade standard and directive drawings.

3.2 SUBGRADE

The subgrade is the finished surface of the trackbed below the subballast. The subgrade supports the loads transmitted through the ballast and subballast. The support of the track depends ultimately on the stability of the subgrade. Uniformity is the goal of subgrade design because it is differential rather than total vertical movement that leads to unsatisfactory track geometry.

The designer shall specify stabilization requirements that will limit differential vertical movement resulting from shrinking or swelling of soil within a 62-foot length to 1 inch. Total settlement due to fill construction shall be limited to 2 inches during a 2 year period following completion of the trackwork installation. Where soil characteristics do not permit the economical achievement of these requirements by soil stabilization methods, alternative trackway designs shall be submitted for consideration.

3.2.1 Stabilization of Subgrade

Lime or cement stabilization of the subgrade shall be provided where indicated by geotechnical investigations. The material and method selected shall be evaluated and recommended by the designer.

3.2.2 Configuration

The subgrade shall be crowned and sloped away from the apex of the crown on a slope of 24 horizontal to 1 vertical. The location of the apex of the crown shall be, for single track, at the centerline of the track; for double track, at a line midway between the two tracks; and for three tracks, at the centerline of the middle track. If the track center-to-center spacing is more than 19 feet, each track shall be considered to be a single track. For single track, where a future double track is planned, the crown shall be located for double track. (Refer to the trackwork standard and directive drawings for further information.)

3.2.3 Elevation

The elevation of the top of subgrade shall be determined from the profile grade line (PGL) of the tracks. The minimum dimension from the PGL to top of subgrade is shown on the trackwork criteria figures and on the trackwork standard directive drawings. The depth of the track structure shall be used to determine the highest allowable subgrade elevation under each track. On curved, superelevated track, the PGL is the top of the inside (lower) rail.

Elevations at the apex and shoulders of the subgrade shall then be developed from the PGL elevation and the slope of the subgrade. When tracks are not all on the same PGL, the top- of-rail to top-of-subgrade distance must be checked on the lower track or tracks to determine that the minimum required depths of ballast and subballast are maintained on all tracks.

3.2.4 Dimensions

The width of the subgrade is determined by the track centers and the track geometry. It is a function of the height of rail, length of tie, depth and configuration of ballast and subballast, and superelevation of the track. All dimensions included in this chapter are based upon a tie length of 8 feet 6 inches and a track gauge of 4 feet 8-1/2 inches. The subgrade must be of sufficient width to support the subballast. Widths of top surface of subballast are shown on Figures 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6 in Chapter 2 - Trackwork.

3.2.5 Single Track

On tangent track, the minimum width of the top surface of subballast shall be 24 feet. For tracks with curvature requiring an actual superelevation (E_a) greater than 2 inches, the width of the subgrade and subballast shall be increased by 18 inches on the outer side of the curve. Where the radius is less than or equal to 1,000 feet, the width shall be increased an additional foot. See Figure 2.5 in Chapter 2 - Trackwork.

3.2.6 Double Track

On tangent track with 15-foot 6 inch track centers the desirable minimum at-grade width of the top surface of subballast shall be 39-1/2 feet. Where track centers are more than 19 feet, they shall be treated as two single tracks. For tracks with curvature requiring an actual superelevation (E_a) greater than 2 inches, the width of the subgrade and subballast shall be increased by 18 inches on the outer side of the curve. Where the radius is less than or equal to 1,000 feet, the width shall be increased an additional foot. See Figures 2.1, 2.4 and 2.5 in Chapter 2 - Trackwork.

3.2.7 Three Tracks

On tangent track the minimum width of the top surface of subballast shall be 55. This assumes track centers of 15 foot 6 inch; if greater track centers are required, they shall be treated as a special case. For tracks with curvature requiring an actual superelevation (E_a) greater than 2 inches, the width of the subgrade and subballast shall be increased by 18 inches on the outer side of the curve. Where the radius is less than or equal to 1,000 feet, the width shall be increased an additional foot.

3.2.8 Subgrade Width Transition

The transition from one subgrade width to another shall take place uniformly throughout the length of the spiral of a curve and at a rate of 1 foot per 100 feet for other locations such as hi-rail access points.

3.2.9 Ballast Walls

Ballast walls shall be used as necessary to prevent ballast contamination from adjacent material or drainage. The condition will occur predominately in narrow right-of-way areas that do not have space for side ditches, and do not require retaining walls. Drainage swales or appropriate grading should be provided behind the wall to prevent the drainage water from entering the track ballast.

3.3 SLOPES

Side slopes of earth generally shall be three-horizontal-to-one-vertical, or flatter. Steeper slopes may be used in rock cuts in accordance with the section designer's recommendations. To minimize maintenance costs, consideration shall be given to the use of slopes flatter than three-horizontal to one-vertical, where sufficient right-of-way is available. All slopes shall conform to the section designer's recommendations, unless otherwise directed by ODOT. A typical treatment of cut-and-fill slopes is shown on Figure 2.4 in Chapter 2 - Trackwork.

Where geotechnical conditions warrant, benches shall be provided along the face of a cut. For deep cuts, intermediate benches shall be provided at locations where the vertical height of slope is 15 feet or more. Where the cut is in rock with an overburden of soil, a bench shall be provided at the rock and soil interface. Where such benches are provided, they shall have a minimum width of 10 feet to permit maintenance by conventional earth-moving equipment. Access to these benches shall be provided to this maintenance equipment.

3.4 DRAINAGE

Track stability requires that water seeping or flowing toward the track shall be intercepted and diverted before it reaches the track, and that water falling upon the track area shall be quickly drained. Drainage shall be provided to prevent the presence of non-flowing water, to an elevation 4 feet below the subballast. In addition, trackway drainage design must be coordinated with existing drainage structures in accordance with the standards set forth in this chapter and ODOT or local agency requirements.

3.4.1 Side Ditches

Side ditches shall be provided parallel to ODOT tracks through sections in cut. Intercepting ditches at the tops of slopes and along benches shall be provided where required. The design of ditches shall conform to criteria given in ODOT or local agency criteria.

Side ditches shall not be used on the tops of fills. They shall be used at the bottoms of fills as necessary to provide continuity of drainage as shown in Figure 2.4 in Chapter 2 - Trackwork.

3.4.3 Underdrains in Retained Sections

Longitudinal perforated drains shall be provided immediately adjacent to retaining walls and immediately below the surface of the subgrade. The underdrain pipe shall be encased in an envelope of suitable filter fabric and crushed stone. The fabric shall extend up to and under the ballast. A similar drainage arrangement shall be provided between the edge of the ODOT trackway and an adjacent railroad track where lateral clearance does not permit a drainage ditch. (For further details see the trackwork directive drawings.)

At a sag in the track profile and 100 feet either side of the low point, an underdrain shall be provided.

3.4.4 Underdrains in Cut to Fill Sections

When on a descending grade from a cut section to a fill section, and high groundwater is indicated, a lateral cross-drain shall be provided at the change of sections.

3.5 UNDERTRACK STRUCTURES

Duct banks, direct burial cable, conduits, utilities, or other structures may cross or run alongside and closely adjacent to the ODOT rail system track. None of these facilities shall infringe, however, upon the envelope shown on Figure 1.7 in Chapter 1 - Track Alignment. Duct banks and direct burial cable shall run longitudinally along the outside of tracks or below the space between tracks. Duct banks, direct burial cables and conduits crossing under the tracks shall be kept sufficiently clear of the subballast. In all cases they shall be below the surface of the subgrade. Where manholes, pull boxes, or conduit "stub-ups" come to the surface, encroachment within the subballast and ballast may be necessary. The extent of this encroachment shall be kept to a minimum. In no case shall the duct banks or direct burial cable be permitted to adversely affect the drainage system.

3.6 WAYSIDE ACCESS

To the fullest extent possible, access to trackway at track level shall be provided for maintenance and emergency work. This requires providing access for:

oTrucks carrying personnel, tools, and material to drive to the trackway.

oVehicles equipped with flanged wheels to drive onto the track at strategic locations.

3.6.1 Highway Vehicle Access Points

Access by highway vehicles shall be provided, as directed by ODOT, to the at-grade trackway near subway portals, crossovers, rail line junctions, and any other at-grade points where high maintenance requirements are anticipated.

3.6.2 Hi-Rail Vehicle Access Points

At strategic points, hi-rail vehicle set-offs shall be provided. The locations of these points will be determined by systemwide overview and furnished to the section designer. In general, a hi-rail set-off shall be provided for both tracks between each interlocking pair, unless there is an at-grade highway crossing. Access, however, shall be provided at intervals not exceeding 2 miles (preferably at 1-mile intervals). Consideration shall also be given at these access points to providing adequate space for vehicle turning and for limited parking for ODOT trucks and other maintenance vehicles.

3.7 SPECIAL TRACKWAY CONDITIONS

Special trackway conditions may be encountered which are not covered by the above criteria. Some are listed in this section. Any others should be referred to ODOT for resolution.

3.7.1 Slab Track At-Grade

Slab track at-grade shall be used to connect two portions of a trackway with direct-fixation track which are no more than 350 feet apart. Ballasted bridge decks shall be no longer than 500 feet. (Refer to directive drawings and standard drawings for the configuration and dimensions of slab track.)

3.7.2 Special Trackwork

To provide for switch operating mechanisms, where tracks diverge to a branch or yard through a turnout, the sub-grade shall be widened by 3 feet between a point 8 feet ahead of and 8 feet behind the point of a switch. The widening shall take place on the side that switch operating mechanisms will be located. (Refer to section 2.8.3 of Chapter 2 - Trackwork for more information.)

CHAPTER 4 - BRIDGE STRUCTURAL MATERIALS

All design of structures constructed as part of the ODOT LRT System shall comply with these criteria to the maximum extent possible. Where not covered by design criteria, design shall comply with applicable municipal, county, state, and federal regulations and codes listed in Appendix A. Where special design cases are encountered that are not specifically covered in these criteria, the designer shall determine the applicable technical sources for the design criteria to be used, and obtain ODOT Light Rail Project Director approval prior to use. Where conflicts are observed in the structural design literature, the following hierarchy of priority should be used to determine the appropriate application:

1. ODOT Light Rail Bridge Design Criteria
2. AASHTO Bridge Design Specifications
3. AREMA
4. All other publications

As part of a preliminary design effort for an aerial structure, a study should be performed to determine the most desirable structure configuration based on economic, social, environmental, and technical needs.

4.1 MATERIALS

All materials shall conform to the applicable specification and codes listed in Appendix A. If significant cost savings can be achieved by the use of different material than those specified in this manual, while providing at least the same level of performance and durability, the designer may substitute alternate material standard after receiving written approval from the ODOT Light Rail Project Director.

