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MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

RAILROAD OPERATIONS

COMMUTER RAIL DESIGN STANDARDS MANUAL

VOLUME I
SECTION I

TRACK AND ROADWAY

Revision No. 1
April 19, 1996

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SECTION I - TRACK AND ROADWAY

CHAPTER 1
INTRODUCTION

A. Background

The Commuter Rail Design Standards are a two-volume series that establish design objectives, guidelines, and criteria for commuter rail track and roadway, communications systems, signal systems and stations. Originally developed in 1976 as part of the Commuter Rail Improvement Program, this two-volume series expanded the Massachusetts Bay Transportation Authority's earlier series of design standards manuals for the rapid transit system--the Manual of Guidelines and Standards--to the area of commuter rail. This document contains extensive revisions and additions to the 1976 edition.

B. Purpose of the Manual

The purpose of this Manual is to provide guidance to the Authority and it's design consultants in commuter rail design and construction work. Due to the constant evolution of products and accumulation of practical experience it is neither practical or necessary to rigidly "standardize" all elements of the commuter rail system. The approach of this Manual is to recommend standardization of design criteria, but of components and material only when it is economically justified or is required for legal or technical reasons.

While the need for total system standardization is not a practical priority, it is a priority that future improvements satisfy all safety requirements and regulations regardless of methods or material used. The designer should also aim to achieve economy of design based on the past accumulation of prior experience with commuter rail improvements as well as consistency with the character and quality of the system's design.

This Manual is an important tool toward achieving the general goals of safety, economy, and consistency. In general, these standards establish three levels of guidance in the design of system improvements--design objectives, design guidelines, and design criteria and details. The design objectives are a very general form of guidance, broadly outlining the desired results of a component or facility.

Design guidelines are a more specific form of guidance. They describe the level of performance a facility should achieve; in general terms, where it should be located; what types of user or other needs it should satisfy; standard dimensions and clearances to be achieved; and where appropriate, several approaches to meeting the guidelines. In short, guidelines represent a planning and programming level of guidance.

The most detailed guidance provided in the Manual is categorized as design criteria and details. These criteria and details may describe specific construction methods or materials which the Authority requires the designer to use in specific circumstances. An example is the use of full depth rubber rubber crossing panels at most grade crossings. More often, however, the criteria describe specific materials or methods of construction simply because they have been successfully used in previous commuter rail facilities and are likely to be applicable and successful on future projects.

Within Section I of the Manual, Design Objectives and Guidelines are contained in one separate chapter. In Section II, Design Objectives and Guidelines are addressed in each chapter.

C. Organization of the Manual

The revised Manual is organized into two loose leaf volumes:

Volume 1. Section I - Track and Roadway. Section II - Stations and Parking
Volume 2. Signal & Communications

The two volume Manual is organized in a loose-leaf format for the reasons of flexibility and convenience. The passage of time and experience will require continuous modifications of the design guidelines and criteria presented in the Manual. The loose-leaf format provides the flexibility needed to insert new pages and delete outdated material. In addition, the format simplifies the process of copying pages or sections of the Manual as needed to guide future design work.

D. Revisions

The revision number and date of issue are noted in the revision box. When revisions are made, the entire chapter and a new table of contents is issued. By consulting the current table of contents, it is possible to determine if the chapters in the Manual are the latest revision. Any designer working on projects for Railroad Operations should check with the Authority to confirm that they are using the most recent revision before proceeding.

E. Other Applicable Documents

In addition to the Design Standards Manual, there are three other documents which supplement the Track and Roadway, Section I of the Manual. The first two are essential for designers to have and use with this document.

- Book of Standard Plans - Track and Roadway
- Railroad Operations - Commuter Rail - Material Specifications
- MW-1 Manual - Maintenance of Way Manual

CHAPTER 2

DESIGN OBJECTIVES / GUIDELINES

A. Design Objectives

The objective of the Design Standards Manual for Track and Roadway shall be to provide a safe, efficient, and reliable fixed plant for the operation of the Massachusetts Bay Transportation Authority (MBTA) commuter rail services as well as through and local freight service over MBTA rights-of-way.

The use of these design standards is required for new installations or when general renewal or replacement of track and roadway materials is to be undertaken. Requirements for maintenance of existing track and roadway elements are contained in the Authority's separate MW-1 (Maintenance-of-Way) Manual. The separate Book of Standard Plans - Track and Roadway shall be considered as an extension of this section of the manual and plans contained therein are cited in this document as appropriate. Material Specifications for track and roadway material are contained in the document titled Railroad Operations - Commuter Rail Material Specifications which are also cited in this document as appropriate.

Track and roadway design and installation practices not specifically addressed in this Manual shall be in accordance with the current American Railway Engineering Association (AREA) Manual of Recommended Practice and Portfolio of Trackwork Plans.

All designers/consultants preparing plans and specifications for any project for MBTA Railroad Operation's facilities shall be required to use this document and the separate Book of Standard Plans as a basis for design. Exceptions are the Northeast Corridor between Boston and the Rhode Island state line where the requirements of Amtrak will be followed and any work on the Worcester Line west of Framingham Station where the requirements of Conrail will be followed.

It is recognized that field conditions and special situations often occur and present circumstances that cannot be addressed in the Manual. In these instances, it is the designer's responsibility to bring this to the attention of the Authority and direction will be given by the Chief Engineering Officer, Railroad Operations for that specific instance. In all cases, issues of safety shall be the primary concern.

B. Design Guidelines

The MBTA commuter rail system extends over portions of three former Class I railroads. Each had its own standards for track and roadway materials, designs, and practices. Since acquiring these properties in the 1970's, changes and improvements have eliminated many of the differences but some still exist.

For all new installations of track and roadway and major rehabilitation projects, the design standards specified herein and related documents noted in Chapter 1, Part E, shall apply in the interest of uniformity of design and maintenance.

Track and roadway components which are renewed shall adhere to current MBTA Standard Plans and Material Specifications.

The following specific design guidelines and policies are basic to all track and roadway engineering design:

1. Safety - The primary purpose of all engineering design shall be to provide for the safe operation of trains and elimination of hazards to personnel and equipment. Application of standard design to all situations is rarely possible. The designer is responsible to recognize when deviation from standards will be necessary and call it to the attention of Railroad Operations. The designer and Railroad Operations will work together to arrive at a satisfactory solution with safety the primary concern.

2. Reliability - The design and choice of component materials shall be in accordance with MBTA Railroad Operations Standards, deviating only when specifically allowed by the Chief Engineering Officer, Railroad Operations.

3. Design Speed - Maximum design speed for commuter rail shall be 70 mph and 100 mph where directed. However, the design for 70 MPH should not preclude a future increase to 79 mph[1]. The present exception is the Northeast Corridor/Shore Line Main Line which will be up to 150 mph. Existing permanent operating speed restrictions shall be maintained unless a change is sanctioned by the Authority. Station areas are to be designed for maximum authorized speed of track in abutting territory to facilitate operation of express trains.

4. Clearances - Minimum horizontal and vertical clearances shall conform to those shown on Standard Plans 1012 to 1019. In general, new design shall provide 14'-0" track centers and 8'-6" side clearance with appropriate compensation for curvature. In no case shall new design provide less than 13'-0" track centers. Vertical clearances will be on a site specific basis. (See Chapter 6)

   For continuous adjacent structures greater than 100 feet in length, measured along the track base line and closer than 8'-6" to centerline of track, safety niches shall be provided. Such restricted clearance will require a variance from the Department of Public Utilities (DPU). Chapter 6 contains additional information on clearances.

5. Load Capacity - Track and roadway shall be designed to accommodate heavy freight train traffic. Track bridges and other structures shall be designed for Cooper E-80 loadings as prescribed in the AREA Manual.

6. Grade Separation and Grade Crossings - In general, new grade separation structures shall be provided wherever possible to eliminate crossings at grade. Existing and future public and private grade crossings shall

[1] 79 MPH is the maximum speed allowed by Federal Railroad Administration (FRA) without cab signals.

be protected with flashers and gates approved by the Massachusetts Department of Public Utilities. Private crossings used less than two crossings of track(s) per week may instead use crossbucks and a locked right-of-way gate. Key for gate to be given to property owner and an agreement signed by owner that gate shall be kept locked except when they are in actual use of crossing.

7. New Grade Crossings - No new public grade crossings, auto or pedestrian, of main tracks shall be permitted without the permission of the Director of Railroad Operations, the local community, the County Commissioners and approval of the warning system by the Massachusetts Department of Public Utilities.

   No new private grade crossings shall be permitted without the expressed consent of the Director of Railroad Operations and subject to an agreement signed by the General Manager of the MBTA.

CHAPTER 3
GEOMETRIC DESIGN CRITERIA

A. Horizontal and Vertical Survey Control Requirements

Unless otherwise directed by the Chief Engineering Officer, Railroad Operations, the horizontal control used to establish rectangular coordinates for track geometry shall be based on the Massachusetts Plane Coordinate System, Mainland Zone. Horizontal control points and supporting survey shall meet U.S. Coast and Geodetic Survey second order specifications for accuracy with Class I requirements (1 part in 50,000) for projects encompassing more than 5 miles. Class II requirements (1 part in 20,000) will be adequate for projects less than 5 miles in length.

Vertical control shall be based on U.S. Coast and Geodetic Survey Mean Sea Level Datum, 1929 General Assessment. All vertical control points or benchmarks shall meet U.S. Coast and Geodetic Survey Second order Class II Specifications for accuracy. On small projects (less than 1 mile in length), third order requirements may be used.

B. Design Speeds

- Design Speed - 70* mph (100 mph where directed)[1] (*Do not preclude future increase to 79 mph)
- Minimum Design Speed - Maximum speed allowed by local conditions
- Station Pass-By Speed - Maximum authorized speed for territory[2]
- Terminals, Terminal Approach Tracks and Servicing Areas[3] - 20 mph desirable - 15 mph absolute minimum

C. Track Geometrics

1. General

The horizontal alignment of tracks shall consist of a series of tangents connected with circular and compound curves with appropriate spirals. Vertical alignment shall consist of tangent grades connected by parabolic vertical curves as required by these criteria.

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[1]On certain routes, such as Northeast Corridor and others where station spacing, geometry, etc. permit - design for up to 150 mph as directed.

[2]Up to 2-3/4" unbalanced elevation permitted in stations to achieve maximum speed so as to minimize actual elevation in station.

[3]Terminal areas include: Major stub end terminals, servicing areas, train storage yards and immediate approaches thereto.

2. Tangent Lengths - Horizontal

a. Mainline

Minimum desirable tangent lengths between reverse curves and/or spirals shall be 100 feet. In very limited areas where design speeds are 50 mph or less, tangents of lessor distance may be permitted with permission of Chief Engineering Officer, Commuter Rail and if spirals are long enough to provide less than a one half inch change in reverse cross level over 62 feet. Short tangents between curves in same direction (broken back curves) should be avoided by compounding to a flatter curve or using a connecting spiral.

b. Yards

In terminals and yard areas where design speed is 20 mph or less, tangent length may be reduced to 65 feet (the approximate truck spacing of an 85' long car) and, within yards only, when space is very limited and with permission of Chief Engineering Officer, the following table may be used:

	Degree of Reverse Curves	Minimum Recommended Tangent Length (Feet)
Less than	7° - 8°	20
	8° - 9°	25
	9° - 10°	30
	10° - 11°	40
	11° - 12°	50
	12° - 13°*	60

*Curves this sharp normally not permitted.

TABLE 3.1

C. Turnouts and Crossovers

The use of "back to back" turnouts of the same hand which results in a reverse curve, is prohibited unless a tangent length of at least 65 feet measured from PS to PS of the turnouts is added. Maintaining this dimension is especially critical with No. 8 & 10 turnouts. In yards and other low speed areas, the criteria indicated in Table 3.1 above may be used with permission. A No. 10 turnout has an equivalent radius of about 8° and a No. 8 about 12°-30'. It should be noted that a No. 8 crossover in track centers less than 14'=0" will not meet the criteria in the above table. No. 8 crossovers should therefor be avoided and used only with permission of the Chief Engineering Officer where absolutely necessary.

3. Curve Length

The minimum curve length (not counting connecting spirals) shall be 100 feet. In compound curves, each curve segment of differing radius should be at least 100 feet long.

4. Horizontal Geometry

a. Curve Definition

Curves shall be defined by chord definition and specified by degree. Arc definition shall not be used.

$$R=\frac{50}{Sin\ D/2} \quad or \quad Sin\ D/2 = \frac{50}{R} \quad or \quad D=2\ Sin^{-1}\frac{50}{R}$$

Formula 3.1

b. Maximum Curvature

The maximum degree of curvature allowed on main tracks is a function of design speed and the amount of superelevation - both actual elevation and unbalanced. Figure 3.1 illustrates the maximum curvature for a given design speed using both the preferred 1.5" as well as the maximum 2.75" unbalanced elevation combined with the maximum allowable 6" actual elevation. (See C.4.e. following for a discussion of superelevation)

Figure 3.1 based on following formulae from AREA:

$$E_a + E_u = 0.0007\ DV^2$$

(See 4.e following for derivation of this formula) Formula 3.2

$$V = \sqrt{\frac{E_a+E_u}{0.0007D}}$$

Formula 3.3

or

$$D=\frac{E_a+E_u}{0.0007V^2}$$

Formula 3.4

V = Velocity in mph
D = Degree of Curvature
Ea = Actual Superelevation in inches
Eu = Unbalanced elevation in inches

Figure 3.1 following uses the maximum allowable 6 inches actual elevation (E_a)

Design Speed - MPH	Max. Curve with 1.5" Eu	Max. Curve with 2.75" Eu
40	6°-42'	7°-49'
50	4°-17'	5°-00'
60	2°-59'	3°-28'
70	2°-11'	2°-33'
80 (79)	1°-43'	2°-00'
100	1°-04'	1°-15'

Figure 3.1

NOTE: Figure 3.1 will be modified if the FRA increases the currently mandated 3 inches maximum E_u to a higher value.

