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16. Abstract

This report is a manual intended to assist in evaluating rail transit proposals and to provide information for preliminary design of trackways and to serve as a guide to the acquisition and use of data required for the final design of a specific system. The standards and characteristics of a number of operating and proposed systems were analyzed and organized to produce this manual. The first three chapters describe and contrast light and heavy rail systems, outline the system planning process, and discuss the implications of choices within systems. These chapters also describe vehicle and facility characteristics and requirements that affect trackway location and design. Finally, they discuss system operational factors and the magnitude and range of major cost elements. The last chapter contains principles, conventions and criteria for trackwork and for the preliminary design of trackways.

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The manual presents typical, generalized standards and criteria in condensed form. It does not obviate the need to prepare detailed standards for specific new facilities, nor can it supplant the manuals developed by or for the various operating properties.

The contents of this manual reflect the views of the authors who are solely responsible for the validity of the information presented herein. This manual is intended as a guide and does not constitute a statement of policies, standards, specifications, or regulations.

Special acknowledgment is due the Division of Mass Transportation within Caltrans and the transportation officials and consultants who furnished information and insights.

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NOTE: The SOURCE abbreviations shown on the figures are as follows:

ASME - The American Society of Mechanical Engineers (See Reference No. P-14)

BART - SF Bay Area Rapid Transit (See Reference Nos. M-17 and M-24)

BRRTS - Baltimore Region Rapid Transit System (See Reference Nos. M-4 and M-5)

CTA - Chicago Transit Authority (See Reference No. M-3)

CUTS - Characteristics of Urban Transportation Systems (See Reference No. M-20)

MARTA - Metropolitan Atlanta Regional Transit Authority
(See Reference No. M-19)

NYCTA - New York City Transit Authority
(See Reference No. M-10)

SCRTD - Southern California Rapid Transit District
(See Reference No. M-22)

SEDH - Subway Environmental Design Handbook
(See Reference No. M-2)

SOAR - LRT: A State of the Art Review
(See Reference R-5)

TTC - Toronto Transit Commission
(See Reference No. M-23)

WMATA - Washington Metropolitan Area Transit Authority
(See Reference No. M-6)

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1-1 BACKGROUND

California legislation created the Department of Transportation (Caltrans) effective July 1, 1973, and mandated a broad approach to multimodal transportation planning involving regional planning agencies and the several divisions of Caltrans.

The Division of Mass Transportation (DMT), one of the statutory divisions within Caltrans, is charged with advocating balanced transportation systems, evaluating public transportation proposals, and facilitating their development.

One of the studies in a research program prepared by DMT was to develop engineering standards for evaluating transit guideway planning and for designing guideway facilities. The study was subsequently narrowed to conventional rail transit systems. This manual thus deals with electric vehicles with flanged steel wheels operating on conventional steel rails.

1-2 ASSUMPTIONS AND PURPOSE

This manual is intended as an introduction to rail transit for engineers who are familiar with highway planning and design. It should assist them in evaluating rail transit proposals and should provide sufficient information for the preliminary design of transit trackways, particularly the tracks, trackbed and structures.

There are marked similarities in the planning and design of highways and railways. The authors, therefore, have attempted in this manual to stress aspects which are unique to rail transit engineering and to present appropriate values and criteria for those elements of rail design which differ from highway design in specifics rather than principle.

1-3 ORGANIZATION AND SCOPE

The four chapters in this manual are:

Chapter 1 - INTRODUCTION
Chapter 2 - RAIL TRANSIT OVERVIEW
Chapter 3 - PLANNING/DESIGN GUIDELINES AND CONSIDERATIONS
Chapter 4 - TRACK DESIGN CRITERIA

Each chapter is divided into sections as shown in the contents on page iv. Tables and figures are listed after the contents and are placed at the end of the section in which they are first described or discussed in the manual. A detailed index is provided at the beginning of lengthy chapters 3 and 4. Definitions of terms and a list of references are among the materials appended to the manual.

Chapter 2 describes and contrasts light rail transit (LRT) systems and heavy rail transit (HRT) systems in terms of typical applications and operational characteristics. It also outlines the system planning process and the implications of choices within a system, but does not evaluate the plausibility of arguments regarding system selection and funding.

Chapter 3 describes vehicle and facility attributes and spatial requirements (established by others) that concern the designer because they affect or establish trackway location, alignment, clearance, and cost. This chapter also discusses operational considerations and tradeoffs and presents ranges and magnitudes of major cost elements to assist in comparing alternatives and in evaluating the completeness and validity of transit proposals.

Chapter 4 contains design principles, conventions, and criteria that relate to various elements of trackway design. The manual can serve as a guide to the acquisition and use of the data required for final design of a specific system. Where extensions of operating transit systems are to interface with highways, or are to be incorporated into existing or proposed highway facilities, the design standards developed by the transit properties will be available for use.

The manual mentions briefly such topics as soils and foundation investigations; roadway and parking lot design; earthwork calculations; drainage design; bridge, tunnel, and retaining wall design; right of way acquisition; and utility relocation. These items are similar in nature to elements of highway work which have been detailed in other manuals and are often performed by specialized functional units within Caltrans.

Design details for such things as stations, shops, ventilation, and electrification are beyond the scope of this manual.

U. S. units of measure and International System (metric) equivalents are used throughout the manual.

1-4 ABBREVIATIONS

A. Organizations

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transit Association
AREA	American Railway Engineering Association
ASME	American Society of Mechanical Engineers
BART	Bay Area Rapid Transit District (San Francisco)
BRRTS	Baltimore Region Rapid Transit System
CPUC	California Public Utilities Commission
CTA	Chicago Transit Authority
DMT	Division of Mass Transportation (Caltrans)
GCRTA	Greater Cleveland Regional Transit Authority
MARTA	Metropolitan Atlanta Rapid Transit Authority
MBTA	Massachusetts Bay Transportation Authority
MUCTC	Montreal Urban Community Transit Commission
MUNI	San Francisco Municipal Railway
NYCTA	New York City Transit Authority

PAT	Port Authority of Allegheny County (Pittsburgh)
PATCO	Port Authority Transit Corporation (Lindenwold Line)
PATH	Port Authority Trans-Hudson Corporation (NYC-NJ)
SCRTD	Southern California Rapid Transit District
SEPTA	Southeastern Pennsylvania Transportation Authority (Philadelphia)
TRB	Transportation Research Board
TTC	Toronto Transit Commission
UMTA	Urban Mass Transportation Administration (Federal)
WMATA	Washington Metropolitan Area Transit Authority

More extensive lists of transportation oriented organizations, agencies, consultants and manufacturers are contained in the Trans Guide prepared by DMT.

B. Transit Vehicles and Systems

CLRV	Canadian Light Rail Vehicle
HRT	Heavy Rail Transit
HRV	Heavy Rail Vehicle
LRT	Light Rail Transit
LRV	Light Rail Vehicle
PCC Car	Presidents' Conference Committee Car

SLRV	U. S. Standard Light Rail Vehicle
SOAC	State-of-the-Art Car

CHAPTER 2

RAIL TRANSIT OVERVIEW

CHAPTER 2

RAIL TRANSIT OVERVIEW

2-1 RAIL TRANSIT RATIONALE

There is renewed worldwide interest in rail transit systems that can provide much needed alternatives to the automobile. Moreover, considerable effort is being directed to the design of systems that will attract motorists.

Fixed-route systems can establish a basis for land use planning and for preserving or improving the quality of urban life. Guided systems can operate on narrower rights of way than driver steered systems and are less obtrusive in many areas. The proven technology of steel wheels on steel rails has low rolling resistance and is attractive environmentally in terms of reducing energy consumption and air pollution. Tracked systems are also adaptable to automated controls that enhance safety and reliability, and vehicles can be coupled to increase system productivity and reduce unit operating costs.

There are some disadvantages in the physical characteristics of guided systems relative to steered vehicles. The long life expectancy of rail vehicles makes modernization awkward, and inflexible rail networks require feeder service and make route changes difficult.

2-2 RAIL MODES DESCRIBED AND DIFFERENTIATED

Light and heavy rail systems are frequently classified in terms of system operating characteristics which are defined and differentiated for use in this manual as follows:

A. Heavy Rail Transit (HRT)

Heavy rail transit operates on an exclusive right of way with full access control. The roadbed is grade separated with frequent use of elevated or subway construction. Heavy rail systems generally employ multicar trains and relatively elaborate stations with passenger platforms at car-floor height. Vehicles tend to be large and designed for maximum passenger comfort. Stops are less frequent, operating speeds faster, schedules more precise, and automatic controls more universal than on light rail systems.

A third-rail system is the usual means for main line electrification. Vehicles are equipped with shoes as current collectors.

BART is an example of a heavy rail system in California.

B. Light Rail Transit (LRT)

Light rail transit is an urban electric railway concept that embraces the full range of operating characteristics from the streetcar to heavy rail systems. Route capacity and speeds are sometimes more restricted and overall performance is usually lower than for heavy rail transit.

Light rail vehicles often operate on reserved, but not necessarily grade-separated, rights of way. LRVs may also run on streets in mixed traffic where passenger stops are more frequent and passenger loading is from street level. Single car operation is common although train-type operation may be used in rush hours. Train length is generally limited to two or three cars.

Many of the cars are articulated and about half of the current models can be coupled.

Normally a very small degree of system automation is employed. Capacity can be increased by providing more separation from conflicting traffic and by improving signal and control systems to permit higher speeds and shorter headways.

An overhead wire system is most often used for power distribution with trolley poles or pantographs serving as vehicle current collectors.

The MUNI system in San Francisco is classified as a light rail system.

A comprehensive report on light rail development is presented in TRB Special Report 161, Light Rail Transit, which contains the proceedings of a national conference held in Philadelphia in June, 1975. The conference, conducted by TRB, was sponsored by UMTA and cosponsored by APTA and the University of Pennsylvania. Another comprehensive discussion of concepts and services in Europe and North America is presented in DOT Report No. UT 50009, Light Rail Transit: A State of the Art Review, Spring, 1976, issued by UMTA. These two documents contain a full array of LRT information and perspectives.

2-3 EXISTING SYSTEM APPLICATIONS AND CHARACTERISTICS

Rail transit systems are numerous and diverse as indicated in the general descriptions which follow. Table 2-3.1 summarizes and compares characteristic data for heavy and light rail systems shown in Appendixes A-2 and A-3. These characteristics provide some insights for relating applications to regions, but do not constitute criteria for decision making.

A. Heavy Rail Systems

The Lea HRT Compendium indicates that there are over 40 heavy rail systems operating throughout the world and another 20 or so are in varying stages of design or construction. Among the latter are systems for Atlanta, Baltimore, and Washington, D.C.

The areas served by HRT systems are nearly all less than 1,000 square miles (2,600 square kilometers) in extent and most are less than 500 square miles (1,300 square kilometers). Population figures for these areas are seldom less than 1,000,000. Most of the HRT systems are less than 50 miles (80 kilometers) long and very few exceed 100 miles (160 kilometers) in length.

HRT line capacity in excess of 40,000 passengers per hour per direction is achievable but is seldom required. Peak-hour corridor demand is often less than half that number.

B. Light Rail Systems

It was brought out at the 1975 conference in Philadelphia that more than 300 cities around the world are operating LRT systems of various sizes and that many of these were inaugurated 50 or more years ago. About 20% of the operating systems are currently being extended or refurbished and fifteen or more new systems are in various planning stages. LRT systems commonly serve areas of less than 400 square miles (1,000 square kilometers). Populations served most often range downward from 1,000,000.

Relatively few LRT lines operate with peak period patronage in excess of 5,500 per hour. Many lines have fewer than 2,000 passengers per hour during the peak, and fewer than 900 per hour off-peak.

TABLE 2–3.1
TYPICAL CHARACTERISTICS
of Light and Heavy Rail Systems

(Source: Appendixes A–2 and A–3)

ITEM	LIGHT RAIL		HEAVY RAIL	
	Typical Range	Extreme Range	Typical Range	Extreme Range
Area Served: Square Miles (km^2)	50–400 (130–1,036)	15–2,000 (39–5,180)	15–1,000 (39–2,590)	5–1,500 (13–3,885)
Population of Service Area: Millions	0.2–2.5	0.2–9.0	1.0–4.0	0.1–9.0
Total System Length: Miles (km)	10–140 (16–225)	5–180 (8–290)	7–100 (11–161)	4–560 (6–901)
Length: Above or Below Grade [1]: Miles (km)	0 (0)	0–13 (0–21)	5–60 (8–97)	0–100 (0–161)
Number of Stations/Stops	30–500	15–1,300	10–100	8–350
Average Spacing of Stations: Miles (km)	0.20–0.4 (0.32–0.6)	0.16-1.0 (0.25-1.6)	0.4–1.4 (0.6–2.3)	0.34–2.2 (0.55–3.5)
Total Annual Passengers: Millions	9–150	3–440	10–275	10–650
Number of Vehicles	40–650	25–1,600	40–1,000	14–4,400
Peak Period Line Capacity: Passengers/Hr [2]	1,200–5,500	700–40,000	10,000–40,000	3,000–84,000
Off-Peak Line Capacity: Passengers/Hr [2]	200–900	200–2,000	1,200–15,000	200–23,000

[1] Using structures only: cut or fill locations considered "at grade".

[2] Line capacity is single direction for scheduled headway, train consist, etc. for peak and off-peak operations.
Peak values based on highest capacity line in system.
Off-peak based on lowest capacity line in system.

2-4 SYSTEM COMPARISONS, OPERATIONAL PROS AND CONS

Either light or heavy rail can serve as the backbone of an urban transit system. Both require secondary modes for collection and distribution. Light rail can supplement heavy rail systems with feeder service in large cities.

One of the advantages of a light rail system is that it can provide some of its own feeder service. In this way it can reduce passenger waiting delays en route, compensate for slower operating speeds, and compare favorably with overall trip times via heavy rail.

Flexibility is considered to be an advantage of light rail systems. Train lengths and turning radii are short and street-level loading is common. Extensive station facilities are not required. Virtually any place where a safe refuge for pedestrians can be developed next to the tracks can serve as a station. Provisions for intermodal transfers are relatively easy to provide, although separating pedestrians from vehicular traffic is a major concern at any transfer facility.

A primary disadvantage of light rail transit is the potential conflict with other vehicles when operating at street level. Closing some streets, preempting traffic signals, and separating selected intersections at grade are steps that can be taken to minimize cross traffic conflicts. When operations are mixed with street traffic, light rail vehicle lengths must be considered. A modern three-car train can be over 200 feet (60 meters) long. This is a significant factor in station design and in signal timing and pre-emption.

2-5 PLANNING PROCESS, MODE SELECTION, AND SYSTEM UPGRADING

Initially, to get to the study stage, and ultimately, to be implemented, each rail transit proposal (or any transportation proposal) must successfully deal with issues of economic feasibility, social equity and desirability, and environmental compatibility. The proposal must gain wide support.

In broad terms, the planning and design process establishes desired system performance criteria and objectives, develops alternatives, and then selects the best balanced combination of modes and elements to fit the situation. This is done by testing site-specific assumptions and costs against financial constraints.

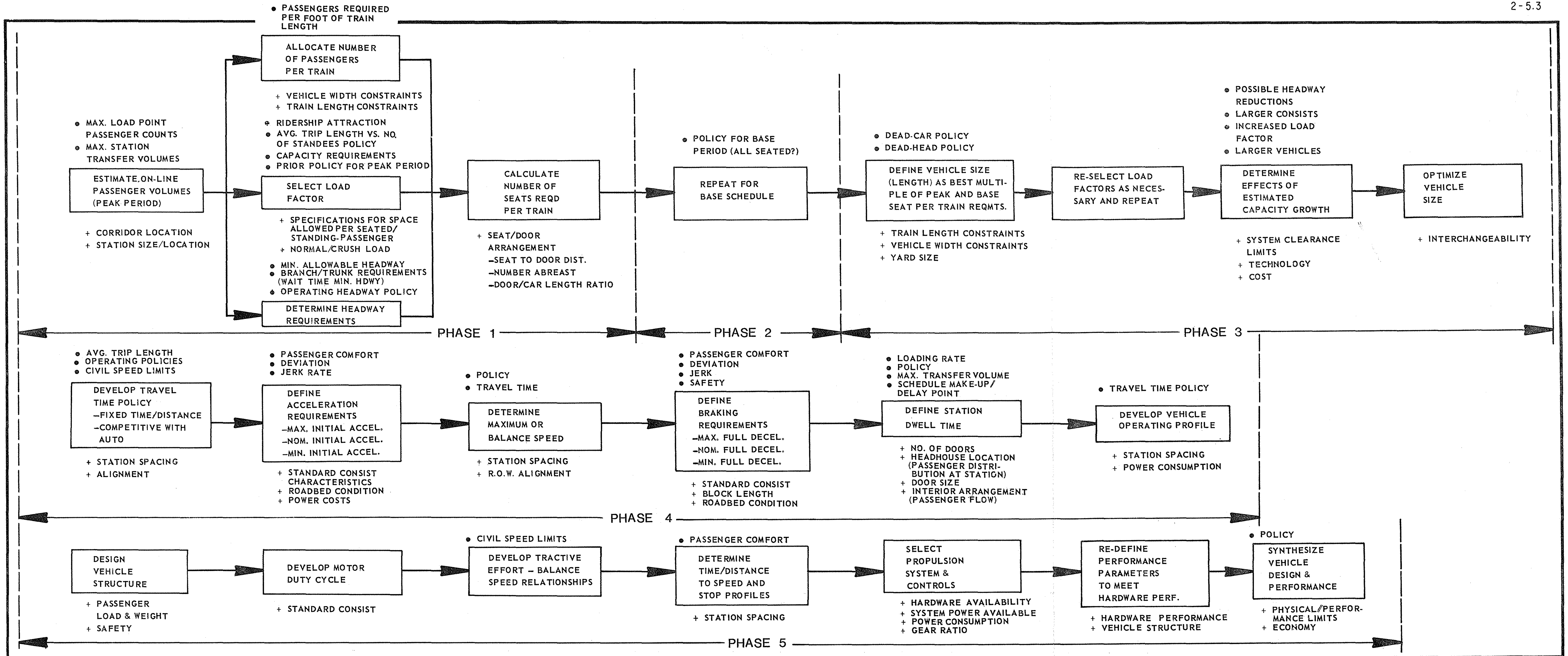
Policy determinations and design criteria are interdependent, and, in a very real sense, criteria evolve from policy. Figures 2-5.1 and 2-5.2 illustrate how policy elements influence physical and operational criteria for vehicles. It is also evident that at some point in the process vehicle selection establishes definite limits for system operations.

The current "rebirth" of the light rail mode, directed at filling the gap between bus and heavy rail systems, makes possible a variety of cost/concept alternatives for rail transit. Vehicles, passenger facilities, and service can range from spartan to very plush. Light and heavy rail costs can vary dramatically.

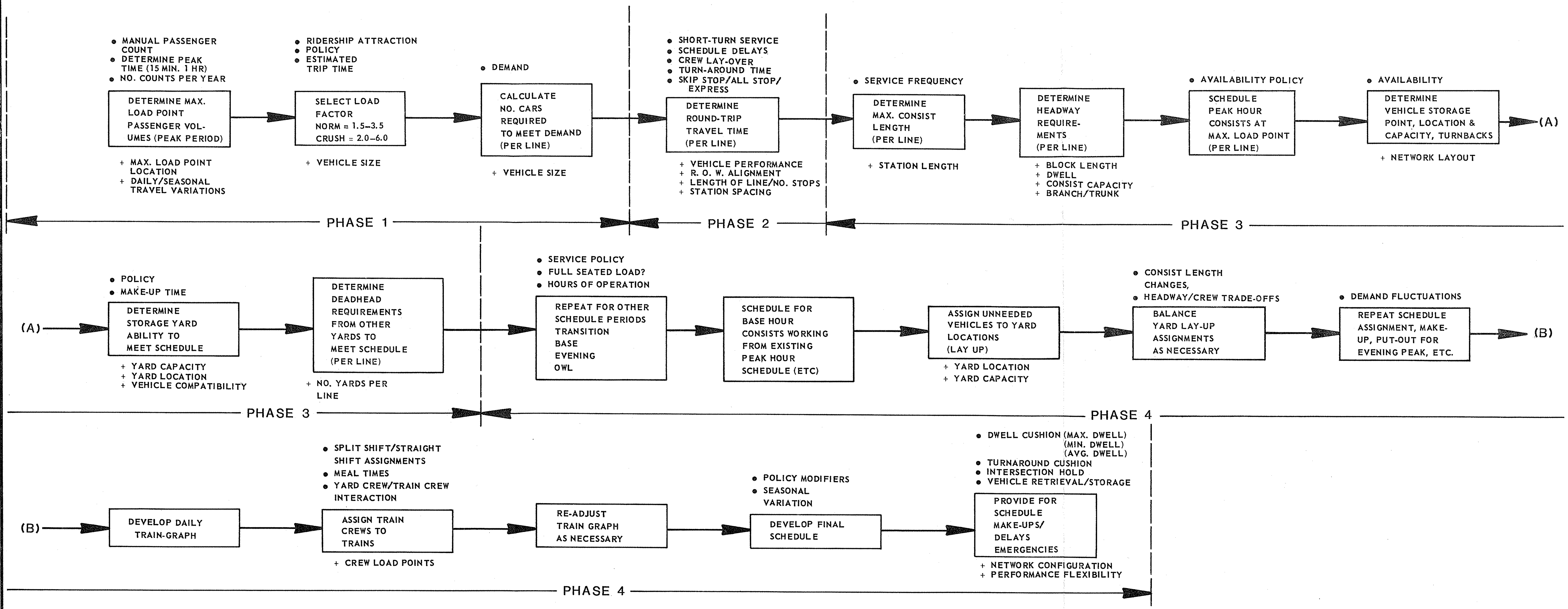
Cost differentials become very significant as elevated or subway structures are added to provide grade separated rights of way, as stations become more elaborate, and as automatic controls are introduced. The costs of individual vehicles and of trackwork (ballast, ties and rails) are quite comparable for light and heavy rail systems and are not apt to influence mode selection appreciably. The choice rests to a large extent on trade-offs between increments of investment and quality of service.

The lesser cost per mile (kilometer) of the light rail mode means it can serve a much wider area than a heavy rail system of equal cost. Also, a less sophisticated light rail line might be financed and constructed more readily and be placed in service more quickly than a heavy rail alternative. Such alternatives, which differ in scope and levels of service, make the comparison and evaluation process more complex.