The following properties shall be used in all design calculations:

<u>Modulus of Elasticity</u>

Structural Steel and
Steel reinforcement E_s = 29,000,000 pounds per square inch (psi)

Concrete $E_c = (W_c^{1.5})\ 33(f'c)^{1/2}$ psi

Where:

W_c = unit weight of concrete between 90 and 155 pounds per cubic foot (pcf)

and:

f'c = specified compressive strength of concrete (psi)

Prestressing Steel. In the event that more accurate data cannot be obtained from manufacturers or from tests, the following values shall be used for the modulus of elasticity of prestressing steel:

Cold drawn wire	29,000,000 psi
Seven wire strand	27,500,000 psi
Strand of more than seven wires	25,000,000 psi
High strength bars	26,500,000 psi

Poisson's Ratio

Concrete	0.20

Coefficient of Thermal Expansion and Contraction

Normal Weight Concrete	0.0000060 per degree Fahrenheit
Steel	0.0000065 per degree Fahrenheit

4.2 STRUCTURAL STEEL

Unless otherwise specified, structural steel shall conform to Standard Specifications for Structural Steel for Bridges (ASTM A709) for bridge structures. The designer shall investigate the use of high-strength steels where their use would result in significant cost savings. High-strength bolts for structural steel joints, including suitable nuts and plain-hardened washers, shall conform to Standard Specification for High-Strength Bolts for Structural Steel Joints (ASTM A325). The use of bolts conforming to Specification for Heat-Treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength (ASTM A490) shall be subject to written ODOT approval. Anchor bolts shall conform to ASTM A36 or to Standard Specifications for Low-Carbon Steel Externally and Internally Threaded Standard Fasteners (ASTM A307).

- Structural Steel –For normal use:
  - Main members- ASTM A709
  - Secondary members and plates – ASTM A709
- High Strength Structural Steel – For uses requiring higher strength steels or where economically justifiable: ASTM 242, A440, A441, A514, A588, A572
- Other types may be used only with the prior approval of the ODOT Light Rail Project Director.

Connections

- Connections- Shop connections shall be welded unless otherwise shown on the contract drawings.
- All welds shall be in accordance with the current code or specification of the *American Welding Society*, D1.1.
- The *AASHTO /AWS- D1.5M/D1.5 Bridge Welding Code* publication shall be used directly or may be used to develop design and construction specifications for welding.

- Field Connections shall be designed for high strength bolts. High strength bolts shall be ASTM A325 or A490 bolts. Welded field splices shall not be permitted.

4.3 REINFORCED CONCRETE

Portland cement shall be used in accordance with ASTM C150.

Type II Portland cement shall be specified for all concrete construction unless otherwise noted on the contract drawings or specifications.

Unless otherwise specified by ODOT, all structural concrete shall have a specified compressive strength (f'c) of 4,000 psi. All reinforcement shall be ASTM A615 Grade 60, with yield strength (f_y) of 60,000 psi as described in Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement (ASTM A615).

4.4 PRETRESSED CONCRETE

Unless otherwise specified by ODOT, all prestressed concrete shall be designed according to the provisions of Section 9 of the AASHTO, except as modified in these criteria. All prestressed concrete shall have a minimum specified 28-day compressive strength (f'c) of 5,000 psi and a minimum initial compressive strength when prestress is applied of 4,000 psi. Prestressing reinforcement shall be high-strength steel wire, high-strength seven-wire strand, or high-strength alloy bars. High-strength steel wire shall conform to Specifications for Uncoated Stress-Relieved Steel Wire for Prestressed Concrete (ASTM A421; hereafter cited as such). High-strength seven-wire strand shall conform to the requirements of Specifications for Uncoated Seven-Wire Stress-Relieved Steel Strand for Prestressed Concrete (ASTM A416; hereafter cited as such), including low-relaxation strand. High-strength alloy bars shall conform to the requirements of Standard Specification for Uncoated High-Strength Steel Bar for Prestressing Concrete (ASTM A722; hereafter cited as such). Bars with greater minimum ultimate strength, but otherwise produced, tested, and meeting the requirements of ASTM A722, may be used as long as they are approved by ODOT. Lightweight concrete shall not be used on any main-load-carrying members. Consideration shall be given to fatigue stresses whenever steel coupling or splicing devices are used. Stresses of all prestressed concrete members shall be checked to cover all loading conditions at every stage of prestressing, including construction and erection.

CHAPTER 5 - BRIDGE TRANSIT AND STATIC LOADS AND FORCES

5.1 INTRODUCTION

The transit bridge designer has a responsibility to ensure that the design is adequate for loads imposed by the construction and maintenance of the transit system

- Dead Load (D)
- Transit Load
    - Light Rail Vehicle (LRV)
    - Alternative or Maintenance Vehicle (M)
        - Maintenance Vehicle
        - Specialized Track-Mounted Crane
            - Only for Overhead Catenary Systems
    - Pedestrian (P)
- Derailment Force (DR)
- Impact (I)
    - Vertical (I_V)
    - Horizontal (I_H)
- Centrifugal Force (CF)
- Rolling (or Rail) Force (RF)
- Longitudinal Force (LF)
- Horizontal Earth Pressure (E)
- Hydrostatic Pressure and Buoyancy
- Wind Load on Structure (W)
- Wind Load on Live Load (WL)
- Stream Flow Pressure (SF)
- Shrinkage and Creep Forces (S)
- Thermal Force (T)
- Differential Settlement

5.2 DEAD LOADS (D)

Dead load shall constitute all loads, which by their nature are fixed and immovable. The dead load shall consist of the actual or estimated weight of the entire structure, such as trackwork, walls, foundations, partitions, electrification, service walks, parapet walls, pipes, equipment, conduits, cables, and other utilities services. Some of these loads are indicated below.

Unless the designer can substantiate other estimates of the weights of materials and installations, the following unit weights shall be used in computing the dead load:

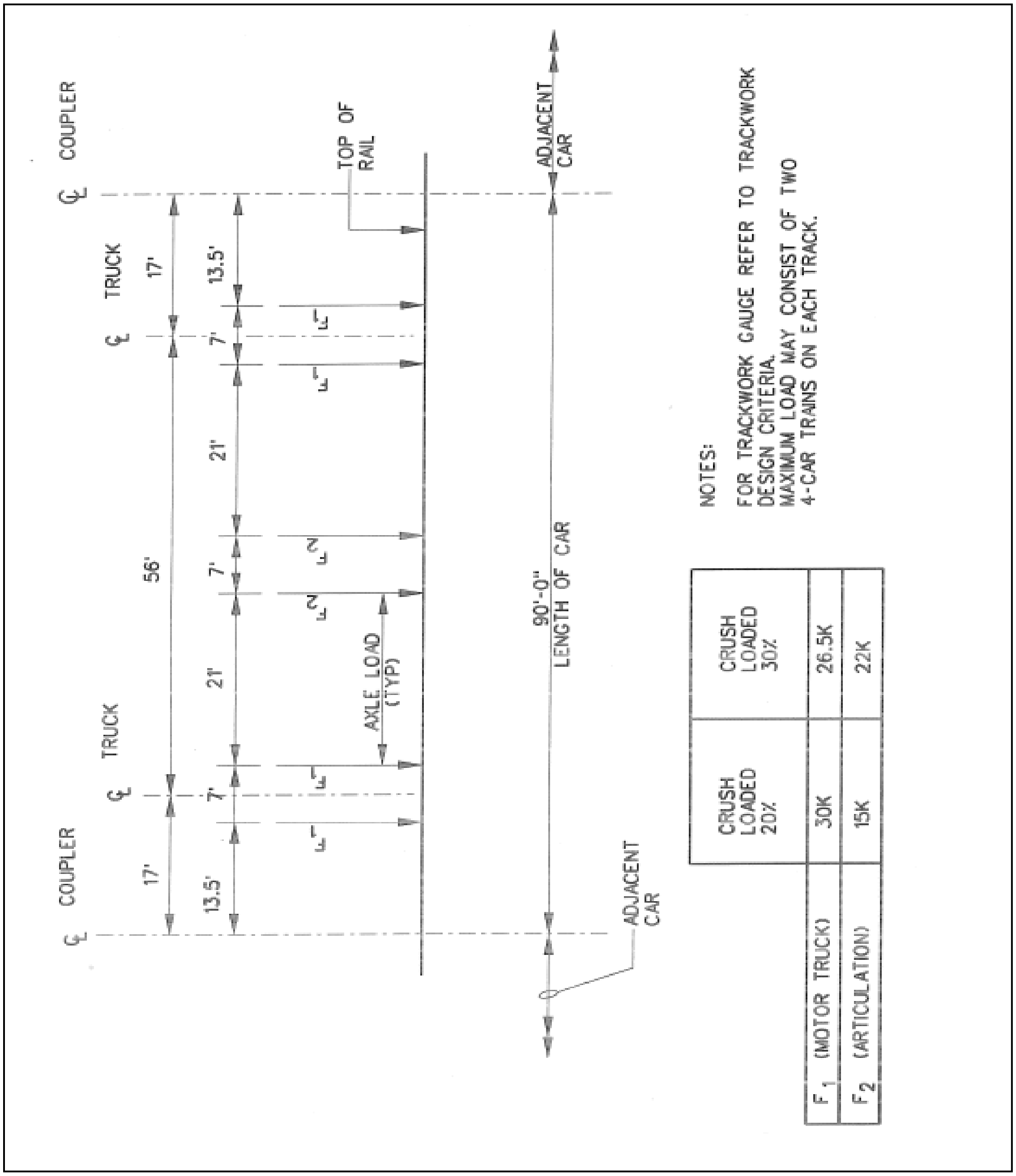
Material	Pounds per Cubic Foot
Steel	490
Cast iron	450
Aluminum alloys	175
Asphaltic concrete	150
Portland cement concrete, plain, reinforced, or prestressed	150
Compacted sand, earth, or gravel	130
Ballast, including ties	130
Timber (treated or untreated)	50
Parapet, or Acoustical Barrier	365 lbs./lin. ft., per side
Track rails, Guardrails, and Fasteners	200 lbs./lin. ft.
Cables - Single or Double Track	100 lbs./lin. ft.

Cable weights include attachment hardware and cables for electric, traction, communication, and signal systems.