Within station platforms, the maximum curvature shall be limited to as flat a curve as possible. On platforms on the inside of curves, the curvature shall not exceed 4°-00' to control gap from door to platform edge.

Within yards and terminals, sharper curves are allowed. Due to rolling stock restrictions, maintenance considerations and historical experience, the preferred maximum curvature on any track regularly used by 85 foot long passenger equipment is 11°-00'. Any curvature in excess of 12°-00' should be avoided as operation above that radius has been found to be unreliable.

c. Design Considerations

Curvature, superelevation, spiral lengths and design speeds are all interrelated. The goal in design is to combine those elements in a way that provides a comfortable and safe operating speed for the predominant traffic. When designing a new or upgraded segment of railroad, the designer should avoid a curve by curve approach, blindly applying the criteria to each curve to achieve maximum possible speed. This may result in a curve with superelevation sufficient for 79 mph bracketed by curves limited to 50 mph. Because trains take a very long distance to change velocity, especially above 35-40 mph, trains will run the 79 mph potential curve at 50 mph. This will result in passengers sensing an inward lean on the curve and cause excessive wear on the inside rail.

The most restrictive curve in a given section of railroad sets the speed for that section. The designer should investigate various means by which the restrictive curve may be modified to increase the speed to that of adjacent lesser restrictions. The cost and other factors should be assessed with Railroad

Operations to determine what level of modifications could be justified or appropriate for each such location.

Signal aspects approaching interlockings may also be a factor in determining the line speed for a section of railroad. The designer should be aware of the locations of interlockings and inquire whether or not they will limit the maximum authorized speed for most trains in the approach area of the interlocking.

Often there are jurisdictional and safety issues that affect the design speed rather than civil restrictions based on geometry. An example would be a hazardous grade crossing which has a speed restriction imposed by the DPU.

Train performance calculation programs are a useful tool in analyzing line segments to determine what the practical maximum speed will be. By factoring in civil and jurisdictional restrictions and reviewing the results, it is possible to develop an overall design that will match the actual speed of most trains.

d. Concentric Curves in Multiple Tracks

In multiple track territory, when tracks follow the same general alignment, the tracks shall be concentric in curves. Track centers must be widened 2 inches per degree for curvature to maintain the equivalent tangent track center. The preferred method of increasing track centers is to lengthen the spirals of the inside track to a length where the spiral offset distance (p) relative to the outside track spiral (p) distance is increased by an amount equal to the required track center increase. The equivalent tangent track center is the nominal tangent track center for the route segment. When redesigning curves, strive to provide equivalent 14'-0" tangent track centers wherever possible, but in no case less than 13'-0".

e. Superelevation

Superelevation is expressed in terms of inches that the outside rail is raised above the level of the inside or low rail. Profile grade is always based on the low rail as superelevation is achieved by raising the outside rail relative to the inside rail.

There are three components to superelevation as used in railway design. It is essential that the use and relationship of these three components is understood.

$$E_e = E_a + E_u$$

(See following page for explanation of terms).

Ee = Equilibrium Elevation
Ea = Actual Elevation
Eu = Unbalanced Elevation

Equilibrium Elevation (Ee) is the amount of elevation required on a given curve at a given velocity for centrifical force to be in equilibrium. That is, the resultant of the overturning force caused by the angular acceleration is directed perpendicular to the centerline of the elevated or "banked" track. When a train traverses the curve at the equilibrium speed, passengers will feel no sideways force and there is no tendency for the inside wheels to lift and the carbody to roll. (Figure 3.2)

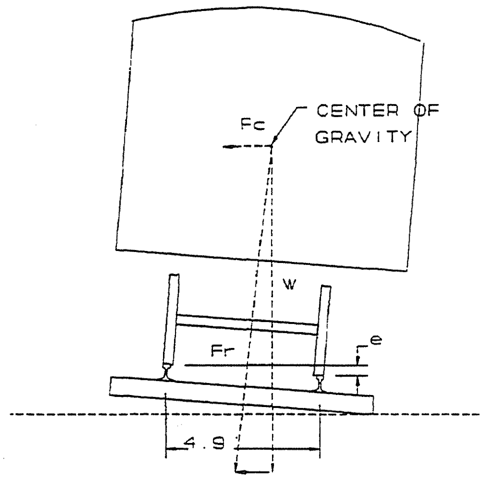


Figure 3.2

$$F_c = Wv^2/gR$$

Where:

Fc	=	Centrifical Force
W	=	Weight of car in lbs.
v	=	Speed in feet per second
g	=	Acceleration due to gravity (32.16 ft/sec/sec)
R	=	Radius of curve in feet
Fr	=	Resultant force of Fc & W directed perpendicular to elevated track
e	=	Equilibrium superelevation in inches

The formula derived from the proceeding used to determine equilibrium elevation on most passenger equipment is:

$$Ee = 0.000686\ DV^2 \text{ (usually rounded to)}$$

$$Ee = 0.0007\ DV^2 \qquad \text{Formula 3.5}$$

Or

$$Ee = 4.01V^2/R$$

Where:
- Ee = Equilibrium elevation in inches
- D = Degree of curve
- V = Velocity in mph
- R = Radius in feet

Unbalanced Elevation (Eu) is an equivalent amount of centrifical force which is not directed perpendicular into the track structure. A more descriptive term is cant deficiency. It has been found that a certain amount of deficiency in the elevation required for equilibrium is both safe and comfortable. For many years, the Federal Railroad Administration (FRA) has mandated that unbalanced elevation (cant deficiency) used in design and setting speed be limited to 3 inches for conventional passenger equipment. The MBTA currently uses a more conservative value for the amount of unbalanced (deficiency) elevation allowed, using 1.5 inches as the preferred limit and allowing up to 2.75 inches as a maximum. This provides improved passenger comfort, better compatibility with freight operations and a margin below the FRA mandated 3 inch maximum. Currently the 3 inch maximum Eu criteria is under review by FRA and an unbalanced elevation of 4 inches or more may be allowed in the future which would still provide a high level of safety and passenger comfort on well maintained track.

Actual Elevation (Ea) is the actual superelevation in track, limited to 6 inches. Based on the preceeding, the actual elevation required for a given curve is calculated as:

$$Ea = Ee - Eu$$

or,

$$Ea = 0.0007\ DV^2 - Eu \qquad \text{Formula 3.6}$$

Where:
- Ea = Actual Superelevation in inches
- D = Degree of Curvature
- V = Velocity in mph
- Eu = Unbalanced elevation in inches. (1.5 inches preferred, 2.75" max).

Minimum and Maximum Superelevation

Minimum Ea shall be 1 inch. Maximum Ea shall be 6 inches except it is desirable to limit Ea to 4 inches on routes where through freights operate and where trains are likely to stop or operate below the design speed on a regular basis. Within stations it is desirable to limit Ea to 3 inches and use 2.75 inches Eu to allow express operation at maximum authorized speed.

Superelevation shall be developed uniformly through the length of transition spirals. Where spirals are not present or are of insufficient length, such deficiencies should be corrected as track is reconstructed. Running out of superelevation on tangents and curves is not permissable on medium to high speed routes and will be done only with permission of the Chief Engineering Officer. Proper spiral length is determined as discussed in the following sub-section.

Although calculated to the hundreth of an inch, actual superelevation in track is normally expressed and set in practice to the nearest one eight or one quarter inch.

f. Spirals

Spirals shall be used to connect all mainline curves to tangents. However, for practical considerations, spirals may be omitted when the required spiral length divided by the curve radius in feet is less than 0.01. Spirals shall also be used to connect compound curves whenever there is any change in Ea (actual elevation) or a change in Eu (unbalanced elevation) of 1/2 inch or more between the compound curves.

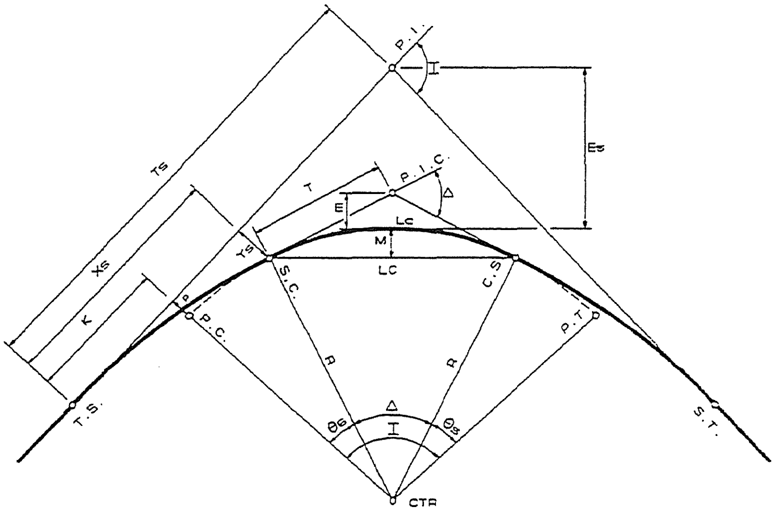
Spirals shall be a cubic parabola based on the so called "ten chord spiral" as shown in Figure 3.4. This is based on chord definition and is consistent with chord definition used with circular curves. The so called "Barnet Spiral", which is based on arc definition, will produce slightly different values.

Spirals shall increase in curvature directly with their length. Superelevation shall be increased uniformly over the length of the spiral reaching full Ea for the curve at the SC (spiral to curve point). The basic design data for spirals and curves is shown on Figures 3.3, 3.4 & 3.5.

In designing spirals and curves, determining the length of spiral (Ls) is a key element. There are three items that need consideration when determining the length of spiral:

1. The rate of run-in and run-out of the superelevation expressed in terms of inches per second, which affects passenger comfort.

2. The slope of the superelevated rail relative to the low rail. This results in a change in cross level between the two trucks of a car and should not exceed a 1 inch difference to prevent undue "racking" or torsional twisting of the car frame. This results in a tendency to lift the inside wheels of the lead truck. *Continuned on Page 3.12*