The conversion from a light rail system to a heavy rail operation is also complex and requires careful analysis. The upgrading of an operating system is governed in great measure by the nature of the existing facilities. A planned conversion, to be accomplished by upgrading staged-segments of a first-phase system, may defer some investment needs, but can also affect initial design concepts and construction costs significantly. Matters such as power collection, access control, vehicle characteristics, and requirements for structure design, need to be considered early in the planning process.



SOURCES	LEGEND	RAIL TRANSIT CRITERIA	
SCRTD (Chart I: Page IX-30)	• POLICY ELEMENT PRIMARY PROCESS + PHYSICAL ELEMENT	VEHICLE SPECIFICATION PROCESS FIGURE 2-5.1	Caltrans JUN 77



SOURCES	LEGEND	RAIL TRANSIT CRITERIA	
SCRTD (Chart 2: Page IX – 31)	• POLICY ELEMENT PRIMARY PROCESS + PHYSICAL ELEMENT	VEHICLE OPERATIONS PROCESS FIGURE 2-5.2	Caltrans JUN 77

CHAPTER 3

PLANNING/DESIGN GUIDELINES AND CONSIDERATIONS

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CHAPTER 3 - PLANNING/DESIGN GUIDELINES AND CONSIDERATIONS

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CHAPTER 3

PLANNING/DESIGN GUIDELINES and CONSIDERATIONS

3-1 GENERAL

This chapter examines major elements of rail transit systems. It further develops specific light and heavy rail comparisons and distinctions, and it discusses design considerations and relationships in some depth. In doing so, it suggests many of the questions regarding options and related consequences to be evaluated and settled in progressive stages of system planning and preliminary design.

This chapter also presents standards and criteria for various elements of rail transit systems and relates them to the track design criteria contained in Chapter 4.

CPUC General Order No. 143 (Appendix A-11) establishes rules and regulations governing the design, construction, and operation of LRT systems. A number of sections in this chapter contain references to related provisions of G.O. 143.

3-2 VEHICLES

The current trend in new car development is toward families of light and heavy rail vehicles which are similar in size, capacity, performance, and cost.

Table 3-2.1 lists some vehicle features and typical values that serve as a basis for the discussions that follow.

Appendixes A-4 and A-5 show data for some representative vehicles which were considered in compiling the "typical" vehicles shown in Table 3-2.1. Among the representative vehicles is the light rail PCC car which was first produced in 1935 as a result of research by the Electric Railway Presidents' Conference Committee. This became a standard for production both here and abroad. UMTA sponsored research and development are currently reflected in the U.S. standard light rail vehicle (SLRV) and in the heavy rail State-of-the-Art Car (SOAC). These were also among the representative vehicles used in compiling the "typical" vehicles.

The typical vehicles and values in Table 3-2.1 are appropriate for preliminary studies and evaluations. Final system design is dependent upon vehicle selection and specific data regarding dimensions, weights, and operating characteristics. Section 9 of Appendix A-11 contains CPUC requirements for new LRVs.

A. Dimensions

1. Length

Both the light and heavy rail series contain a number of vehicles about 50' (15 m) long and another group in the 70' to 75' (21 m to 23 m) range. The "typical" 73' (22 m) LRV shown in Table 3-2.1 is articulated by a flexible joining of two equal segments. The other three typical cars are not articulated.

A group of HRVs about 68' (21 m) long has not been represented in Table 3-2.1 because most of its features are similar to those listed for the 75' (23 m) HRV.

A group of double-articulated LRVs 80' to 90' (24 m to 27 m) long has also been omitted. These cars, used mostly in Europe, are less than 8' (2.4 m) wide, have less passenger capacity than single jointed cars, and would appear to be suitable for special, limited situations only.

2. Width

LRVs range from 7.2' to 8.9' (2.2 m to 2.7 m) in width. HRVs vary from 9.3' to 10.5' (2.8 m to 3.2 m). The SOAC is 9.75' (3.0 m) wide, somewhat narrower than the "typical" 10.33' (3.2 m) width which is more representative of new and proposed HRT systems in this country. The SOAC width was chosen so that it would be less restricted as a demonstration vehicle on a variety of transit systems.

Width selection is influenced primarily by existing external clearance and cost constraints on the one hand and by the desire for interior spaciousness and passenger comfort on the other. Passenger capacity considerations are discussed in Subsection C.

3. Truck Spacing, Wheel Base, and End Overhand

All of the "typical" rail vehicles employ double axle, four-wheeled trucks. Axle and wheel positions are fixed rigidly with respect to truck assemblies which have centered pivot points.

Truck spacing (from pivot point to pivot point) and wheel base (axle spacing on the truck) affect vehicle load and impact distribution to the rails and track support system.

The track gauge must be widened slightly on sharp curves (see Section 4-5) to permit the flanged wheels to slide freely around the curves. This sliding phenomenon is a significant noise source. Truck spacing also affects the minimum turning radius of the vehicle. The greater the spacing, the longer the required radius of curvature.

Unarticulated vehicles are supported on two trucks. Single articulated vehicles employ a third unmotorized truck under the joint. Both versions of the "typical" LRV have nearly identical truck spacing and end overhang dimensions. Their lateral clearance requirements for inswing and outswing on curves are therefore similar.

4. Wheel Diameter and Gauge

The typical wheel diameters have no direct bearing on the other vehicle characteristics shown. For instance, vehicle floor heights (and passenger platform heights) are governed by other considerations. Whatever the diameter, however, wheel wear in combination with track wear can produce more than an inch (2.5 cm) of vertical displacement and must be taken into consideration. Wheel gauge-track gauge tolerances are also affected by wheel flange and rail wear of one-half inch (1.3 cm) or more. This variable is compensated for in the dynamics of the vehicle clearance envelope discussed in Section 4-3.

5. Height of Roof and Floor

The 11.75' (3.58 m) height of roof above top of rail tabulated for HRVs is a direct indication of the vertical clearance required. This is a critical dimension since these vehicles operate on grade separated trackways, often in subway structures.

Many of the HRVs have flush roofs; others have antenna protuberances on the order of 0.5' (15 cm) or so. The typical 11.75' (3.58 m) value accommodates these projections and embraces most representative vehicles. Exceptions are the 12.0' (3.66 m) Boeing Vertol and Budd cars used in Chicago and the 12.13' (3.70 m) high prototype of the variable height SOAC which has a pantograph option.

The 11.50' (3.51 m) roof height shown for the LRVs includes an allowance for a locked down pantograph and other above-the-roof projections. This dimension is seldom a control. Of more concern is the operating range of the trolley pole or pantograph collector which is normally 15' to 20' (4.5 m to 6 m) above tracklevel. The collector must accommodate a catenary power supply suspended overhead in conformance with safety requirements for vertical clearance. Overhead structures may impose vertical clearance restrictions. (See Appendixes A-7, A-8, and A-11 for CPUC overhead electrical and structural clearance requirements.) Third rail electrification is usually employed in underground operations.

The 34" and 44" (86 cm and 112 cm) floor heights, shown for the "typical" light and heavy rail vehicles respectively, are standardized within narrow limits and the requirements for floor-level loading platforms differ accordingly. Floor height may be governed by vertical clearance requirements for chopper control, air conditioning, and dynamic braking components, etc., placed beneath the car floor to preserve usable floor space.

B. Performance

The relationships of vehicle performance to system operations and track geometry, mentioned briefly in this subsection, are presented in greater detail in Section 3-9 and in Chapter 4.

1. Speed, Acceleration, and Deceleration

Modern transit vehicles are capable of the listed maximum speeds and more, but much track geometry is not based on top speed cruising. Top speed is often not attainable. The acceleration-deceleration rates shown in Table 3-2.1 are frequently specified service rates which are comfortable for standing passengers. Figure 3-2.1 shows the usual range in initial acceleration rates for HRV and LRV performance, and the curves illustrate the characteristic loss of acceleration as speed increases. The typical range of deceleration rates shows that nominal braking rates are relatively constant over the entire speed range.

These typical speeds and speed-change rates are based on level, tangent track and specified vehicle loadings. The speed-distance relationships of acceleration and braking and the effects of grades on performance are discussed in Section 3-9, Subsections F and G.

2. Minimum Horizontal Turning Radius

Vehicle characteristics such as truck spacing govern minimum radii for track curvature. The typical values shown in Table 3-2.1 are fairly representative, but can vary significantly for a particular vehicle design. This limitation becomes a factor mainly for yard and secondary tracks. The 45' (13.7 m) radius capability of the LRVs permits turning corners at street intersections. Usually, trains of coupled vehicles have the same turning characteristics as the basic unit comprised of a single vehicle or a married pair.

3. Vertical Curve Limitations

The typical minimum values for vertical curves in Table 3-2.1 are expressed in terms of circular curve radii to provide a comparison of vehicle capabilities. Track design standards for vertical curves are sometimes expressed as an allowable change in rate of grade per unit of distance or as a parabolic curve length related to the magnitude of change in grade as described in Section 4-7, Subsection B.

For most vehicles, minimum vertical curve limitations are usually reported to be the same for crest and sag vertical curves and for single or coupled cars. Vehicle capabilities vary greatly within the groups represented by each of the four "typical" vehicles, so the values shown give only a rough indication of relative group performance and overlaps.

The minimum vertical curve limit seldom comes into play. In HRT systems, particularly, other considerations dictate much higher vertical alignment standards.

4. Maximum Grades

The maximum grade on nearly all operating HRT systems is between 3% and 5% in order to maintain high performance and to provide a high quality profile and ride. The 4% maximum listed in Table 3-2.1 is also representative of current design for HRT systems. The maximum grade designated for the SOAC is 3%.

The maximum grades for LRT systems may approach the limits of vehicle performance. The +6% and -8% are desirable limits for up and down grades. Under compelling circumstances, +8% and -10% might be considered. In neither case should these rates be used for sustained grades.

The up grades are limited by vehicle power, desired performance, and wheel-rail traction. Braking capability, which is influenced by train length and loading, is an added consideration for down grades. Most LRT systems are basically single car operations with a 2- or 3-car limit for peak period trains.

Examples of maximum grades near the extremes of the tabulated light rail range are the ±6.5% suggested grade limit for the PCC car and the ±9% limit for the SLRV as shown in Appendix A-4. Section 4-7, Subsection A, suggests some additional maximum grade considerations.

The steeper grades employed in LRT operations permit quicker, less costly accommodation of selected grade separations and afford opportunities to roll the grade up to and down from station stops in order to assist vehicle braking and acceleration.

Vertical alignment criteria at station platforms are covered in Section 4-7, Subsection B.

C. Capacity

1. General

The passenger capacity of rail vehicles is one of several variables, along with train consist and scheduling, to be considered in balancing line haul capacity against peak/off-peak route demand.

The number of seats to be provided and the load factor (ratio of total passengers to seats) to be selected to limit standees are based on consideration of passenger comfort, vehicle constraints, operating criteria, and other factors as indicated in Figures 2-5.1 and 2-5.2.

In Table 3-2.1 and in the following discussion, vehicle capacity is expressed in two ways: design capacity and crush capacity. Design capacity is the number of seats plus the number of standees that can be accommodated in reasonable comfort without impairing passenger movement. Crush capacity is the number of seats plus the maximum allowable number of crowded standees to be tolerated.

2. Seating

A variety of seating schemes is possible for any vehicle. The number and arrangement of seats are influenced by the number and location of doors and by space allowances for vehicle operators for either single or dual directional car operation. Longitudinal seating allows for maximum passenger capacity while transverse seats stress comfort.

The number of seats shown in Table 3-2.1 is typical for each class of vehicle. Based on data in the Lea Transit Compendia, the range of seat numbers relative to the numbers shown would be $\pm$10% for HRVs and $\pm$25% for LRVs.

3. Standees

The number of "design standees" for proposed and operating systems is extremely variable. Table 3-2.1 shows that the number of standing passengers typically corresponds to 2.7 ft.^{2} (0.25 m^2) for each standee in three vehicle groups, while 2.1 ft.^{2} (0.20 m^2) is more representative for the 50' (15 m) LRV group. Variations within the HRVs include suggested design allowances of 8 ft.^{2} (0.74 m^2) and 11 ft.^{2} (0.10 m^2) for different SOAC configurations as shown in Appendix A-5(2).

An allowance of 1.4 ft.^{2} (0.13 m^2) per passenger is most frequently cited in the Lea compendia as the absolute limiting value for establishing crush standing capacities for all types of vehicles. This is listed as the typical value for three of the vehicle groups in Table 3-2.1. The exception is the 75' (23 m) HRV group where 2.0 ft.^{2} (0.19 m^2) is shown as being more representative of current practice in the United States and Canada.

DMT recommends the use of 2.0 ft.^{2} (0.19 m^2) and 3.0 ft.^{2} (0.28 m^2) per standee for crush and design load limits respectively. With longitudinal seats facing aisles, an allowance of 13" (33 cm) for knee and foot room at each seat should be deducted from the floor area available for standees.

4. Crush Loading

Crush capacity totals (seats plus standees) are ultimately limited by interior space constraints and show less variation among vehicles than do their sit/stand components.

D. Weight

1. Vehicle (Empty)

The typical weights shown in Table 3-2.1 exceed or equal the actual weights reported for nearly all vehicles in each of the four groups. The only major exception is the SOAC in the 75' (23 m) HRV group. It has an empty weight of 90,000 lb. (40,800 kg) as shown in Appendix A-5(2).

Suspension and propulsion equipment contribute a large portion of the vehicle weight. Despite variations in the weight of this equipment, and despite the variety of materials used in car frames and bodies, vehicle weights are surprisingly proportional to overall vehicle size.

Based on the nominal area of vehicles (body length x width), the unit weights of vehicles within each group are close to the values for lb/ft.^{2} (kg/m^2) shown in Table 3-2.1. The values will yield reasonable estimates of vehicle weights if it is desired to calculate the effects of moderate changes of up to 10% or 15% in "typical" lengths and/or widths. Again, exceptions to the tabulated unit weights are in the 75' (23 m) HRV group. The exceptions are the relatively heavy 125 lb/ft.^{2} (610 kg/m^2) stainless steel SOAC, and the lightweight 75 lb/ft.^{2} (366 kg/m^2) aluminum cars manufactured for BART and Toronto.

2. Passengers (Crush Weight)

It is recommended that 150 lb. (68 kg) be used as the average weight per passenger. The crush passenger weights shown in Table 3-2.1 are based on this figure. The difference between empty and gross vehicle weights listed in the Lea Compendia indicates assumed passenger weights ranging from 135 lb. to 175 lb. (60 kg to 80 kg) although most fall in the 145 lb. to 155 lb. (65 kg to 70 kg) range. The latter range is not significant in terms of gross vehicle weight estimates.

It is significant, however, that crush passenger loadings consistently represent about one-third of the gross weight of vehicles in all four groups.

3. Vehicle (Gross)

The gross vehicle weights shown in Table 3-2.1 reappear in Section 4-2 in the axle loadings that may be used for the preliminary design of structures and other track support systems. These are conservative loadings that are seldom exceeded by the reported gross weights of vehicles in any of the four groups, even when high density passenger loadings have been utilized. The only significant exception is the SOAC which is estimated to gross 123,000 lb. (56,000 kg) with a 220-passenger (low density) loading or 135,000 lb. (61,000 kg) with a 300-passenger (high density) loading as shown in Appendix A-5(2).

E. Configurations and Operations

1. Purpose

The purpose of this subsection is to discuss some additional vehicle features and alternatives that affect system operations and trackway design.

2. Vehicle Shapes and Clearance Features

The HRV is characteristically blunt-ended and is rectangular in plan view as shown in Appendix A-5(3). Many cars are flat-sided, but recent designs are often slope-sided and are widest in cross section at a point somewhere between threshold and window sill height. This shape compensates for vehicle roll and reduces lateral displacement. Three rub rails are often provided along sides of vehicles designed for subway use. One is below the threshold at the face of the passenger platform; the second (belt rail) is at the highest point of maximum width (the break point for a slope-sided cross-section); the highest rail is placed at a critical point for vehicle roll where the roof-rounding begins. The typical roof-top rounding tends to keep vertical clearance requirements more nearly constant.

The cross-sectional area of HRVs usually varies from 90 $ft.^2$ to 124 $ft.^2$ (8.4 m^2 to 11.5 m^2). A typical value is 108 $ft.^2$ (10.0 m^2) which represents over 50% of the area of a typical single-track tunnel section which is about 200 $ft.^2$ (18.6 m^2), regardless of whether the tunnel is circular, rectangular, or horseshoe shaped. This percentage relationship assures a piston effect which is often counted on to provide much or all of the underground ventilation between stations as discussed in Section 3-5, Subsection E, under "Ventilation" and "Portal Design."

As shown in Appendix A-4(3), the LRV usually has tapered or rounded ends in plan view. This is not done for aerodynamic reasons, but to reduce outswing clearance requirements on short radius curves and to be compatible with radial couplers that swing in a semi-circle.

The sides of HRVs and LRVs are generally free of projections. The vehicle clearance envelopes and running clearances discussed in Section 4-3 allow for slight projections such as lights and mirrors.

3. Basic Vehicles and Trains

Recent HRT system developments and proposals provide for dual-directional operation of the basic train unit. The basic units are sometimes single independent cars with an operator's compartment (with controls, wind-shield, headlights, etc.) at each end of the car. More often, a pair of similar cars, each with one operator's compartment, is married (or permanently coupled) so that the pair is a dual-directional unit with a control cab at each end.

Off-peak service is provided by one or more basic units (up to the equivalent of four cars) while 6- to 8- or sometimes 10-car trains are utilized during peak periods. Most often trains are comprised of a series of married pairs. In some instances, as in the BART system, up to eight "B" cars without operator's cabs are inserted between the paired "A" cars to form a train. Train lengths and operations must be compatible with platform length and capacity.

A majority of the non-articulated 50' (15 m) LRVs have been constructed for single-directional operation (with right side boarding only), although some, including the PCC car, have been designed to operate in either direction. These LRVs can be coupled, but are usually limited to a train length of 2 or

3 cars. The single-direction CLRV, designed as a compatible replacement for the PCC car in Toronto and elsewhere, is intended for train operations up to six cars in length.

The various single-articulated LRVs in use throughout the world are about evenly divided between one-way and two-way operation. The single-direction vehicles are often comprised of one motorized segment with a trailer unit behind the articulated joining. The vehicles in the 73' (22.25 cm) articulated group, perhaps more typical of current development intended for use on this continent, are designed for two-way operation, either exclusively or as an option. The two-way vehicles are usually powered at the end trucks, while the middle (third) truck under the joint is not motorized. These articulated vehicles often operate as single units, but can be coupled into trains of 2, 3, or 4 units for high (line-haul) capacity, usually in conjunction with a grade separated right of way. The new SLRVs being acquired by the San Francisco Municipal Railway (MUNI) are to be used in 3-to 4-car trains when in the subway below Market Street, but will operate singly on city streets.

New HRVs or LRVs must be compatible with old vehicles if they are to be operated in mixed trains during expansion or upgrading of the system.

4. Single/Double-Ended Vehicle Considerations

As mentioned previously, virtually all HRVs or basic units are designed for two-way operation, while LRVs may be either single or double ended. Some additional vehicle characteristics and system operational consequences related to single and double-ended units are considered herein.

A single-ended car with doors on only one side and a single operator's compartment has a greater seating capacity potential than a double-ended car with similar dimensions. Seats may be fixed in a forward facing position for one-direction operation. With two-way operation, seats may be reversible or arranged so that half of the transverse seats face backwards. With either mode, seating arrangements may include some longitudinal bench-type seating along one side or both sides of the car.

The single-direction LRV (which has a limited ability to back up) imposes certain operational requirements. Loop tracks are needed to reverse direction at each end of the line and for intermediate turn-backs and in yard and shop areas. This is equally true for single track and for double track lines.

The ability of LRVs to negotiate slow speed, short radius turns minimizes right of way requirements for turnarounds which can sometimes be accomplished on lightly traveled streets.

Double-ended cars can change direction with simple crossovers between multiple tracks and can use dead end tracks at terminals.

5. <u>Access to HRVs: Platforms and Car Doors</u>

In HRT systems, fares are prepaid and the rapid loading and discharging of passengers is facilitated by platforms which are approximately level with the vehicle floor. Such systems normally employ dual tracks and often utilize a single platform between the tracks (rather than an outside platform to serve each track) in order to minimize the stairs, ramps, elevators, and escalators required for passengers to reach the platform from another level. This concept is equally appropriate for grade-separated access to platforms whether the tracks are at ground level or above or below ground.

The fit between vehicle and platform must make allowances for vertical and horizontal tolerances. Platform heights for

HRVs vary from 39" to 46" (99 cm to 117 cm) and are often 44" (112 cm) above the rail. Platforms are sometimes designed to be flush with the vehicle floor, but more often are 1" to 5" (2.5 cm to 13 cm) below the car floor. The nominal horizontal clearance gap between platform and car for most HRT systems in this country is between 2" and 3 3/8" (5 cm and 9 cm). A gap of 2 3/4" (7 cm) is a representative value. Some cars are equipped with automatic leveling valves to compensate for changes in passenger loading and distribution and to maintain a constant floor height and car-platform relationship. See "Handicapped Access" in Subsection F of Section 3-6 and "Platforms" in Subsection C of Section 4-3 for more on clearance gaps between vehicles and platforms.

In both HRT and LRT systems, the vehicles are boarded from one side only at any given stop. The doors of HRVs are designed to accomplish maximum anticipated passenger exchange rapidly, usually within a station dwell time of about 20 seconds, in order to maintain headways and schedule speeds. Since fares are prepaid, all doors can be used for boarding. Sometimes the number of seats is limited to make interior passenger movement easier.

The 50' (15 m) HRVs typically have two doorways per side, while the 75' (23 m) HRVs usually have three or four doorways per side. The doorways are typically 50" (127 cm) wide and 76" (193 cm) high with double doors that slide apart (rather than fold). The doorways are above floor/platform height and all side door thresholds are parallel to the platforms.

Appendix A-5 contains representative data and diagrams to illustrate a number of HRV doorway features. Most HRVs are equipped with narrow doors through one end or both ends of the car. The end doors, which are approximately as wide as the center aisle, are not usually intended for car-to-car passenger movement during normal operations.

6. Access to LRVs: Steps, Platforms, and Doors

LRVs have been adapted to accommodate passenger exchanges at curb stops or platforms or both. On double-track systems, center platforms can be utilized where LRVs run on an exclusive grade-separated right of way. The many single-ended LRVs with doors on the right side only are limited to passenger traffic from outside the double track unless reverse direction operation is instituted to make center loading possible.

Fares are often collected on board in the case of street operations. In this mode, the manned front and rear doors are designated as entrances and the doors in between are exits.