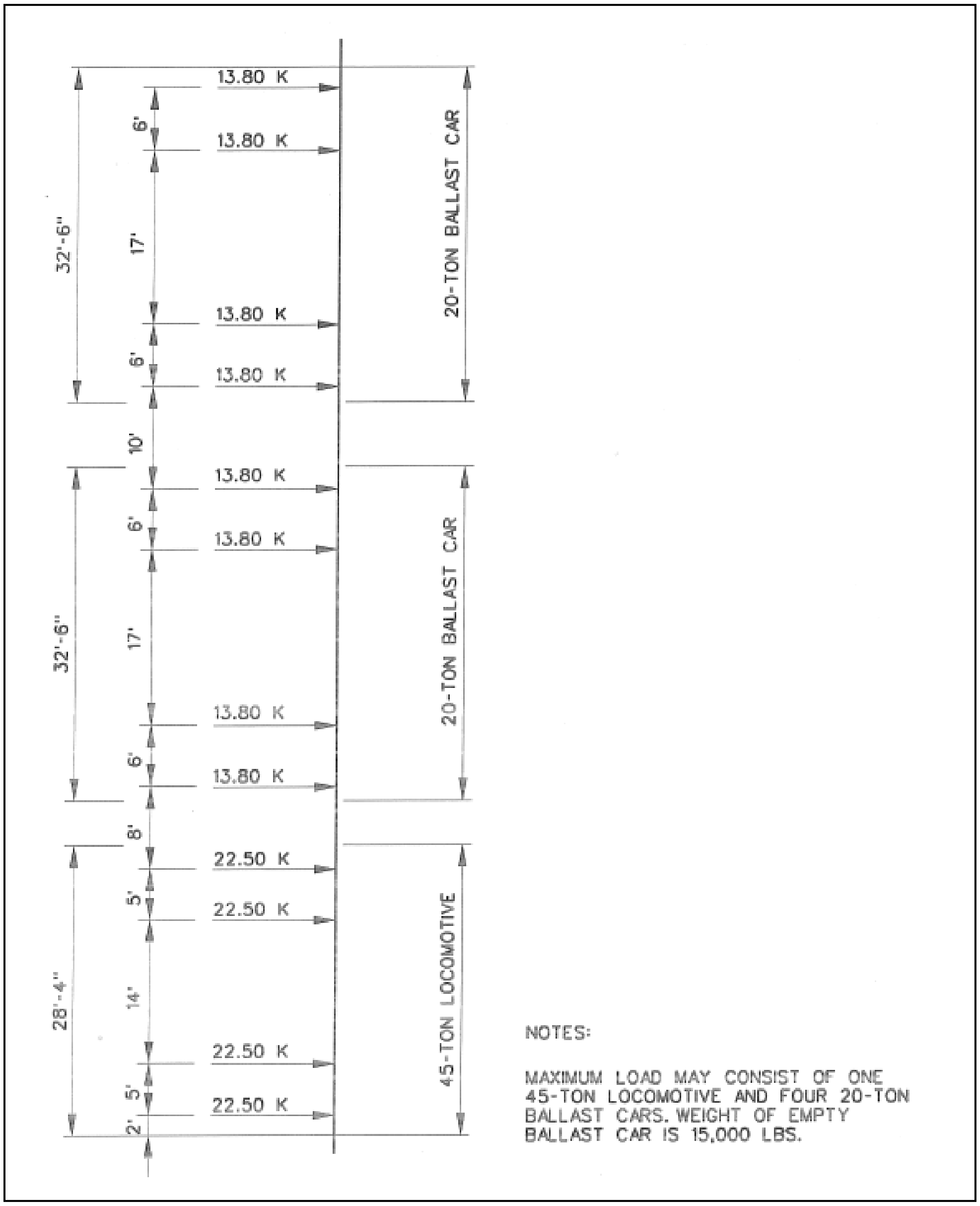
5.3 LIVE LOADS (LRV, M, P)

5.3.1 Light Rail Transit Vehicle Design Loading

Standard ODOT loading, for design purposes, is defined as the axle spacing, axle loading and car spacing shown in Figure 5.1 and Figure 5.2. Any one train may consist of one, two, three, or four cars. The standard ODOT loading shall be used for all stress, deflection, and stability calculations. The weight of the railcar used in any loading combination to produce maximum stress shall be based on the "Crush Loading" condition.



I-244 LRT BRIDGE OVER ARKANSAS RIVER
STANDARD LRV
FIGURE 5.1



I-244 LRT BRIDGE OVER ARKANSAS RIVER
TRACK MAINTENANCE
FIGURE 5.2

5.3.2 Crane Car/Maintenance Car Design Loading

A special live load used during maintenance of the track shall be considered in the design of all structures subject to ODOT loading. The loading will consist of a 45-ton locomotive pulling one, two, three, or four 20-ton ballast cars. They shall be placed on the structure in a position to produce maximum stress. The axle spacing, axle loading, and car spacing, for design purposes, are shown in Figure 4.2.

Other maintenance or construction load limits shall not exceed the loads shown in Figure 4.1 or Figure 4.2. These limitations shall be noted on all designs. The designer shall determine the vehicle configuration and arrangement to produce the maximum loading condition for the member under consideration.

5.3.3 Pedestrian Load

Aerial structure walkways and their immediate supports shall be designed for a pedestrian live load of 85 pounds per square foot of walkway AREMA. Girders, trusses, arches, and other members shall be designed for the following walkway live loads (AASHTO 3.14.1.1):

Spans 0 to 25 feet in length 85 lb./ft.^{2}
26 to 100 feet in length 60 lb./ft.^{2}
Spans over 100 feet in length according to the formula:

$$P = \left(30 + \frac{3{,}000}{L}\right)\left(\frac{55 - W}{50}\right)$$

Where:

P = live load per square foot, max. 60-lb. per sq. ft.
L = loaded length of sidewalk in feet
W = width of sidewalk in feet

In calculating stresses in structures that support cantilevered sidewalks, the sidewalk shall be fully loaded on only one side of the structure if this condition produces maximum stress.

Service Walkways - Service walkways and their immediate supports shall be designed for a live load of 85 pounds per square foot of walkway AREMA, or a concentrated load of 500 pounds acting on an AREMA measuring 1 foot by 1 foot and placed in a position that will cause maximum stress. Except for aerial structures and pedestrian bridges, all members supporting 50 square feet of walkway or more may be designed for a reduced live load of 60 pounds per square foot of walkway AREMA.

5.4 LOAD (DR)

Derailment load shall be that produced by the standard ODOT train loading placed with its longitudinal axis parallel to the track, with a minimum distance from the centerline of track of 1 foot 6 inches and a maximum distance of 3 feet 0 inches. The derailment load, DR, shall be as follows:

DR = L + ID

or

DR = L + I + RB

Where: L = Standard ODOT loading (see Fig. 4.1)

ID = Derailment Impact, 100 percent of the axle load to be applied to any two adjacent axles at a time and normal vertical impact factor for all other axles, which produces critical loading condition for the structures.

RB = Loads on structure due to single broken rail.

5.5 VERTICAL AND HROIZONTAL IMPACT (I)

The standard ODOT loading shall be increased for dynamic, vibratory, and impact effects for the design of piers and superstructure elements, but need not be applied to the design of foundations or elastomeric bearings.

The vertical impact force, I_v, shall be determined in accordance with the provisions of Section 3.8.2.1 of Standard Specifications for Highway Bridges, (American Association of State Highway and Transportation Officials (AASHTO). The vertical impact force is additive to the standard ODOT loading. For spans longer than 125 ft., a minimum vertical impact factor of 20 percent shall be used.

Provision shall be made for a transverse horizontal impact force, I_h, equal to 10 percent of the standard ODOT loading. This force shall be applied horizontally in the vertical plane containing each axle and shall be assumed to act, normal to the track, through a point 3.5 feet above the top of the low rail. The horizontal force component transmitted by an axle to the rails and supporting structure shall be concentrated at the rail having direct wheel-flange-to-rail-head contact.

5.6 CENTRIFUGAL FORCE (CF)

In horizontal curves, a centrifugal force (CF) shall be applied horizontally in the vertical plane containing each axle. The force shall be assumed to act through a point which is on a line perpendicular to the plane of the tops of the rails and midway between the rails, and at a distance along said line 3.5 feet above the plane of the tops of the rails. The magnitude of the centrifugal force shall be computed as follows:

$$CF = \text{Axle Load} \times 0.0668 \times \frac{V^2}{R}$$

Axle Load = As per Figure 4.1 or 4.2, in kips.

Where: V = Design speed in miles per hour, and
R = Radius of curvature of the track center line in feet.

If the design speed is unknown at the time of design, use V max of 70 MPH for radii of 2,150 feet and greater; for radii less than 2,150 feet use the following equation to determine maximum speed:

$$V = (2.27R)^{1/2}$$

5.7 ROLLING (OR RAIL) FORCE (RF)

Provisions shall be made for transverse (radial) and longitudinal rail/structure interaction forces due to temperature variations in the rail and superstructure. These forces shall be applied in a horizontal plane at the top of low rail as follows:

- Transverse Force. The transverse force shall be applied in each direction. Its magnitude per linear foot of structure per rail shall be determined by the designer.

- Longitudinal Force. The magnitude of the longitudinal rail forces shall be determined by a rigorous analysis of the total structural system: rails, rail fasteners, girders, bearings, and substructure.

- Forces Due To Rail Restraints. Wherever a continuous welded rail is terminated, provisions shall be made to fully restrain its end. This restraint will introduce a significant longitudinal force. The continuous welded rail shall not be terminated on the aerial structure unless it is designed to withstand the imposed load.

Termination, as used in the above paragraph, means absolute termination. The continuous welded rail is not considered to be terminated at a turnout or crossover.

Replacement and Broken Rails. Loads due to broken or replacement rails shall be treated as thermal load for the derailment load group combination as described in Section 4.1.3. Aerial structures shall be designed for the interactive force between the continuously welded rail and the structure and, to accommodate the temporary loads associated with rail replacement. In addition, the aerial structure shall be capable of adequately sustaining a single broken rail. The structure shall be capable of having the rail installed at any temperature between 30°F and 90°F.

When considering the effects of broken rail or rail replacement in combination with other loading conditions, the percentage of Basic Unit Stress shown in Table 5.1 is applicable.

5.8 LONGITUDINAL FORCE (LF)

Provision shall be made for the longitudinal force (LF) due to train acceleration and deceleration. The magnitude of the longitudinal force shall be computed as follows:

- For decelerating trains, LF shall be equal to 28 percent of standard ODOT loading.
- For accelerating trains, LF shall be equal to 16 percent of standard ODOT loading.

This force shall be applied to the rails and supporting structure as a uniformly distributed load over the length of the standard ODOT train in a horizontal plane at the top of low rail.

Consideration shall be given to combinations of acceleration and deceleration forces on structures where there is more than one track.

For double-track structures, three longitudinal-loading cases shall be considered, each acting in either direction:

- Single Track Loaded. Longitudinal force acting, applicable forces on supporting structure.

- Both Tracks Loaded. One train accelerating, one decelerating. Maximum longitudinal forces acting, applicable forces on supporting structure.

- Both Tracks Loaded. Both trains accelerating or decelerating. Longitudinal forces acting in opposite directions, applicable forces on supporting structure.

5.9 HORIZONTAL EARTH & HYDROSTATIC PRESSURE (E)

The effects of hydrostatic pressure shall be considered whenever the presence of groundwater is indicated. It shall be computed at 62.5 pounds per square foot per linear foot of depth below groundwater table. Where hydrostatic pressures pertain, lateral earth pressures shall be based upon the submerged unit weight of the soil. The possibility of future significant changes in groundwater elevation shall be considered. Full hydrostatic pressure shall be assumed to act on all external structural members for the maximum likely height of the water table, unless specific permanent provisions to remove these effects are included in the overall design of the structural members.