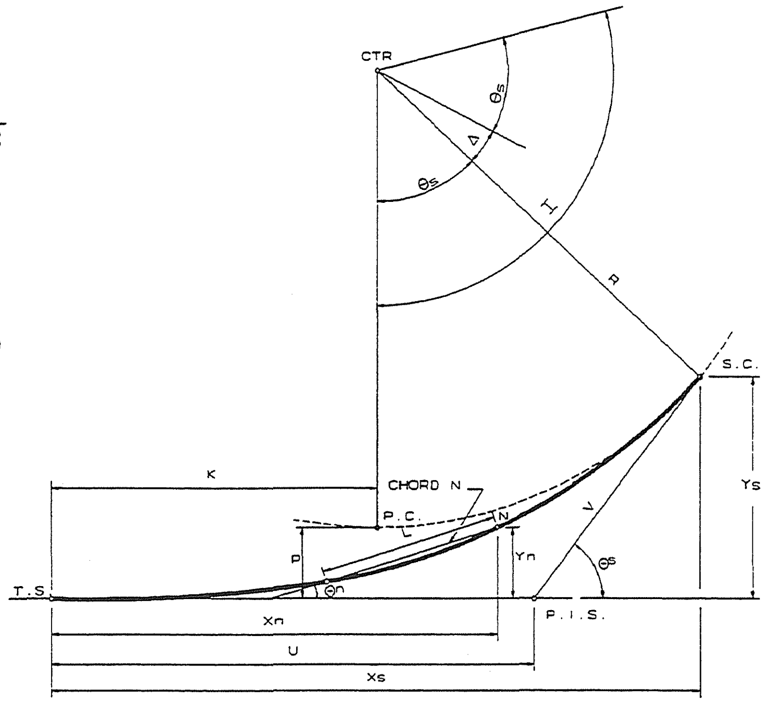


DEFINITIONS
Also See Figure 3.4

C.S.	CURVE SPIRAL, THE POINT OF CHANGE IN ALIGNMENT FROM CURVE TO SPIRAL
CTR	CENTER OF CIRCULAR CURVE
D_c	DEGREE OF CURVE DEFINED BY THE 100 FT. CHORD DEFINITION
E	EXTERNAL DISTANCE FROM MIDPOINT OF CIRCULAR CURVE FROM P.I.C
E_s	EXTERNAL DISTANCE FROM CURVE TO P.I.
I	ANGLE OF INTERSECTION OF MAIN TANGENTS AT P.I.
K	DISTANCE ALONG MAIN TANGENT FROM T.S. (OR S.T.) TO OFFSET P.C.
L	THE LENGTH OF EACH EQUAL CHORD
L_c	LENGTH OF CIRCULAR CURVE BETWEEN S.C. AND C.S. MEASURED ALONG 100 FT. CHORDS.
LC	CHORD LENGTH OF CIRCULAR CURVE FROM S.C. TO C.S.
L_s	THE LENGTH OF SPIRAL FROM T.S. TO S.C. (OR C.S. TO S.T.) AS MEASURED ON TEN CONSECUTIVE EQUAL CHORDS.
M	MID-ORDINATE DISTANCE OF CIRCULAR CURVE.
n	A NUMBER BETWEEN 1 AND 10 USED TO IDENTIFY CHORDS.
P	OFFSET FROM P.C. (OR P.T.) TO MAIN TANGENT.
P.C.	POINT OF CURVE, THE POINT OF CHANGE IN ALIGNMENT FROM TANGENT TO CIRCULAR CURVE, ON SPIRALLED CURVES THIS POINT IS OFFSET A DISTANCE P FROM THE MAIN TANGENT.
P.I.	POINT OF INTERSECTION OF MAIN TANGENTS.
P.I.C	POINT OF INTERSECTION OF LINES TANGENT AT S.C. AND C.S.
P.I.S.	POINT OF INTERSECTION OF MAIN TANGENT AND LINE TANGENT AT S.C. (OR C.S.)
P.T.	POINT OF TANGENCY, THE POINT OF CHANGE IN ALIGNMENT FROM CIRCULAR CURVE TO TANGENT, ON SPIRALLED CURVES THIS POINT IS OFFSET A DISTANCE P FROM THE MAIN TANGENT.
R	RADIUS OF CIRCULAR CURVE.
S.C.	SPIRAL CURVE, THE POINT OF CHANGE IN ALIGNMENT FROM SPIRAL TO CURVE.
S.T.	SPIRAL TANGENT, THE POINT OF CHANGE IN ALIGNMENT FROM SPIRAL TO TANGENT
T	DISTANCE FROM SC OR CS TO P.I.C. IN SPIRALED CURVE OR TANGENT FROM PC OR PT TO PI IN A SIMPLE CURVE
T.S.	TANGENT SPIRAL, THE POINT OF CHANGE IN ALIGNMENT FROM TANGENT TO SPIRAL.
Ts	LONG TANGENT, DISTANCE FROM P.I. TO T.S. (OR P.I. TO S.T.)
U	LONG TANGENT OF SPIRAL. DISTANCE FROM P.I.S. TO T.S. (OR P.I.S. TO S.T.)
V	SHORT TANGENT OF SPIRAL, DISTANCE FROM P.I.S. TO C.S. (OR P.I.S. TO S.C.)
Xn	DISTANCE ALONG A MAIN TANGENT FROM T.S. (OR S.T.) TO OFFSET CHORD POINT N.
Xs	DISTANCE ALONG MAIN TANGENT TO PERPENDICULAR OFFSET TO S.C. (OR C.S.)
Yn	OFFSET FROM CHORD POINT N TO MAIN TANGENT
Ys	PERPENDICULAR OFFSET FROM MAIN TANGENT TO C.S. (OR S.C.)
Θn	CHORD ANGLE, THE ANGLE BETWEEN THE MAIN TANGENT AND CHORD N.
Θ_s	SPIRAL ANGLE, CENTRAL ANGLE OF SPIRAL.
Δ	ANGLE OF INTERSECTION OF TANGENTS OF CIRCULAR CURVE ONLY

<u>MAIN TANGENTS</u> - THOSE LINES TANGENT TO ALIGNMENT AT T.S. AND S.T. WHICH INTERSECT AT P.I.

CURVE WITH SPIRALS AND DEFINITIONS
FIGURE 3.3



1. $D_c = 2\ ARCSIN\ \frac{50}{R}$ $\quad R = \frac{50}{SIN\ D/2}$

2. $\Theta_s = \frac{L_s\ D_c}{200}$

3. $L = \frac{L_s}{10}$

4. $\Theta_n = \frac{3n^2-3n+1}{300}\ \Theta_s \quad n=1,\ldots 10$

5. $X_n = L \sum_{n=1}^{N} COS\ \Theta_n \quad n=1,\ldots 10$

6. $Y_n = L \sum_{n=1}^{N} SIN\ \Theta_n \quad n=1,\ldots 10$

7. $X_s = X_{10}$

8. $Y_s = Y_{10}$

9. $P = Y_s - R(1-COS\ \Theta_s)$

10. $K = X_s - R\ SIN\ \Theta_s$

11. $U = X_s - \frac{Y_s}{TAN\ \Theta_s}$

12. $V = \frac{Y_s}{SIN\ \Theta_s}$

13. $\Delta = I-2\Theta_s$ (*WHEN BOTH SPIRALS ARE OF EQUAL LENGTH*)

14. $T = R\ TAN \frac{\Delta}{2}$

15. $L_c = 100\ \frac{\Delta}{D_c}$

16. $E = R\left(\frac{1}{COS \frac{\Delta}{2}} - 1\right)$

17. $LC = 2R\ SIN \frac{\Delta}{2}$

18. $M = R\left(1-COS \frac{\Delta}{2}\right)$

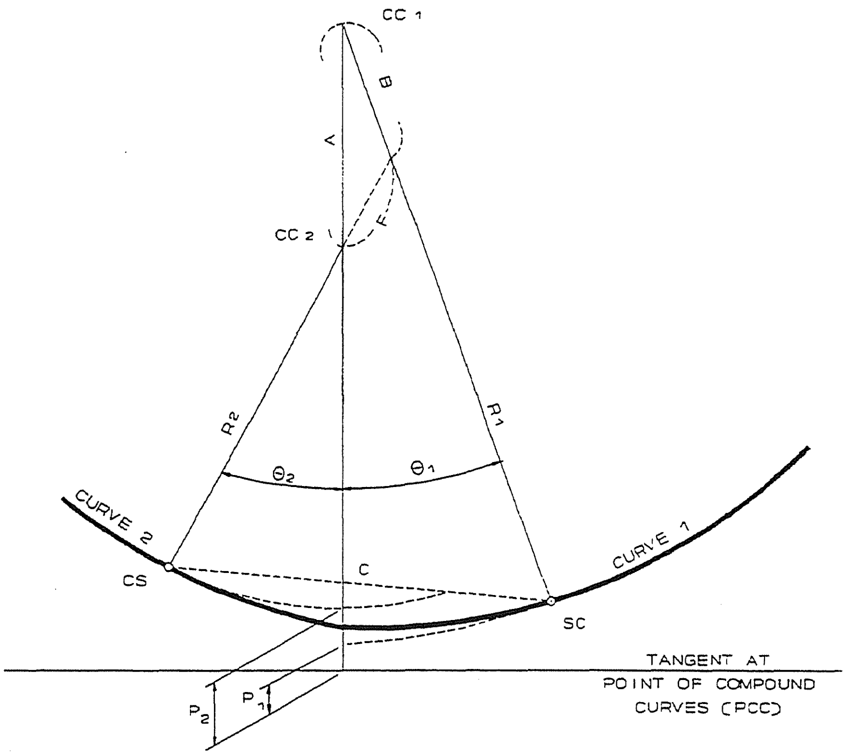
19. $T_s = K+(R+P)\ TAN\ \frac{I}{2}$ (*WHEN BOTH SPIRALS ARE OF EQUAL LENGTH*)

20. $E_s = \frac{T_s - K}{SIN \frac{I}{2}} - R$ (*WHEN BOTH SPIRALS ARE OF EQUAL LENGTH*)

NOTES:

1. Spiral criteria shown is for spirals between tangents and curves
2. For definitions, see Figure 3.3

SPIRAL AND RELATED FORMULAE
FIGURE 3.4



$$\Theta_1 = \frac{Dc_1 \times L_S}{200}$$

$$\Theta_2 = \frac{Dc_2 \times L_S}{200}$$

$$A = (R_1 - R_2) - (P_2 - P_1)$$

$$B = A\ SIN\ \Theta_2 / SIN\ (\Theta_1 + \Theta_2)$$

$$F = A\ SIN\ \Theta_1 / SIN\ (\Theta_1 + \Theta_2)$$

$$C^2 = (R_1 - B)^2 + (R_2 + F)^2 - 2(R_1 - B)(R_2 + F)\ COS(\Theta_1 + \Theta_2)$$

K = RATE OF CHANGE IN DEGREE OF CURVE

$$K = \frac{100\ (Dc_2 - Dc_1)}{LS}$$

$$P_n = Y_s - R(1 - COS\Theta_n)$$

COMPOUNDING SPIRAL
FIGURE 3.5

3. Lateral acceleration increase and decrease induced by the onset and then release of centrifical force caused by unbalanced superelevation when entering and leaving curves should be kept to low values for comfort. This acceleration rate is generally accepted to be 0.03 g/sec.

The first item (rate of superelevation run-in) is generally recommended to be 1-1/4 inches/sec for speeds up to 60 mph, 1-1/6 inches/sec from 60 to 80 mph and 1-1/8 inches/sec from 80 to 100+ mph. This can be expressed as:

Ls=1.17 Ea V (1-1/4"/sec)
Ls=1.26 Ea V (1-1/6"/sec)
Ls=1.30 Ea V (1-1/8"/sec)

The second item is a function of the truck spacing of an 85 foot long car. That dimension is typically 59'-6" for an 85' long car, however 62' is the figure used.

Ls=62 Ea

It has been normal practice to express elevation run-in in terms of inches per 31 foot chord (the usual stringlining interval). A run-in of 1/2 inch per 31' is typically used up to 50 mph and 3/8 inch per 31' from 50 to 80 mph and 1/4 inch per 31' from 80 to 100+ mph.

The following rates provide an expedient way of satisfying the first two items:

Ls=62 Ea Up to 50 mph
Ls=83 Ea 51 to 80 mph
Ls=124 Ea 81 to 110 mph

The third element - lateral acceleration increase - is expressed by the formula:

Ls=1.63 EuV (produces a lateral acceleration of 0.03g/sec)

In "tight" situations a shorter spiral is permitted:

Ls=1.22 EuV (produces a lateral acceleration of 0.04g/sec)

Summarizing: the minimum spiral length should be determined by using the longer result of the two following criteria:

1. $Ls=62EaV \leq 50$ mph
   $Ls=83Ea\ 50 < V \geq 80$ mph
   $Ls=124Ea\ 80 < V \geq 110$ mph — Formula 3.7

2. Ls=1.63 EuV (whenever possible)
   Ls=1.22 EuV (in "tight" situations) — Formula 3.8

The minimum length of spiral shall be 100 feet in mainline track. A spiral of 62 feet is permitted in secondary track as a curve easement and when superelevation is not over one inch.

g. Gauge Widening in Curves

The MBTA does not normally widen track gauge in curves on commuter rail. However, in certain instances it may be beneficial to consider widening gauge 1/8" per degree of curve in excess of 10 degrees up to a maximum of 4'-9 1/8". This should be discussed with Railroad Operations on a site specific basis.

5. Vertical Alignment

a. General

Railroads are very sensitive to gradient due to very low power to weight ratios and frictional limitations imposed by the adhesion of steel to steel. For these reasons, as well as general safety and economy, grades must be kept to a minimum. Vertical curves connecting changes in gradient must be gradual, long enough to prevent coupler slack action run-in and run-out in long freight trains from generating forces great enough to break the couplers and separate the train or buckle the train. Passenger trains are normally not subject to slack-action problems. Operating at high speed, vertical curves need only to be long enough to prevent passenger discomfort caused by relatively small vertical g forces. However, good design dictates that more conservative values be used that will fit the available space, especially if through freight service is operated.

b. Maximum Grade

. Maximum Grade[4]	0.70% Preferred Max. 1.50% Absolute Max.
. Maximum Grade at Stations or any locations where trains may stop on a regular basis	0.50% Preferred Max. 0.75% Absolute Max.
. Maximum Grade at Maintenance Facilities & Unattended Storage Yards	0.00% Preferred Max. 0.25% Absolute Max.[5]

The ruling or maximum grades on a section of railroad must be compensated for the increased resistance caused by curvature by

[4]Under very special conditions a grade up to 3.00% is permissible with permission of the Chief Engineering Officer

[5]If steeper grades are required - derails and other protection from rolling should be considered.

reducing the grade through the curve by 0.04 percent per degree of curvature.

c. Minimum Length of Constant Grade

Frequent changes in gradient are to be avoided. Eliminate grade changes wherever physically and economically possible.

Minimum Length of Tangent Grade	200 Feet
Absolute Min. Length of Tangent Grade	75 Feet

d. Vertical Curve Length

The only generally recognized criteria used by railroads for 100 years in determining the length and corresponding rate of change of a vertical curve is in the AREA, Manual Chapter 5, Part 3, Section 13 which gives the required rate of change as 0.05 feet per 100' station in sags and 0.10 feet per station in summits. Up to twice that rate is possible in track of "lesser importance". This criteria is currently under review by AREA Committee 5 and it appears that a considerable reduction in the required vertical curve length recommended by AREA is forthcoming.