Prepaid fares are used to enhance rapid passenger boarding from floor-level platforms. However, because of body taper, the front and rear doors in most LRVs are skewed to platform alignment. They are not usable at platform stops, and passenger exchange is limited to the remaining doors. This situation tends to be counter-productive because it occurs on those portions of the system where high-capacity performance is most desired. In such circumstances, dwell times at less crowded "streetcar stops" can be shorter than at platform stops.

Since dwell times on LRT systems can accumulate to an appreciable portion of total travel time, "Pre-Metro" vehicles have been developed for systems where future upgrading to "rapid transit" operations is judged to be an overriding consideration. These cars are designed with quick-acting doors that can be used efficiently at platform stops. The term "Pre-Metro" indicates that LRT system planning and development call for the progressive elimination or reduction of street operations and the extension of rapid transit operations.

Most operating LRVs have fixed steps which are recessed into the vehicle. They are designed for street operation exclusively, and two-thirds of them operate in a single direction only. The floors in these fixed-step vehicles are 34"± 1 1/2" (86 cm± 4 cm) above the rail. Step rise increments of 15", 10", and 9" (38 cm, 25 cm, and 23 cm) are typical. The lower step, 15" (38 cm) above the rail, works well with a curb about half as high. Low platforms approximately even with the lower step are used also, although passengers must negotiate a gap between the platform and the skewed front and rear steps. Platforms at second step or car floor level are not used with fixed steps because of the wide gaps involved at all the stairwells.

Appendix A-4 supplements Table 3-2.1 with additional information about LRV step and door arrangements.

The doors on fixed-step LRVs are the 2-leaf, folding type. Most are double doors which fold aside in a doorway about 52" (132 cm) wide. A few vehicles have one or two single doors about 25" to 30" (63.5 cm to 76 cm) wide. The doors are typically about 86" (220 cm) high and extend to the bottom step so that they enclose the stairwells. The doors open by folding into the stairwells which must be located clear of the trucks. This limits side door positioning.

A number of LRVs are equipped with folding or swiveling steps that will adjust for high or low level passenger exchange. These adjustable steps are standard equipment on some vehicles, and are also available as optional equipment in lieu of fixed steps on others.

With the exception of the nonarticulated CLRV, all cars with a high/low capability or option are articulated, dual-directional cars over 65' (20 m) in length. Two articulated LRVs being developed for Pre-Metro use (in England and Belgium) are designed for high platforms only. Both of these are two-directional, but one has a single-directional option.

The floors in Pre-Metro cars are typically about 34" (86 cm) above the rail (as in fixed-step vehicles). The floors in cars with adjustable steps are 38"± 1" (965 cm± 2.5 cm) high and the steps usually rise in 15", 12", and 11" (38 cm, 30.5 cm and 28 cm) increments from rail level.

The majority of 50' (15 m) nonarticulated LRVs have 3 doors per side, but a number of them, including some versions of the PCC car and the newer CLRV, have only 2 doors per side. Nearly all of the 65' to 90' (20 m to 27 m) articulated cars have 4 doors per side. Two cars have more doors, but the only car with fewer is the SLRV with 3 doors.

LRVs do not have end doors for passage between cars in multicar trains, but the articulation units which join main car sections are mounted on the center truck bolster and form an integral part of the car body that provides for safe passenger access between car sections.

Most cars equipped to handle platform loading use double, 2-leaf, folding doors about 60" (150 cm) wide. Pre-Metro cars tend to use sliding, bi-parting doors about 51" (130 cm) wide. The English Pre-Metro car and the SLRV have plug-type doors. These are flush, bi-parting doors which move outward and then slide along the side of the vehicle to open. When open, they project 2" (5 cm) or so from the side of the vehicle.

When cars are equipped to accommodate high platforms, no matter how the doors operate, they most often are about 75" (190 cm) high and extend upward from the car floor. The doors therefore open at or above platform height. With few exceptions (one being the SLRV) all doors are positioned parallel to platforms.

7. <u>U.S. Standard LRV: MUNI Configuration</u>

The SLRV was conceived as a replacement for the PCC car and for use in LRT systems. Power collection is by overhead pantograph.

The Massachusetts Bay Transportation Authority (MBTA) and the San Francisco Municipal Railway (MUNI) have ordered similar double-ended, 73' (22.25 m), single-articulated vehicles that differ most notably in seating and step arrangements. MUNI is acquiring 100 vehicles to replace the present PCC fleet.

The proposed MUNI application provides an illustrative example of how vehicle selection and option choices can fit and affect system operations.

The new vehicles, in trains up to 4 cars in length, will operate in a new subway with nine high-platform stations and turnstile fare collection. The platforms are 34" (86 cm) high, 8' to 10' (2.4 m to 3.0 m) wide, 300' to 450' (91 m to 137 m) long, and have a capacity of 10,000 to 13,000 passengers per hour.

The design headway is 2 minutes for subway operation and 4 to 10 minutes for street running on the balance of the system. Subway dwell times are planned to be in the 20 to 30 second range, and street stops are expected to be 8 to 15 seconds.

The cars have 3 doors per side, but the skewed front doors (with fixed steps) will not be used at platform stops. A mechanical device at the two central doors will lower a portion of the floor to form a 2-step stairwell for street running.

All the doors are plug doors that extend down to the lower step rather than to the car floor in the usual Pre-Metro configuration. The doors when open are to project no more than 2" (5 cm) from the car body in order to minimize the clearance gap at platforms.

8. Vehicle Features and Equipment Options

The transit vehicle contributes to the safe, reliable, efficient, and comfortable operation of a transit system. In selecting a vehicle, such considerations as performance, comfort, revenue, and environmental factors are weighed against acquisition, maintenance and operating costs. Some of the possible material and equipment choices are presented in the following considerations.

- Interior and exterior materials can be selected for their ability to resist vandalism and to discourage graffiti. Different degrees of maintenance effort are required.

- Materials and structural designs can affect vehicle weight and crashworthiness.

- Features such as air conditioning, heating, waste-heat utilization, insulation, and regenerative braking can influence energy requirements and costs.

- Sound proofing can minimize interior noise, while modern suspension systems and resilient wheels, especially in conjunction with continuous welded rail (CWR), can reduce both wayside and on-board noise levels.

- Primary and secondary suspension systems can provide vertical and lateral cushions to improve ride quality.

- o Chopper controls that modulate power for smooth acceleration and braking will also permit the use of regenerative braking.

- o Automatic detection and control of wheel slip and spin, augmented by automatic load weighing systems, can be provided to help achieve uniform acceleration and braking rates.

- o A weighing system, combined with a pneumatic secondary suspension system and control valves, can adjust for changes in passenger loading and can level the car floor at a constant height above the rail.

- o The degree of complexity of on-board instrumentation can be selected to match requirements for vehicle performance, system control, and communications.

- o Other options that might be appropriate for certain systems include automatic coupling and uncoupling, high-level and low-level boarding, and a combination of overhead and contact rail current-collecting devices.

F. Vehicle Costs

The vehicle cost data herein provide a basis for preparing or reviewing preliminary estimates.

1. Cost Ranges and Trends

Vehicle costs have been rising more rapidly than construction cost indexes. Figure 3-2.2 shows that the cost per vehicle in the United States more than trebled in the decade from 1965 to 1975.

In 1975, the cost range was on the order of $300,000 to $600,000 for modern HRVs and LRVs which are much alike in size, comfort, and performance. This 2:1 relationship between the high and low limits of the cost range has been typical since the early 1950's.

Vehicle costs depend on the size of vehicle, equipment options, and the number of vehicles ordered. All electrical components may account for one-half the cost of the vehicles and chopper control alone can add about 5%. Within the current range, HRVs with sophisticated control equipment tend to be 10% to 20% more expensive than less sophisticated vehicles. The correlation between vehicle cost and any given vehicle feature is not very strong. Vehicle area (nominal length x width) appears to be the best index, but in 1975 even this varied from $450 to $700 per square foot ($4,850 to $7,550 per square meter) for vehicles of all types.

In contrast to the cost of $300,000 and up for new vehicles, DMT estimated in 1976 that PCC cars might be acquired, reconditioned, and modernized for $110,000 each.

Various projections indicate that by 1980 rail transit cars will range in cost from $0.5 to $1.0 million. Figure 3-2.2 indicates that if recent trends continue, vehicles could cost one or two million dollars apiece by 1990.

2. Number of Vehicles

The number of cars utilized in any given rail transit system depends on the physical characteristics of the system and on related policies and decisions affecting its operations. Operating factors and their effects on fleet size are discussed in Section 3-9, Subsection E.

Figure 3-2.3 is based on the number of vehicles employed by operating systems in North America and abroad and on projections for systems under construction. The figure gives ranges that include most HRT and LRT systems of various sizes as measured by single track increments of length up to 140 miles (225 km). Vehicle ranges can be extrapolated to double or more the track length shown. The broad ranges with respect to mileage (or any other system feature) illustrate the influence of specific conditions and factors. The figure sets limits for reasonable expectations. Therefore, it would require special or unusual circumstances to stretch these.

3. Vehicle Miles and Life

The service-life expectancy for rail transit vehicles is usually considered to be 20 to 40 years. A normal life of 30 years is most commonly used for amortization. To minimize LRT costs, consideration might be given to reconditioning 30-year old PCC cars with the expectation of extending their service life by 15 years.

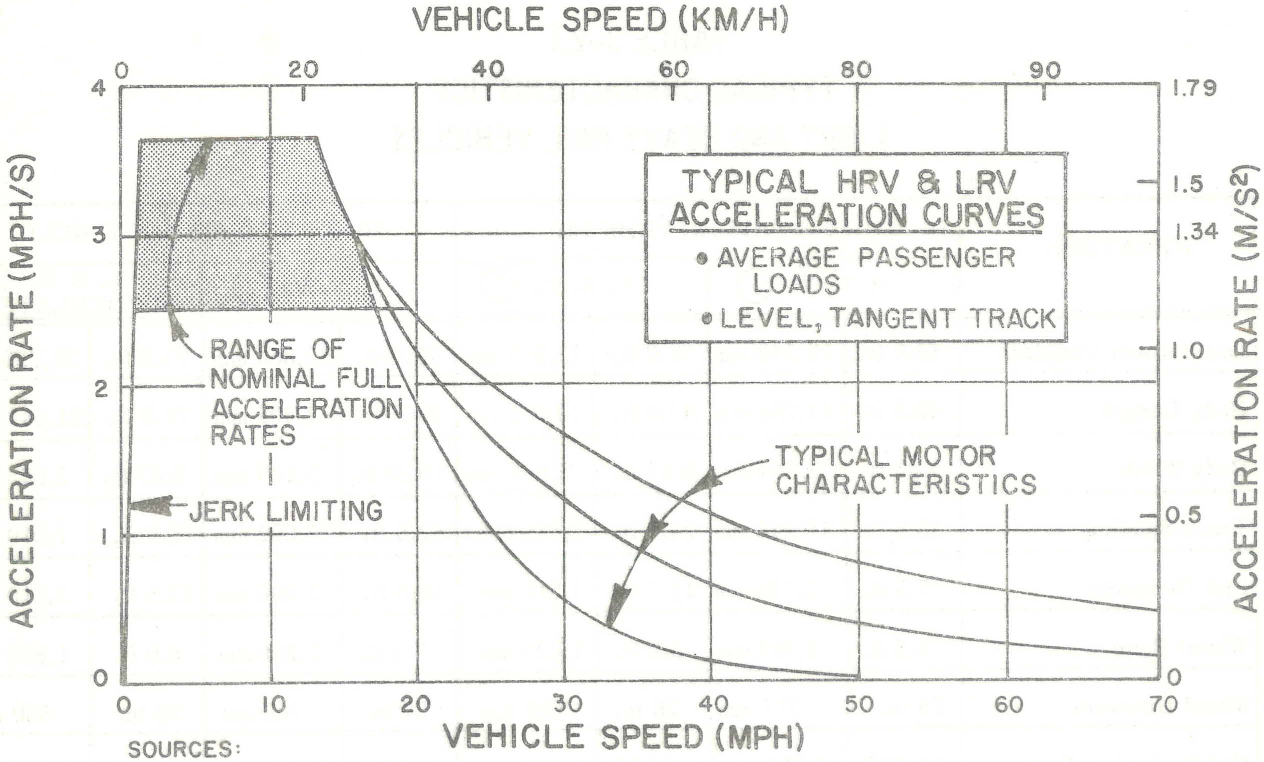
The average annual mileage reported for most operating LRT systems falls in the range of 20,000 to 35,000 miles (32,000 to 56,000 km) per vehicle. For HRT systems the range is more on the order of 30,000 to 50,000 miles (48,000 to 80,000 km). Actual and projected vehicle maintenance costs are often expressed in terms of vehicle miles. Inspection intervals and mean time between failures (MTF) are also expressed in this manner. MTF is used as a measure of equipment performance and reliability.

TABLE 3-2.1
TYPICAL CHARACTERISTICS
LIGHT AND HEAVY RAIL VEHICLES

CATEGORY	FEATURE	50-FT.(15 m.) VEHICLE				70-75FT.(21-23 m.) VEHICLE			
		H. R. V. (1)		L. R. V. (1)		H. R. V. (2)		L. R. V. (2) (ARTICULATED)	
DIMENSIONS	Length over Couplers	50.0 ft.	15,240 mm	51.0 ft.	15,545 mm	75.0 ft.	22,860 mm	73.0 ft.	22,250 mm
	Body Length	48.5 ft.	14,783 mm	49.0 ft.	14,935 mm	73.5 ft.	22,403 mm	71.0 ft.	21,641 mm
	Body Width	9.33 ft.	2,844 mm	8.67 ft.	2,643 mm	10.33 ft.	3,149 mm	8.67 ft.	2,643 mm
	Truck Spacing	33.5 ft.	10,211 mm	24.0 ft.	7,315 mm	52.5 ft.	16,002 mm	23.0 ft.	7,010 mm
	End Overhang	7.5 ft.	2,286 mm	12.5 ft.	3,810 mm	10.5 ft.	3,200 mm	12.5 ft.	3,810 mm
	Wheel Base	6.5 ft.	1,981 mm	6.0 ft.	1,829 mm	7.5 ft.	2,286 mm	6.0 ft.	1,829 mm
	Wheel Diameter	28 in.	711 mm	26 in.	660 mm	30 in.	762 mm	26 in.	660 mm
	Height-Rail to Roof	11.75 ft.	3,581 mm	11.50 ft.	3,505 mm	11.75 ft.	3,581 mm	11.50 ft.	3,505 mm
	Height-Rail to Floor	44 in.	1,118 mm	34 in.	864 mm	44 in.	1,118 mm	34 in.	864 mm
PERFORMANCE	Maximum Speed	70 mph	113 kmph	50 mph	80 kmph	75 mph	121 kmph	50 mph	80 kmph
	Accel. & Decel. Rates	3.0 mph/s	1.34 m/s^2	3.0 mph/s	1.34 m/s^2	3.0 mph/s	1.34 m/s^2	3.0 mph/s	1.34 m/s^2
	Min. Horiz. Turn Radius	90 ft.	27.4 m	45 ft.	13.7 m	300 ft.	91.4 m	45 ft.	13.7 m
	Min. Vert. Curve Radius	900 ft.	274.3 m	900 ft.	274.3 m	2,000 ft.	609.6 m	500 ft.	152.4 m
	Maximum Grade	± 4%	± 4%	+6%, −8%	+6%, −8%	± 4%	± 4%	+6%, −8%	+6%, −8%
CAPACITY	Number of Seats	50	50	38	38	72	72	52	52
	Standees (Design)	52 @ 2.7 ft.^{2} ea.	52 @ 0.25 m^2 ea.	90 @ 2.1 ft^2 ea.	90 @ 0.20 m^2 ea.	111 @ 2.7 ft.^{2} ea	111 @ 0.25 m^2 ea.	83 @ 2.7 ft.^{2} ea	83 @ 0.25 m^2 ea.
	Standees (Crush)	100 @ 1.4 ft.^{2} ea	100 @ 0.13 m^2 ea.	135 @ 1.4 ft.^{2} ea	135 @ 0.13 m^2 ea.	150 @ 2.0 ft^2 ea.	150 @ 0.19 m^2 ea.	160 @ 1.4 ft.^{2} ea.	160 @ 0.13 m^2 ea.
	Total Passengers (Crush)	150	150	173	173	222	222	212	212
WEIGHT	Vehicle (Empty)	50,000 lb. (110 lb/ft^2)	22,680 kg. (537 kg/m^2)	42,000 lb. (100 lb/ft^2)	19,051 kg. (488 kg/m^2)	72,000 lb. (95 lb/ft^2)	32,659 kg. (464 kg/m^2)	65,000 lb (106 lb/ft^2)	29,483 kg. (518 kg/m^2)
	Passengers (Crush)	23,000 lb.	10,432 kg.	26,000 lb.	11,793 kg.	33,000 lb.	14,968 kg.	32,000 lb.	14,515 kg.
	Vehicle (Gross)	73,000 lb.	33,112 kg.	68,000 lb.	30,844 kg.	105,000 lb	47,627 kg.	97,000 lb.	43,998 kg.

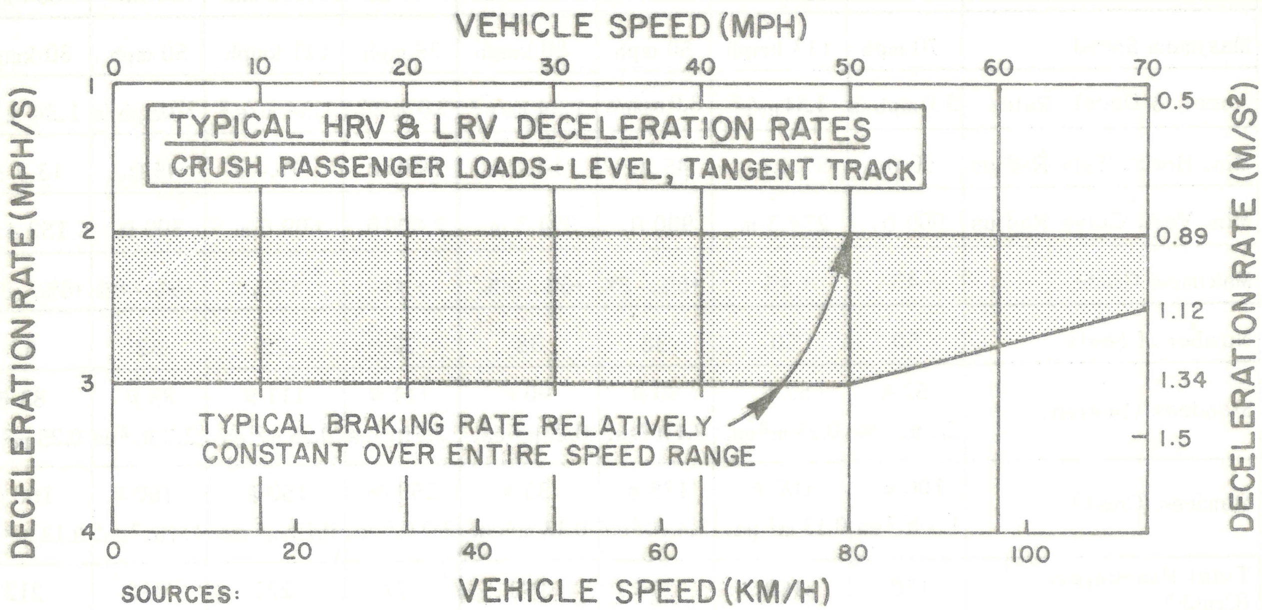
Data Sources: Lea Transit Compendia (HRT Vols. I & II; LRT Vols. I & II)

Note: HRV and LRV designators (1) and (2) shown in column headings serve as reference devices for these "Typical Vehicles." See Figures 4-2.1, 4-2.2, 4-3.4, and 4-3.5.