5. 10 WIND LOAD (W, WL)

The aerial structure shall be designed to withstand wind loads of uniform pressure acting upon the superstructure, the substructure, and the live load.

5.10.1 Wind Load on Superstructure.

A horizontal, uniform wind load of the intensities given by Sections 3.15.1.1.1 and 3.15.1.1.2 of AASHTO shall be applied at the centroids of the exposed AREMAs. In addition to the horizontal wind loads, an upward load shall be applied at the windward quarter point of the transverse width of the superstructure in accordance with Section 3.15.3 of AASHTO.

5.10.2 Wind Load on Live Load

Provision shall be made for a transverse horizontal wind load of 100 pounds per linear foot of train and a longitudinal horizontal wind load of 40 pounds per linear foot of train. These loads shall be based on the length of the train as seen in elevation normal to the longitudinal axis of the structure and shall be applied simultaneously. The transverse wind load shall be applied to the train as concentrated loads at the axle locations in a plane 7 feet above the top of low rail, and normal to the track. The horizontal force component transmitted to the rails and superstructure by an axle shall be concentrated at the rail having direct wheel-flange-to-rail-head contact. The longitudinal force shall be applied to the rails and superstructure as a uniformly distributed load over the length of the train in a horizontal plane at the top of low rail. Minimum train length shall be four cars.

5.10.3 Wind Load on Substructure

The substructure shall be designed to withstand the above loads applied to the superstructure as they are transmitted to the substructure and the wind loads applied directly to the substructure as follows:

A uniform transverse pressure of 40 pounds per square foot shall be applied to the exposed AREMA of the substructure as projected onto a vertical plane perpendicular to the axis of the superstructure.

5.11 STREAM FLOW PRESSURE (SF)

The effects of stream flow and drift on bridge substructures shall conform to the provisions of Section 3.18.1 of AASHTO.

The design of waterway crossings shall be performed in accordance with Hydraulics of Bridge Waterways (U.S. Department of Transportation (DOT)) and local agency requirements. For major conditions, the effects of bridge backwater and the stability of the stream bed and bank beneath the structure shall be considered in footing design.

5.12 SHRINKAGE AND CREEP FORCES (S)

In concrete structures, provisions shall be made for movement and stresses resulting from concrete shrinkage and creep. The shrinkage coefficient for normal weight concrete shall be assumed to be 0.0002 inch per inch. For the purpose of calculating effects of creep due to sustained load, the modulus of elasticity of the concrete may be assumed to be 1/3 the value given in Section 8.5 of ACI 318 for the design strength of the specified concrete.

5. 13 THERMAL FORCE (T)

Provisions shall be made for stresses and movements resulting from temperature variations. The maximum and minimum temperature and the coefficients of thermal expansion shall be taken as follows:

Material		Thermal Coefficient
Concrete:		0.0000060 in/in-degree F
Maximum Temperature	110° F.	
Minimum Temperature	20° F.	
Steel Plate and Girders:		0.0000065 in/in-degree F
Maximum Temperature	125° F.	
Minimum Temperature	5° F.	
Steel Rail:		0.0000065 in/in-degree F
Maximum Temperature	135° F.	
Minimum Temperature	-5° F.	

The neutral rail laying temperature is 90° F.

The thermal force in the rail is calculated by the following equation:

$$F_r = A_r E_r \alpha (T_i - T_o) \qquad \text{(Eq. 1- 1)}$$

Where: F_r = thermal rail force

A_r= cross-sectional AREMA of the rail

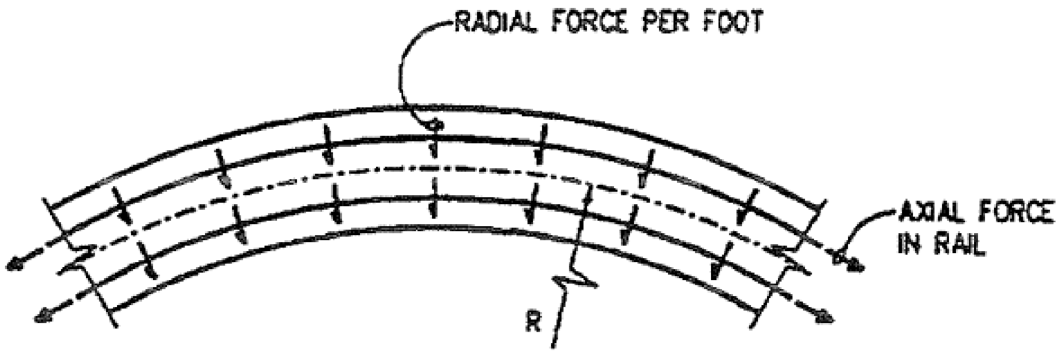
E_r = modulus of elasticity

α = coefficient of thermal expansion

T_i = final rail temperature

T_o = effective construction temperature of the rail

On horizontal curves, the axial forces in the rail and superstructure result in radial forces. Refer to Figure 5.3 as for the equation to calculate the radial rail/structure interaction force.



$$\text{RADIAL FORCE PER FOOT PER RAIL} = \underbrace{\frac{E \alpha \Delta T A_R}{R}}_{\text{THERMAL COMPONENT}} + \underbrace{\frac{K_F \, l_{CONT}}{4}}_{\text{INTERACTION COMPONENT}}$$

WHERE:
- E = MODULUS OF ELASTICITY OF RAIL STEEL
- α = COEFFICIENT OF THERMAL EXPANSION OF RAIL STEEL
- ΔT = CHANGE IN RAIL TEMPERATURE FROM STRESS-FREE TEMPERATURE
- A_R = AREA OF RAIL SECTION
- R = RADIUS OF HORIZONTAL CURVE
- K_F = FASTENER SLIP VALUE DIVIDED BY FASTENER SPACING
- l_{CONT} = LENGTH OF STRUCTURE BETWEEN EXPANSION JOINTS

Figure 5.3 Radial Rail/Structure Interaction Forces

5. 14 BUOYANCY (B)

The effects of buoyancy shall be considered in the design of the substructure, including piling (AASHTO 3.19 & 4.5.13).

5.15 DIFFERENTIAL SETTLEMENT

Simple Span Aerial Structure. The differential settlement between two adjacent aerial structure piers shall not exceed 1/2400 times the sum of the lengths of any two adjacent spans.

Continuous Span Aerial Structure. The designer shall investigate the differential settlement and design accordingly. In any case the differential settlement shall not be more than that described in the preceding paragraph.

5.16 LOAD COMBINATIONS

All structures shall be designed for maximum passenger load. Rush hour passenger loads. The following groups represent various combinations of loads and forces to which components of the aerial structure may be subjected. Each part of the structure shall be proportioned for all combinations of these loads multiplied by the load combination factor and coefficients indicated in Table 5.1

All aerial structures shall be analyzed utilizing group combination VIII or H for a temporary overload condition. The axle spacing, axle loading as well as cars and locomotive spacing shall be as shown in Figure 5.1 and 5.2

Elements Supporting Two Tracks. For elements supporting two tracks with both tracks loaded simultaneously, the value of CF, LF and horizontal impact may be reduced by 25 percent in all applicable load groups when applying these loads on both tracks.
Group VIII or H loading combinations only applicable to single track loading from track maintenance live loading described in Paragraph 5.1.2.2

Service Load Design. The design of prestressed concrete members, stability and deflection calculations, and soil bearing pressures shall be based on the following groups of loading combinations.

Strength Design. Reinforced concrete members and structural steel members shall be designed by the strength method. Prestressed concrete members shall be checked using the strength method. Reinforced concrete, structural steel, and prestressed concrete members shall have the capacity of resisting any of the load groups listed in Table 5.1

Table 5.1 Table of Load Combination Coefficients γ and β

Col. No.		1	2	3	3A	4	5	6	7	8	9	10	11	12	13
Group		γ	β FACTORS												%
			D	(LRV + I)	M	CF	E	B	SF	W	WL	LF	S+T	DR	
Service Load	I	1.0	1	1	1	β_{CF}	β_E	1	1	0	0	β_L	0	0	100
	II	1.0	1	0	0	0	1	1	1	1	0	0	0	0	125
	III	1.0	1	1	1	β_{CF}	β_E	1	1	0.3	1	β_L	0	0	125
	IV	1.0	1	1	1	1	β_E	1	1	0	0	0	1	0	125
	V	1.0	1	0	0	0	1	1	1	1	0	0	1	0	140
	VI	1.0	1	1	1	β_{CF}	β_E	1	1	0.3	1	β_L	1	0	140
	VII	1.0	1	0	0	1	1	1	0	0	0	1	0	1	150 *
	VIII	1.0	1	1	1	1	β_E	1	1	0	0	0	0	0	125
Load Factor Design	A	1.3	1	1.67	1.67	β_{CF}	β_E	1	1	0	0	β_L	0	0	Not Applicable
	B	1.3	1	0	0	0	β_E	1	1	1	0	0	0	0	
	C	1.3	1	1	1	β_{CF}	β_E	1	1	0.3	1	β_L	0	0	
	D	1.3	1	1	1	1	β_E	1	1	0	0	0	1	0	
	E	1.2 5	1	0	0	0	β_E	1	1	1	0	0	1	0	
	F	1.2 5	1	1	1	β_{CF}	β_E	1	1	0.3	1	β_L	1	0	
	G	1.2 5	1	0	0	1	β_E	1	0	0	0	1	0	1	
	H	1.3	1	1	1	1	β_E	1	1	0	0	0	0	0	

The following Groups represent various combinations of loads and forces to which a structure may be subjected. Each component of the structure, or foundation on which it rests, shall be proportions to withstand safely all group combinations of these forces that are applicable to the particular site or type. Groupe Loading combinations for service Load design and Load Factor Design are given by:

$$\text{Group (N)} = \gamma\ [\ \beta_D \cdot D + \beta_L (\ LRV + I\ ) + \beta_M \cdot M + \beta_C \cdot CF + \beta_E \cdot E + \beta_B \cdot B + \beta_S \cdot SF + \beta_W \cdot W + \beta_{WL} WL + \beta_L \cdot LF + \beta_R (R + S + T) + \beta_{EQ} EQ + \beta_{ICE}\ ICE\ ]$$

Where maximum stresses are produced in any member by loading a number of tracks simultaneously, the following K factors shall be used in view of the improbability of coincident maximum loading:

B_L, B_{LF} = 1.0 for single track loading.
B_L, B_{LF} = 1.0 for multiple track loading less than 1000 feet from stations.
B_L, B_{LF} = 0.75 for multiple track loading greater than 1000 feet from stations.