Experience has shown that application of the current AREA criteria in the MBTA's Commuter Rail Territory will often require vertical curves far too long to fit either existing or new conditions. The current AREA criteria's very low rate of grade change is to control the "accordion effect" that occurs in long freight trains which generally have about one foot of slack between each car. This slack is needed to start heavy trains as it would be impossible to start the entire train all at once. This slack creates adverse train handling conditions and high buffing and draft forces on undulating profiles with short vertical curves. These forces can contribute to breaking a train apart or buckling the cars. Considering only passenger equipment, which has little slack between cars and fewer units than a long freight, much shorter vertical curves would not affect train buffing and draft forces, the primary concern being passenger comfort. Even very slight gravitational ("g") forces in a vertical plane produce a "queasy" feeling in many passengers.

The following criteria is suggested in determining the minimum length of vertical curve in main track. This criteria is more conservative than the revised AREA criteria currently under consideration.

$L=0.05\ (G_1-G_2)V^2$ Formula 3.9

Where:

L = Length of vertical curve in feet.
G_1-G_2 = Net or algebraic difference of the grade change in percent.
V = Velocity in mph.

AREA criteria currently under consideration:

$L = 0.036\ (G_1-G_2)V^2$

The rate of change in grade per 100 feet is the way the "sharpness" of vertical curves are usually expressed.

$$r=\frac{G_1-G_2}{L}x100$$

Formula 3.10

Where:

r=rate of change in %/100'

Following is a summary of various vertical curve criteria:

Current AREA Criteria	Rate of Change %/100'
(Double rates if necessary)	0.05% Sags 0.10% Summits

Northeast Corridor (Amtrak) criteria - 1970's

0.30%
Summits & Sags

"Suggested" MBTA criteria:

$$r = \frac{2000}{V^2}$$

Formula 3.11

(r not to exceed 0.80%/100')

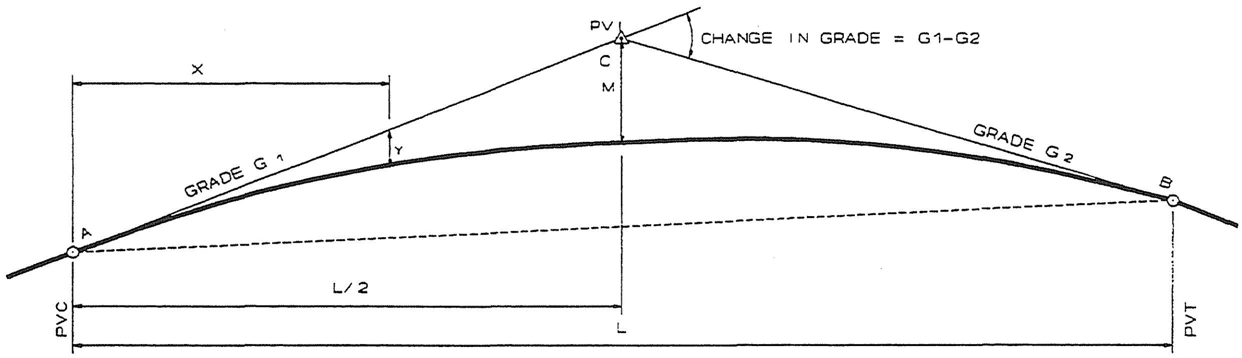
AREA Revision Under Consideration

$$r = \frac{2800}{V^2}$$

Formula 3.12

(r not to exceed 1.12%/100')

Unless otherwise directed, use Formulae 3.9 and 3.11, limiting rate of change to 0.80% per 100 feet. (Also see part "g" following).



Vertical Curves

Figure 3.6

Vertical curves shall be parabolic and have the following mathematical characteristics:

$$M = \frac{L/100\ (G_1 - G_2)}{8}$$

Formula 3.13

$$Y = \left(\frac{X}{L/2}\right)^2 x\ M$$

X cannot exceed L/2. Leftside of curve, use point A as origin for X. Right side of curve, use point B as origin for X.

Formula 3.14

$$L = \frac{G_1 - G_2}{r} x\ 100$$

Formula 3.15

$$Elevation\ of\ V.C.\ at\ any\ point = \left(\frac{r}{2}\right)\frac{X^2}{100} + G_1\frac{X}{100} + PVC\ Elev.$$

Formula 3.16

Where:

- M = Mid ordinate of vertical curve at PVI
- Y = Offset from tangent to vertical curve at any point on curve in feet
- X = Any distance from PVC in feet
- L = Length of vertical curve in feet
- G_1 = Grade at PVC, in %
- G_2 = Grade at PVT, in %
- r = Rate of change in grade in %/100'

e. Vertical Curves Within Turnouts

It is good practice to avoid vertical curves in turnouts. When this is not possible, vertical curves may be introduced through turnouts with the following restrictions:

1. Keep vertical curves flat enough so that calculated vertical mid ordinate through the entire length of frog is 1/32 inch or less.

   This results in the following maximum permissible rates of change: Halve these rates in summit curves in switch area of turnout. This is in deference to concern that the switch points be forced upward - even slightly.

		Sag. Curves	Summit Curves
No. 8 T.O.	-	0.50%/Sta.	0.25%/Sta.
No. 10 T.O.	-	0.35%/Sta.	0.18%/Sta.
No. 15 T.O.	-	0.25%/Sta.	0.13%/Sta.
No. 20 T.O.	-	0.15%/Sta.	0.08%/Sta.

2. In yards or low speed areas where higher rates of change and shorter vertical curves may be necessary, vertical curves may be confined to the closure area of the turnout, the area between the switch and frog.

f. Minimum Length of Vertical Curve

Vertical curves shall not be less than 100 feet long on main lines. Curves with a calculated mid-ordinate less than 1/4 inch (0.021 feet) are too inconsequential to lay out in the field and maintain. Such vertical curves should be avoided by either lengthening the curve or using a vertical angle point when the algebraic difference of the grades is 0.10% or less.

Within yards and low speed areas such as servicing areas and approaches to stub end terminals, vertical curves may be shorter than 100 feet and have rates of change in excess of 0.80%/100 feet, but never so short as to produce a vertical curve sharper than an equivalent radius[6] of 4,000 feet as determined by the formula:

$$Equivalent\ Radius^{6} = \frac{L}{G_1 - G_2} \times 100$$

Formula 3.17

Where:

L = Length of vertical curve in feet
$G_1 - G_2$ = Difference in connected grades in percent

g. Combined Horizontal and Vertical Curvature

Another consideration in the design of both horizontal and vertical curves is the combined effect of "g" forces resulting when both horizontal and vertical curves are combined. The horizontal forces are discussed in Section 4 of this chapter and are related to lateral acceleration forces developed through the spiral and centrifical force from cant deficiency. Generally, the combined effect is not significant except when one or the other or both are at or near their maximum allowable value. In either case, the following check should be made and the design adjusted as required.

- In locations where horizontal curves are the controlling factor the rate of change of grade (r) which may be allowed to act concurrently shall be determined by the following formula:

$$r = \frac{2000}{V^2}(1-0.33Eu)(1-0.018Ee)$$

Formula 3.18

Where:

r = Rate of change of grade in percent/100' Station.
v = Velocity in mph.
Eu = Unbalanced Elevation of Horizontal Curve
Ee = Calculated Elevation for Equilibrium.
D = Curvature in Degrees

- In locations where vertical curves are the controlling

[6]Note that "equivalent radius" formula calculates a circular curve, not parabolic as an actual vertical curve is. Parabolic curve is flatter on both ends and somewhat sharper opposite the PVI than equivalent radius curve. Formula 3.17 provides an expedient way of determining relative sharpness of vertical curves.

factor, the unbalanced superelevation Eu allowed to act concurrently shall be determined by the following formula:

$$Eu = (3.00)\left(1 - \frac{rV^2}{2000(1-0.0000126V^2D)}\right)$$

Formula 3.19

Note: If a negative number is produced by above formula, either *V* or *r* must be reduced until a positive number is obtained.

This combined effect is not an issue with current AREA vertical curve criteria. Whenever the "suggested" criteria or "currently under consideration" AREA criteria is used, the combined horizontal/vertical effect should be investigated, and adjusted accordingly per above formulae.

CHAPTER 4
TRACKWORK CRITERIA

A. General

All track materials and special trackwork shall conform to the current MBTA "BOOK OF STANDARD PLANS - TRACK AND ROADWAY" and the "MATERIAL SPECIFICATIONS" which are referenced as appropriate.

All new installations or track renewals shall be with resilient fasteners on either timber or concrete ties as directed by the Chief Engineering Officer.

Ballasted track construction will be used at all locations except on bridges, viaducts, subways and tunnels, where direct fixation track construction may be used when directed by the Chief Engineering Officer.

New open deck bridges shall not be permitted except on a temporary basis. Existing open deck bridges shall be rebuilt to ballasted deck or direct fixation wherever possible.

Main track subgrade shall be designed to the dimensional requirements of Standard Plans 1000 and 1002 and as defined in Chapter 5 of this Manual.

B. Rail

Reference Material Specifications No. 9233 & 9236.
Reference Standard Plans - 1300 & 1302.

The standard MBTA rail section for new construction is 132 RE continuous welded rail. 115 RE CWR may be used in certain applications only when directed by the Chief Engineering Officer. Suitable, available fit relay rail sections, either CWR or bolted, may be used when replacing secondary tracks as and when approved by Railroad Operations.

Standard control cooled rail shall be used on all main line track with curves up to and including 2°-00'. Fully heat treated rail shall be used on all main line curves where curvature is in excess of 2°-00'. Carry heat treated rail through spirals and through tangents between adjacent curves over 2°-00' wherever the tangent is less than 300 feet long.

Fully heat treated rail shall not be used in curves outside of main lines, unless specifically directed.

Fully heat treated rail shall be used within all turnouts and other special trackwork units.

All rail shall be weldable by either electric flash-butt or thermite process.

C. Timber Cross Ties

Reference Standard Plans - 1100, 1104, 1106 and 1108
Reference Material Specification - 9209

Transition ties shall be used in areas of changing track modulus as shown on Standard Plan 1108.

Timber cross ties shall be spaced at 19-1/2 inches except use 18 inches within grade crossings. Within full depth rubber crossings, 9'-0" long ties shall be used.

Material specifications, seasoning and other requirements to be as specified in No. 9209.

D. **Concrete Ties**

Reference Standard Plan - 1120

Concrete tie are increasingly being used on the MBTA system. Use on a specific route/project shall be determined by the Chief Engineering Officer. Standard tie spacing for concrete ties is 24".

E. **Subballast**

Reference Standard Plans - 1000 & 1002
Reference Material Specification - 9251

Subballast shall be used on all new track construction or major reconstruction when the underlying material is not clean, free draining, well graded, granular material. The typical section shown on the standard plans should be considered adequate only for fair to moderately good subgrade conditions. If there is a history or direct evidence of difficulty in maintaining good surface and line at an existing track location or, if on new location, test borings indicate any condition other than good, granular material; the designer should recommend measures to provide adequate support for the track structure, including a change from the 8 inch depth of sub-ballast shown on the typical sections. Additional discussion of subgrade treatments is found in Chapter 5, Roadway Criteria.

F. **Ballast**

Reference Standard Plan - 1000 & 1002
Reference Material Specification - 9248

Crushed stone ballast per the referenced material specification shall be used on all trackwork. 12 inches depth under bottom of tie is the mainline standard. Ballasted deck bridges should also have 12 inches of ballast under the tie with 8 inches minimum when conditions warrant and when approved by the Chief Engineering Officer.

Maintenance of adequate ballast shoulders of 18" beyond the end of tie and good ballast compaction is essential to track stability and to control track buckling. All projects involving track reconstruction or realignment of track must provide construction specifications and phasing plans which both enforce and enable the proper preparation and compaction of the ballast section prior to opening track to service.

G. Tie Plates

Reference Standard Plans 1220, 1222, 1224 & 1225
Reference Material Specifications - 9269 & 9272

Tie Plates shall be used on all tracks regardless of use.

The MBTA standard for new timber tie track construction is resilient fastener plates with lock spikes. Within turnouts - either with tropical hardwood or treated oak - plates shall be fastened with screw spikes.

Cut spike tie plates shall not be used on new construction or track renewal projects unless specifically directed by the Chief Engineering Officer.

H. Spiking

Reference Standard Plans - 1104 & 1230
Reference Material Specifications - 9274 & 9275

Spiking patterns within standard timber and ballasted track construction shall be as per Standard Plan 1104. Within turnouts, screw spikes shall be used throughout as follows:

Gage Plates	-	6 screw spikes per plate
Shoulder Slide Plates	-	4 screw spikes per plate
Adjustable Brace Slide Plates	-	4 screw spikes per plate
Heel Plates	-	4 screw spikes per tie per plate.
Frog Tie Plates/Self Aligning Shoulder Plates	-	2 screw spikes per plate
All Standard Plates within Turnout	-	4 screw spikes per plate
Guard Rail	-	4 screw spikes per tie per guard plus 2 drive screw spikes per rail seat.

Holes for lock spikes shall be pre-drilled 9/16" dia. x 6" deep and 11/16" dia. x 6" deep for screw spikes. Holes not used, shall be plugged with treated or cedar tie plugs. Within turnouts using tropical hardwoods, pre-drill spike holes at gauge side of both switch points to allow spiking switch out of service with a cut spike. Plug such holes with cork tie plugs.

I. Rail Anchoring

Reference Standard Plan - 1232
Reference Material Specifications - 9239 & 9242

Anchoring patterns shown on Plan 1232 are for cut spike fastened tracks only. Track using the standard resilient fasteners does not require additional anchoring unless specified by the Chief Engineering Officer.