SOURCES:

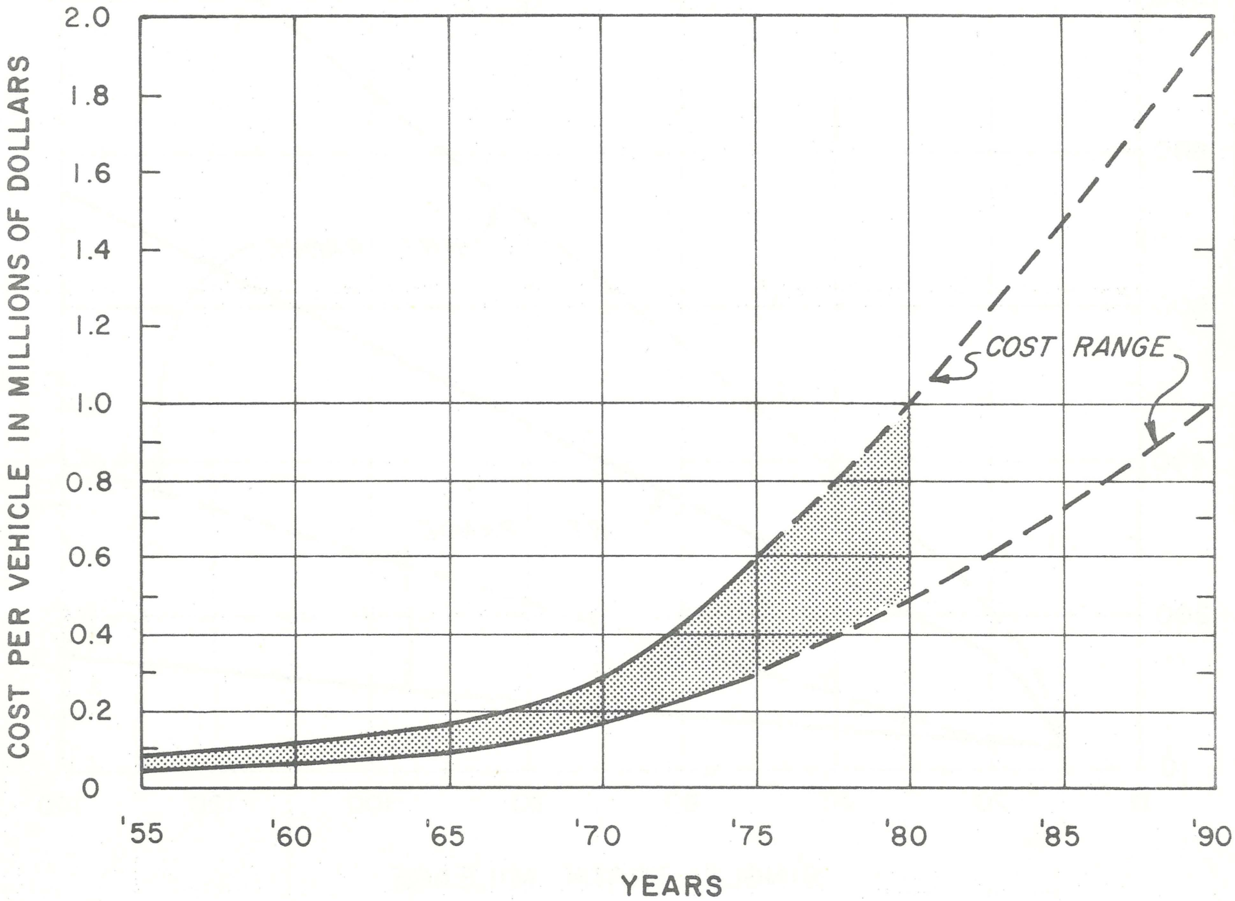
NYCTA (Fig. 5.10)
ASME (Fig. 2)
WMATA (Fig. VII.3)
SOAR (Fig. 59)



SOURCES:

NYCTA (Fig. 5.12)
SOAR (Fig. 90)
ASME (Fig. 2)
TTC (D. S. 3.1. 2. B)
BART (Fig. 2. 1. 2)
BRRTS (Fig. IV. 3)
WMATA (Fig. II. 8)

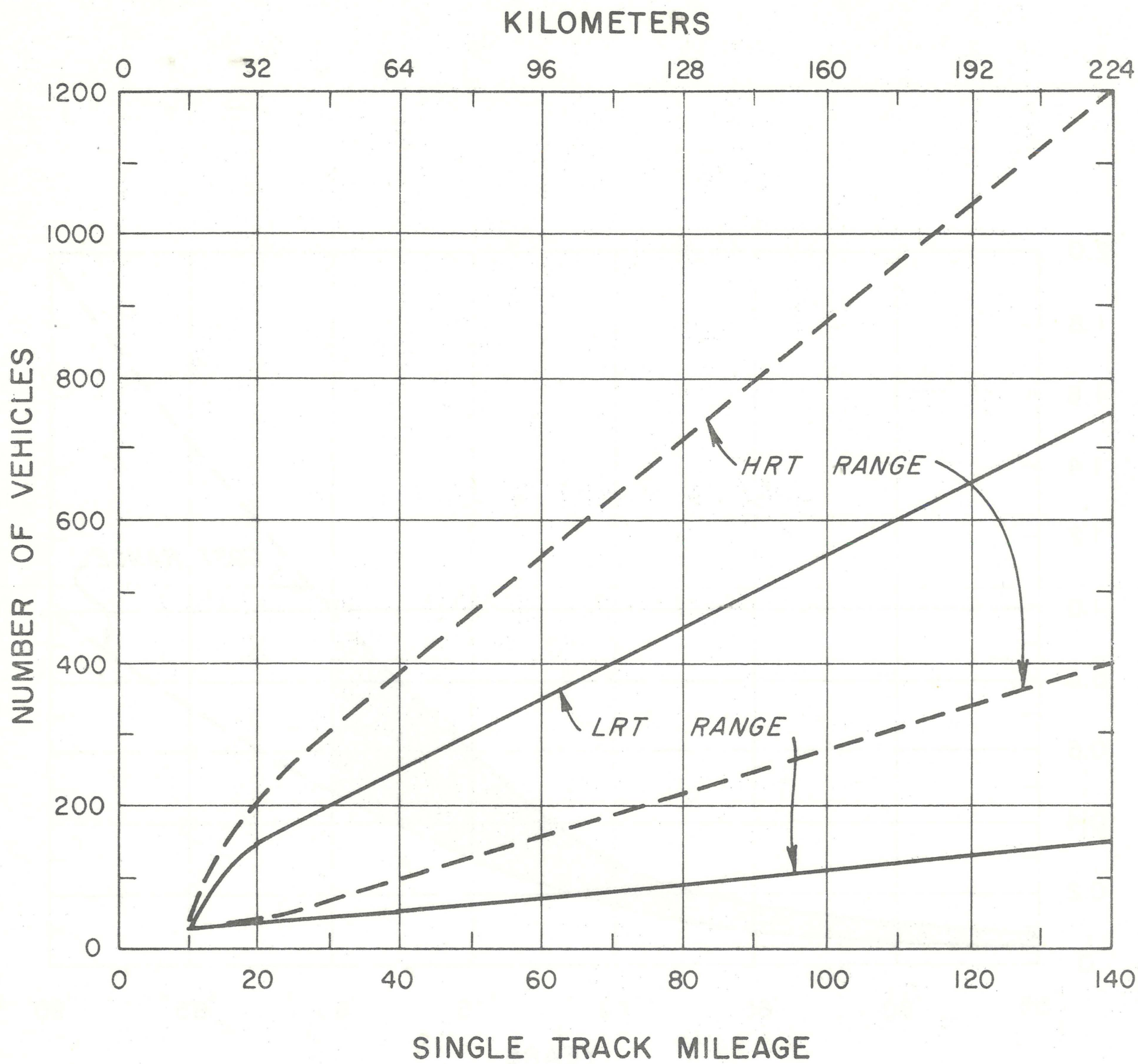
SOURCES: SEE ABOVE	RAIL TRANSIT CRITERIA HRV AND LRV ACCELERATION/DECELERATION CHARACTERISTICS FIGURE 3-2.1	Caltrans JUN. 77



SOURCES:

SOAR (Table 33; P.222)
CUTS (Tables 15 & B-9; Fig. B-8)
Ref. CP-2 (Pp. 25, 95 & 119)
Ref. R-2 (Cost Est. Factors 8 & 9
Ref. R-5 (Table 1)
Ref. R-7 (Tables 4-1 & A-9; Pp. 44 & 69)
Ref. C-7 (Pp. 1, 29, 57, 85 & 113)

SOURCES	RAIL TRANSIT CRITERIA	
SEE ABOVE	HRV AND LRV TYPICAL COSTS FIGURE 3-2.2	Caltrans OCT 77



NOTES:

1. Single track length is double the route (or system) length for a double-track system.
2. HRV count includes each vehicle (whether or not motorized or equipped with a cab) regardless of how coupled (married pair = 2 vehicles, etc.)
3. LRV count includes motorized vehicles and trailers, but single-and double-articulated vehicles are counted as one vehicle only.

SOURCES

Refs. C-3 & C-5
Refs. R-7 (Tables 4-2 & 5-1)

RAIL TRANSIT CRITERIA

NUMBERS OF VEHICLES for HRT and LRT SYSTEMS

FIGURE 3-2.3

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3-3 RIGHTS OF WAY

A. General

LRT systems are distinguished from HRT systems by the broad spectrum of rights of way that may be employed. The degree of traffic separation to be provided is a major determinant of system capital costs and of performance limits.

Location, design, system operations, and costs cannot be considered separately. A location cannot be selected without considering the nature and purpose of the facility. Desired system operating characteristics, land forms and development, and total environment influence the manner in which right-of-way access is to be controlled. The utilization of public space such as streets and sidewalks tends to dictate surface or cut and cover locations and is a strong influence on aerial locations. Tunneling can minimize right-of-way costs, traffic handling problems, and other construction disruptions. Tunnel aligment is independent of surface development to some degree, but location is still influenced greatly by geologic and soils conditions, requirements for stations and mode change facilities, and other considerations such as ventilator shaft locations and underground utility conflicts.

B. Classification

Rail transit rights of way are classified into three basic categories:

- Category A is an exclusive, fully controlled right of way with complete grade separation of vehicular and pedestrian crossings. HRT systems operate only in this manner, but portions of LRT systems may use this category.

- Category B is a semi-exclusive, partially controlled right of way. This category includes operations primarily on reserved rights of way separated from other traffic except at grade crossings. It may share reserved lanes with buses or be located in roadside areas or medians of separated roadways.

- Category C is a non-exclusive, shared right of way typified by street car operation in mixed traffic with autos and buses.

Section 4 of Appendix A-11 describes these categories in some detail. LRT systems are characteristically Category B operations, but may contain segments of all categories. In Category C, the speed of transit vehicles can be no greater than that of other traffic, and travel time is extended by additional passenger stops.

C. Use of Existing Corridors

A number of existing right-of-way opportunities look attractive, especially for HRT usage, from the standpoint of minimum community disruption and in terms of cost and time savings for acquisition. Such things as abandoned or little-used railways, trolley car lines, electric power transmission lines, old canal beds, linear parks, and highway medians and roadsides have been used in the past. They are worth considering where their locations coincide with travel corridors and user activities.

Some general considerations for several types of corridors are presented below. Illustrations and more detailed discussions of the advantages and disadvantages of various corridor opportunities may be found in References P-13, R-6, and R-9 listed at the end of this manual.

1. Railroad Rights of Way

The conversion of abandoned or relinquished railroad trackage may be the simplest and least costly right-of-way adaptation for rail transit use, but could still present the usual at-grade street crossing problems.

The sharing of lightly used railroad freight trackage poses institutional, jurisdictional, and operational problems. Initial schedule conflicts may be aggravated by a desire to change either transit or freight service, or both, in the future. Differing clearance requirements would be governed by railroad standards and would be complicated by the introduction of electrification and passenger loading facilities. Train lengths and stopping characteristics also differ markedly. Where separate tracks share a common roadbed or right of way, adequate space must be provided for track maintenance, including tie replacement.

2. Freeways

Much interest has been shown in combining rail transitways and appurtenances with existing or proposed freeways in order to utilize a fully controlled right of way and to take advantage of a completely grade-separated facility in a heavily traveled corridor. However, much of the apparent advantage of a joint facility is lost unless the trackbed is constructed at essentially the same elevation as the freeway roadbed regardless of whether it is elevated, at-grade or depressed. For instance, aerial transit structures placed in freeway medians, and requiring a third level of separation at street crossings or interchanges, are costly and tend to complicate rather than simplify design and construction problems.

A double-tracked light or heavy rail installation requires a minimum of 25-27 feet (7.5-8.0 meters) of clear width in or on structures or between barriers separating rail vehicles from other adjacent vehicles. This basic width accommodates a walkway 2 feet (60 centimeters) wide on each side, but does not include allowances for the following elements that are additive and tend to be cumulative:

- o Barriers and shoulders
- o Passenger islands, platforms, and shelters or structures
- o Stairways, escalators, and elevators
- o Bridge supports and other freeway structural elements
- o Spiral track offsets to circular freeway curvature
- o Transit vehicle overhang on curves

Tracks can be placed alongside the freeway lanes or in a median location, but with either scheme, concentrations of mixed-mode traffic and a variety of activities tend to produce conflicts in freeway interchange areas. Some problems are common to all joint freeway-transit schemes and others are unique to each situation. Typical advantages and disadvantages to be weighed and difficulties to be overcome have to do with:

- o Providing structures for rail access to freeway median locations
- o Separating alongside rails from freeway ramps
- o Fitting on-line stations within median or interchange constraints.
- o Providing access to stations
- o Providing parking facilities or alternatives

Many physical difficulties such as those relating to the compatibility of alignments and horizontal and vertical clearances, construction site access, and construction disruption are more easily dealt with when planning and designing a joint facility than when fitting a rail system into an operating freeway. On the other hand the coordination required for the design, funding and construction of a combined facility adds appreciably to the complexity of a joint project.

3. <u>Other Potential Corridors</u>

The availability and feasibility of using existing rights of way should be investigated at an early stage in the consideration of alternatives. There may be valid reasons why corridors have remained unused or lightly used.

Some of the factors to be considered in connection with inserting rail transit are:

- Accessibility for construction and maintenance
- Accessibility to users
- Compatibility of joint usage
- Compatibility with surroundings
- Suitability for desired degree of access control
- Feasibility of other potential uses that would be foreclosed

D. Criteria and Requirements

The right-of-way take must provide sufficient space to construct, maintain, operate, and protect all aspects of the transit system. Temporary easements may be appropriate for some construction purposes or other needs, but operational interests require permanent takes in most instances.

The take is influenced by topography, drainage, utilities, service roads, structures, side slopes and retaining walls, and by affected properties. In some instances involving aerial and underground structure considerations, upper and lower limits, as well as lateral limits, are established. The limits of such envelopes are defined by vertical and horizontal planes.

1. Limits

Table 3-3.1 summarizes typical limits and minimum right-of-way dimensions for basic grade line and structural configurations. The guideline limits shown are for Category A rights of way, but also serve as a basis for establishing Category B and C limits when modified appropriately to fit existing conditions and future needs.

As noted in Table 3-3.1, lower limits are normally not prescribed, but where required by local limiting conditions, the dimensions shown represent desirable minimums.

Permanent surface easements are preferred for surface and aerial construction, but must be modified where undue restrictions would be imposed as in the case of an aerial transit structure crossing another right of way.

The preferred upper limit for underground structures is 10 feet (3 meters) above the high point of the structure. The ground surface may be used as an upper limit when it is less than 10 feet (3 meters) above a structure if the minimum depth of cover requirement, often 8 feet (2.5 meters), can be met.

When it is necessary to designate an upper limit for a surface trackway, it must be compatible with specified vertical clearance requirements.

The lateral limit of 13 feet (4 meters) for surface construction is increased to 15 feet (4.5 meters) on the high side of superelevated sections. These suggested minimum lateral dimensions are appropriate for exclusive rights of way, but may be otherwise designated and agreed to on restrictive rights of way in shared highway or railroad corridors. Minimum lateral limits must be extended to provide for such things as slopes, service roads, and drainage. In retained cut or fill sections, the outside face of retaining wall footings may be used as the minimum distance for right-of-way width.

The limit of right of way for stations is often set 3 feet (1 meter) from the outside face of the structure. When multi-level stations are located within multi-purpose buildings, different easement limits may be designated at each level.

Easement areas must be provided for installations such as fan and vent shafts, substations, and escalators. Preferred locations are contiguous to the transit system right of way, but they may be isolated. The installations must be accessible whether they are located in public space or within private property.

Rail transit rights of way should be suitably monumented.

2. <u>Access Control</u>

Category A rights of way are protected so that external vehicles and pedestrians are denied access except at points of passenger ingress and egress such as stations and parking areas. Right-of-way barriers are erected along surface locations to prevent public access to the tracks and to third-rail electrification. Suitable barriers for separating the public from the transit right of way include fences and walls (or fences on walls) with a minimum overall height of 6 feet (1.8 meters) facing the public side. Where minimum-height barriers might otherwise be mountable, they are topped with barbed wire or some other deterrent.

During construction, work sites and contractors' areas require temporary fencing and barricades to protect pedestrians and vehicles.

E. Costs

Right-of-way requirements and acquisition costs vary greatly and are highly site-specific. Acquisition costs can change rapidly and are therefore also time-specific.

Right-of-way costs can be nominal for Category C locations or for trackbeds utilizing or sharing pre-existing rights of way. Where acquisition is involved for either light or heavy rail systems, right-of-way costs may vary from less than $0.25 million per mile in a suburban area to more than $10 million per mile in the central business district of a city. In addition to different requirements for right-of-way categories and for single or multiple trackways, varied requirements for storage and shop areas and for station and parking facilities contribute to the wide range in right-of-way costs even though relatively low-cost areas are sought for such facilities. Underground construction is an expensive alternative to the acquisition of costly rights of way in metropolitan areas.

TABLE 3-3.1

MINIMUM RIGHTS OF WAY
(GUIDELINES FOR CATEGORY "A" R/W)

TYPE CONSTRUCTION		AT GRADE	CUT & COVER	TUNNEL		AERIAL
				EARTH	ROCK	
TYPE EASEMENT (PERMANENT)		SURFACE	UNDERGROUND			AERIAL
LIMITS	UPPER	* 13' (4m) Above T/R (Where Required)	10' (3m) Above Top of Structure 40' (12m) Above T/R at Stations	10' (3m) Above Top of Structure	10' (3m) Above Top of Structure	13' (4m) Above T/R
LIMITS	LOWER (Where Required by Jurisdictions)	* 10' (3'm) Below T/R	* 10' (3m) Below Low Pt. of Structure 20' (6m) Below T/R at Stations	* 10' (3m) Below Low Point of Structure	* 10' (3m) Below Low Point of Structure	* Surface of Ground (Except Where Crossing Other Rights of Way
LIMITS	LATERAL	EXCLUSIVE R/W 13' (4m) Fr. ℄ Ea. Track, 15' (4.6m) on High Side of Super., or Varies (See Directive Dwgs.) RESTRICTIVE (HWY or RR) R/W As Approved (See Directive Dwgs.)	3' (90 cm) From Outside Face of Structure (Track or Station)	3' (90 cm) From Outside Face of Structure	12' (3.7m) From Inside Face of Tunnel Lining	25' (7.6m) From ℄ Each Track

NOTES

1. Minimum distances shown are to be modified where engineering requirements such as clearances, service roads, rock bolts, or drainage dictate additional needs.
2. All limits are to be vertical or horizontal planes.
3. Use ground surface for upper limit for subways if distance shown extends above ground and minimum depth of cover requirements can be met.
4. Asterisk (*) indicates limits not normally required.

SOURCES: BRRTS (Fig. IV. 12)
SCRTD (Fig. IV. 48)
WMATA (Fig. XII.2)

3-4 ELECTRIFICATION AND CONTROL SYSTEMS

A. Introduction

This section discusses electrification systems used to supply power to rail transit vehicles and presents an overview of vehicle propulsion controls and system-wide operational control features. Appendix A-11 contains CPUC safety control requirements for LRT operations.

The direct-current traction motor has ideal characteristics for the frequent starts and stops inherent in transit operations. Electromechanical cams or solid-state choppers permit operation at various speeds and provide simple control for smooth acceleration and deceleration.

B. Electrification Systems

The principles applicable to the electrification of LRT and HRT systems (and mainline railroads) are much the same. With the present state of the art, overhead wire systems are used for electrified mainline railroads, streetcars, and LRT operations, while a third rail is used for HRT systems.

On mainline railroads, single phase AC high voltage is used to overcome power losses in long distribution systems and the equipment needed for current rectification and voltage reduction is readily accommodated on board the large, powered vehicles.

In the case of transit systems, the use of smaller, lighter vehicles makes it difficult to place power rectification and step-down packages on board. Also, distribution distances are shorter and power losses are reduced. These factors favor the use of a low voltage DC power supply. The distribution system, including transformer substations and feeder systems, becomes somewhat complex, but the onboard system is relatively simple.

1. Power Supply

Rail transit operational requirements for service flexibility and reliability are better met by an external power source than by an on-board power generator. Most often in the United States, commercial high voltage AC is purchased and delivered to transit-owned substations where it is rectified and reduced to low voltage DC. In some cases the utility company constructs the substations and sells DC to the transit system. This trade-off between capital outlay and operating costs warrants thorough consideration.

In determining traction power requirements, consideration is given to the following items:

- o Power demand per car
- o Number of cars
- o Scheduled headway
- o Average speed
- o Length of track section
- o Track profile
- o Number of tracks

If a blended braking option is selected, dynamic/regenerative braking can supplement friction braking and also deliver power back to the substation during deceleration.

The location and capacity of traction-power substations is based on supplying power to cars or trains as demanded by schedules during maximum traffic periods while staying within the limits of permissible voltage drops. For a nominal potential of 600 Vdc, a tolerable variation would be on the order of 450 to 675 Vdc. The power supply should also be designed to keep the system operating when segments of the system fail.

Low-voltage direct current suffers severe transmission losses and cannot be stepped back up to usable voltage, so frequent substations or additional distribution lines must be provided to feed power to the overhead or third-rail systems.

Most existing and planned HRT and LRT systems fall within the 600 to 750 Vdc range. However, BART and BRRTS have chosen 1000 Vdc third-rail systems. This voltage may be found attractive for increasing the operating efficiency of future new systems.

Although a potential of 1500 volts is considered the upper limit for a third-rail system, line voltages of 1200 Vdc or 1500 Vdc are usually carried by overhead distribution systems. The new Tyne and Wear pre-metro system in England uses 1500 Vdc overhead lines with pantograph collectors.

In Chapter V of Moving People Safely, the APTA Committee on Power and Signals presents guidelines for third-rail and overhead power distribution systems.

2. LRT Overhead Power Distribution Systems

Safety considerations require the use of overhead power supply systems for LRT operations at grade. Third-rail power distribution is seldom appropriate because LRT rights of way are usually not completely fenced or grade separated and LRVs may also operate on city streets. Appendix A-8 gives CPUC rules for clearances for overhead conductors and for the use of third-rail electrification.

Typically, LRT substations are spaced 1.5 to 2.0 miles (2.4 to 3.2 kilometers) apart and power is fed to the overhead wire at intervals of about 1,000 feet (300 meters).

There are two basic designs for overhead distribution systems. One is a single contact wire supported at 100' to 125' (30m to 38m) intervals. The largest size contact wire used in LRT systems weights about one pound per foot (1.5 kilograms per meter). In Europe, on some intensely used sections of track, two contact wires are placed side by side to increase electrical capacity.

The other basic overhead system is a multi-wire catenary consisting of one or more messenger (support) wires that maintain the contact wire in an approximately level profile. This system requires fewer support points and the large diameter messenger wire increases the current carrying capacity of the system. This can be an important consideration in LRT system design.

Because of the sag inherent in the simple contact wire suspension system and the varying stiffness of the wire throughout its span, this arrangement is not suitable for top speeds exceeding 65 mph (104 km/h). The catenary suspension systems, normally used on high-speed transit lines, are usually tensioned by weights to secure constant wire tension and eliminate thermal sag.

3. LRT Overhead Power Collectors

LRVs collect power from the overhead contact wire by means of a trolley pole or a pantograph. The less expensive trolley pole is free to track horizontal and vertical wire deflections and has a U-shaped shoe that slides along the wire. Two poles, one for each direction, are required for bi-directional LRVs.

Several forms of pantographs and shoe variations are in use, but they all function in much the same manner. The pantograph is heavier, more complex, and about three times as costly as the $850 trolley pole. At LRV speeds, a single pantograph can be used in either direction. The pantograph provides more efficient current pick up than the pole and is free from dewrirement. The wide pickup shoe on the pantograph can accommodate a zig-zag wire alignment that distributes wear and extends shoe life. Shoe ends are typically turned down to prevent snagging on converging or intersecting wires. The pantograph, supported by springs, exerts 10 to 20 pounds (4.5 to 9 kilograms) of shoe pressure against the contact wire.

The pantograph can be used with a single contact wire or with a multi-wire catenary system. It can be made compatible with trolley pole use so that both can be used during a system change over from poles to pantographs even though overhead designs for each usually differ somewhat. Some LRVs are designed to carry either pickup system, or both systems, without appreciable difference in performance.