B_E =0.5 or 1.0 for lateral loads on rigid frames. (Check both loadings and use the one which governs)
B_E = 1.0 for vertical loads and lateral loads on all other structures.
* =Prestressed concrete girders shall be checked against loading by train derailment. The stress of prestressed strand shall not exceed 0.85 fpu, and concrete shall not exceed 0.6 f'c, in lieu of 150 percent as shown in table 5.1.

For values of B_L and B_{LF}, refer to the service load design section above.

B_E = 1.3 for lateral earth pressure for retaining walls, reinforced concrete boxes, and rigid culverts.
B_E = 0.5 for lateral earth pressure when checking positive moment in either rigid frames.
B_E = 1.0 for vertical earth pressure.

A multiplier 0.75 shall be applied to D, in all the load groups, when checking members for minimum axial load or maximum eccentricity. (Column Design)

Load Distribution on Slabs and Beams

In the absence of an elastic analysis, the following empirical methods of load distribution may be employed. These methods are limited to monolithic concrete deck slabs on skews of less than 20 degrees. The skew angle is defined as the angle intersected by a horizontal line parallel to the pier or abutment and a horizontal line perpendicular to the girder centerline. These methods are applicable for <u>unballasted track only</u>. For ballasted bridges, the effects of the ballast in distributing the wheel loads may be considered. For the effects of ballast on distribution of live load, refer to Section 8-2-3 of the <u>Manual for Railway Engineering</u> (American Railway Engineering Association (AREMA)).

<u>Contact AREMA</u>. Under service condition, each wheel load shall be dispersed through the running rail to produce an effective contact AREMA of six inches (measured parallel to rail) by 12 inches measured at the bottom of the elastomeric bearing pad under the rail fastener.

Under derailment condition, each derailed wheel in direct contact with the deck slab shall be assumed to make a groove 0.25 inch to 0.50 inch deep with a wheel-to-concrete contact AREMA 2 inches wide by 8 inches long.

One-Way Slabs (Excluding Cantilever Slabs).

- Dispersion of Loads along the Span. The effective length of the slab on which a wheel load acts shall be taken as equal to the dimension of the contact AREMA in the direction of the span plus twice the depth of the slab measured to the centerline of the bottom reinforcement of the slab.

- Effective Width of Slab Resisting Bending Moment and Shear. A solid one-way slab supported on two opposite edges shall be designed to resist the maximum bending moment and shear force caused by the applied loads. Such bending moment and shear force shall be assumed to be resisted by an effective width of slab E (measured parallel to the supported edges, in feet) according to the following empirical formula:

  - Case 1. Main Reinforcement Perpendicular to the Track (Spans 2 to 24 feet inclusive):

$E = KX(1 - X/L) + W$ but should not exceed 7.0 feet

Where:

X = distance in feet from the center of gravity of the wheel load to the near face of support

L = the effective span as defined in Section 3.24.1.2 of AASHTO in the case of simply supported slabs, and the clear span in the case of continuous slabs

K = 2.5 for simply supported slabs

K = 2.2 for continuous slabs over three or more supports

W = spacing of the rail fasteners

W = 2.0 feet for a derailed wheel load in direct contact with the slab

In the case of a load near the unsupported edge of a slab, E should not exceed the above value nor half the above value plus the distance from the load to the unsupported edge.

- Case 2. Main Reinforcement Parallel to the Track

The effective width (in feet) of the slab resisting a wheel load should be taken as:

$$E = 4 + 0.06L \text{ but not to exceed 5.0 feet.}$$

Full edge beams shall be provided for all slabs having main reinforcement parallel to the track. The beam may consist of a slab section with additional reinforcement, a beam integral with and deeper than the slab, or an integral reinforced section of slab and curb.

For simple spans, the edge beam shall be designed to resist a live load moment of M = 0.10 (PL) where P is the wheel load and L is the span length. For continuous spans, 80 percent of the above calculated value shall be used for both positive and negative moments, unless a greater reduction can be justified based on a rigorous analysis.

Two-way Slabs

Two-way slabs are those supported on all four sides and reinforced in both directions. For rectangular slabs simply supported on all four sides, the proportion of the load carried by the short span of the slab may be estimated by the following equations:

For load uniformly distributed:

$$P = \frac{L^4_2}{L^4_1 + L^4_2}$$

For load concentrated at center:

$$P = \frac{L^3_2}{L^3_1 + L^3_2}$$

Where:

P = proportion of load carried by short span

L_1 = length of short span of slab

L_2 = length of long span of slab

In cases where L_2 exceeds 1.50 (L_1), the slab shall be designed as a one-way slab spanning in the short direction (span L_1).

For a concentrated load, the effective slab width, E, for the load carried in either direction shall be determined as specified above for one-way slabs.

The moments obtained shall be used in designing the center half of the short and long spans. The reinforcement steel in the outer quarters of both short and long spans may be reduced 50 percent.

Cantilever Slabs.

- Wheel Load. In the design of a cantilever deck slab in which the main reinforcement is perpendicular to the track, a concentrated wheel load may be assumed to be uniformly distributed over an effective width E of the slab, not exceeding 7.0 feet:

$E = 0.8X + 3.75$ for service condition
$E = 0.8X + 3.00$ for derailed condition

Where X = distance in feet from the load to the face of cantilever support.

- Railing, Acoustical Barrier or Parapet Load. Loads transmitted from railing, barrier or parapet attachments to a cantilever deck slab shall be distributed over the effective width E as specified above for wheel loading under service condition, except that X is the distance in feet from the railing or parapet support to the point along the cantilever that is under investigation, and E shall be limited to the longitudinal spacing of the railing or parapet supports.

Unsupported Edges, Transverse. The design assumptions of the sections on one-way and two-way slabs above do not provide for the effect of loads near unsupported edges. Therefore, at points where the continuity of the slab is broken, the edges shall be strengthened by diaphragms, strengthening of the slab, or other suitable means, and shall be designed to resist the full moment and shear produced by the applied wheel loads.

Longitudinal Beams. In calculating bending moments in longitudinal beams, no longitudinal distribution of the ODOT vehicle axle loads shall be assumed. The axle loads shall be taken as concentrated loads and shall be placed to cause the maximum bending moment in the longitudinal beams.

Distribution of Wheel Load on the Girders Due to Derailment. For the purpose of calculating the distribution of the wheel load on the girders due to the derailment load, the following shall be used:

- Deck slab shall be assumed to be simply supported between the girders when the load falls in between the girders.

- Deck slab shall be assumed to be continuous over the girders when the load falls on the cantilevered portion of the slab.

CHAPTER 6 - GENERAL DESIGN OF LRT AERIAL BRIDGE STRUCTURES

Emergency egress shall be provided for patrons to evacuate a train at any point along the guideway and proceed to an exit or the nearest station or await evacuation. These egress provisions shall include the following: 1) ballast shall be considered a walkway surface for exit purposes for at-grade AREMAs only; and 2) a transition in the walkway shall be provided at all grade-to-aerial guideway and all underground-to-at-grade abutments. There shall be adequate provisions for access and egress by emergency rail vehicles and crews to aerial guideways.

A continuous service walkway shall be provided along the aerial structure. For a height of 6 feet above the top of the walkway, the service walkway shall have a minimum clear width of 22 inches beyond the dynamic clearance envelope of the vehicle. The service walkway shall be readily accessible from the superstructure deck. The service walkway shall have a cross slope for drainage unless otherwise directed. The service walkway will carry all system cables and conduits, and shall be designed for this additional load. Walkway width shall be 22 inches with 24 inches desirable.

6.1 INSPECTION ACCESS

The greater frequency of operations and the transit customers' sensitivity to on-time performance require that the design of transit structures allow easy inspection of the critical members without extensive use of track-mounted snooper trucks. Transit structures over highways should not require extensive lane closures for inspection, if possible. Provisions for safety line attachment, including anchor points, should be an integral part of the transit structure design. Cat walks and other access facilities can reduce the time required for bridge inspection and may eliminate operational impacts of the inspection. The inspection time for a transit structure can be reduced by providing adequate space between members to allow the inspection team to gain access to all sides of the members.

6.2 ELECTRIFICATION

Space shall be provided for the installation of the catenary support system, train control and communications systems, auxiliary power transmission system, primary power distribution system (in some locations), and other electrical appurtenances.

6.3 HORIZONTAL AND VERTICAL CLEARANCES

The minimum clearances between the aerial structure and the ODOT standard vehicle shall conform to the provisions of ODOT transit vehicle design criteria. The clearances between the aerial structure and privately or publicly owned streets, highways, railways, utility lines, and other structures or property shall be those prescribed by the agencies involved.

Walkways and ladder ways for operational and emergency access should also be considered in the vertical and horizontal clearance determinations. On large structures, consideration should be given to providing additional electrical isolation clearances and devices to allow maintenance of the structure without de-energizing the traction power.

All bridges over waterways require vertical clearance (freeboard) above the expected water level of the design storm. A minimum of 1’ is recommended above the water surface of the design storm predicted by the hydraulic analysis.

All bridges over navigable waterways are required to provide both vertical and horizontal clearances as required by the governing agency (the US Coast Guard in the United States). The vertical clearance required may be provided by either a fixed bridge at the proper elevation difference, or by a movable bridge. Lighting, signage, and marine protection structures are additional items required at a crossing of a navigable waterway. These items may require adjustments to the supporting structure to provide the required horizontal and vertical clearances.

6.4 ALIGNMENTS

If practical, construct bridges on vertical and horizontal tangents. Horizontal curves require widening the deck on ballasted deck structures and designing for eccentric loads. Vertical curves require addition depth between the running rails and the structure to accommodate the varying grades, resulting in increased dead loads. The simplified detailing results in lower construction costs and better-constructed quality.

Except where tracks diverge or converge, the edges of the aerial structure deck slab shall be parallel to the ODOT system control line.

6.5 APPROACH SLABS

Except where the abutting at-grade trackbed consists of a track slab, an approach slab shall be provided at each abutment to ensure a smooth transition from the at-grade section to the aerial structure. The approach slab shall have a length of not less than 20 feet.

Approach slabs shall have ballast checks to minimize ballast creep, and provisions shall be made to prevent the scatter of ballast onto the superstructure deck; refer to the trackwork standard drawings.

6.6 PEDESTRIAN RAILINGS

Wherever the edge of the deck or aerial structure is not protected by an acoustical barrier, pedestrian railing shall be provided. Pedestrian railing shall meet the requirements of Standard Specifications for Highway Bridges (American Association of State Highway and Transportation Officials, AASHTO) for protection of open-sided platforms except, that no toe board is required.

Rail shall be designed for a horizontal and vertical force of 50 pounds per linear foot acting simultaneously on each longitudinal member. Further, all handrails shall be designed for a force of 200 pounds applied in any direction at any point.