J. Resilient Fasteners

Reference Material Specification - 9245

Resilient fasteners and matching tie plates shall be used on all new installations and track renewal projects. In addtion to the standard plate used on timber ties and rag stem inserts, tie pads and insulators used on concrete ties, there are other systems to be considered in certain applications. These applications include direct fixation slabs and possibly open deck bridges. Impact attenuating, composite tie plates with provision for holding the rial with the standard resilient fastener are a system to be considered where appropriate.

K. Special Trackwork

Reference Standard Plans 2000 to 2499
Reference Standard Specifications - 9278, 9281, 9284 & 9287

Unless otherwise directed, use "floating heel block" design turnouts as detailed on the Standard Plans.

No. 20 turnouts shall be used for mainline crossovers and junctions of diverging mainlines wherever there is sufficient room. Allowable design speed for the Standard No. 20 turnout is 45 mph through the curved side of turnout. No. 20 equilateral turnouts may be used at ends of double track and such locations where they may be used to advantage. Allowable design speed through both legs of a No. 20 equilateral turnout is 65 mph (2.75 inches unbalanced elev.). With authorization of the Chief Engineering Officer, a speed of 70 mph may be used (3 inches unbalanced elev.).

No. 15 turnouts shall be used for mainline crossovers where there is insufficient room for No. 20's or where the design speed is limited to 30 mph or less because of other civil restrictions. No. 15 turnouts shall also be used to connect secondary lines and primary yard leads to the main line. Allowable design speed for the standard No. 15 turnout is 30 mph through the curved side of the turnout. No. 15 equilateral turnouts may be used where feasible. Allowable design speed through both legs of a number 15 equilateral is 50 mph (2.75 inches unbalanced elev.)

No. 10 turnouts shall be used for all sidetrack connections to the main line and all yard leads and yard tracks wherever possible. The No. 10 turnout is the preferred minimum size turnout for any commuter rail application. The maximum allowable design speed through the curved side of the standard No. 10 turnout is 20 mph, however, 15 mph is the preferred maximum for safety and maintenance considerations.

No. 8 turnouts shall be used only within yards and servicing facilities, only when it is physically impractical to fit No. 10's and only with permission of the Chief Engineering Officer. The maximum allowable design speed through the curved side of the Standard No. 8 turnout is 15 mph, however, 10 mph is the preferred maximum for safety and maintenance considerations.

Turnouts shall have 5 inch hot mix asphalt underlayment installed per MBTA Standard Plan No. 1030 and as indicated in Chapter 6, Section A4.

L. Switch Stands

Reference Standard Plans - 3020, 3023 & 3030
Reference Material Specification - 9257

Manual switch stands on mainline turnouts shall be intermediate height-model Racor 17D or New Century 50-B with operating rod sufficient to provide required side clearance and mounted on 16'-0" long headblock timbers. Electric lock is required on any installation in signal territory. Racor moded 17D or New Century 50-B shall also be used in yards where there is sufficient room for the 16'-0" headblocks.

Low stands - Racor model 36D or New Century Model 50A - shall only be used in yards and terminals where there is limited side clearance. Do not use in main track without specific authorization of the Chief Engineering Officer.

The Racor Style 22 is a "run through" type mechanism allowing automatic operation of trailing point movements through either leg of the turnout regardless of switch position. Use only in yards and servicing areas as directed by the Chief Engineering Officer.

All switch stands shall be furnished with the MBTA Standard Red/Green switch stand target unless specifically directed otherwise.

M. Bumping Posts

Reference Standard Plan - 3010
Reference Standard Specification - 9206

A steel, model "WA" bumping post per referenced standards shall be installed on all stub end tracks subject to operation (either revenue or non-revenue) by commuter rail equipment. Tracks used only for dead storage or work equipment storage may have other types of bunters. End of line stub end terminals will have energy absorbing impact attenuators capable of disapating energy equivalent to a nine car & one locomotive consist travelling at 10 mph. This requirement may be waived by the Chief Engineering Officer at locations where there is insufficient room and/or there are no buildings or structures in the path of a train which overshoots the end of track.

N. Emergency Guard Rails

Reference Standard Plans - 3060 & 3062
Reference Material Specification - None

1. Bridges

   Guard rails (double rail) shall be used on all through girder and through truss bridges regardless of the span length and on any bridge when the structure length between abutment backwalls is over 40 feet.

Resiliently fastened guard rail as detailed on Standard Plan 3062 shall be used on all ballasted deck bridges and approaches and ballasted approaches to open deck bridges to aid in removal and reinstallation during surfacing operations.

The 39'-0" end approach section shall be lengthened at design speeds in excess of 60 mph as follows:

Length of guard rail end approach = 0.74V

V = design speed in mph.

2. Other hazardous locations

Single rail guard rails and/or crash walls may be used at such other locations where a derailment would cause significant structural damage to adjacent, vulnerable structures or to the railroad's equipment. Examples where such installations may be considered include:

a. Adjacent to steep drop-offs to water or where derailment would cause significant damage from the length of potential fall.

b. Adjacent to near-by high voltage structures.

c. Adjacent to any supporting column of an overhead bridge or structure which if struck by a train would very likely cause catastrophic failure of the structure. A crash wall may be appropriate in such cases. See Section "N" below.

O. Crash Walls

When tracks are immediately adjacent to supports for bridges, buildings and air rights development over the right-of-way, consideration must be given to protecting supporting structures from impact of a train in event of derailment.

The impact design loading for crash walls shall be as follows:

- Train weight, 1,666,000 lbs consisting of locomotive at 280,000 lbs and nine coaches-fully loaded at 154,000 lbs each.
- The angle of attack (measured from tangent to the track) shall be ten degrees.
- The impact speed shall be authorized track speed at the location plus a 50 percent safety factor.
- Place piers and abutments at such an angle that a square hit is not possible. Provide "wing" or angled section to deflect train away from blunt ends.

Refer to AREA Manual Chapter 8 for additional considerations with respect to crash walls.

P. Derails

Reference Standard Plans - 3000, 3004, 3006 & 3007
Reference Material Specifications - 9215

Split switch derails shall be used on all side tracks which connect to the main line with a descending grade.

Where less positive protection is required, sliding block derails may be used as directed by the Chief Engineering Officer.

Hinged block type derails shall be used only on engine house ready and storage tracks when power operated derails and interlocked blue flag protection is not available.

Derails used to protect main lines in signal territory must include circuit controllers, insulated joints and connections to signal system. If necessary, provide for sign installation - "Siding not to be used to clear main line".

CHAPTER 5
ROADWAY CRITERIA

A. SUBGRADE

1. General

The trackbed cross section will be designed to the dimensional requirements of Standard Plans 1000 & 1002. The minimum subgrade cross slope should be 1/4 inch per foot to facilitate the removal of water from under the track structure. Final subgrade elevation in either cuts or fills shall be set to allow placement of design trackbed section at design profile grade. The section shown on the Standard Plans will be used only when existing subgrade conditions are satisfactory. Design of trackbed section in poor subgrades and design of additional measures to provide a stable and maintainable track structure shall be responsibility of the designer.

At existing track locations, when track renewal is planned, the designer must investigate the following to determine the need for additional subgrade preparation.

a. Inspect track structure and note any areas with obvious problems such as muddy, fouled or pumping track, poor surface and alignment, wet conditions, instability in slopes supporting or above the trackbed, gullying or potential washouts, ditches and pipes filled or partially filled with silt or clay and trees or other vegetation which could undermine track bed if dislodged.

b. Interview maintenance personnel to determine any locations that are difficult to maintain or have a known history of stability or drainage problems.

c. Recommend and observe cross track test pits at any locations suspected of poor subgrade conditions.

d. Recommend and observe a soils boring program as required for any locations where a major subgrade problem is suspected.

At new track alignment locations, test borings, test pits or other suitable means should be included as a part of the design process to determine the nature and depth of soil strata that will be supporting and draining the track bed.

Hot mix asphalt underlayment shall be installed under all new turnouts and grade crossings per Standard Plans. Composition of mix shall be as indicated in Part 4 of this heading of "Subgrade".

2. Fill Sections

New fill foundations must be explored and then designed to prevent failure of the subsoil or excessive settlement. The exploration program should be developed and carried out as detailed in the AREA Manual - Chapter 1, Part 1.1. Use of sand or wick drains and surcharging may be necessary to consolidate compressive soils prior to final construction.

When widening existing fills, benching the existing slope and placing new fill in compacted lifts not over two to three feet in depth must be detailed in the plans and specifications. Simply dumping material down the slope is not permissible except for shallow fills (less than 5 feet high) or when dumping stone rip-rap for erosion control. Existing culverts, including equalizing culverts, should be investigated, protected or extended as necessary prior to widening fill sections.

3. Cut Sections

Cut sections pose particular problems related to drainage and soil stability. Within existing cuts it is imperative that the side ditches be cleaned, enlarged and lowered to a depth not less than four foot six inches below top of rail. Ditches should also be graded to drain. Where ditches of sufficient depth and cross section are not possible, underdrains and closed drainage systems must be provided.

Visually inspect all cut slopes for signs of instability and excessive moisture which could lead to instability. If widening of cut slopes is indicated, investigate stability of slope and recommend construction methods and materials necessary to maintain slope stability. Top of cuts must be inspected for water retention or ponding areas caused by low points, beaver dams, etc. and methods to remove water away from the cut detailed.

The track bed within existing cuts often is composed of non-granular material which fouls ballast quickly and does not allow water to drain. This condition should be remedied as much as possible during track renewal projects. Excavation of unsuitable material, additional underdrains, placement of hot mix asphalt underlayment, geotextiles, are some of the methods that may be considered in various combinations to improve roadbed stability and lower the cost of maintenance.

4. Hot Mix Asphalt Underlayment

Hot mix asphalt underlayment (HMA) shall be installed as subgrade under roadway crossings and turnouts as shown on Standard Plans 1030, 3100, 3106 and 3108. HMA may also be installed under normal track where subgrade conditions are poor.

The recommended job mix formula for HMA underlayment shall be as specified in MBTA Standard Specification 02513, Table 02513-c supplemented by the following table:

Standard Sieves	Underlayment Mix (HMA)
2"	
1-1/2"	100
1"	90 - 100
3/4"	
1/2"	56 - 80
3/8"	
No. 4	29 - 59
8	19 - 45
16	
30	
50	5 - 17
100	
200	1 - 7
Bitumen	3 - 9

Table 5.1

HMA mix shall be installed in one course using sufficient material to provide a compacted mat 5 inches thick.

B. DRAINAGE

1. General

Drainage in stations and landscapped areas is also discussed in Section II, Chapter 6, Landscapping.

Good drainage and it's maintenance are absolutely essential to the safe and economical operation of a railroad. Safety is of paramount concern and certain drainage related problems can result in failure of either the roadbed or structures. During the design of both new facilities and reconstruction of existing, it is essential that close attention be paid to roadbed drainage, cross culverts and structures over water courses.

In designing for removal of surface and groundwater from the trackbed section, the following general conditions shall apply:

- Existing drainage patterns shall be maintained wherever possible.
- To the maximum extent possible, surface and subsurface drainage of the roadbed should be handled by a system of gravity - flowing longitudinal ditches that feed into catch basins, transverse ditches or streams. Ditches should be designed to handle anticipated flows without silting or scouring.
- Low points in ditches should be avoided but when required, positive means of removal of water must be supplied at the low points. Those means may include tieing into municipal storm

sewer systems by use of catch basins, leaching basins or groundwater recharge ponds (if permitted by subsurface geology and local ordinances), transverse ditches, culverts and natural or artificial watercourses.

- When absolutely necessary, where gravity outfalls are impractical, pumps may be considered to ensure positive drainage. In such instances, the design flow shall include an allowance for groundwater infiltration as appropriate.

- Drainage systems that discharge to an existing wetland or are within 100 feet of a wetland must comply with the rules and regulations of the Wetlands Protection Act and local bylaws. The local conservation commission must be contacted and informed of project details and probable wetland impacts. The commissions issue "Orders of Conditions" which should be incorporated into the design. Conservation commissions may also require an EIR or EIS.

- Drainage systems connecting to an existing storm drain must also comply with the Wetlands Protection Act if it discharges to a wetland. Approval is also required from the drainage system owner. The owner should be contacted early in the design process to determine their specific requirements.

2. Mainline Trackbed Drainage Criteria

a. Do not drain subgrade from one track across or towards an adjacent track. The area occupied by each track should drain to its own ditch or subdrain.

b. Do not drain areas from beyond the track bed through the track structure. Typically, a ditch or subdrain should lie between the track and the adjacent ground area to intercept fines from an adjacent slope which would foul the ballast.

c. At locations where there will be a future track, crown the subgrade on the centerline between the tracks. Where practical, keep the ditch or subdrain on the field side of the future track <u>clear</u> of the future track so it doesn't have to be changed later.

d. Typical drainage pattern for double track roadbed section is from a crown between the tracks to a ditch or subdrain on the field side of the tracks. When double track is between walls a single subdrain may be located between the tracks. "Walls" may include a retained cut or a retained fill where the walls are too close to the tracks to allow ditches or subdrains.

e. Typical drainage pattern for single track is a crown line on the centerline of the track to ditches or subdrains on each side. When a single track is between walls, the ditch or subdrain may be located on one side and the subgrade sloped in one direction to the ditch or underdrain.

f. At <u>side</u> platform stations, the platform should drain away from the track. A subdrain should be placed between the track and the platform to drain half of the track bed, and any water from platform canopies or areas behind the platform that are not handled by other site drainage. If there is a wall on the opposite side of the track from the platform, the entire track area should drain to the subdrain lying between the track and platform.

g. At <u>island</u> platforms, the platform should drain into the track area to avoid ponding at the center of the platform. Subdrains should be placed between track and platform so that track drainage is handled the same way as at a side platform station.