Both poles and pantographs are designed to operate over a wide range of wire heights. A range typical of many LRVs would be 12' - 19' (3.7 m - 5.8 m) above the top of rail. Vertical clearance to structures must make an allowance for the depth of the catenary and its support system in addition to the minimum operating height of the pickup device. Under certain conditions defined in Section 5 of Appendix A-11, the CPUC permits a minimum contact wire clearance of 9" (23 cm) above the height of an LRV pantograph in a retracted position.

4. HRT Third-Rail Distribution and Collector Systems

Third-rail electrification employing a contact rail alongside the running rails is used for HRT systems that have grade-separated or completely fenced, exclusive rights of way and high-level loading platforms that minimize the chances of lethal contact.

The third rail has a greater electrical cross section than an overhead wire and it can, therefore, be used with fewer feeder lines or with longer trains. Most overhead LRT systems are limited to three or four car trains.

Current is collected by means of sliding metallic shoes mounted on HRV trucks and held in contact with the third rail by gravity, springs or pneumatic pressure.

5. Combined Overhead and Third-Rail Systems

A few mixed systems operating with both third-rail and overhead electrification have evolved in this country as a result of transit system expansion. In Chicago, the transition is made with vehicles in motion; in Boston, the transition occurs in an underground station when it is adjacent to an above-ground location. There may be operational or system circumstances where vehicles equipped for both track-level and overhead power collectors would serve to advantage. Some vehicles, including the SOAC, are designed for selection of a third-rail or a pantograph pickup option.

6. Design Aspects and Considerations

- Third-rail electrification is less conspicuous than overhead wires where a transit system is above ground.

- The visual impact of overhead electrical systems can be minimized by some design concepts.

- Both single contact wires and catenary systems may be supported by poles placed between or outside double tracks.

- Support poles are needed along reserved rights of way; pre-existing or joint-use support systems may be available at other locations.

- In storage yards, third rails may be placed back to back on alternate pairs of tracks.

- The diameter of a circular tunnel is usually governed by horizontal clearance requirements for LRV widths and safety walks rather than by overhead power collectors and contact wire systems.

- The height of many underground structures is independent of width; clearance requirements for an overhead contact wire may dictate structure height.

- Third-rail systems carry current effectively for relatively high-powered transit vehicles, but their structure and power-collection devices are such that transit system speeds must be limited to 85 mph (136 km/h).

- Third-rail systems are generally limited to 1000 Vdc and overhead systems are used for higher voltages.

- A precisely aligned catenary system allows the overhead collector to function at speeds up to 200 mph (320 km/h).

- Separate pantographs are usually employed on high speed, bi-directional vehicles.

- In the near future, propulsion systems may be developed to combine chopper-like control with an AC traction motor and thereby reduce motor maintenance while retaining DC motor performance characteristics.

C. Control and Communications Systems

The purpose of control and communications systems is to ensure that the transit system operates safely, reliably, and effectively within its inherent operational limits. Each powered vehicle should operate smoothly and all trains should operate in a coordinated manner on all parts of the system.

The appropriate degree of control and automation varies with the nature of the transit operation.

1. Control System Variations and Characteristics

Rail vehicles can be run manually without signals, but transit systems usually employ controls involving some form of signal system. Wayside or cab signals are used to relay information about the condition of successive track blocks and to alert the operator to take appropriate action. Control features can be added to override the operator and limit speed or stop the vehicle.

In semi-automatic operation, the operator presses a button when ready to leave a station and wayside or track code signals govern operation between stations.

In an automatic, computerized system (such as BART), trains are run from a control center while the operator monitors the operation and communicates with the center. A manual backup system permits the operator to cope with bad weather, multiple delays, and unusual situations or simultaneous incidents that are beyond the ability of the computer control system.

Fully automated, unmanned operation is somewhat experimental and has been confined to special installations of limited scope. Full automation has the same problems as automatic control systems monitored by an attendant, but with full automation there is no one on board to close malfunctioning doors, to handle control functions, or to respond in emergencies.

Although all gradations of these control systems can be used on LRT systems, a high degree of automatic control is usually not warranted or needed. When automatic control seems desirable, an HRT system, not LRT, is indicated. In any case, however, the design of an initial control system can allow for the future addition of various control features.

2. LRT Controls

In general, the degree of protection provided for LRT systems is as much as is feasible and necessary to operate on a particular right of way. In mixed traffic, or in reserved lanes on street portions of LRT systems (Right-of-Way Category C), the vehicle operator can observe traffic conditions on the right of way and control movement of the train or vehicle accordingly.

For LRT operations on reserved (Category B) rights of way, relatively simple signals are needed for rear-end protection at locations where speeds are high or sight distances are limited. Signals are used at grade crossings to actuate crossing protection devices or to pre-empt traffic lights on cross streets. Signals are also used where two-way travel over a single track is necessary and at other locations where tracks converge or cross. In such instances, signaling and track switches can be interlocked.

3. HRT Controls

HRT automatic train control (ATC) systems encompass equipment situated along the wayside, in transit vehicles, in a control center, in stations, and in storage and maintenance yards.

CPUC General Order No. 127 contains regulations governing the construction, maintenance, and operation of ATC systems. A document entitled Automatic Train Control in Rail Rapid Transit, published in May 1976 by the U.S. Congress, Office of Technology Assessment, constitutes a guide for ATC implementation.

The ATC system accomplishes three basic functions by means of the following subsystems:

- Automatic Train Protection (ATP) - includes continuous train detection, train separation, interlocking protection, and speed-limit enforcement features which maintain safe train operation.

- Automatic Train Operation (ATO) - performs the on-train functions of speed regulation and programmed stopping.

- Automatic Train Supervision (ATS) - provides centralized traffic control that monitors the operation of all trains and provides the necessary controls to maintain traffic patterns and make adjustments to minimize schedule delays.

The ATC system can be designed so that it reverts to a state known to be safe when malfunctions affecting safety are detected. In this regard, the ATO and ATS subsystems are subordinate to the independent failsafe features of the ATP subsystem and cannot override it.

Vital ATP equipment should comply with applicable portions of the AAR Signal Manual of Recommended Practices.

4. Communications Systems

Communications systems are increasingly important in the design and operation of rail transit systems. Each system has its own needs for voice communications and telemetry.

The purpose of the communications system is to transmit information between locations and among management, operating, maintenance, and security personnel, and to advise and assist patrons. Sophisticated systems may contain some or all of the following:

- Cable Transmission System - provides two-way voice and digital communications among fixed terminals located at operations central control, passenger stations, yards, and along the transit routes. Digital data transmission provides for storing, displaying, and recording information about performance, operational status, train control, traction power, and mechanical and electrical support facilities.

- Private Automatic Branch Exchange Telephone System - provides voice communications among all administrative, operational, security, and maintenance locations.

- Emergency Telephone System - enables passengers and operating and security personnel to communicate directly with passenger station agents or control supervisors using telephones in stations and along the wayside. These telephones can be used during emergencies or to obtain operating information.

- Operations and Maintenance Telephone System - provides voice communications among employees at all working locations including telephone jack locations throughout the transit system.

- Two-Way Radio System - provides direct voice communications among personnel at central control, at maintenance headquarters, on each train, in maintenance vehicles, in other mobile units, at stations, and at security headquarters.

- Public Address System - provides for announcements to passengers and employees at each passenger station and on each transit vehicle and to employees at each yard.

D. Electrification and Control System Costs

Table 3-4.1 shows significant variations in the ranges of unit costs for electrification and control systems. Electrification costs vary with the number and length of trains and peak demand levels. The costs for signal and communication features required for controlling trains with minimum headways is roughly proportional to maximum operating speed.

TABLE 3-4.1

CAPITAL OUTLAY for ELECTRIFICATION and CONTROL

CATEGORY: ELEMENT	CATEGORY: ITEM	DOUBLE TRACK BASIS	COST RANGE Millions of 1975 Dollars: LRT	COST RANGE Millions of 1975 Dollars: HRT
600 Vdc ELECTRIFICATION (Including Substations)	OVERHEAD	Per Mile	0.30 – 1.40	Same as LRT
		(Per Kilometer)	(0.19 – 0.87)	(Same as LRT)
	THIRD RAIL	Per Mile	Same as HRT	0.80 – 2.10
		(Per Kilometer)	(Same as HRT)	(0.50 – 1.31)
CONTROL SIGNALS and COMMUNICATIONS	Wayside Signals	Per Mile	0.03 – 0.29	0.45 – 1.05
		(Per Kilometer)	(0.02 – 0.18)	(0.28 – 0.65)
	Supervisory Controls	Per Mile	0.00 – 0.10	0.21 – 1.50
		(Per Kilometer)	(0.00 – 0.06)	(0.13 – 0.93)
	Communications	Per Mile	0.00 – 0.03	0.03 – 0.05
		(Per Kilometer)	(0.00 – 0.02)	(0.02 – 0.03)
	SIG. & COM. SUBTOTAL	Per Mile	0.03 – 0.42	0.69 – 2.60
		(Per Kilometer)	(0.02 – 0.26)	(0.43 – 1.62)
	Grade Xing Protection	Ea. Xing.	0.03 – 0.06	NA
	On-Board Equipment	Ea. Car	0.00 – 0.02	0.02 – 0.03
	Yard Control	Ea. Yard	0.00 – 1.00	1.00 – 10.00

SOURCES

- SOAR (Table 33)
- Ref. CP-2 (Pp. 119, 120 & Var.)
- Ref. R-2 (Est. Factors)
- Ref. R-5 (Table 1)
- Ref. R-7 (Pp. 8, 34, 35, 59 & 60)
- Ref. R-9 (Table 4)

3-5 AERIAL AND SUBWAY STRUCTURES

A. Purpose and Scope

HRT and LRT requirements for grade separations, retaining walls, and bridges over watercourses are similar to those encountered in highway work. Therefore, this section of the manual deals principally with elevated and underground line structures unique to HRT vehicles and operations.

The purpose of this section is to present in broad terms some of the considerations influencing selection of aerial or subsurface structures, to outline structural requirements, and to suggest the nature of the many design problems to be investigated and resolved.

B. Structure Design Assistance

Requests for assistance with transit-related structural (and architectural) planning studies, cost estimates, and design studies are welcomed by the Transit and Structural Design Section that has been established in Sacramento within the Office of Structures Design.

Planning and design of rail transit structures and of highway viaducts, bridges, and tunnels are similar in many respects. However, single-track structures are significantly narrower than typical highway structures and are therefore better suited to the use of prefabricated or precast units.

AASHTO truck loadings are somewhat lighter than LRV and HRV loadings, but may be used to produce satisfactory preliminary cross sections and estimates for rail transit structures. See Subsection 5.2 of Appendix A-11.

C. Profile/Structure Considerations and Selection

Selection of the most appropriate type of HRT line structure is an iterative process involving the examination of alternatives to determine the best overall combination of track profile and horizontal alignment. This critically important decision is based on consideration of many complex feasibility, economic, impact, and service factors. However, the balance of this section is concerned mostly with the particular requirements imposed by the selection of an aerial or underground profile and with the various design choices available to best meet those requirements.

Although economic, safety, environmental, and aesthetic factors are generally overriding in choosing basic structure types, many considerations related to such matters as traffic handling, utilities relocation, and business access along the route must be well thought out during early planning and project development stages in order to avoid pitfalls during construction.

Basic profile choices and specific structure proposals can also be affected in important ways by such factors as:

- Time required for on-site construction
- Surface activities and constraints
- Access to construction site
- Utility relocation
- Construction equipment and methods
- Traffic control
- Materials handling and storage
- Noise, vibration, and settlement
- Falsework requirements and feasibility
- Geologic features and ground water

Some considerations are unique to each basic type of HRT line structure. Some requirements, common to both aerial and underground structures, are more critical for one than for the other and the design response may vary accordingly. In terms of a given system, such factors as the following may be important:

- The possibilities of power failure, fire, derailment, and other occurrences are of special concern in elevated locations and especially underground.

- Both aerial and subway structures require continuous walkways for emergencies and for maintenance.

- Walkways should provide a width of at least 2.0' - 2.5' (0.61 m - 0.76 m) outside the vehicle clearance envelope.

- Walkways are generally located between double tracks and on the trackside opposite third-rail electrification.

- Requirements for ventilation and the control of pressure changes pose problems and add costs in subway construction.

- For many reasons it is desirable to standardize elevated and underground line structures throughout a given system.

- Aerial structure form is greatly influenced by visual and noise considerations.

- Alignment curvature, particularly horizontal curvature, tends to complicate some aspects of structure design above and below ground.

- Separated, single-track structures, especially tunnels, are often employed in rail systems and track separation is increased where stations are to be accommodated between the tracks.

- Aerial structures avoid many of the problems and costs associated with importing embankment material for an elevated gradeline or associated with the disposal of excess material from construction below ground.

- In some instances, short-term construction advantages must be weighed against long-term operational advantages.

- Generally, concrete structures require less maintenance than steel structures and problems with electrolysis are reduced.

The relationships of vehicle clearance envelopes to various structural shapes and conditions are given in some detail in the clearance diagrams and cross-sections in Chapter 4.

D. Aerial Structures

Many types of aerial structures are suitable for carrying single- or multi-track transit lines. The characteristics of one type may best fit the requirements for a particular location or situation.

1. Structure Types and Characteristics

General characteristics for various types of concrete and steel structures are summarized in absolute and comparative terms in Volume III, Section 10 of the Caltrans' Bridge Planning and Design Manual. The summary includes a number of box, beam, and girder shapes with several pre-cast and cast-in-place concrete variations. The range of suitable spans for each type of structure is given within the overall limits of 30' - 500' (9 m - 150 m). The depth-to-span ratios for the various concrete simple spans approximate 0.045 for highway purposes and 0.08 for conventional railroads, not including an approximate 24" (61 cm) depth for ballast and rail height. For LRV and HRV loads, the depth-to-span ratio for simple spans may be assumed as 0.045 for concrete and 0.055 for steel. Ratios for continuous spans are about 10% less than for simple spans. (Segmented)

The summary also provides notes regarding the special attributes of certain structures with respect to appearance and appropriate siting, future modifications, falsework, deflections, torsion, irregularities, utilities housing, and simplicity of design and construction. Also, the Transit and Structural Design Section has developed typical sections, quantities, and cost data for various types of aerial line structures for rail transit.

2. Design Considerations

Some additional considerations influencing aerial design are:

- Distinctly different vibration, harmonic, and noise characteristics result from the use of ballasted, open tie, or direct fixation trackwork on elevated structures.

- Ballasted trackwork produces the smoothest, quietest ride.

- Closed abutments are usually more costly than open abutments and are harder to modify.

- Superelevation and skewed crossings can affect structure appearance and cost adversely.

- Cast-in-place structures require falsework openings and guard rails when traffic cannot be diverted.

E. Subway Structures

1. Structure Types and Characteristics

Primarily, underground construction is accomplished either by tunneling or by the cut-and-cover method. The latter consists of open trench excavation which usually involves temporary shoring and covering. The line structure is often a single- or multiple-cell reinforced concrete box.

In the tunnel method, boring machines are supplanting conventional mining methods in all kinds of rock. Tunnel boring machines have recently proved effective in soft ground as well. The circular shape is the most common tunnel shape. Most tunnels require a permanent lining of concrete or steel and may need temporary support also. Sunken tube methods are used for construction under water.

The Transit and Structural Design Section has developed typical sections, quantities, and construction costs for a series of mole driven, circular tunnels. Cost information from this planning study is summarized in Table 3-5.1. Inquiries regarding underground structures may be directed to the Transit and Structural Design Section.

The cross-sectional area for most subsurface, single-track structures is approximately 200 square feet (18.5 square meters). The inside diameter for a circular tunnel is usually close to 16' (4.9 m). Single-track, rectangular box sections are 14' to 15' (4.3 m to 4.6 m) wide and 13' to 14' (4.0 m to 4.3 m) high. Horseshoe shapes are typically 14.5' to 15' (4.4 m to 4.6 m) wide and 8' (2.4 m) high to the spring line of a circular arch of half-width radius.

2. Structural Aspects and Considerations

Underground construction is generally more expensive than surface or aerial construction. It is mostly restricted to metropolitan areas where the cost is perceived to be less than the "total costs" imposed by the temporary disruptions and continuing socioeconomic and environmental impacts of alternative proposals.

Conceptually, underground routes avoid high acquisition costs and achieve a protected right of way on alignments that are free of many physical conflicts and restrictions. Cut and cover construction is inherently more limited as to location and is more disruptive of surface activities than is tunnel construction. However, in either case, station requirements can serve as major factors in fixing underground route locations and profiles.

The avoidance of major utilities can also influence the type of subway construction to be employed and the structure profile depth below the surface.

Although a number of physical conflicts and restrictions can be minimized by tunneling, the removal of tunnel excavation is subject to the same regulations and urban environmental constraints as the handling of material in connection with any and all other types of construction which are viewed and permitted as necessary nuisances.

3. Geological Studies

Appropriately thorough, competent subsurface materials investigations are necessary for the proper consideration and design of all transit strucutures and roadbeds, but they are especially critical in the evaluation of underground proposals. Knowledge of the nature of material to be encountered is critical to structure design, construction methods, and costs. Related matters of concern include such things as soil bearing capacities and thermal characteristics, earthquake faults, dewatering requirements and hydrostatic uplift, subsidence control, vibration transmission, underpinning needs and potential damage to nearby structures, depth of cover, and the need for pressurized work areas.

4. Ventilation

This discussion deals mostly with ventilation in subsurface line structures. Important related matters, having to do with climate and noise control in underground station vaults, are presented in Section 3-6, Subsection 1. It should be noted here, however, that underground environmental control considerations may influence major elements of system and structural design. Subway and station design are interdependent. When local conditions and transit system operating concepts are taken into account, subway line structure configurations may be affected. For instance, certain combinations of environmental parameters may influence the choice between cut and cover structures (with or without dividing walls) and dual tunnels. Temperature control considerations may even influence profile grade lines and the type of dynamic braking selected for vehicles. At stations, up-grade approaches and down-grade departures can significantly reduce power and heat loads.

The primary purpose of providing for positive and effective ventilation of line-section trainways under normal (non-emergency) conditions is to ensure that the heat generated by equipment and people is carried off fast enough to prevent an objectionable temperature rise and to avoid offensive odors.

Normal ventilation can be supplied by the piston action of vehicles operating through subway structures. From a ventilation standpoint, separate structures enclosing each trainway are more efficient than larger structures enclosing two or more trainways. Structures designed for piston-effect ventilation provide a high blockage ratio of vehicle to structure cross-section. This ratio is usually on the order of 50% as discussed in Section 3-2, Subsection E (under "Vehicle Shape and Clearance"), as discussed next under "Portal Design," and as discussed in Section 3-6, Subsection I.

Ventilation shafts spaced along the subway structure provide for air supply and exhaust to ensure air change for heat removal. During periods of no train movement (no piston action) the ventilation must be provided by mechanical means. Some shafts are fitted with dampers and fans to take care of this situation and to provide for emergency ventilation.

The primary purpose of emergency ventilation is to control smoke migration by supplying fresh air and exhausting smoke as an aid in evacuating passengers and in fire fighting. The ventilation rate must provide a satisfactory supply of fresh air to evacuees in the event of fire and the purge rate must be adequate for entry of fire fighting and maintenance personnel and for return to service.

Fan shafts must be located relative to vent shafts and stations so that all underground sections can be purged. Fans can be reversible to supply or exhaust as circumstances require. Large vent shafts are often provided where each single-track line structure interfaces with a station. Intermediate shafts are usually provided where subway runs exceed 1500' (460 m) between stations. The size, shape, and location of vent shafts can be determined mathematically or by model tests. In some systems, ventilation shafts also serve for emergency egress. In such cases, emergency ventilation requirements, considered together with overall safety and passenger evacuation, may be controlling in establishing shaft locations and sizes. There are no definitive rules or guidelines. In the past, vent shaft spacing at intervals of

1200' to 1500' (370 m to 460 m) coincided with what was thought to be the desirable limit of traverse for evacuees and the desirable frequency for subway access by firemen on the surface.

The location, nature, and accessibility of vents and fan shaft openings, at or above the surface, can be important considerations in subway location and design. Shaft construction may cost from $100,000 to $500,000 each and must be integrated with real estate development.

In the BART trans-bay tubes, where there are no shafts for over three miles, a duct between trainways runs full length between ventilation buildings at each end and serves for emergency ventilation and passenger evacuation.

Several problems are related to providing piston-type ventilation. One is the blast effect which must be dissipated at the subway entry to underground station vaults. This is discussed in Section 3-6, Subsection I. Another problem is the control of a rapid pressure build up that can occur at subway portals. This is presented in the discussion immediately hereafter.

5. Portal Design

Subway portals are relatively expensive and critical features in transit location, design, construction, and operation.

In locating subway portals and determining the ends of variable height approach walls, special consideration must be given to protection against flooding and to the prompt removal of water from rainfall, drainage, and seepage. Adequate resistance to hydrostatic uplift must be provided. Also, attenuation of sudden changes in air pressure and noise levels, due to vehicle passage into or out of enclosed structures, must be considered.

Transition structures, such as shown in Figure 3-5.1, are designed primarily to accommodate a profile grade change from the ground surface to an underground structure and to provide an entrance section that will minimize the rate of change of pressure on a train passing through the portal. The pressure rise at portals is a function of the cross-sectional area of the portal entrance and the entrance speed of the train.

The ratio (R) of car cross-sectional area to subway area for circular, box, or horseshoe shapes often ranges form 0.48 to 0.56. For a typical R value of 0.52, with no attenuation at the structure entrance, the estimated rate of pressure rise would be about 65 psi/sec. at 40 mph (448 kPa/sec at 64 km/h) and about 190 psi/sec at 60 mph (1310 kPa/sec at 96 km/h).

One type of entrance design provides a flared transition so that the increase in cross-sectional area approximates a 6 degree (0.1 radian) conical flare starting at the constant area section of the tunnel or box and extending to the portal opening. The transition can be formed by flaring the top and sides provided no plane or surface of the transition section is at an angle in excess of 6 degrees (0.1 radian) relative to the subway structure centerline and provided the side tapers are symmetrical about centerline. It is estimated that this treatment will reduce the pressure rise per second to about one-fifth of the no-taper rates. Flared entrance areas and transition lengths for various speeds are given in Table 3-5.2.

In lieu of constructing a flared transition, a tapered slot can be constructed at the portal of a box-shaped subway section. From a 1.0' (0.30 m) minimum width, the slot should increase to a maximum width at the portal at a taper rate of 12' (3.66 m) per 100' (30.5 m) of length. Slot lengths and corresponding maximum widths for various train speeds are also given in Table 3-5.2.

Other pressure considerations are the previously mentioned piston-effect that helps ventilate subways and a corresponding blast effect that occurs when subway trains enter underground stations. Blast control is discussed in Section 3-6, Subsection I.