6.7 TRACK CONFIGURATION

When the use of continuous welded rail, combined with direct fixation of the rails to the supporting structure is used the designers of the aerial structure shall consider:

- Providing sufficient rail restraint to prevent horizontal or vertical buckling of the rails
- Providing anchorage of the CWR to prevent excessive rail gaps from forming if the rail breaks at low temperature
- Determining the effect a rail break could have on an aerial structure
- Calculating the thermal forces applied to the aerial structure, the rail, and the fasteners as the aerial structure expands and contracts, while the CWR remains in a fixed position
- Providing a connection between structure (direct fixation fastener) that is resilient enough to permit the structure to expand without overstressing the fasteners

6.8 BEARING ARRANGEMENT AT THE PIERS

If CWR is used on the structure and the adjacent spans are of similar length and geometry, a symmetrical bearing arrangement, shown on Figure 6.1, is desirable. A symmetrical bearing arrangement is having the same bearing type (fixed or expansion) from adjacent spans on the same pier. In this arrangement, the thermal interactive forces induced into the rail tend to cancel out each other.

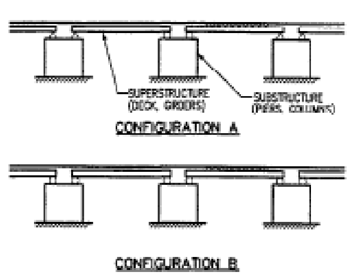


Figure 6.1 Bearing Configurations for elevated Structure Girders

Although the interactive forces at symmetrical bearing arrangements tend to cancel each other out before loading the piers, the structural engineer must still design the bearings and their bolts to resist these forces.

6.9 TERMINATING CWR ON AERIAL STRUCTURES

CWR should not be terminated on an aerial structure due to the large termination force transferred to the structure.

Designers should avoid special-work on aerial structures. When this cannot be avoided, to accommodate the large forces occurring at locations of special- work, rail anchors or rail expansion joints could be used.

The use of sliding rail expansion joints must consider the following:

- The construction length of the sliding rail joints
- The length of structure required to accommodate the special- work and sliding rail joint
- The design, location, and installation details of the rail anchors

With permission/approval of ODOT, a tie bar device can be used to accommodate special-work on the aerial structure.

6.10 RAIL BREAK/RAIL GAP OCCURRENCES

Limits on the size of the rail gap shall be reevaluated once the light rail vehicle has been selected and the wheel diameter is known. For now the designer can assume a gap of 2 inches based on a 16-inch diameter wheel rail.

The designer can assume that only one rail of a single- or double- track alignment will break at any one time.

Designer shall limit the size of the gap by adjusting the rail fastener spacing and stiffness to be within the allowable gap size. Limiting the size of the gap reduces the possibility of derailment but also increases rail/structure interaction forces which increase the cost of the structure.

6.11 DECK CONSTRUCTION

Of the three distinctly different types of deck construction (open, ballasted and direct-fixation), only ballasted and direct-fixation decks shall be consider for design. For each aerial structure, the decision concerning which type of deck construction to use with CWR will need approval of ODOT.

6.11.1 Ballasted Deck Construction

Ballasted decks shall only be considered for bridges with lengths of 300 feet or less. The use of such deck construction on bridges will need prior approval of ODOT.

To eliminate the path for stray current leakage from rail to ballast, the ballast section should be a minimum of 1 inch below the bottom of the rails.

6.11.2 Direct Fixation Fasteners

Direct fixation fasteners spacing shall be determined by analysis of rail bending stresses, interaction forces of the rail and rail fasteners, and the rail gap size at a rail break location.

The elastomer shall provide adequate resistivity to insulate and deter current leakage.

On sharply skewed bridges (>30 degrees), the trackwork and structural engineer shall coordinate fastener spacing to ensure that the fasteners are adequately supported on each side of the joints in the deck.

When a concrete pad, or plinth, is used to support the direct fixation fasteners, intermittent gaps shall be provided along the length of the plinths to accommodate deck drainage and to provide openings for electrical conduits placed on the decks. In addition, the deck slab shall be recessed for the second-pour plinths to form a shear key to help resist the lateral loads from the rail and vehicles. The second-pour concrete plinths shall be constructed to meet the alignment and profile requirements of the CWR and fasteners. The use of zero longitudinal restraint (ZLR) fasteners shall need prior approval by ODOT. If ZLR are used, the rail gap size at a rail break has to be re-evaluated.

6.12 RAIL/STRUCTURE INTERACTION

Where the rails are to be fastened to the superstructure deck by direct-fixation methods, adequate provisions shall be made in the design of the deck for the mounting of the rails.
Rail fasteners shall be designed to prevent buckling of the rail.

The CWR ends shall be anchored in ballasted track beyond the abutments off the bridge. The designer shall address the following three design issues when an aerial structure has CWR:

1. Controlling the stresses in the rail attributed to the differential longitudinal motions between the rail and the superstructure because of temperature changes or other causes
2. Controlling the rail break gap size and resulting loads into the superstructure
3. Transferring of superstructure loads and moments into the substructure

Depending on the method used to attach the rails to the substructure, the structural engineer must design the structure for longitudinal restraint loads induced by the fasteners, horizontal forces due to a rail break, and radial forces caused by thermal changes in rails on curved alignments.

6.13 RAIL/STRUCTURE INTERACTION ANALYSIS METHODOLOGY

The interaction of the rails and supporting structure involves the control of rail creep, broken rail gaps, stresses induced in the guideway structure, and longitudinal and transverse forces developed in the supporting substructure.

If the aerial structure is located on a curved alignment, varying span lengths or other complexities ODOT will determine if hand calculations will be accepted or a three- dimensional structural analysis will need to be preformed for the following CWR –related design elements:

- The control of stresses in rails attributed to thermally induced differential movements between the rail and the supporting superstructure
- The control of the rail break gap size and the resulting loads transferred into structures during low-temperature rail pulling apart failures
- The transfer of thermally induced loads from the superstructure, through the bearings, into the substructure

6.14 STEEL GIRDERS

<u>Fracture Critical Members</u>

The designer should avoid fracture critical members in their design if possible. The use of any fracture critical members shall need prior approval by ODOT.

Refer to the *AASHTO Guide Specifications for Fracture Critical Non-Redundant Steel Bridge Members* Publication on requirements for identifying, fabricating, welding, and testing of a fracture critical, non-redundant steel bridge member whose failure can be expected to result in a bridge collapse.

Except as modified in this document, steel structures subject to ODOT train loading, individual structural steel elements subject to ODOT train loading, and other structures as specifically directed in the ODOT design criteria, shall be designed in accordance with the provisions of the "Strength Design Method" of

Section 10 of Standard Specifications for Highway Bridges (American Association of State Highway and Transportation Officials, AASHTO; hereafter cited as such).

In addition to the requirements of Sections 10.20 and 10.21 of AASHTO, refer to Sections 10.30.5 and 10.30.6. Unless approved by ODOT and effectively connected to both flanges, the lateral bracing of compression chords shall be as deep as the chords. In addition to the shear from lateral forces, the lateral bracing of the compression chords of trusses, and the flanges of deck girders shall be proportioned for a transverse shear in any panel equal to 2.5 percent of the axial stress in both members in that panel. Girders shall be cambered to compensate for dead load deflections and for any vertical curvature required by profile grade.

6.15 CAMBER

Girders supporting the superstructure shall be cambered to compensate for deflection due to its own dead load and all superimposed dead loads. In superstructures supported on prestressed girders, the camber induced by the prestressing forces shall be included. In concrete superstructures the track rail supports and fastenings shall contain provisions for correcting the long-term effects of creep.

6.16 REINFORCED CONCRETE

Details of Reinforcement. Reinforcement details shall conform to those outlined in Chapter 7 of ACI 318 and in the ACI Detailing Manual (ACI SP-66) except as modified or revised in these criteria. The spacing of reinforcement for all ODOT structures shall be a multiple of even inches. Main reinforcement spacing, however, shall not exceed 12 inches. Secondary reinforcement spacing shall not exceed 18 inches and shall be compatible with the main bar spacing. The length of lap splices for distribution, temperature, and shrinkage reinforcement shall not be less than 24 bar diameters nor less than 12 inches. The provisions for controlling flexural cracking described in Section 10.6 of ACI 318 or in Section 8.16.8.4 of AASHTO shall apply as a minimum for distribution of flexural reinforcement.

Creep and Shrinkage. Creep and shrinkage shall be accounted for in the design of reinforced concrete structures and shall be considered when calculating camber and deflection. All calculations shall be done in accordance with Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures (ACI 209R; hereafter cited as such).

Distance between Lateral Supports. Provisions of Section 10.4 of ACI 318 when applied to members subject to impact and vibration other than ODOT loading shall be revised as follows:

- "Should W, the ratio of the distance between lateral supports and the least width of the compression flange, exceed 24, then the allowable stress shall be reduced. The magnitude of the stress reduction shall vary proportionally from 0 to 50 percent for values of W between 24 and 36, respectively. Under no circumstances shall W exceed 36."

Combined Shear and Torsion. Combined shear and torsion shall be designed in accordance with Section 11.6 of Building Code Requirements for Reinforced Concrete (American Concrete Institute ACI 318; hereafter cited as such).

Effective Concrete Flange Width. Section 10.38.3 of AASHTO shall be modified as follows: Unless a finite element analysis or other rigorous mathematical analysis approved by ODOT is performed to determine stresses in the cross section of a composite girder, the effective width of the slab as flange in composite girder construction shall not exceed the least of the following:

- Independent Single-Cell Box Girders:

    1. One-fourth the span length of the girder.

    2. Twice the distance from the centerline of the girder to the nearest edge of the slab.

    3. Twice the width of the box, measured at the intersection of the bottom of the top slab and the outside faces of the webs.

    4. Six times the least slab thickness on the outer side of each web plus six times the least slab thickness on the inner side of each web.

- Multiple Single-Cell Box Girders:

    1. One-fourth the span length of the girder.
    2. For an interior girder, the center-to-center distance of girders; for an exterior girder, twice the distance from the centerline of the girder to the nearest edge of the slab, or a point midway between the exterior girder and the adjacent girder, whichever is less.
    3. Six times the least slab thickness on the outer side of each web plus six times the least slab thickness on the inner side of each web.

        - Interior T-Beam Girders:

            - Refer to Section 8.10.1 and 10.38.3.1 of AASHTO.

        - Exterior T-Beam Girders with Overhanging Flanges:

            - The above limitations for interior girders.

- The distance from slab edge to exterior girder (not exceeding six times the least thickness of the slab) plus 1/2 the center-to-center distance to the next girder (not exceeding six times the thickness of the slab).

Composite Box Girders. Replace Sections 10.39.1 and 10.39.2 of AASHTO with the following criteria: "Steel-concrete composite box girders shall be designed by rigorous analytical methods with due regard to torsional and other stresses imposed when the rails do not lie in the plane of the webs. Thorough analysis shall be made of the lateral distribution of ODOT train loads."