3. Design Considerations

a. <u>Design Storm Computation</u>

1. Rational Equation:

Design flows for local drainage shall be computed by the Rational Equation:

$$Q = CIA \qquad \text{Formula 5.1}$$

where:

Q = Runoff quantity, in cfs
C = Coefficient of Runoff
I = Rainfall intensity, inches/hour
A = Drainage area, in acres

2. Design Frequency:

The track drainage system including all open track bed areas exposed to direct precipitation shall be designed to accommodate the peak flows produced by the 50 year rainfall event. All runoff shall be fully contained within the drainage system, no surcharge will be allowed for undepressed catch basins and the capacity of all pipes, ditches, etc. shall equal or exceed the 50 year runoff. In addition, the storm drainage system shall be designed to maintain a maximum water level 18" below top of tie during the 100 year rainfall event.

The drainage systems for non mainline track areas such as parking lots, station accessways and layover facilities shall be designed to accommodate flows produced by a 10-year storm unless otherwise specified by regulatory authorities. The capacity of the receiving storm-drain system shall be investigated to determine if there is adequate capacity to comply with this requirement.

3. Time of Concentration:

The minimum time of concentration used shall be 5 minutes.

Time of Concentration shall be determined by the equation:

$$Tc = (0.0078\ K\ L^{0.77})/S^{0.385}$$ [1] Formula 5.2

Where:

Tc = Time of Concentration, minutes
L = Maximum length of Travel from most remote point in drainage basin to outlet, feet
S = Average slope (feet/foot) = H/L
H = Difference in elevation between most remote point and drainage outlet
K = 1.0 for natural basins with well defined channels, for overland flow on bare earth, and for mowed grass roadway channels.
K = 2.0 for overland flow over grass surfaces
K = 0.4 for overland flow, concrete or asphalt surfaces
K = 0.2 for concrete channel

For areas with abrupt changes in topography or surface, the calculation shall be done for each segment and the total time of concentration shall be arrived at by adding the computed values for each segment.

4. Rainfall Intensity:

Rainfall intensity shall be obtained for specific design storm frequencies and times of concentration by using the Rainfall intensity-Duration-Frequency Curve for Boston, Massachusetts, as found in Technical Paper No. 25 of the U.S. Department of Commerce, Weather Bureau, December, 1966 on Rainfall Intensity-Duration-Frequency Curves.

[1] This equation is based on a study by Z.P. Kirpich (1940)

5. Coefficient of Runoff:

Values of runoff coefficient for use in the Rational equation (Q = CIA) shall be as defined in ASCE Manual No. 37, Design and Construction of Sanitary and Storm Sewers or Table 1 on Page 53 of Design of Roadside Drainage Channels, Hydraulic Design Series No. 4, U.S. Department of Commerce, Bureau of Public Roads, May, 1965.

b. Ditches

1. Geometric Requirements:

Ditches shall be of trapezoidal section, with a minimum depth of 18 inches and a minimum bottom width of 2 feet. They shall have a minimum gradient of 0.25% and a maximum design velocity of 2 feet/second for unlined channels. Water levels in ditches at design flow rates shall be at least 3 feet below the top of rail.

2. Flow Computation:

Drainage velocities and capacities shall be computed by use of Manning's Equation:

$$V = \frac{1.486}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$$ Formula 5.3

where:

V = Velocity, ft/sec
n = Manning's Coefficient of Roughness
R = Hydraulic Radius, feet
= area/wetted perimeter
S = Slope, feet/foot

Manning's "n" values shall be determined from ASCE Manual No. 37 or Table 2, Page 53-54 of Design of Roadside Drainage Channels, Hydraulic Design Series No. 4, U.S. Department of Commerce, Bureau of Public Roads, May, 1965.

3. Gutter Flows and Inlets

Where curbing is proposed along roadways, gutter flows and gutter inlets shall be designed in accordance with the U.S. DOT - Federal Highway Administration Hydraulic Engineering Circular No. 12, Drainage of Highway Pavements, March, 1984. At least 10' of the travel way shall be free of gutter flows.

c. STORM DRAINS

1. Material, Cover and Structural Requirements:

Either reinforced concrete or asphalt-coated corrugated metal pipes shall be used. Minimum diameter pipe size shall be 12 inches. Culverts shall have a minimum diameter of 18 inches.

Pipes under railroad tracks shall be designed for Cooper E80 loading and shall have a minimum cover of 2 feet from bottom of tie to top of pipe.

Pipes under highways, parking lots and driveways shall be designed for H20 loading. They shall have a minimum cover of 1 foot from top of pavement to top of pipe.

2. Flow:

Manning's Equation, as defined in the ditch section and as shown below, shall be used.

$$Q = \frac{0.463 D^{\frac{8}{3}}}{n} S^{\frac{1}{2}}$$ Formula 5.4

Where:

full capacity
- S = Pipe slope feet/foot)
- Q = Flow (cubic feet per second)
- n = Manning's roughness coefficient (Feet $^{1/6}$)
- D = Pipe diameter (feet)

Pipes shall be designed for uniform flow, with a preferred velocity in the range of 3 to 9 feet per second. Maximum headwater for culverts shall be 1-1/2 times the pipe diameter. At design flows, water shall not back up at the pipe entrance to an elevation higher than six inches below top of railroad subgrade or roadway pavement.

No pipe shall be designed with a size smaller than the next pipe upstream.

3. Manholes:

Manholes shall be installed at all pipe junctions and grade or alignment change points. Maximum pipe length between manholes shall be 300 feet.

4. Catch Basins:

Catch basins shall be installed at all ground or pavement surface low points and all grades not drained by ditches or other means. The maximum interval between catch basins shall be 300 feet.

Catch basins shall have a 30 inch deep sump and a cast iron hood, frame and grate. Bicycle safe grates shall be used in station access roads, parking lots, and other areas where bicycle traffic is possible. Design of catch basins, cover and general arrangement must be done in a way to allow cleanout of sump with a clam shell bucket.

If leaching catch basins are used, they shall have a minimum of 12 inches of 2 inch diameter crushed stone placed around the outside. Their design shall be based on "perc" test data taken at the basin site. The design leaching capacity of the basin shall be increased to allow for partial blockage by debris and fine sediment.

d. <u>Perforated Pipe Drains</u>

Where ditches are not permitted by space, where additional flow capacity is needed, or where required to reduce underground hydrostatic pressure, perforated pipe drains shall be used. The pipes shall be perforated bituminous coated galvanized corrugated metal or perforated PVC. Minimum size shall be eight inch diameter in grade crossing installations and 12 inch diameter when used in place of ditches.

Where perforated pipes are used only as underdrains to reduce underground hydrostatic pressure and control groundwater elevation, the perforations shall face down. Where perforated pipes are being used to carry water with groundwater control a secondary requirement, the pipe shall be laid with perforations up. Use of perforated pipes to carry water shall be limited to the upper runs of a drainage system and checked to ascertain that they will not be subject to surcharging. Separate carrier pipes, for storm drainage shall be used in combination with perforated pipe underdrains in most cases.

Filters shall be used with all perforated pipe drains to prevent accumulation of sediment in the pipes. Filter material may consist of suitably graded crushed stone, synthetic filter material, or a combination thereof. The filter envelope shall extend a minimum of eight inches beyond the outside diameter of the pipe.

Perforated pipe drains shall discharge to a gravity drainage system or pump station. Care shall be taken to ensure that perforated pipe drains are not blocked by high water levels at the outlet. Relatively impervious materials such as loam or topsoil shall not be installed vertically above these pipe drains.

MHWA design gas traps or oil-water separators shall be provided in areas where runoff is subject to contamination with petroleum products and where required by regulatory authorities.

e. Recharge and Detention Ponds

1. Detention Ponds

Detention Ponds shall be designed when necessary to limit peak outflow from the design storm to an acceptable value. When these detention ponds discharge into a wetland a review by the local conservation commission is required. The detention ponds shall include provisions for removing sediment, if warranted. Each pond must be evaluated individually to determine if enough sediment will enter to justify a sedimentation basin.

Ponds shall be provided with an emergency overflow section to allow the safe discharge of water in excess of the design storm. Multiple outlets may be used when needed to accommodate maximum and minimum design storms. Required storage volume shall be determined using inflow and outflow hydrographs based on the Soil Conservation Service criteria or another approved method.

2. Recharge Basins

Recharge basins shall be designed with both a sedimentation basin section and a recharge basin section. The sedimentation basin shall be designed to remove all sediment that might plug the pores and reduce the basin's infiltration capacity.

The recharge basin section shall be designed to allow infiltration of the design storm within a reasonable period of time. The recharge basin capacity may be supplemented using recharge wells or trenches if necessary. The infiltration capacity shall be based on percolation field tests. Deep hole field tests shall be used to determine the depth to ground water and/or the location of impervious strata.

The combined storage capacity of the recharge and sedimentation basins shall be adequate to contain the runoff from the design storm. The basins shall have an emergency overflow to allow the safe discharge of water in excess of the design storm.

f. Sedimentation and Erosion Control

1. Grading

Cut and fill slopes shall be as flat as practical. Minimum slopes shall be adequate to provide positive drainage. Mowed lawns shall have a 1% minimum slope and unmowed lawns or areas with groundcover shall have a minimum slope of 2%. Maximum mowable slopes shall not exceed 3:1 horizontal to vertical with an unmowable maximum slope of 2:1. Slopes steeper than 2:1 will require geotextile, rock or other protection treatments. The tops and toes of all slopes shall be rounded.

Roadways and parking areas shall be graded in accordance with the station and parking section of the Manual contained in Volume II.

2. Diversion Channels:

Diversion channels shall be located at the top of all steep cut slopes where terrain rises away from the track centerline. They shall be designed in accordance with the requirements of this chapter. Diversion channels shall discharge to the storm drainage system or a natural water course. Diversion channel outlets shall be designed to minimize erosion. All discharges into existing wetlands or within 100 feet of such shall comply with the rules and regulations of the local conservation commission.

3. Grade Stabilization Structure:

When it is necessary to convey storm water from one level to another across a steep slope, a grade stabilization structure shall be used. It may be a lined chute, drop box culvert, pipe drop inlet, channel with check dams, or other suitable structure.

4. Vegetation and Revegetation:

Grading operations shall minimize disturbance of existing vegetation. The design shall allow staged construction whenever practical to minimize the exposure of bare earth and the resulting sedimentation. Erosion control matting shall be used when necessary to avoid erosion of slopes before new vegetation can become established.

Vegetation requirements shall be coordinated by a landscape architect with the MBTA and each respective municipality.

5. Local Requirements

Whenever work takes place in a wetland area or within the buffer zone, the local conservation commission must be contacted, a notice of intent filed if required, and any orders of conditions issued incorporated into the design. Conservation commissions typically will require control of sedimentation and erosion during construction. Appropriate measures such as silt fences, straw bale checks, staged construction, and revegetation requirements shall be incorporated into the design.

C. FENCING

1. General

Fencing is a critical element of the commuter rail physical plant. Fencing provides safety for the general public, protects passengers using our facilities and the operation of both the Authority's trains as well as the freight carriers. Fences perform various functions in a wide variety of locations. Selection of the proper size and type of fence as well as it's proper installation is important. No trespassing signs shall be attached to all gates and on fences, facing in both directions, at intervals not exceeding 200 feet and as detailed on Standard Plans.

2. Types of Fences

Reference Standard Plans - No. 3200, 3204, 3206 and 3208.

The primary fence type is chain link at heights of 48 inch, 72 inch, 96 inch and 120 inch. The three strand barbed wire top is an option on all chain link fence.

High Security Fence consists of a very dense, close-spaced, difficult to climb mesh fabric with closer post spacing.

At overhead bridges, special mounting details are required. Also, special fence details using posts and fabric that curve back over the bridge to prevent throwing objects, (anti-missile fencing) at trains may be necessary at high risk locations.

Gates may be single swing, double swing or sliding as appropriate for the location, size of opening and use. In all cases, the design of the gate and related hardware must be of the heaviest, most durable material available to provide reliable operation over the life of the installation.

Snow fences are usually a portable type installed seasonally by maintenance forces. Treated timber fences of permanent construction may be used for this purpose and/or as a view block in areas where snow drifting is a regular problem and where a visually solid fence would not be objectional.

3. Uses of Fences

a. Right-of-Way Fence

Fencing along the Authority's right-of-way is used to prevent unauthorized entry as well as to define the property of the Authority and abutters. The size and exact type of fence to use at a specific location is a function of the existing and potential degree of trespassing at that location. The following is a general guideline arranged in ascending order of control of trespassing:

. Very rural-wooded	No fence
. Rural-fields or farmland	72" CLF
. Light Suburban	72" CLF
. Medium to Dense Suburban	72" CLF with B/W
. Urban	96" CLF with B/W
. Urban areas with severe trespassing problems	96" HS-CLF with B/W

B/W = Barbed wire top-3 strands
HS = High Security Type fence

Gates must be located at suitable sites and frequency to allow maintenance personnel access to the right-of-way. This is especially critical at interlockings.