6. <u>Special Subway Design Features</u>

A number of special features and facilities related to emergencies, safety, and drainage must be considered and provided for in subway design.

- <u>Walkways</u> are provided on one side of all trackways in line section subway structures. The walkway should be at least 2'-0" (61 cm) above the top of rail and provide 7'-0" (213 cm) headroom. Walkways should provide direct access to platforms where possible and should extend beyond the portals and through open cut structures to an exit point near the surface grade point. Handrails should be provided on subway and open cut walls along the walkway. Walkways should be lowered at appropriate locations to provide access to the undersides of vehicles. The third rail should be located on the side of the track opposite walkways and platforms unless special conditions dictate otherwise.

- <u>Cross passages</u> are installed between separate subway structures in order to evacuate patrons from an endangered trackway or immobilized vehicle and to provide access between trackways for emergency and maintenance personnel. The maximum spacing for cross passages is often set at 300' (90 m) for cut-and-cover subways where trackways and walkways are separated by a common wall. Cross passages are spaced at a maximum interval of 1000' (305 m) in tunneled subways when trackways are in separate tunnels. Cross passages should be adequately signed and lighted and provided with at least one suitable door. Where track centerlines are 35' (10.7 m) or more apart, doors are provided at each end of the passage.

- Crosswalks are provided where emergency exits leading to the surface are located on the trackside opposite the continuous walkway. The crosswalk should be at least 5' (1.5 m) wide and connect to a walkway on the exit side. This walkway should extend at least 40' (12.2 m) each side of the exit in order to match at least one car door if a stopped train blocks the crosswalk. The crosswalk should be at the same elevation as the top of rail and have adequate steps at either end. The third rail should be gapped by at least 15' (4.6 m) at crosswalk locations.

- Wall niches are indentations in subway walls which provide refuge for workmen where unusual trackway conditions are such that the walkway is not considered a safe refuge. Grab bars should be placed on each side of the niche and it should be deep enough to provide adequate space outside the train clearance envelope.

- Refuge space is provided adjacent to the track underneath the edge of platforms.

- Emergency exit stairways are provided where cross passages are not feasible and distances to subway station or portal exit points are excessive. Emergency exit doors must be equipped with panic hardware and the exits should be located so that the distance to adjacent exit points is not more than 1000' (305 m). Emergency exits may be incorporated into ventilation, sump pump, or electrical substation structures.

- Emergency access adits equipped with suitable hatches and ladders for use by firemen and trained emergency personnel should be incorporated in other shafts and structures wherever practicable.

- Subway line alarm and fire protection systems must be provided underground. Such systems include emergency signals and telephone communications through a control center to obtain fire, police, ambulance, and wrecking crew services. Emergency communications equipment should be housed in panels located along subway walkways at intervals not exceeding 1000' (305 m). Panels should also contain portable fire extinguishers. Adequate fire hose connections, accessible from each separated subway structure, must also be provided at 1000' (305 m) maximum intervals.

- Drainage facilities, including longitudinal collectors and pump sumps, must be adequate to handle the accumulated flow from all potential sources above and below ground. The longitudinal collector in a trackway floor slab consists of a center trough. The floor slopes transversely toward the trough at 2.5% and the longitudinal collector trough slopes at 0.03% minimum to sumps at each low point. Each sump should be accessible from the surface through a shaft and should be equipped with automatic pumps, check valves on discharge lines, and connections to suitable outfalls.

F. Loads and Forces

1. General

All transit structures are designed to sustain the maximum dead loads (DL), live loads (LL), and other loads to which they may be subjected, including erection loads occurring during construction.

The purpose of this discussion is to present the basic loads and forces to be considered in the design of retaining walls and aerial and subsurface line structures. Many of the basic considerations apply to the design of stations and other transit structures as well.

The Transit and Structural Design Section should be consulted and will coordinate efforts to conduct soils investigations, provide seismic data, establish loading criteria, and perform design analyses for line structures and other significant structures to be considered in connection with transit proposals. Earth and water pressures on underground structures (and allowable bearing values) vary considerably with geographic location and must be investigated at the site.

2. Live Loads (LL)

Live loads consist of any non-permanent loads such as the weight of transit vehicles, people, crane cars, equipment, machinery, elevators and escalators, stored materials, construction loads, and loads due to maintenance operations.

Figures 4-2.1 and 4-2.2 show axle loads and spacings for typical design vehicles and Section 4-2 discusses the live load elements associated with transit vehicles and trains that are considered in the design of line structures. These elements include the dynamic effects of live load impacts; centrifugal, rolling, braking, and tractive forces; and wind loads on live loads.

3. Dead Loads (DL)

Dead loads consist of the actual weight of the structure including permanently installed trackwork, walks, walls, floors, roofs, utilities and other construction fixtures.

Some basic dead load aspects and considerations are:

- Cut-and-Cover Structures. The dead load includes the weight of earth cover supported by the top of structure and acting as a gravity load. Consideration must be given to accommodating variable dead loads during the life of the structure. For example, the addition or removal of earth cover on a structure must be analyzed and the structure designed for critical stress or deflection.

- Earth Tunneled Structures. The long-term dead load is the same as for cut-and-cover structures. Construction and short-term loadings depend on particular location and circumstances.

- Rock Tunneled Structures. Construction and long-term loading depend on the particular location under consideration.

- Minimum Earth Cover. All underground structures should be designed for actual cover depth or for a minimum depth of 8' (2.4 m) when the actual cover is less than 8' (2.4 m).

- Loads From Adjacent Building Foundations. Underground structures must be designed for increased horizontal and vertical loadings (from foundations of adjacent buildings and other structures) or underpinnings must be provided to avoid increased loads.

4. Seismic Forces

All structures must be designed to resist earthquake motion. The Caltrans Office of Structures Design and the Office of Transportation Laboratory have particular expertise in earthquake research, analysis, and design.

5. Lateral Earth Pressure (E)

Structures must be designed for lateral pressure due to earth loads and surcharges placed on abutting earth. Allowances must be made for both dry and submerged earth pressures and for hydrostatic pressure.

6. Hydrostatic Pressure and Buoyancy (B)

The effects of hydrostatic pressure and buoyancy must be considered in the design of substructures, including piling. Buoyant forces may be most critical during construction and structure backfill operations. Possible future changes in ground water elevation must be considered.

7. Other Loads and Forces

Wind loads; stream flow, local flooding, and vibration effects; differential settlement; and thermal forces may be significant considerations in the design of various structures.

G. Structure Cost Considerations and Ranges

Subways are generally more costly than aerial structures and both are more expensive than surface trackways, although costs for the latter rise sharply where bridges are frequent and where retaining walls are employed in restricted areas to retain embankments or to protect depressed sections. Route construction costs within above-grade and below grade categories can vary widely with location and other factors. Structure choices are often governed by considerations other than relative cost.

Aerial construction costs vary between open and solid decks and for ballasted track or direct fixation.

Subway costs vary appreciably depending on circumstances and construction methods such as cut-and-cover, tunneling in earth or rock, or sunken tubes. Costs are also affected substantially by such factors as maintaining traffic, removing and disposing of excavated material, depth of cover, dewatering or other hydraulic concerns, underpinning requirements, and the need for pressurized work areas.

Table 3-5.3 gives cost ranges for several structure types and conditions and emphasizes the cost variations that can occur within each type.

TABLE 3-5.1

SINGLE TRACK TUNNEL COSTS

16.5' (5.0m) I.D. MOLE DRIVEN CIRCULAR TUNNELS				* 1975 CONSTRUCTION COSTS	
TYPE OF CONSTRUCTION	SOIL CONDITION	DEPTH OF COVER FEET	DEPTH OF COVER METERS	$ MILLIONS PER MILE	$ MILLIONS PER KILOMETER
CONCRETE LINING	ROCK	NA	NA	10.5	6.5
PRECAST CONCRETE	SOFT GROUND (DRY)	≤ 50'	≤ 15m	13.5	8.4
		50'-100'	15m-30m	13.8	8.6
STEEL LINER		≤ 50'	≤ 15m	18.4	11.4
		50'-100'	15m-30m	27.2	16.9
	SOFT GROUND (WET)	≤ 50'	≤ 15m	31.0	19.3
		50'-100	15m-30m	40.0	25.0

* Construction cost estimates include tunnel excavation, lining, grouting, invert concrete and 20% contingencies for single-track line structures only. Trackwork, ventilation, electrification, stations, portal and transition structures not included.

SOURCE: Caltrans Transit and Structural Design Section

TABLE 3-5.2

GUIDELINES FOR SUBWAY PORTAL TRANSITIONS FOR SINGLE TRACK BOX & CIRCULAR SUBWAY SECTIONS

TRAIN SPEED AT PORTAL		LENGTH OF SLOTTED OR FLARED TRANSITION		MAX. WIDTH OF TAPERED SLOT IN TOP OF BOX		AREA OF FLARED OPENING FOR BOX OR CIRCULAR SHAPE	
MPH	(KM/H)	FEET	(METERS)	FEET	(METERS)	SQ FEET	(SQ METERS)
40	(64)	0	(0)	0	(0)	200	(18.6)
50	(80)	50	(15.2)	7.00	(2.13)	325	(30.2)
60	(96)	75	(22.9)	10.00	(3.05)	415	(38.5)
71	(114)	100	(30.5)	12.75	(3.89)	510	(47.4)
78	(125)	112.5	(34.3)	14.50	(4.42)	570	(52.9)

NOTE:
- Values based on subway cross-sectional area $= 200\ ft^2$ ($18.6\ m^2$) and $"R" = \frac{\text{car cross-sectional area}}{\text{subway cross-sectional area}} = 0.52$
- Transitions not required for:
  - — Train velocities 40 mph (64 km/h) or lower
  - — Tunnels of length less than 200' (61m)
  - — Portals at underground Stations

SOURCES: SCRTD (Figs. V-11 & V-12)

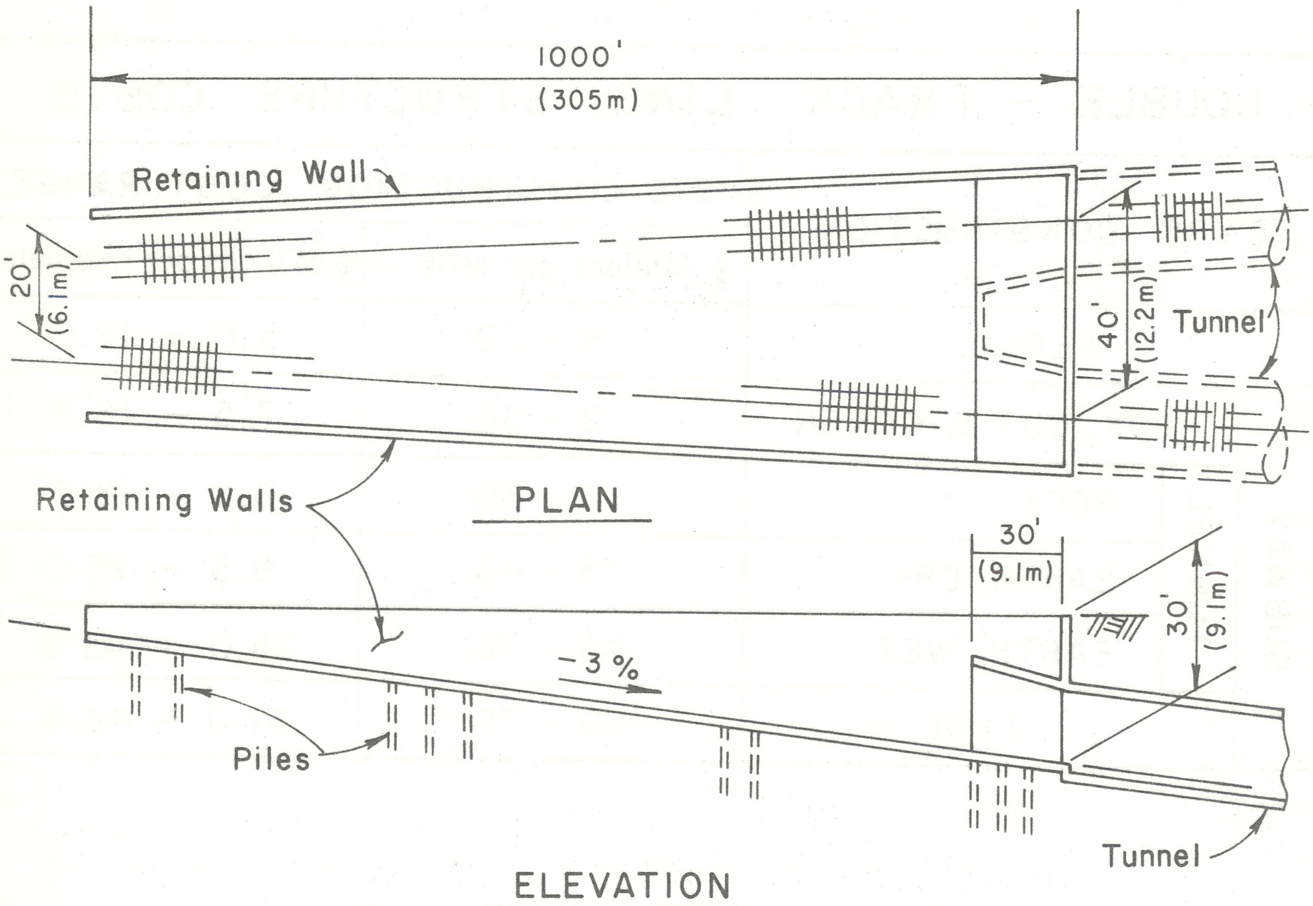
BRRTS (Figs. V-4 & V-5)

TABLE 3-5.3

DOUBLE - TRACK LINE STRUCTURE COSTS				
TYPE CONSTRUCTION			1975 CONSTRUCTION COST RANGE	
			$ Millions per Mile	$ Millions per Kilometer
AERIAL			8 — 20	5.0 — 12.5
SUBWAY	BOX, CUT & COVER		12 — 30	7.5 — 18.5
SUBWAY	TUNNEL	ROCK	10 — 30	6.0 — 18.5
SUBWAY	TUNNEL	EARTH, DRY	15 — 40	9.5 — 25.0
SUBWAY	TUNNEL	EARTH, WET	40 — 70	25.0 — 43.5
SUBWAY	TUBE		50 — 75	31.0 — 46.5

Var. SOURCES including:

Ref. CP-2
Ref. R-7
Caltrans Transit & Str. Des. Section



Notes:
- No Scale
- Approximate 1975 Construction Cost = $1,200,000

SOURCES:	RAIL TRANSIT CRITERIA	
CALTRANS TRANSIT AND STRUCTURAL DESIGN SECTION	TYPICAL TUNNEL PORTAL TRANSITION STRUCTURE FIGURE 3-5.1	Caltrans OCT 77

3-6 STATIONS, PLATFORMS, AND PARKING

A. Introduction

Passenger facilities are critical to the operation of any rail transit system. They can range in complexity from an island "platform" in the street, or a simple shelter, to a regional multimodal transportation center. Even so, stations share design principles and a common purpose to facilitate passenger access to a line-haul operation. In addition to their relationship to line-haul system effectiveness, stations can serve as interchange points for various modes and systems, and can be major determinants of the effectiveness of an entire multimodal regional transportation system.

The Transit and Structural Design Section has developed a number of concepts and renderings for transit stations, especially for on-line stations, to serve bus or rail systems located within freeway medians or rights of way. A report by DMT, Bus Passenger Waiting Shelters, January 1977, contains findings and recommendations applicable to LRT shelter designs and costs.

Station design and construction must comply with applicable municipal, county, state, and federal regulations and codes, including those relating to access by the handicapped.

B. LRT and HRT Station Characteristics and Contrasts

The range of station concepts and facilities is wide for both LRT and HRT systems. Further, for any type of station, considerable discretion can be exercised when matching appearance and amenities to the site and to the operating characteristics of the system and in providing for patron safety, comfort, and convenience.

HRT systems, because of the very nature of their operations, provide complete grade separation for pedestrians and vehicles. HRT stations have three basic elements: platforms, facilities for pedestrian access from one level to another, and control areas for collecting fares and for separating paid and unpaid passengers. A mezzanine level or concourse is often provided to collect, serve, and sort out pedestrian traffic between station entrance/exit points and trackside platforms. Figures 3-6.1 through 3-6.4 illustrate some typical arrangements of basic station elements.

LRT stations need not be elaborate. Although the "station" may vary from a typical streetcar stop to a controlled-access, grade-separated facility, in many cases a low-level, well-lighted platform with a simple shelter is appropriate. LRT shelters are normally provided with benches. Additional amenities such as interior lighting, newsstands, information displays, and telephones may be warranted. Heating is not usually provided.

Canopies over platform areas for on-line HRT stops along at-grade locations or on aerial structures are relatively extensive and may extend trackward 2 ft. (0.6 m) or more beyond the edge of platform. Canopy drainage should be well controlled.

At LRT stations, pedestrian and vehicle flows are not necessarily separated, and special attention is required to design for safe and efficient pedestrian flows. When on-board fare collection is used, LRT operations need not have fenced stations, but at busy double-track stations, with either center or side platforms, it may be desirable to place fencing between the tracks to control or prohibit pedestrian crossing. If LRT fares are to be prepaid, security needs may become as great and as expensive as for HRT systems.

Controlled access LRT stations are usually grade-separated from street level. They are sometimes at grade level with pedestrian overcrossing access to platforms. In either case, they are usually designed for the introduction of in-station fare collection. Another configuration, used with relatively inexpensive trackways at grade in the street, is to place the station below grade for pedestrian circulation. Such inverted stations, connected to sidewalks and platforms by stairs and escalators, may contain shops and other facilities.

In pre-metro operations or other LRT systems that must be compatible with HRT operations, multilevel, mezzanine-type stations and prepaid fares may be required.

C. Station Location and Frequency

The problem of determining station frequency presents a dilemma in which access from service areas must be weighed against high-speed line haul.

The number of stations and their location are influenced by the considerations presented herein and by the related design considerations listed in Subsection D hereafter.

When trains are loaded to maximum capacity in outlying areas with passengers who are destined for the CBD, intermediate station stops are unnecessary. In such cases, facilities for through express or skip-stop service may be appropriate. Frequent station stops in the CBD are in keeping with express service since the entire passenger load is discharged (or picked up) in a relatively short distance. Frequent CBD stops minimize transfers between express and local service and lessen passenger concentrations and congestion.

In intermediate zones, station locations are determined through consideration of business, commercial, industrial, and entertainment stops.

Station intervals in residential areas may be less than 0.5 mile (0.8 km) for local service where passenger demands (and the foregoing considerations) warrant and they may be more than 2 miles (3.2 km) for express stops. Appendixes A-2, A-3, and A-5 list the average station spacing for a number of operating LRT and HRT systems.

The location and frequency of stations are also influenced by the spacing of feeder lines and the need for transfer facilities where main lines cross or converge. LRT stops are sometimes located at grade intersections and coordinated with cross traffic.

Consideration of passenger and station employee security from annoyances and criminal acts may tend to reduce station frequency and influence location. The probability of certain types of incidents decreases as the number of station users and observers increases. Added stations could be relatively less secure and could lessen security at adjacent stations if patronage is diverted.

Stations which coincide with shopping or activity centers can provide added conveniences and inducements for transit patronage. So, too, can park and ride stations which are often located away from built up areas to minimize land costs and auto congestion. Some LRT boarding locations and shelters may be located away from direct conflict with auto traffic in residential areas.

D. Design Concepts and Considerations

Within system and operating constraints, stations should provide appropriate facilities to accommodate all passengers - young, old, and handicapped included - in a safe, convenient, comfortable, and efficient manner.

1. General

The type of station to be provided and its design are functions of the following variables:

o Passenger volume

- o Train frequency
- o Type of service
- o Station intervals
- o Number and cost of stations
- o Climate
- o Method of fare collection
- o Compatibility with immediate environs

In HRT aerial and subway locations especially, station design must be integrated with line structures. In LRT systems, construction of at least a minimum shelter should be considered to protect patrons from the sun, rain, and wind.

The design of shelters or structures for all types of stations should provide good visibility and avoid creating areas hidden from view in order to improve the security of employees and patrons. Even shelter sides and windscreens should be constructed of transparent material.

Architectural concepts can influence security and contribute to a sense of patron safety. Some general considerations are:

- o Provide an open, spacious design.
- o Provide open stairways.
- o Reduce or eliminate columns on platforms.
- o Provide high ceilings.
- o Eliminate dog-leg passages and reverse stair landings.
- o Create uncluttered spaces and provide glass partitions.
- o Maximize surveillance by attendants or closed-circuit TV.
- o Provide good lighting and eliminate dark corners.

These desirable features must be considered in terms of their cost, maintainability, and other factors. For instance, ceiling heights affect environmental (temperature and pressure) control systems. In multilevel, underground station construction, the minimum clear ceiling height for mezzanines has been set as low as 9.0' (2.74 m), but the "optimum" height is usually described as 12.0' (3.66 m). In most cases there is a 2.0' (0.61 m) space allowance above the ceiling for ducts and conduits. The minimum ceiling height for platforms is often specified as 10.0' (3.05 m) with a 2.5' (0.76 m) allowance for ductwork above the ceiling. Figures 3-6.1 and 3-6.4 show plan and section views of representative subway stations.

The need to provide for future upgrading or expansion of LRT or HRT station facilities and amenities is an important design consideration in terms of compatibility, disruption, space, and cost.

Station design must also consider maintenance. Much of the cleaning and repair will be done under both pedestrian and train traffic and features should be included to facilitate this work. Easy cleaning of windows, floors, and other surfaces and access to lighting fixtures, utilities, and equipment should be incorporated in the design.

Additionally, the designer must consider the relative advantages and disadvantages of locating stations at crests on the profile grade. In a cut and cover subway this configuration might not permit the use of a mezzanine and it could increase the cost of line structures. The cost of station construction and providing for transporting passengers vertically might also be increased significantly for aerial stations.

2. Pedestrian Circulation

Good pedestrian circulation to, from, and across train platforms is essential for the smooth, safe operation of stations of all types. Circulation patterns should be as simple, obvious, and comfortable as possible. Some of the points that warrant careful review for applicability and consideration in achieving good pedestrian orientation and circulation are:

- Avoid unnecessary turns and dead ends.

- Provide adequate space to avoid bottlenecks.

- Avoid cross circulation at fare collection and decision points. Generally provide right-hand circulation.

- Provide adequate assembly space on platforms. Preferably allow 8 sq. ft. (0.7 sq. m) of space per person for peak crowds.