6.17 PRESTRESSED CONCRETE

Allowable Stresses. See Section 9.15 of AASHTO, Chapter 18 of ACI and Chapter 8 of AREMA as applicable.

Creep and Shrinkage. Creep and shrinkage shall be accounted for in the design of prestressed concrete structures and shall be considered when calculating camber and deflections. All calculations shall be done in accordance with Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures (ACI 209R; hereafter cited as such).

Shear and Torsion. The required AREMA of shear and torsion reinforcement shall conform, where applicable, to the requirements of Chapter 11 of ACI 318, except that lightweight concrete shall not be used in any main-load-carrying members.

Anchorage Zones. Refer to the provisions of Sections 9.21 and 9.27 of AASHTO, and Section 18.19 of ACI.

Cover and Spacing of Steel in Prestressed Concrete. In addition to the provisions of Section 9.26 of AASHTO, the following shall also apply:

Corrosion Protection. Anchorages and end fittings of prestressing steel shall be permanently protected against corrosion with a minimum concrete cover of 2 inches.

Fire Protection. To conform to the relevant code requirements, additional concrete cover may be required in structural members subject to exposure to fire.

Loss of Prestress. Calculation of prestress losses shall be in accordance with Section 9.16 of AASHTO for structures subject to ODOT loading and highway structures, in accordance with Section 18.6 of ACI for structures not subject to ODOT loading, and in accordance with Section 8.17 of AREMA for railroad structures.

The mean annual ambient relative humidity used in calculations of losses due to shrinkage shall be 65 percent.

6.18 SUBSTRUCTURE

Bridge bents shall be located radially for curved structures where practical. Skewed concrete bridges should be avoided when possible. The maximum bridge skew shall be less than 30 degrees away from radial supports, if practical.

The following angles are the maximum recommended skews for different types of concrete bridges.

TYPE OF STRUCTURE SKEW IN DEGREES
Precast concrete slabs and box girders 15 degrees
Precast concrete I-girders and T-girders 30 degrees
Cast-in-place concrete slabs and girders 60 degrees

To account for variability in backfilling and the dynamic effects of axle loads, abutment backwalls above bridge seats shall be designed for earth pressures and live load surcharge increased by 100%. This does not apply to the portion of the abutment below the bridge seat nor the stability of the abutment. (AREMA Volume 2- 5.3.1)

6.19 FOUNDATIONS

Drill Shafts shall have an Aspect Ratio (Length/Diameter) of less than 30.

6.20 VIBRATION AND DEFLECTION CONTROL

To limit potential dynamic interaction between aerial structure girders and light rail transit vehicles, all structures supporting ODOT trains shall be designed so that the unloaded natural frequency of the first mode of vibration of the longitudinal girders is not less than 2.5 cycles per second. Furthermore, no more than one span in any series of three consecutive spans shall have a first mode frequency less than 3.0 cycles per second.

Designers may find that compliance with the above criterion necessitates the inefficient use of certain materials, particularly where the girders are of structural steel and the span lengths are relatively long. Where such a finding is made, the proposed design shall be discussed with ODOT to determine, for that particular instance, whether a lower natural frequency may be acceptable.

Members having simple or continuous spans shall be designed so that the deflections due to live load plus impact do not exceed 1/1000 of the span length. The deflection of cantilever arms due to live load plus impact shall be limited to 1/375 of cantilever arm.

6.21 FATIGUE

The requirements of Section 10.58 of AASHTO shall apply for structures subject to the ODOT train loading. Over the life of the structure, 3 million cycles of maximum stress shall be used in estimating the number of repetitive maximum stress cycles.

6.22 FIRE PROTECTION

Refer to Fixed Guideway Transit Systems (NFPA 130) or the applicable local code for fire protection requirements.

6.23 DECK DRAINAGE

The superstructure deck shall be designed to provide both longitudinal and transverse drainage. Transverse drainage shall be secured by suitable cross slopes, and longitudinal drainage by camber or gradient of the deck or gutter. Runoff shall be computed in accordance with HEC 21 using a runoff coefficient of 0.90. Collected water from a storm of 100-year frequency shall be carried from the deck by a system of inlets and down spouts at each pier. Inlets and down spouts shall be rattle-proof and made of non-corrosive material. Down spouts shall be rigid, have a minimum inside dimension of 4 inches, and be provided with suitable clean- outs and splash blocks. The concrete decks shall be provided with drip notches.

6.24 NOISE CONSIDERATIONS

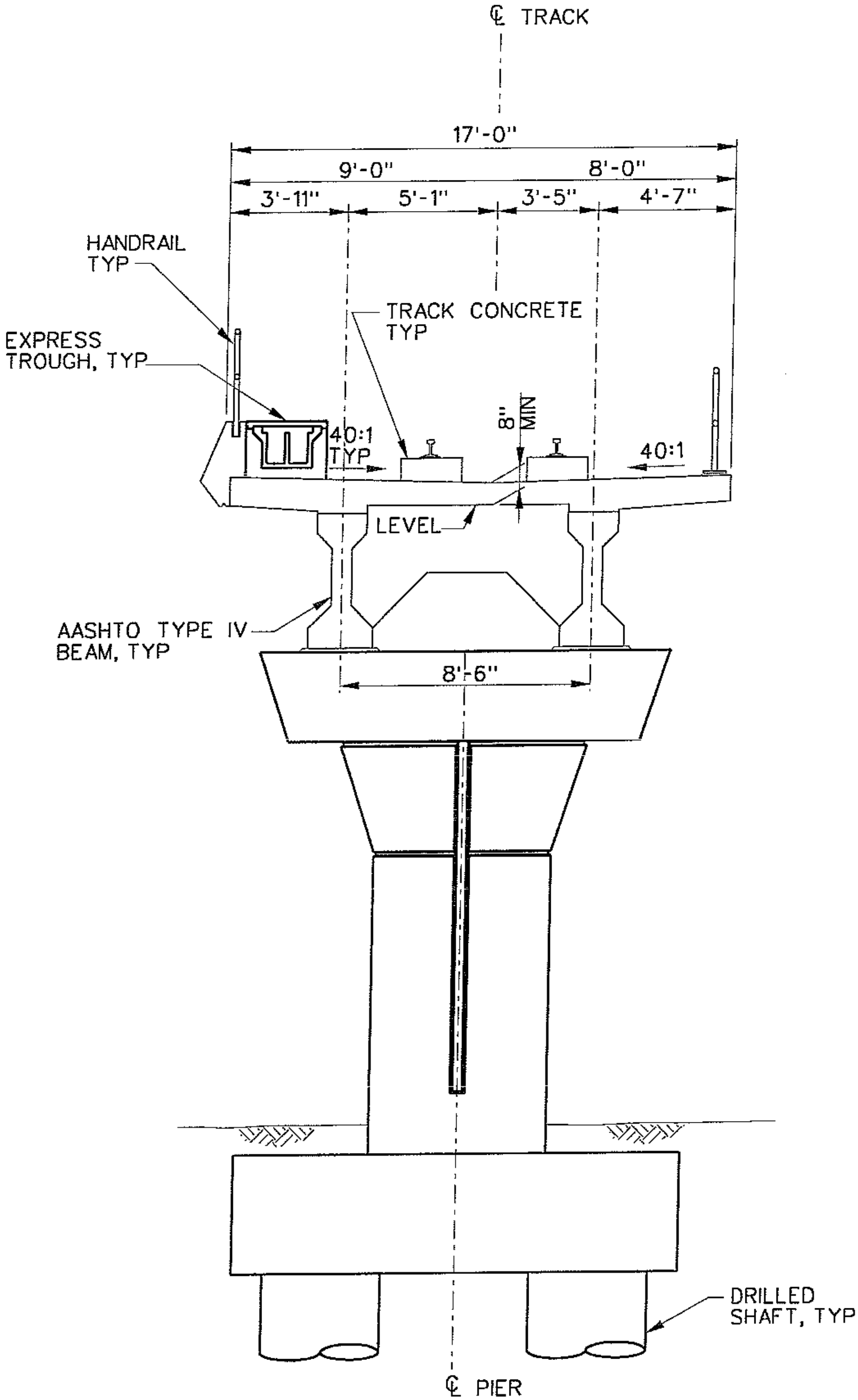
At locations identified by ODOT or its noise and vibration subconsultant, an acoustical barrier shall be provided along one or both edges of the aerial structure deck to limit noise transmission to noise-sensitive developments along the wayside. At locations where no need for an acoustical barrier is identified, provisions shall be made to the deck, superstructure, and substructure for the future installation of a barrier.

At locations identified by ODOT or its noise and vibration subconsultant, certain steel girders may require sound damping panels to minimize their propagation of low frequency vibrations. Where required, ODOT will provide the section designer with sound damping details.

6.25 UPLIFT

Aerial structures shall be designed so that under dead load conditions anchor bolts attaching the superstructure to the substructure are not in tension.

Anchor bolts shall be provided or other provisions shall be made for adequate attachment of the superstructure to the substructure to resist uplift from transit loads, including the derailment load, as per the section on transit loads of these criteria in addition to the requirements of Section 3.17 of AASHTO.