At a specific location, where trespassing has been a problem, a short segment of a more restrictive fence may be installed than used in the balance of the installation.

b. On-Site Access Control

Fences may be used at stations and parking areas to control where and how people move about. This is generally for their safety but may also be a means of directing them to the areas intended. In most situations, 48 inch CLF is appropriate for this purpose. Intertrack Fence is a particular use of this type of fence and is detailed on Standard Plan No. 3204. Its installation details and lack of a top rail is unique to that use. (See Station Design Section of Manual also.)

c. Snow Fences

Reference Standard Plan - 3200

Drifting snow caused by prevailing winds from the direction of open areas and accumulation of snow in cuts can be a problem for maintenance forces and have adverse affects on train operations, station platforms, parking areas and access roads. Installation of snow fences is usually seasonal using portable type fences. In certain instances, it may be appropriate to use a permanent fence such as the "Wood Open Board Fence" shown on Standard Plan 3200. Landscape plantings of evergreens may also be effective barriers to use on a permanent basis where fences may be inappropriate.

d. Overhead Bridges

Overhead bridges, both vehicular and pedestrian, pose problems related to debris being thrown and dropped on the right-of-way and trains. Anti-missile fencing may be used as a barrier in these locations with special curved posts and extra wide fabric utilized at locations where vandalism is prevalent. Fan guards or short cantilever fence sections may be helpful at the ends of fence on bridge approaches.

e. Fence Setback from Property Lines

In most cases, right-of-way fences shall be installed 12 inches from the actual property or ROW line and on Authority property. Where clearances are close and where directed, this dimension may be reduced to 6 inches.

D. RIGHT-OF-WAY SIGNS, POSTS AND MARKERS

Reference Standard Plans 3300 to 3399

1. General

Various signs, both informational and regulatory, are required around any railroad. During reconstruction or new installation of right-of-way facilities, replacement, reinstallation and furnishing new signs shall be considered an integral part of the project. Specific signs related to stations and parking facilities are not covered in this section. These signs are covered in Section II, Stations and Parking.

Right-of-Way signs generally fall into two categories - informational and regulatory. Informational signs include:

- Mileposts
- Close Clearance Warnings
- Yard Limits
- Flanger Warning Boards

Regulatory signs include:

- Speed Boards - Permanent and Temporary
- Whistle Posts

2. Lettering shall be Helvetica Medium with certain applications in condensed form. Exceptions to the above only with direction from the Chief Engineering Officer. Letters shall be black gloss silk screen conforming to Mass Highway Department (MHD) material spec. M7.04.12 or reflectorized press-on vinyl equal to black "Scotchal".

3. Background shall be reflectorized white paint meeting Federal Specification FSL-S-300 A type, Class 1 or 2, reflectivity 1 for mileposts and no trespassing signs.

   Other signs with colored background shall use an adhesive vinyl covering as follows:

   - Yellow - No. 2271 Yellow Scotchlite
   - Green - No. 2277 Green Scotchlite
   - Silver - No. 2870 Silver Scotchlite

4. Sign boards shall be made from 0.081 inch thick aluminum alloy 6061-T6. Mile posts shall have a 1/4 inch thick steel sign back behind each sign panel as per Standard Plan 3302. Other permanent signs shall also include a 1/4 inch thick steel sign back when scrap rail sections are used as a post. Steel board to be welded to base of rail along both edges.

   Aluminum sign boards shall be mounted to steel sign back with a minimum of four 5/16 inch x 1 inch bolts with lock nuts and washers, all cadmium plated.

   Steel sign backs shall be cleaned with a grease cutting solvent, primed and painted with two coats of white enamel prior to mounting sign boards.

5. Sign posts for free standing, permanent signs are preferred to be fabricated from used rail sections at least 112 lb section, free from bends, kinks or visible damage. Rails shall be cleaned with a grease cutting solvent, primed and painted with two coats of white enamel after welding on steel sign boards.

   Temporary signs or small (18 inch x 24 inch or less) signs may use steel "U" posts or square posts pre-drilled for mounting. Posts shall have 1/4 inch thick anchor plates attached per detail on Standard Plan 3306.

   Any sign post which could be struck by a motor vehicle shall include a break-away mounting.

6. Sign locations

   a. General - The designer shall coordinate required signage and location with Railroad Operations. In general, the following signs and markers are required.

b. Mileposts - Are located based on mileage from the primary terminal (North or South Station) and are located to the right of the outbound track with the mileage signs facing in both directions. Miles should be based on the original railroad stationing whenever possible.

If the existing mileposts are made of granite and are in good condition, they may be repainted (white) on top and lettering redone (black) and reused instead of the rail post mile marker.

c. Permanent speed boards shall be placed at every point where there is a change in the authorized speed and at least every two miles.

d. Yard limit signs shall be placed at yard limits facing both inward and outward tracks at locations where there are defined yard limits. Yard limit locations should be checked with Railroad Operations. Yard limits are normally defined by the carrier operating freight service, not by the Authority.

e. Whistle posts shall be located 1000 feet in advance of location for which locomotive whistle is to be sounded.

f. Ring post shall be at location where locomotive bell ringing is to commence and repeated every 1000 feet where prolonged ringing is required.

g. Crossing circuit sign shall be placed at start of grade crossing protection circuit. On bi-directional tracks (signalled for movement in either direction), signs shall be provided on both approaches to the crossing. When crossings are close together and the crossing circuits overlap, signs shall also include small letters to indicate the crossing number (in mileage from terminal) of the respective crossing. Signs shall be placed directly opposite the insulated joints concerned.

h. Stop posts shall be used to indicate a grade crossing for which no protection is provided or for a crossing where a full stop must be made before activating the protection. Sign shall be placed 25 feet in advance of the crossing or opposite the insulated joint.

CHAPTER 6
CLEARANCE CRITERIA

Reference Standard Plans - 1012 to 1019

A. General

Providing and maintaining adequate horizontal and vertical clearance is a key element in the safe operation of a railroad. Existing clearances on many routes in the Authority's territory are sub-standard by today's requirements due to the age of the facilities. During reconstruction and renewal, improvements in clearance that can be achieved are a priority item.

To the extent possible, new facilities or major rehabilitation and reconstruction shall conform to current Commonwealth of Massachusetts Statutes for clearance within yard limits. These statutes require a 22'-6" vertical clearance above top of rail, 8'-6" to any side obstruction from centerline of track and 13'-0" track centers with suitable increases for curvature. Various exceptions to the above are noted on the referenced standard plans and discussed in more detail below.

B. Vertical Clearances

1. Background

Vertical clearance within yard limits is defined by state statute as 22'-6" above top of rail. Yard limits were or are defined by the freight carriers, not by the MBTA. Historically, the requirement for 22'-6" clearance is based on protecting personnel walking on top of a box car that typically was about 15'-6" high. This is now a prohibited practice, roof walks are no longer placed on cars and brake wheels have been moved from the top of cars to a height just above the coupler.

Today, freight carriers are very concerned with improving clearances so they can remain competitive and handle cars which are considerably taller than the 14' to 15-1/2' box car of previous times. Fully enclosed tri-level automobile carriers and double-stack containers (shipping containers stacked two high on special drop-well flat cars) require a clearance just under 21 feet.

The MBTA has an interest in providing sufficient clearance for future electrification. This will be practical if the 22'-6" dimension is used and would be possible for passenger operation and very limited freight operation with 18'-0" clearance.

2. Minimum Vertical Clearance

When and if 22'-6" is not possible, lesser clearance will be permissible. Standard Plan 1016 gives the minimum vertical clearance by route segment which will satisfy both the MBTA's and current freight carrier's requirements. These clearances are subject to frequent revision due to changing requirements of freight carriers. Designers must check with railroad operations before design is advanced.

The absolute minimum clearance that is required to clear equipment of the MBTA and allow for dynamic movement plus a nominal safety factor and minimal resurfacing raise is 16'-4". Any clearances between 16'-4" and those indicated on Standard Plan 1016 must be approved by the Chief Engineering Officer.

3. Compensation for Superelevation

If tracks are superelevated under an overhead structure, clearance must be increased to allow the required vertical clearance out to a point 7'-0" from centerline of track on a plane even with the top of rail of superelevated track. (See sketch on Standard Plan 1016).

Relative to the low rail, which is the profile grade line, the required increase is defined by the following formula:

Increased clearance in inches = 1.43 x Ea

Formula 6.1

Where:

Ea = Actual Superelevation in Inches

4. Compensation for Vertical Curves

When there are vertical curves at overhead obstructions, allowance must be made for the vertical mid-ordinate of a car up to 90 feet long.

$$Increased\ clearance = \frac{0.90 \times G_1 - G_2}{8}$$

Formula 6.2

Where:

G_1 = Grade at PVC in percent
G_2 = Grade at PVT in percent

C. Horizontal Clearances

1. Background

By state statute, horizontal clearance within yard limits is 8'-6" from centerline of track from a plane at the top of rail vertically upward to the vertical clearance restriction. Yard limits were or are defined by the freight carriers, not the MBTA. The reason for 8'-6" is to allow a brakeman riding the side of a car to clear any obstructions. 8'-6" also provides room for a train to clear someone standing along side. The exception to the above is switch stands and other individual obstructions necessary for the operation of the railroad which are less than 3'-0" above top of rail. The reasoning being that a man riding the side of a car will be over that height and because they are only point obstructions, a pedestrian would not get trapped between it and a train.

Although 8'-6" side clearance is dictated only within yard limits, it is imperative that this clearance be maintained everywhere possible for safety. Where 8'-6" side clearance cannot be maintained, safety niches must be provided and warning signs posted. (See Part E following).

2. Allowable Exceptions to 8'-6" Side Clearance.

Due to operational and physical requirements, certain elements, under certain conditions may intrude into the 8'-6" tangent clearance envelope as follows:

a. Low switch stands and electric locks less than 3'-0" above top of rail may be 6'-6" from centerline.

b. Low passenger platforms (less than 8" above top of rail) may be 5'-1" from centerline.

c. High passenger platforms (4'-0" above top of rail) may be 5'-7" from centerline. On certain routes, a breakaway, foldup edge to allow 7'-3" for over-dimension freight movements shall be provided. (See Article 5, following). At major terminals with direct fixation track and no freight operation, 5'-4" may be used.

d. Intertrack fence at passenger stations may be 6'-0" from track centerline if fence is not more than 4'-0" high. (See Standard Plan 3204).

e. Top flange of through plate girder bridges less than 4'-0" above top of rail may be closer than 8'-6" as shown on Standard Plan 1017 and with the conditions indicated in the asterisk note (*) on that plan.

f. Dwarf signals outside of track to be 7'-6" from centerline. Dwarf signals between multiple tracks permitted only if not over 2'-0" above top of rail.

g. Platform canopies may be 7'-6" from centerline of track except on Framingham/Worcester Line, maintain 8'-6".

3. Side Clearance Increase for Superelevation

All side clearances must be increased on the inside or low side of curves to compensate for the inward lean of equipment. The formula used for this purpose is:

$$\text{Increased side clearance in inches} = h/5 \times Ea \qquad \text{Formula 6.3}$$

Where:

h = Height of obstruction above top of rail in feet.
Ea = Actual superelevation in inches.

4. Side Clearance Increase for Curvature

Side clearances must be increased for curvature on both the inside and outside of curves. This is to maintain equivalent tangent clearance which would otherwise be decreased due to end overhang of the car on the outside of curves and mid-ordinate swing-in on the inside of curves.

Side clearance increase, both inside and outside of curves, shall be 1 inch per degree of curvature. Exception - at passenger platforms, on the outside or high side of curves, side clearance shall be increased only one half inch per degree. At platforms, clearances for curvature in excess of two degrees and in excess of one inch actual superelevation shall be reviewed by the Chief Engineering officer. (See Standard Plan 1019).

5. Special Side Clearance at High Platforms for Freight Operations

On certain routes shared by through freight operations, the 5'-7" side clearance to high platforms is not always sufficient for all types of freight equipment under all operating conditions. Provision must be made for providing 7'-3" side clearance on an occassional basis by swinging the platform edges up and locking in a vertical position. This will allow passage of over-dimension equipment. In addition, the outer 9 inches of the platform must be made of a material that will shatter and the supports swing out of the way when accidently struck.

Special details for this type of platform edge have been previously developed and are available from Railroad Operations.

All high level platforms in territory where through freight service operates shall have the collapsible edge. The fold-up edge or other means such as a gauntlet track to allow 7'-3" side clearance, must be provided on the following routes or segments thereof.

<u>NORTHSIDE</u>

West Route - Wilmington Junction to State line
New Hampshire Main Line - Boston to State Line
Wildcat - Wilmington to Wilmington Junction
Fitchburg Main line - Willows to Fitchburg

<u>SOUTHSIDE</u>

Framingham (B&A) Main Line - Beacon Park to Worcester
Middleboro Secondary - Braintree to Middleboro
Franklin Branch - Walpole to Readville

6. Side Clearance - Special Issues

The designer should always be diligent in looking for and checking points that have or will have substandard side clearance. Even on tangents adjacent to curves, it should be remembered that car overhang resulting from curvature extends the full length of the car into the tangent.