- Provide 7.5' (2.3 m) of clear space where possible between the edge of platform and obstructions such as stairs, escalators, railings, or columns.

- Provide adequate mezzanine and entrance lobby space so that queues at fare collection areas do not block traffic.

- Provide separate facilities, where feasible, for entering and leaving the station.

- Locate passageways and stairways, etc., to encourage balanced train loading and unloading. Passengers tend to board at such connection points on the platform.

- Provide escalators for ambulatory patrons whenever the vertical change exceeds 12' (3.7 m) up or 24' (7.3 m) down.

- Provide ramps and elevators as required for handicapped patrons.

Although not all the preceding points are relevant or achievable for every station, the principles embodied in them can be applied to all types of stations. Figure 3-6.4 illustrates a mezzanine circulation pattern for one HRT station configuration.

3. Pedestrian Levels of Service

Many of the pedestrian design principles and criteria currently in use are derived from Fruin's Pedestrian Planning and Design (see reference M-7). Fruin proposes that, insofar as possible during peak hours, people in a station should be able to select their own walking speed, pass slower pedestrians, avoid interference from cross traffic, and queue comfortably without crowding. He developed six levels of service - a concept he borrowed from the Highway Capacity Manual - as a basis for relating the design of pedestrian spaces to service standards for walkways, stairways, and queues. Fruin also relates behavioral characteristics and various personal comfort zone radii to theoretical and nominal capacities for pedestrian movers, such as elevators, escalators, and moving walks.

The initial, rather arbitrary selection of design criteria for the various elements of any given station should be reassessed and revised repeatedly during the design process. Levels of service in different areas may be out of balance and selected design criteria may prove to be economically or physically not feasible.

4. Handicapped Access

The vehicles and vehicle access facilities on most operating rail transit systems have no consistent provisions for the physically handicapped. However, existing state and federal laws such as California Government Code Section 4450 and Section 16(a) of the Urban Mass Transit Act of 1964, as amended, and the Department of Transportation's final rule implementing Section 504 of the Rehabilitation Act of 1973, together with related policy statements by Caltrans and other governmental agencies, in effect declare that elderly and handicapped persons have the same rights as other persons to public transportation facilities and services, and that transit vehicles and buildings are to be accessible to them.

It is possible to design transit facilities to be more accessible to the physically handicapped without impairing operations. In fact, research suggests that systems designed to meet the needs of the handicapped will be more useful, more convenient, and safer for all passengers. BART is an example of a system designed for full access.

Sight, hearing, and ambulatory disabilities require that consideration be given to such things as the use of audible and visual signals, and to the location of control switches and buttons as well as to the accessibility of all facilities and services provided for patrons.

Providing wheelchair access to some or all vehicles at any or all stops imposes special design requirements on vehicles and stations. Station designers must pay particular attention to details such as entrance parking and approaches, automatic doors, unobstructed door and ramp widths, ramp grades and surfaces, turnstile bypass gates, and elevator dimensions.

In LRT operations, because of station diversity, access to vehicles is inherently difficult. Cars designed for street loading are not accessible to wheelchairs without such things as ramps or the addition of lifts to the vehicle.

In HRT operations, car-platform transfers of wheelchairs require close vertical and horizontal tolerances or provisions for bridging. In the United States, the nominal horizontal clearance gap between the vehicle and the edge of platform ranges from about 2" to 4" (5 cm to 10 cm). In Subsection 5.3 of Appendix A-11, the CPUC specifies a minimum 3" (7.6 cm) clearance between LRVs and high-level platforms.

The vertical disparity between car floors and high-level platforms is often 1" (2.5 cm) or more. See subsequent Subsection F as well as Section 3-2 (Subsection E) and Section 4-3 (Subsection C) for more on platform characteristics and vehicle clearance requirements.

Fundamentally, full access for the handicapped argues in favor of providing wheelchair securement space and equipment aboard vehicles, using high-level platforms, and providing elevators and ramps, where appropriate, from street level to the concourse area as well as from there to the platform.

Elevators are the only level-change devices utilizable by nearly all passengers. They are expensive, but should be included in all new terminal facilities. Outside elevators might be considered for older buildings constructed without shafts. Fold-out, stair-side lift platforms or inclined elevators that operate in an escalator channel might also be considered.

Standard model wheelchairs of all manufacturers fall within the following limits:

- o Length: 42" (107 cm)
- o Width: 27" (69 cm) average
- o Height of seat from floor: 19.5" (50 cm)
- o Height of armrest from floor: 29" (74 cm)
- o Folded width of collapsible model: 11" (28 cm)

The fixed turning radius of a standard wheelchair is 18" (46 cm) from the pivot point of a 21" (53 cm) diameter rear wheel to the track of the 7" (18 cm) caster wheel on the same side. From the rear wheel pivot point to the opposite side front footrest, the fixed turning radius is 36" (91 cm). The average turning space required is 63" x 63" (160 cm x 160 cm), but a space 63" x 56" (160 cm x 142 cm) is actually more workable and desirable. In an area with two open ends, 446-5057

such as a corridor, a minimum width of 54" (137 cm) between walls will permit a 360-degree turn. A minimum width of 60" (152 cm) is required for two individuals in wheelchairs to pass each other.

The average reach of individuals functioning in a wheelchair has been found to be:

- o Unilateral vertical reach: 60" (152 cm)
- o Horizontal working (table) reach: 31" (79 cm)
- o Bilateral horizontal reach, arms extended to each side: 65" (165 cm)
- o Diagonal reach to a wall-mounted telephone or towel dispenser (distance above floor): 48" (122 cm)

Most individuals ambulating on braces or crutches, or both, or on canes, are able to function within the limits described for wheelchairs.

In subsequent discussions of station design elements, wheelchair operational characteristics will be mentioned where relevant.

E. Pedestrian Design and Flow Criteria

This subsection discusses the physical and operational characteristics of various passive and powered pedestrian facilities.

Design capacities of pedestrian facilities are often stated in terms of pedestrians per minute. One concept expresses capacity for unpowered facilities in terms of pedestrian lanes. A miminum effective width of 54" (137 cm) between handrails is considered to provide two passenger lanes. It may be noted that a 54" (137 cm) two-lane pedestrian corridor is the minimum width needed for a wheelchair to turn around in an enclosed passageway, but that a more comfortable 60" (152 cm) is required for wheelchairs to pass each other. The standard height for handrailings to be used in conjunction with wheelchairs is 32" (81 cm), just above the 29" (74 cm) height of the armrest of a standard wheelchair.

Following are some design criteria for various facilities:

1. Stairs

- Treads and Risers - Recommended tread depth is 11"-12" (28 cm - 30 cm). Sum of tread depth and riser height should be 17" - 18" (43 cm - 46 cm). The product of tread and riser dimensions should be in the 70 - 75 (178 - 191) range. Treads must be "nonskid" with rounded nosings. Where elevation change is less than 13" (33 cm), a ramp should be used.

- Width - Minimum effective width is often set at 48" (122 cm). Service stairs may be slightly less and public stairs are preferably wider. Maximum width without an intermediate handrail is 88" (224 cm). A 72" (183 cm) minimum width should be used where a future escalator installation is planned.

- Landings - Maximum height between landings should be 12' (3.7 m) except for a continuous run between platform and concourse levels. Minimum landing depth should be at least equal to effective stair width. Stair landings and stair slopes may be adjusted to conform when placed alongside an escalator.

- Handrails - Continuous each side, 32" (81 cm) high measured vertically from the nose and extending a minimum of 18" (46 cm) beyond the rise at each end. Handrails may extend 3.5" (9 cm) into required stair width.

- Headroom - Minimum, measured perpendicular to tread at nosing, is 7.5' (2.3 m). Continuous soffits, without obstructions, should be held at 10.0' (3.0 m).

- Capacity - 25 pedestrians per lane per minute going up and 35 going down.

2. Ramps

- Grade - Preferred maximum is 6% (1:15 slope); absolute maximum is 8.33% (1:12 slope).

- Width - Minimum width between handrails is 54" (137 cm).

- Landings - Ramps used by the handicapped should have level platforms for rest and safety at 30' (9 m) intervals and wherever turns are unavoidable. A 5' x 5' (1.5 m x 1.5 m) platform is desirable at the top of a ramp and 6' (1.8 m) of straight clearance at the bottom.

- Handrails - Both sides, 32" (81 cm) above nonskid surface of ramp.

- Capacity - Considered to be 100 pedestrians per minute for the minimum width (double lane) ramp on a 6% grade.

3. Passageways

- Width - Minimum between handrails is 54" (137 cm).

- Enclosure - Side enclosures should be noncombustible and permit full view of interior.

- Capacity - 110 pedestrians per minute for minimum (two-lane) width of horizontal passageway.

4. Moving Walkways

- Capacity - Considered to be 60 passengers per minute maximum for a 25" (63 cm) walk with a speed of 125' (38 m) per minute.

5. Escalators

- Considerations - Escalators are often specified when stair rise exceeds 12' (3.7 m). Rise between platform and concourse may be standardized throughout system. Stairways or ramps should supplement escalators and provide alternatives. System design criteria sometimes state that escalator capacity alone should accommodate two-thirds of the peak period traffic load and that the combined stairway-ramp-escalator capacity should handle peak traffic with one escalator out of service. Some escalators should be reversible for peak direction and emergency uses.

- Rise and Run - Escalators are installed at a standard slope of 30 degrees from the horizontal. Therefore, the run = 1.732 x rise between working points where the slope intersects each floor level.

- Landings - Escalator handrails extend a maximum of 6.3' (1.9 m) beyond the working point at the lower landing and 8.0' (2.4 m) beyond the upper landing area. An additional 15' (4.6 m) of unobstructed space beyond the handrail is specified for run-off or queueing at both ends.

- Width - Escalators are designated by their nominal clear width at handrail level. An escalator with a 32" (81 cm) nominal width has a tread width of 24" (61 cm) and an overall width of 54.5" (138 cm). A 48" (122 cm) escalator has a 40" (102 cm) wide tread and is 70.5" (179 cm) overall.

- Speed - Operating speeds of 90' (27.4 m) per minute to 100' (36.6 m) per minute are standard. Escalator direction and speed can be changed selectively by control switches.

- Capacity - 100 persons per minute on a 48" (122 cm) width escalator is a value in common use.

6. Elevators

- Considerations - Each multilevel station should be provided with an elevator from the street to the concourse and from the concourse to each platform. Elevator cab equipment and operational controls should be suitably designed for use by the handicapped. Elevator machine rooms should be located as near as possible to hoistways, but clear of public platform and mezzanine areas.

- Speed - Hydraulic elevators have a maximum average operating speed of 75' (22.9 m) per minute.

- Cab Dimensions - Elevators should be sized to at least allow a 27" x 42" (69 cm x107 cm) wheelchair to execute a 180-degree turn within the cab and to permit passage of a standard 30" x 72" (76 cm x 183 cm) hospital rolling stretcher.

F. Platforms

The platform area where passengers board and depart halted vehicles is a key station element whether it is a designated area at a LRT street stop or a platform within a HRT station replete with conveniences and amenities. Platform size is a function of train length, passenger volume, and required clearances from vertical circulation facilities, obstructions, and hazards. As previously noted, 8 sq. ft. (0.7 sq m) of platform area per person is a desirable minimum for peak period HRT operations.

1. Length

Platform length between end railings depends on the length of operating units (single cars or multicar trains) and on the number of units utilizing the platform simultaneously.

For LRT systems, platform lengths range typically from 100' - 300' (30 m - 90 m) and for HRT systems, from 300' - 700' (90 m - 215 m). Platform lengths for operating and proposed LRT and HRT systems are shown in Appendixes A-9 and A-10.

2. Width

The minimum clear width for center or side HRT platforms is often set at 12' (3.7 m) and the upper limit ranges to about 36' (11.0 m) to allow a minimum clear width of 7.5' (2.3 m) for circulation around escalators and stairways. Figure 3-6.1 illustrates a 21' (6.4 m) center platform in a subway station.

LRT platforms are usually in the 6' - 14' (1.8 m - 4.3 m) range. The lower limit approaches the practicable minimum width for a raised platform.

3. Height Above Rail

HRT platform height above top of rail is typically set at car floor height or 1" (2.5 cm) or so below. Most platforms are 39" - 42" (99 cm - 107 cm) high.

For better roadbed clearance, the first step on LRVs is somewhat higher than the remaining step intervals. Most LRT systems use at least a 6" (15 cm) ± high platform to make the first step less difficult. Some systems employ low-level platform heights of 14" (36 cm) ± or 22" (56 cm) ±, and others have full-height platforms in the 34" - 39" (86 cm - 99 cm) range for easier and faster loading. Recent LRV designs can accommodate both high- and low-level platforms. See "Access to LRVs" in Section 3-2, Subsection E.

High-level platforms improve vehicle accessibility for the handicapped. Low-level platforms could be difficult to justify in the design of new LRT systems unless suitable lifts or other devices are provided on the vehicle or platform.

G. Entrances and Exits

Each station site and environment is unique. Pedestrian and vehicular access situations vary and requirements for underground, surface, and aerial stations differ so that station designs and their entrance-exit relationships warrant careful consideration.

Each station should be an efficient link between the rail transit system and other surface transportation systems. This may involve bus platforms, park-and-ride and kiss-and-ride facilities, and special provisions for the drop-off and pickup of handicapped persons. Parking spaces not less than 12' x 22' (3.7 m x 6.7 m) should be provided for the handicapped near station entrances. At least one entrance and exit at each station should be usable by individuals in wheelchairs. This includes access to elevators at multilevel stations. In some cases, it may be desirable to separate station entrance and exit facilities.

Platform and station exits should be sized to accommodate the volume of patrons being served. Exits should be located along the platform to provide uncongested passenger movement and permit safe exiting from trains and platforms under emergency conditions. It is desirable that each underground platform have at least two fully separated exits although they may lead to a single concourse area.

It is recommended that the average volume of passengers per minute boarding and leaving trains during the peak 15-minute period under normal operating conditions be used to size exits so that passengers from a train are able to exit from the platform before the next train arrives. If, for example, trains are operating on a 2-minute headway, exits should permit clearing the platform within 2 minutes.

The possibility of emergency evacuation from a train on the line must also be examined. Again, the passenger load to be considered is the average train load entering the station over the peak 15-minute period under normal operating conditions. For emergency conditions, the exits should be sized to evacuate a loaded train and clear the platform within a 4-minute period. This criterion will frequently establish minimum exit capacity.

H. Fare Control and Collection

This subsection discusses some major aspects of in-station fare payment. Fare collection can be a primary determinant of station layout.

1. Operations

Fare control takes place in a concourse area at a point of separation between "free" space in a transit station requiring no payment of fare and "paid" areas associated with ticketed passage to and from transit vehicles. Patrons entering the station enter the free area, but must pass into the paid area before boarding trains. Disembarking passengers must also move into a free area before leaving the station. The areas are separated by a barrier and all entering and exiting patrons are channeled through a collection array which also serves to meter pedestrian flow through the station. Mezzanine space outside the public circulation areas is used to house mechanical and electrical systems and is restricted to system employees.

In some systems, in effect, fares are determined and "collected" at the destination exit or transfer point. Some entering patrons may hold previously purchased fare cards, others may need to purchase fares. The ticketing operation may be designed to take place in full view of a station control center.

Station entrance elevators and escalators, when required, operate in the free area of the mezzanine. Station mezzanines and platforms are connected by vertical transfer facilities located in the paid area.

Currently, consideration is being given to minimizing the free area as much as possible in order to eliminate loitering areas where patrons might be harassed and to limit access to restrooms, concession stands, vending machines, telephones, and other amenities to paid patrons only.

Fare control equipment includes such things as fare vending machines, deficit fare collectors, transfer validating machines, agent booths and agent-controlled turnstiles, ticket-operated gates, coin-operated turnstiles, and exit turnstiles or gates. Control area layout should provide simple, rapid ingress and egress.

Emergency exitways must be provided through the control barrier adjacent to the ticket gates. These 5' (1.5 m) emergency gates may be supplemented by entrance gates designed for reverse flow. There should also be a 4' - 5' (1.2 m - 1.5 m) wide service gate in the barrier for use by handicapped patrons and by maintenance personnel and emergency crews.

2. Criteria

Some representative guidelines for automatic fare control are:

- Fare Gates/Collecting Machines (reversible for peak flow)

  - Function: To permit entering and exiting the free area.

  - Number: Provide one gate for every 100 patrons during peak 5 minutes. Minimum of three machines.

  - Equipment Space: Machines are 12" (30 cm) wide, 60" (152 cm) long, and are mounted 36" (91 cm) on centers.

  - Queue Space: Allow a minimum of 15'- 20' (4.6 m - 6.1 m) of space (on both sides of gates) clear of other queues, circulation patterns or physical obstructions.

- Ticket Vendors and Money Changers (in free area)

  - Function: Ticket purchase for admission to paid area.

  - Number: Provide a minimum of two vendors and one changer for each fare gate.

  - Equipment Space: Each machine is 24" (61 cm) wide, 24" (61 cm) deep, and they are spaced 36" (91 cm) on centers.

  - Queue Space: Allow 6' - 8' (1.8 m - 2.4 m) minimum queue clearance between machines and circulation routes or other queues and allow 12' (3.7 m) between fare gates and nearest vendor.

- Added-Fare Ticket Vendors and Money Changers (for exiting paid area)

  - Function: To rectify deficient fare balance before exit to free area permitted. (Required with variable fares only, not with fixed fares.)

  - Number: Provide one vendor and one changer for each four exiting fare gates.

  - Equipment Space: Same as for ticket vendors in free area.

  - Queue Space: Same.

- Transfer Validators and Dispensers

  - Function: To verify or provide feeder service transfer tickets. (Ticketing procedure not required for train-to-train transfers within rail system.)

  - Number: Provide one validator and one dispenser for every 100 transfer passengers during peak 5 minutes. Minimum of one per station.

  - Equipment Space: Machines are 24" (61 cm) wide and 30" (76 cm) deep and spaced 30" (76 cm) on centers.

  - Queue Space: Allow minimum of 8' (2.4 m) of space.

The following guidelines relate to alternative fare collection methods:

- Ticket Agent Booth

  - Number: Provide at least one booth for each fare collection area.

- Production: One agent position can handle 800 passengers per hour.

- Equipment: Provide each agent position with one agent-controlled turnstile.

o Turnstiles and Transfer Issuing Machines

- Number: Provide two coin-operated turnstiles (coinstiles) and two transfer-issuing machines for every 800 cash passengers expected per peak hour. Provide a minimum of two coinstiles and two transfer machines in each fare collection area. Coinstiles are designed to allow exiting movement. In addition, provide at least one "exit only" stile at each collection area and at any other area where departure from the paid area is required.

- Capacity: Exit turnstile capacity is 40 persons per minute for low turnstiles and 50 per minute for high turnstiles.

I. Environmental Control

Environmental control systems needed for the comfort and well-being of patrons and operating personnel vary with climatic conditions, system operations, and station design.

Environmental conditions and control system requirements are generally most critical in underground stations. Environmental concerns include temperature, humidity, air velocity, pressure, noise, reverberation time, vibrations, odors, dust, haze, and smoke. The Subway Environmental Design Handbook, Volume I (Reference M-2), treats these matters in a comprehensive manner.

The increasing use of air conditioning systems in homes and automobiles tends to increase the desire for air conditioning in transit vehicles. This, in turn, increases the heat generation in subways and the need for temperature regulation, air replenishment, and overall environmental control in stations. However, there are many trade-off evaluations and compromises between environmental systems and the entire transit system. These include energy consumption, heat generation, and the space requirements for mechanical-electrical systems. The unique configuration of station structures imposes constraints on mechanical and electrical rooms. Also, when a station is air conditioned, it is usually desirable to minimize the ventilation effect of shafts. In the case of BART, the combination of circumstances, considerations, and trade-offs was such that, although vehicles are air conditioned, environmental control for stations and line sections, both below-ground and above, relies entirely on ventilation and the "natural" air conditioning of the bay area.

Subway piston action produces a blast effect in stations which is minimized in the station approach by providing blast shafts (to the surface) and cutbacks in the wall separating single-track line structures, each with a cross-sectional area of 200 sq. ft. (19 sq. m) ±. See "Ventilation" in Section 3-5, Subsection E. The cross-sectional areas of center-platform station vaults in this country vary from about 600 sq. ft. (56 sq. m) to 1,500 sq. ft. (140 sq. m).

Much attention is focused on the platform area. A "spot cooling" concept has been devised to maintain a comfortable environment within an invisible envelope of air enclosing the platform. This limits the air conditioning load to the space within the envelope except when it is broken by trains entering or leaving the station. New ventilation concepts often employ underplatform exhaust systems to exhaust heat from the propulsion and braking elements of the vehicles while they dwell in the station.

Acoustically absorbent material is effective when placed in the sound-baffling area beneath the platform overhang and on the opposite wall, sometimes below an equalizing baffle which projects in a fashion similar to the edge of platform. Depending on the size and shape of a station, as much as 35% of its ceiling and wall surfaces may be treated with acoustic material. In addition to train and ventilation noise, other acoustic problems are associated with patron speech and movement, escalators, vending and collecting systems, mechanical equipment, commercial activities, public address system announcements, and external sources.

Environmental control must extend beyond the platform and concourse areas to corridors, agent booths, concession stands, restrooms, custodial and storage rooms, and electrical and mechanical rooms.

Some typical criteria related to environmental control in stations are listed here. Additional noise and vibration criteria for vehicles and wayside are presented in Section 3-8, Subsections F and G.

- o <u>Noise on Underground Platforms</u> (Max. Levels)

- Trains entering and leaving	80 dBA
- Trains passing through	85 dBA
- Trains stationary, vehicle auxiliary equipment only	65 dBA
- Station ventilation and other ancillary systems only	55 dBA

- o <u>Noise on Above-Ground Platforms</u> (Max. Levels)

- Trains entering/leaving on ballasted track	75 dBA
- Trains entering/leaving on concrete trackbed	80 dBA

o <u>Mechanical Ventilation</u>

- Filtered air intakes, min. height above ground	10' (3 m)
- Excess fresh air supply over exhaust capacity	5%
- Air supply grilles, min. height above floor	8' (2.4 m)

o <u>Air Velocity</u> (Maximum)

- Through agent booths	100' (30 m) per min.
- Entrances and vert. circulation routes	300' (91 m) per min.
- Platforms and other public areas	500' (152 m) per min.
- Ductwork	2,000' (610 m) per min.
- Sidewalk exhaust grating	400' (122 m) per min.
- Roadway exhaust grating	1,000' (305 m) per min.

o <u>Smoke Purge Time</u> (Usual Range)

- Underground spaces	3-15 minutes

J. Parking Facilities

Integrated park-and-ride facilities must be part of station location and design. Coordinated architectural-engineering planning for parking facilities requires consultation with parking, lighting, and landscaping experts and with law enforcement, fire protection, and building inspection officials.