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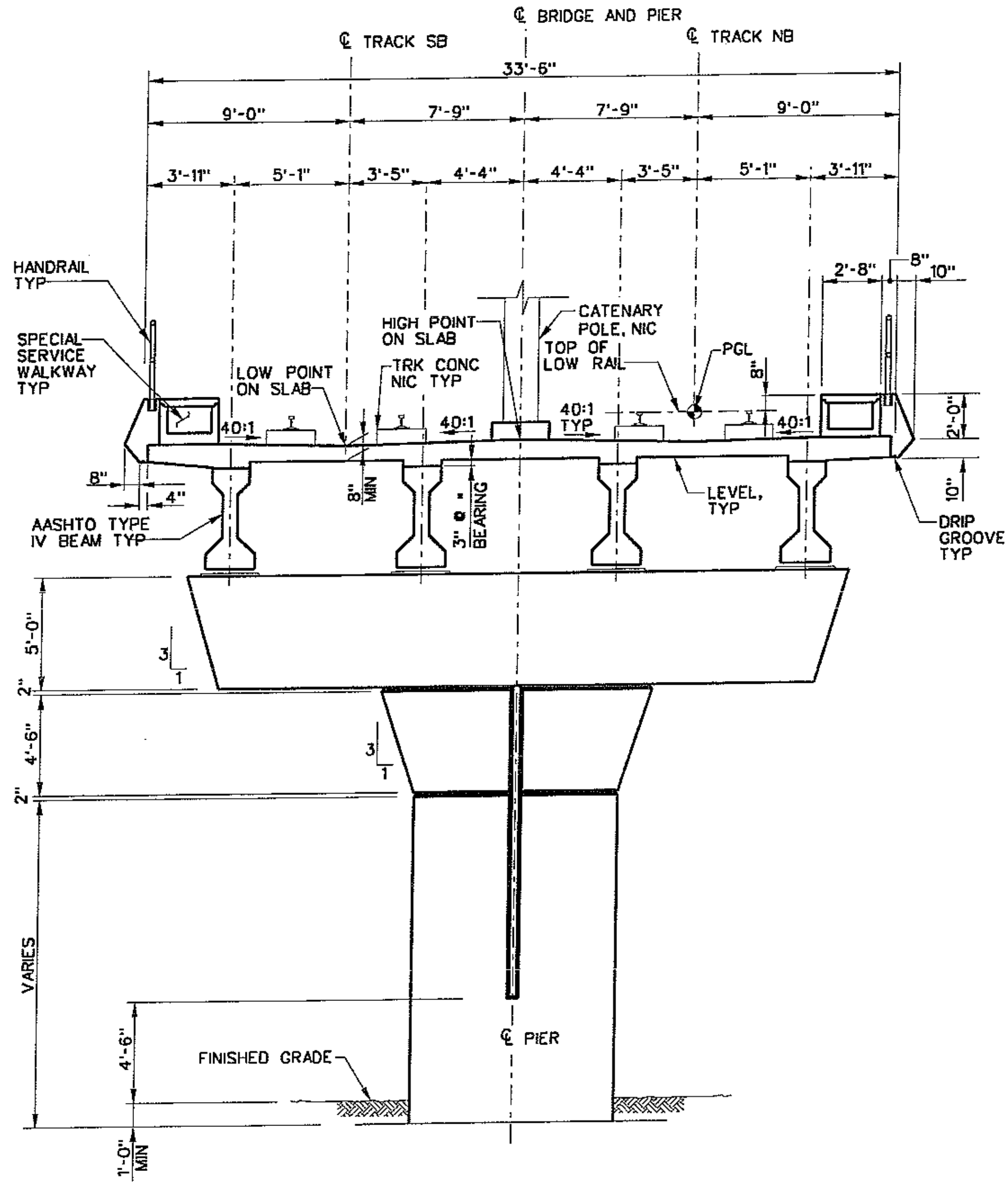
I-244 LRT BRIDGE OVER ARKANSAS RIVER

AERIAL STRUCTURE
TYPICAL BENT ELEVATIONS

SCALE: NOT TO SCALE

FIGURE: 6.1



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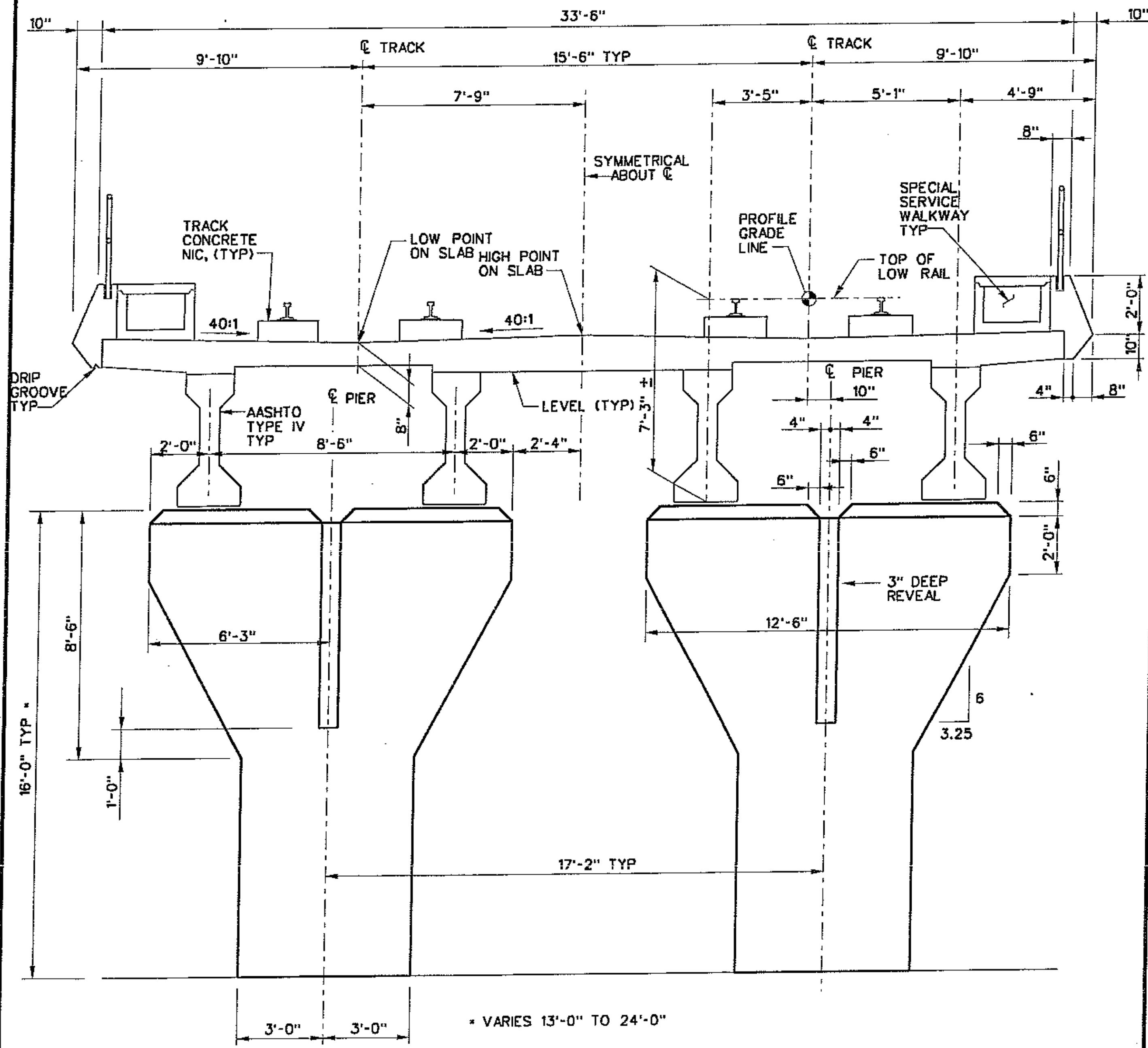
I-244 LRT BRIDGE OVER ARKANSAS RIVER

AERIAL STRUCTURE TYPICAL BENT ELEVATIONS

SCALE: NOT TO SCALE

FIGURE: 6.2



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AERIAL STRUCTURE TYPICAL BENT ELEVATIONS

SCALE: NOT TO SCALE

FIGURE: 6.3

APPENDIX A : Design Codes, Manuals, and Specifications

CODES, STANDARDS, AND REFERENCE PUBLICATIONS

The following codes and standards are provided as an aid to designers and other subconsultants, and are not to be considered a comprehensive list. ODOT's position remains that it is the responsibility of the professional consultant or contractor to comply with all appropriate and applicable codes and standards, based upon his professional judgment. Contractors or consultants wishing to use standards other than those referenced in this appendix or in the text of these design criteria should be a comparison of the proposed standard and the referenced standards. The comparison shall demonstrate that ODOT is being given designs or materials equal to or better than that specified. The comparison shall be certified as being accurate by an engineer licensed in Oklahoma. If the alternative standard is not originally published in English, the contractor shall certify through an independent translator that the translation is complete and correct. Specified test results will not be accepted in translated form unless the exact test procedures using calibrated test equipment accompanies them. The contractor also will require to certify in writing that compliance with all codes, standards, and reference documents has been achieved.

Unless otherwise specified, all consultants and contractors shall comply in all respect with these codes and standards, which shall be the latest edition or issue, and the most recent revision, amendment, or supplement in effect at the date of notice to proceed with each specific project. Where the requirements of more than one code or standard apply (except the variances described in the criteria), the consultant or contractor shall determine which code is in the best interest of safety and cost effectiveness. All such potential conflicts should be presented to ODOT for resolution.

Due to the unique nature of rail transit, variances from existing specific codes and standards must be provided for certain functional elements. If a condition is found which is not covered by the codes, regulations, or criteria, the consultant or contractor shall refer the matter to ODOT for guidance in reaching and acceptable solution.

The first part of this appendix is organized by criteria chapter and/or section. The second part provides an alphabetical listing or referenced organizations, with addresses.

REFERENCES

American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Highway Bridges, including all subsequent AASHTO Interim Specifications for Bridges.

American Association of State Highway and Transportation Officials (AASHTO), Guide Specifications for Horizontally Curved Highway Bridges.

American Concrete Institute (ACI) 318, Building Code Requirements for Reinforced Concrete, including commentary.

American Society of Civil Engineers, ASCE 7-95 Minimum Design Loads for Buildings and Other Structures.ACI SP-66, manual of Standard Practice for Detailing Reinforced Concrete Structures.

AWS D1.5M Structural Welding Code

U.S. Navy Design Manual for Soil Mechanics, Foundations, and Earth Structures

Suggested Design and Construction Procedures for Pier Foundations

ACI 209 R-82, Prediction of Creep, Shrinkage and Temperatures Effects in Concrete Structures.

ACI 336.3R, Suggested Design and Construction Procedures for Pier Foundations.

American Institute of Steel Construction (AISC), Load and Resistance Factor Design Specification for Structural Steel Buildings.

American Institute of Timber Construction (AITC), National Building Code-Timber.

American National Standards Institute (ANSI), American Standard Building Code.

American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering.

American Society for Testing and Materials (ASTM), current manuals.

ASTM A36, Specification for Structural Steel.

ASTM A185, Specifications for Welded Steel Wire Fabric for Concrete Reinforcement.

ASTM A307, Specifications for Low-Carbon Steel Externally and Internally Threaded Standard Fasteners.

ASTM A325, Specifications for High-Strength Bolts for Structural Steel Joints.

ASTM A416, Specifications for Uncoated Seven-Wire Stress-Relieved Steel Strand for Prestressed Concrete.

ASTM A490, Specifications for Heat-treated Steel Structural Bolts, 150 ksi Minimum Tensile Strength.

ASTM A497, Specifications for Welded Deformed Steel Wire Fabric for Concrete Reinforcement.

ASTM A572, Specifications for High-Strength Low-Alloy Columbium-VA Nadium Steels of Structural Quality.

ASTM A615, Specifications for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement.
ASTM A709, Specifications for Structural Steel for Bridges.

ASTM A722,Specifications for Uncoated High-Strength Steel Bar for Prestressing Concrete.

American Welding Society (AWS), Welding Handbook.

Building Officials and Code Administrators International, Inc. (BOCA), Basic Building Code.

City code of each municipality served by ODOT.

Federal Highway Administration (FHWA) Standard Specifications for Construction of Roads and Bridges of Federal Highway Projects, FF-74.

International Conference of Building Officials (ICBO), Uniform Building Code.

National Fire Protection Association (NFPA) Standard 130, Fixed Guideway Transit Systems.

U.S. Department of Transportation, Hydraulics of Bridge Waterways.