High platforms pose especially critical clearance concerns, particularly when curvature is involved and freight operations use the track. All elements affecting clearance including curvature, superelevation, vehicle outlines and dynamic movement must be considered.

D. Track Centers

1. Standard Track Center Dimension

The standard track centers for tangent main line track effective the date of issue of this standard is 14'-0". Track centers of 13'-0" are permissable on an interim basis at such locations where 14'-0" is currently not possible.

The standard track centers for tangent main line track to an adjacent track used as a yard or switching lead, where personnel may be standing or walking in the space between the tracks, is 17'-0".

2. Track Center Increase for Curvature

Track centers must be increased at the rate of 2 inches per degree of curvature to allow for both end overhang and mid ordinate swing-in on adjacent, concentric tracks. It is essential that equivalent tangent track centers be maintained on curves. The equivalent tangent track center is the nominal tangent track center for the route segment. When re-designing curves, strive to provide equivalent 14'-0" tangent tracks centers wherever possible, but in no case less than 13'-0".

3. Absolute Minimum Track Centers

No commuter rail operations will be permitted on track centers less than 11'-8" on tangent. Track centers must be increased above 11'-8" for curvature and check that adjacent tracks have the same superelevation. No new construction will be allowed at 11'-8" track centers except temporary layouts during phased construction when absolutely necessary.

4. Track Center Increase For Unequal Superelevation

When the outer track has more actual superelevation than the inner track, increase the track center dimension 3 1/2 inches per inch of superelevation difference. This is in addition to the 2 inches per degree for curvature.

5. Concentric Curves in Multiple Track

In curved multiple track, the tracks shall be concentric unless the curve is being used to spread tracks for a center platform, bridge pier, etc. Track centers providing less than 14'-0" equivalent tangent clearance shall be spread at 2 inches per degree on the curve. Transition back to standard tangent centers within the spirals by increasing the length of spirals on the inside track to a length such that the spiral offset (p) is increased over that of the outside track spiral by an amount equal to the track center increase.

E. Safety Niches

1. Where Required

Safety niches shall be provided at all locations where side clearances from center line of track on both sides of the track bed are less than 8'-6" over a total distance along the track in excess of 100 feet.

2. Dimensional Requirement

Safety niches shall be no less than 7'-0" high by 2'-0" wide. The base or floor of the niche shall be not more than 8 inches above top of rail or in no case higher above adjacent finihsed grade than 18 inches. Backwall of niche shall be at least 8'-6" from centerline of track and niches shall not be less than 1'-0" deep.

3. Placement Interval

Where niches are required, they shall be spaced every 25'-0" on center and when on both sides of the trackbed they shall be staggered from those on the opposite side of track by 12'-6".

CHAPTER 7
GRADE CROSSING CRITERIA

Reference Standard Plans 3100, 3106, 3108, 3120

A. General

Vehicular grade crossings pose acute problems from both a safety and maintenance perspective. As stated in Design Objectives/Guidelines, Chapter 2, no new grade crossings, either public or private, will be permitted except with approval of various agencies and then only when no other reasonable alternative is available.

By their very nature, grade crossings are a potential hazard to all who use them, both in trains, motor vehicles and pedestrians. Elimination of grade crossings whenever possible is a first order priority on any project. In addition to new grade separation structures, crossings may also be eliminated by combining multiple crossings and diverting vehicular traffic onto a nearby grade separation.

There are many elements to consider in designing or improving a crossing. These include road profile, vehicular sight distances, type, number and placement of warning devices, traffic turning movements, traffic volume, percent of truck traffic, pedestrian travel paths, railroad sight distance, railroad operating speed, track geometry and superelevation as it would affect road profile and traffic signal pre-emption if their are signalized intersections in the immediate area. These elements all affect the safety of a crossing, which is the primary concern.

Maintenance of a crossing is also a major concern. The track structure at a grade crossing experiences increased deterioration due to wet conditions, sand and salt infiltration from road surfaces, loadings from highway traffic, all exacerbated by the fact that the track structure is encapsulated by the crossing surface, making track maintenance difficult and costly. It is essential that crossings be constructed to high standards and that crossing surface material can be removed and replaced in an expedient manner.

B. Types of Crossing Surfaces/Usages

Permanent mainline track crossings shall use full depth rubber when the Average Daily Traffic Volume (ADT) for the roadway exceeds 2500 or if more than 100 trucks per day use the crossing.

Permanent crossings with lesser volumes may use the rubber rail seal and bituminous type crossing.

Temporary construction type crossings and very low volume private crossings - as determined by the Chief Engineering Officer - shall use the pressure treated timber type crossing surface.

The full depth rubber crossing shall be of a design which allows installation without bolting or lagging from the top surface into the ties and must be designed to allow installation over the standard resilient fasteners.

C. Design Criteria

1. Highway Design

a. Horizontal Geometry

The geometric design criteria for the highway approach to a grade crossing must maximize sight distance to the crossing and remove any hazards and visual distractions to the driver. Curved approaches to the crossing are undesirable. Intersections at or near the crossing are extremely undesirable. Driveways or any entrance to the roadway within 75 to 100 feet of the crossing are undesirable. Changes in pavement width or number of lanes near the crossing are undesirable. Crossing angles less than 60 degrees are undesirable.

b. Vertical Geometry

Sight distances must be maximized by removing or flattening any vertical curves which limit the stopping sight distance to values less than the predominant traffic speed on the road. Very sharp vertical curves in the vicinity of the crossing are prohibited.

c. Pavement Design

Permanent pavement shall be hot mix asphalt applied in not less than two lifts consisting of a 5 inch base course and a 3 inch top course. New pavement shall extend not less than 9'-0" from edge of crossing surface. Existing pavement shall be saw cut to produce a clean, uniform pavement edge. Pavement specifications shall conform with MBTA Standard Specification, Section 02513 - Bituminous Concrete Pavement, for Base Course and Top Course.

The pavement subgrade in the approach to crossings should be disturbed as little as possible. Where conduits, underdrains and storm drains are installed, the width of trench should be kept to a minimum and gravel backfill placed and compacted in lifts not more than 6 inches each.

2. Railroad Design

a. Geometry

Curvature through a grade crossing is undesirable. When curvature is necessary, track superelevation should be limited to 2 inches to minimize the abrupt grade changes that occur to the road surface in multiple track crossings from one track to the other. If additional superelevation is mandated, the profile of the outer track should be adjusted upward at the crossing to provide a uniform cross slope across both tracks. This type of profile adjustment is undesirable and increasing superelevation in the crossing in excess of 2 inches will not be permitted without the approval of the Chief Engineering Officer.

Low points in the railroad profile at grade crossings should be avoided as this will exacerbate the retention of water in the subgrade at the crossing.

b. Subgrade

Maintenance of a firm, dry subgrade is essential to the satisfactory performance of a grade crossing. When a crossing is to be rebuilt, the nature and condition of the subgrade should be determined. The maintenance history of the crossing should be obtained from interviews with maintenance personnel and visual observations made to note poor track surface, fouled ballast, excess moisture and other indications of subgrade problems.

If poor subgrade problems are suspected, subsurface investigations must be undertaken to determine depth, extent and nature of the poor subgrade material. A program of subgrade modification/remediation must be prepared to allow construction of a crossing that will maintain track and roadway surface. The 5 inch hot mix asphalt underlayment, which is standard at all grade crossings, provides a good separation layer and load distribution medium. However, it should only be placed on granular material which will allow movement of moisture laterally to underdrains. The depth of excavation required below the bottom of the asphalt and replacement with granular material should be determined by the designer. In general, subgrade remediation measures beneath the asphalt layer should be initiated when the subgrade resilient modulus (Es) is less than 7500 psi or the California Bearing Ratio is less than 5.0.

The hot mix asphalt layer must be a low modulus mix with 1-3 percent air voids, (compacted), a high asphalt cement content and a high mineral-aggregate fines component. The job mix formula recommended for the hot mix asphalt is stated in Chapter 6, Section A.4.

c. Track Structure

The track structure on top of the HMA underlayment shall consist of 12 inches of crushed stone ballast (measured from bottom of tie), 7 inch x 9 inch treated timber ties 9'-0" long at 18 inch spacing through the actual crossing surface limits plus 3 ties beyond on each end and 8 foot 6 inch long ties at 19½ inch spacing to the limits of the HMA. (See Standard Plan No. 3100). In concrete tie territory, standard concrete ties may be used, however spacing and design of crossing panels must be coordinated. Rail through the crossing shall be 132 RE section continuous welded rail. Joints will not be permitted in the crossing or within 50 feet either side of the crossing surface except bonded insulated joint plug rails beyond the crossing surface as required for crossing circuits. Transition tie section shall be placed in advance of HMA underlayment per Standard Plan No. 1108. Standard resilient fasteners and plates will be used throughout. No tie pads shall be used in the crossing when timber ties are used.

3. Conduits - Signal & Communication

a. General Requirements

Standard Plan No. 3100 indicates the minimum number and general arrangement of 4 inch Galvanized Rigid Steel (GRS) conduits required at each crossing installation. These conduits are necessary for the automatic highway crossing protection, the signal system, communication system and provision for future expansion - in most instances. At certain locations, additional conduits may be required as directed by Railroad Operations. It is essential that the ends of conduits be plugged and located by the installer by preparing an 8½" x 11" minimum sketch with swing ties to existing physical features and then a witness stake placed over the ends after backfilling. In addition, conduits which do not have cable in place shall have a pull wire installed.

Where there are fibre optics installations, the owning company(s) must be contacted during design. Measures to protect their facilities or schedule and coordinate the fiber optics company's relocation or modification must be incorporated into the contract documents.

b. Location

The general location of required conduits is defined on Standard Plan 3100. This plan is generic in nature and individual crossings may require some modifications and additions. The lateral conduits must be installed under the HMA underlayment. The side of the right-of-way to receive the 9-4 inch conduits versus the 4-4 inch conduits is a function of the location of the primary signal cables and equipment case for the crossing protection.

The location of the conduits must be coordinated to avoid interference with underdrains and storm drains or other existing and proposed utilities.

Trenching for conduits must be kept to the minimum width possible and backfill placed around the conduits must be free of rocks or other sharp, hard material.

D. Drainage Considerations

1. General

Removal of surface water and effective reduction of pore water pressure in the subgrade are important measures for providing a crossing which will maintain smooth rail and highway surface with minimal maintenance. Measures which will accomplish these are well known, commonly used in general site work and include perforated pipe underdrains in combination with french drains (ballast filled trenches).

2. Avoid Low Points At Crossings

Highway profiles which have a low point in the crossing are very undesirable. To the extent possible, highway profiles and grading should be set to form a low point or swale off the crossing area parallel to the track on either side of the crossing. This will intercept the surface runoff from the road before reaching the crossing. This water can be directed into a closed drainage system, where available, or directed into adjacent Right-Of-Way (ROW) ditches if they are available.

3. Underdrains

Perforated pipe underdrains set in ballast filled trenches on either side of the HMA underlayment (see Standard Plan 3106) and protected from clogging with filter fabric are an effective means of removing water from the crossing area and lowering pore water pressure. However, they are fully effective only when the underdrains can outlet to some lower point. ROW ditches are the primary choice for this purpose, if present, and if water levels are normally not so high as to prevent flow from the underdrains.

Existing storm water drainage systems, if present, can provide a positive discharge point. Permission from the local department of public works is necessary and the capacity and hydraulics of the system should be investigated to determine if it surcharges on a regular basis.

Piping to a nearby natural low point away from the right-of-way is another option. If wetlands or watercourses are the ultimate discharge point, an order of conditions and other requirements may be imposed by the local conservation commission.

Piping to a drywell, removed from the immediate area of the crossing, is a possible solution when no other option is available. This would typically not be effective during periods of high rainfall but provide for removal of water from the crossing at other times.

4. Storm Drains

Separate storm drains must be used to carry surface water runoff through the crossing area where right-of-way ditches are present. Use of perforated pipe underdrains for this purpose is prohibited.

Where there are existing municipal storm drains passing through the crossing, their condition and type of material should be determined prior to crossing reconstruction. If they are in poor condition, consideration may be given to replacement during crossing reconstruction.

E. Existing Utilities

The designer should determine the presence and condition of all utilities in the crossing area and coordinate protection and possible replacement with the responsible utility or municipality during crossing reconstruction.

F. Plan Preparation/Design Requirements

1. General Requirements

When grade crossings are to be reconstructed, the designer shall provide an overall site plan detailing existing and proposed physical features and location of all existing and proposed signal equipment and cases. The plan should include, or be supplemented by an additional plan, delineating existing utilities above and below ground and show the proposed location of new ducts, cables, drainage and pole lines. Road profiles must be provided, and if trackwork is being done, profiles of the railroad and amount of superelevation at the crossing. Limits of pavement renewal shall be defined on the plans and road profiles.

2. Design

In addition to elements noted in this chapter, the designer must determine placement of equipment cases, crossing gates and all other proposed construction, considering sight distance, clearances, maintenance access and interference with existing facilities. Placement of new equipment must be fully defined on the plans. If crib walls, embankment or cut widening, or ditch relocation is required for placement or support of new equipment, these elements must be delineated and detailed on the plans.