All-day parking, hourly parking, and preferential parking for the handicapped, for carpools, bicycles, motorcycles, and for compact cars, should all be considered in the planning and design of parking facilities. Priorities for access to stations, in terms of distance to the platform, are usually set as follows:

- o Handicapped
- o Buses
- o Kiss-and-Ride; Taxis
- o Paid Parking Areas
- o Free Parking Areas

Park-and-ride lanes should be laid out at right angles to the station wherever possible and walking distances should not exceed 1,000' (305 m).

Preliminary estimates for parking lot space are usually based on an allowance of 400 sq. ft. (37 sq. m) per car including stalls, internal circulation roadways, pedestrian paths, and limited landscaping. Recent studies of express bus commuting from suburban communities to downtown areas suggest that efficient commuter parking facilities should have a capacity of 300 to 1,000 cars. The 1,400-space El Monte Busway park-and-ride is an exception to this capacity range. In any event, a parking facility should not be so large that movement in and out causes problems, or that walking distances are excessive.

Parking stalls should be 9' - 10' (2.7 m - 3.0 m) wide, in most cases, to allow car doors to open. Sometimes 8.5' (2.6 m) is used for all-day parking. Parking stall angles may be 90^o, 60^o, 45^o, or 30^o. In accordance with the angle, required curb length varies from 9.0' to 18.0' (2.7 m to 5.5 m); stall depth varies from a 21.0' (6.4 m) maximum at 60^o to a 17.3' (5.3 m) minimum at 30^o; and aisle width varies from 24.0' to 11.0' (7.3 m to 3.4 m).

Parking structures may in many ways be considered as multilevel lots and many surface lot criteria can be applied, but with reservations. The relationships between external street access and internal circulation patterns, and between vehicular and pedestrian movement, safety, and security, are more complex in structures.

Whether above ground or below, parking structures need stairs and elevators. Fire protection and security problems are somewhat intensified.

Transit parking facilities are usually self-parking since salaries and wages of attendants would otherwise constitute about two-thirds of the total operating cost of the garage.

Parking demands may require lots or structures that are more spacious and larger than the facilities they are designed to serve. Parking structures can become significant or dominant elements in urban settings and must be treated with appropriate environmental concern.

K. Station Costs

Station construction costs vary in the extreme from simple LRT stops to complex HRT stations and regional transportation centers. The cost depends on the height and area of platforms, need for shelters and mezzanines, number and size of escalators and elevators, rest rooms, air conditioning, and ancillary area requirements. Costs are affected noticeably if the station is elevated or on the surface or below ground. The total cost of stations is also a function of the number per mile or the total number per system.

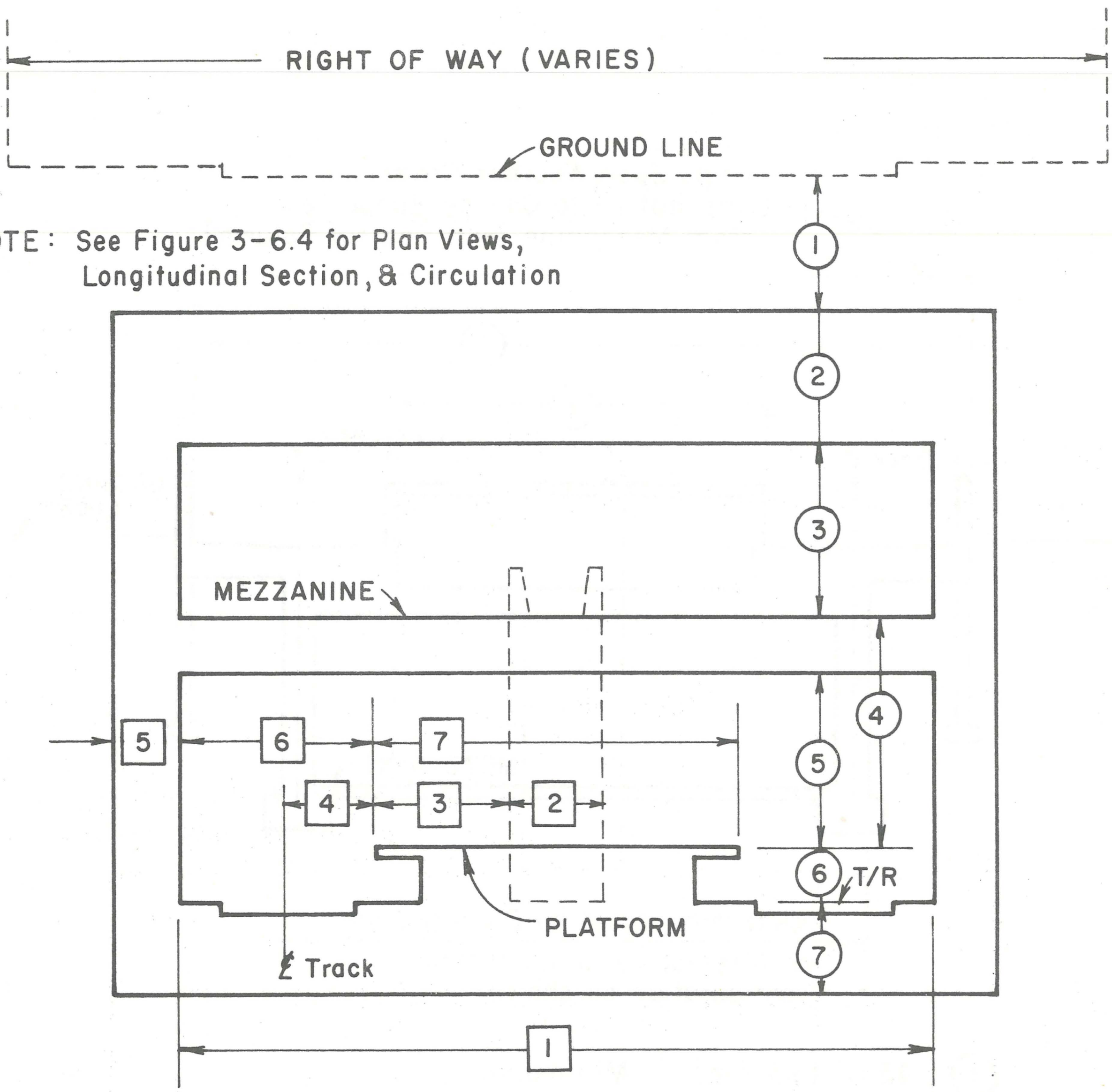
Simple LRT shelters cost on the order of $2,000 to $5,000 each. The following 1975 cost ranges reflect variations in the cost of stations with platforms. The parking figures are based on a cost of $1,000 to $1,600 per space for parking lots with capacities of 300 to 1,000 spaces.

o <u>Stations</u> (Each - $ Millions)

- At Grade	0.02 - 2
- Elevated	0.6 - 5
- Underground	4 - 14

o <u>Parking Lots</u> (Each - $ Millions)

- At Grade	0.3 - 1.6



HORIZONTAL DIMENSIONS	
1	45.0' (13.7m)± Minimum (Single Escalator)
2	6.0' (1.8 m)± Single Escalator/Stair 11.5' (3.5 m)± Double Escalator/Stair
3	7.5' (2.3m) Minimum Clearance
4	5.5' (1.7m)± As Required for Vehicle Clearance
5	4.0' (122cm)± As Required
6	12.0' (3.7m)± As Required
7	21.0' (6.4m)± Minimum (Single Escalator)

VERTICAL DIMENSIONS	
(1)	8.0' (2.4m) Minimum Cover (Varies)
(2)	8.0' (2.4m)± Plan Allowance (Varies as Required)
(3)	10.0' (3.0m) Minimum
(4)	13.5' (4.1m) Specified Height for Standard Escalators / Stairs
(5)	10.0' (3.0m) Minimum
(6)	39"—42" (99cm-107cm) Varies as Required
(7)	5.0 (1.5m)± Varies as Required

SOURCES

BRRTS (Pp. VI. C9a, 12a & 14a)

RAIL TRANSIT CRITERIA

HRT SUBWAY STATION
TYPICAL CROSS SECTION

FIGURE 3-6.1

Caltrans

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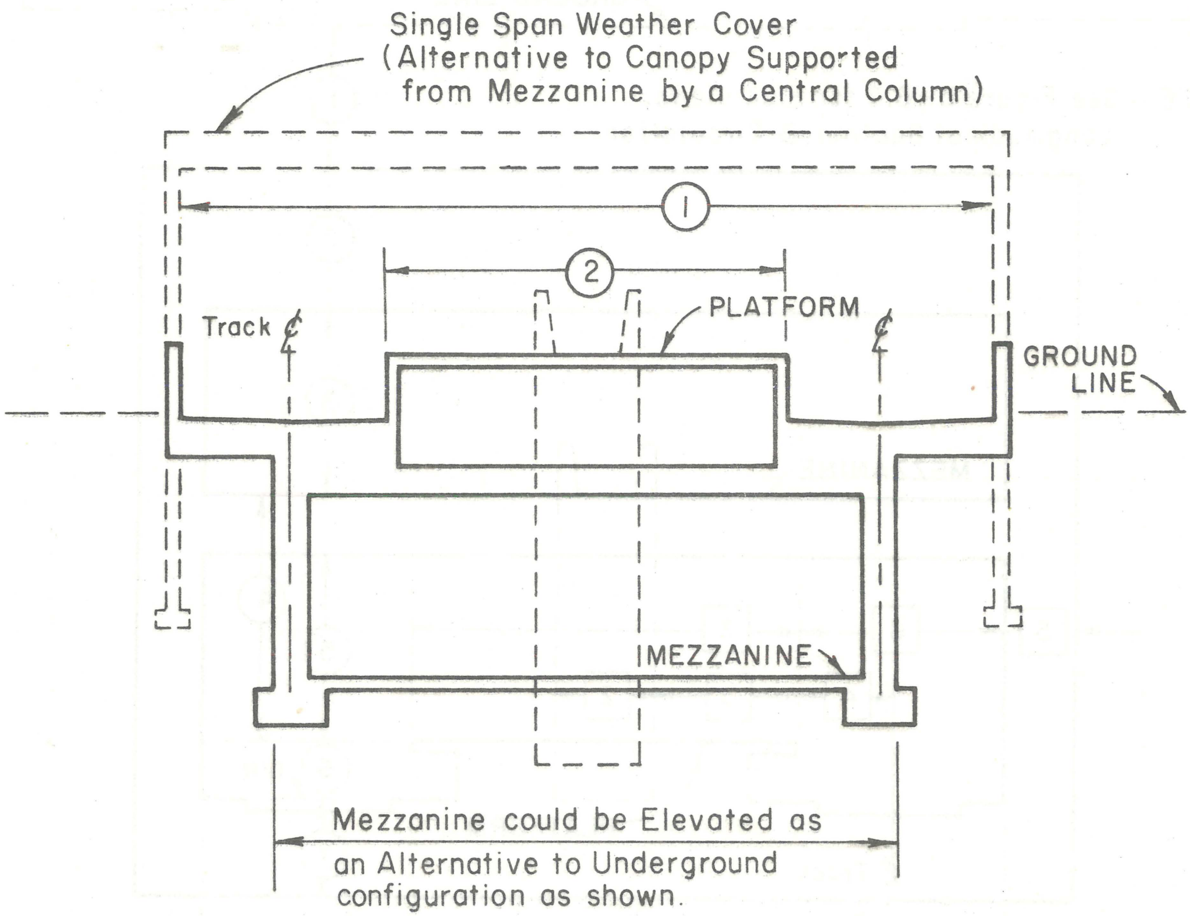
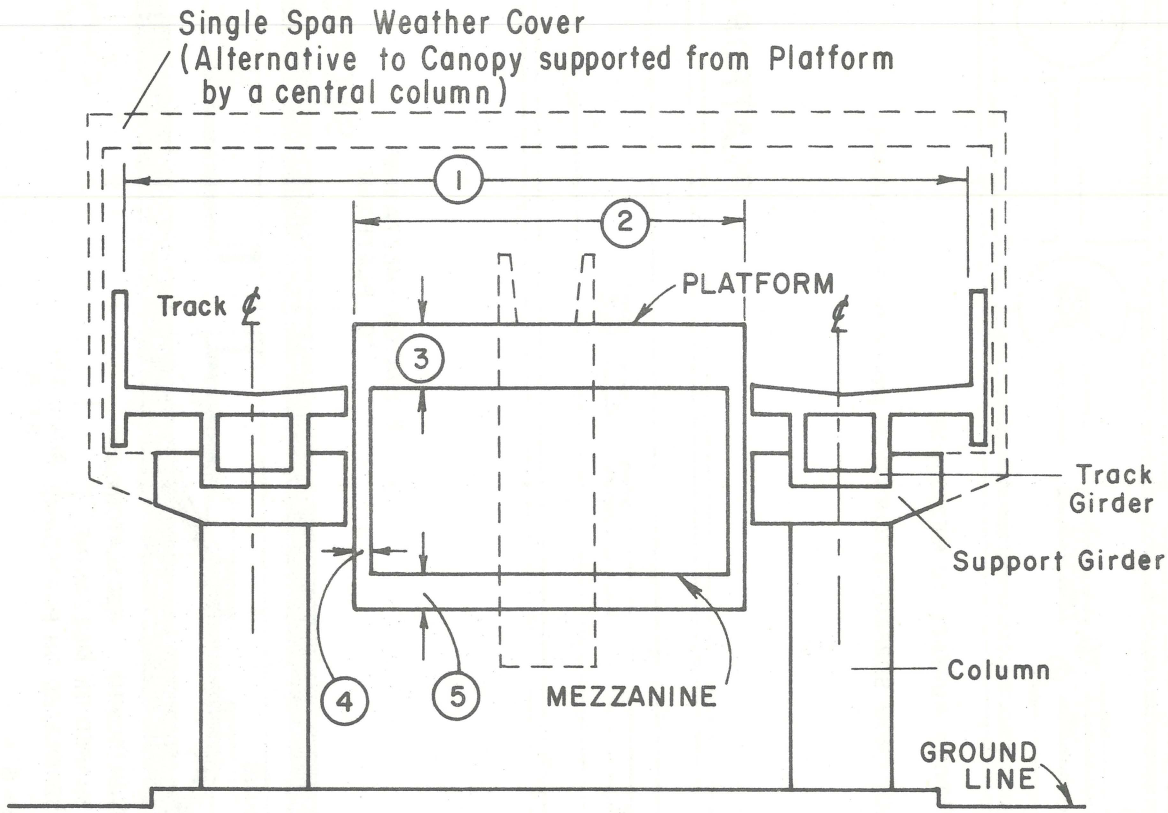


(1) 45.0' (13.7m) ± Minimum
(2) 21.0' (6.4 m) ± Minimum
(Single Escalator)

Note: See Figure 3-6.1 for additional dimensions and notations.

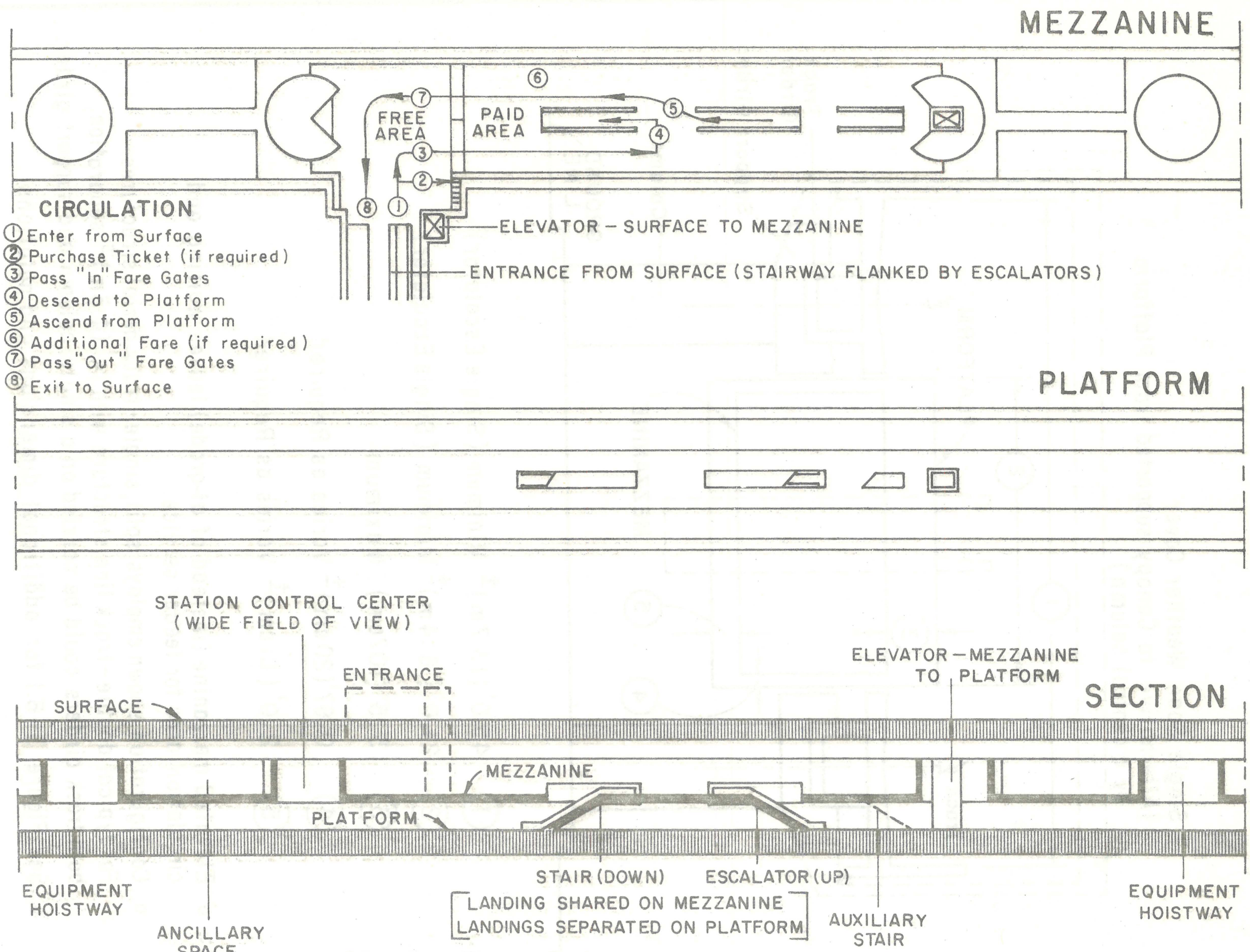
SOURCES	RAIL TRANSIT CRITERIA	
BRRTS (Pp.VI. E 2a 16a & 16b)	**HRT STATION AT GRADE TYPICAL CROSS SECTION** FIGURE 3-6.2	Caltrans APR 78



1. 45.0' (13.7m)± Minimum (Single Escalator)
2. 21.0' (6.4m)± Minimum (Single Escalator)
3. 3.5' (107cm) Maximum
4. 0.67' (20cm)± Varies as Required
5. 2.0' (61cm)± Varies as Required

NOTES:
- Elevated mezzanine (instead of at-grade) leaves waiting and circulation area for feeder service.
- Configuration shown employs split, single-track aerial structures. For typical double-track line structure with 14' (4.3m)± separation, both track girders could be carried on a single column and support girder.
- See Figure 3-6.1 for additional dimensions and notations.

SOURCES	RAIL TRANSIT CRITERIA	
BRRTS (Pp. VI. F2a, 9b, 17a & 17b)	HRT AERIAL STATION TYPICAL CROSS SECTION FIGURE 3-6.3	Caltrans APR 78



NOTE: See Figure 3-6.1 for Cross Section View

SOURCES
BRRTS
(Pp VI.C 15a,19a,23a,23c,D2a)

RAIL TRANSIT CRITERIA
HRT SUBWAY STATION
PLANS, SECTION &
CIRCULATION PATTERN
FIGURE 3-6.4

Caltrans
APR 78

3-7 STORAGE, MAINTENANCE, AND TEST FACILITIES

This section discusses general requirements, considerations, and criteria for vehicle yards and shops, for systemwide maintenance, and for test facilities.

A. Yards and Shops

1. Siting Considerations

Yards and shops for vehicles are large, critical facilities that must be treated as integral parts of new system designs and operations. Site availability, cost, and selection are important factors and may influence transit corridor location. Visual, noise, and traffic impacts, and mitigation measures, as well as possible future expansion, are also influential considerations. Yard configuration and size requirements limit potential sites for yards and influence selection. Sites for yard and shop facilities should be determined early in the planning process to minimize deadheading distances and to ensure that present and future needs can be met in a satisfactory manner.

2. General Functions, Requirements, and Relationships

Yard and shop facilities serve the following operational and maintenance functions:

- o Storage for revenue vehicles, maintenance equipment, and stockpiled materials.
- o Routine inspection, maintenance, and service of vehicles.
- o Overhaul and major repair of vehicles.
- o Support of mainline operations.

o Miscellaneous maintenance and support services.

Vehicle maintenance operations are generally separated into routine maintenance and major repair operations.

Routine maintenance, often preventive in nature, involves the detection and resolution of minor problems before a malfunction requires a major overhaul or causes a breakdown in service. This is done at rather frequent intervals and is generally accomplished during overnight storage.

Major or heavy repair usually involves replacing or rebuilding vehicle components.

The nature of equipment and manpower requirements for these two types of maintenance makes it desirable to perform the work at separate shop facilities. Routine inspection, maintenance, and service of vehicles are performed at service and inspection shops. Heavy, specialized overhaul and repair work are done at a major repair shop.

The yards supporting these shops are designed to accommodate the various shop functions. Yards should also provide off-line storage for the maximum number of vehicles not in use at any one time. This could amount to 100% of the fleet if storage is not allowed along the mainline.

Usually, each rail system requires at least one major repair shop. Routine inspection and maintenance can be performed at storage locations. Miscellaneous support services may be performed at both service and inspection shops and at major repair shops.

All yard and shop facilities should be sited and designed to function efficiently and to provide easy access and minimum movement for personnel and equipment. With third-rail electrification, each yard complex should be entirely fenced so that access can be limited to controlled gates only. Flood lighting is usually provided for 24-hour operations.

Interior paved roads should permit access around shop buildings, to ladder tracks at each end of the yard, and to transfer facilities. If possible, these access roads should be provided without crossing the body of the storage yard at grade.

In addition to providing anticipated car fleet storage capacity, yards should provide separately dedicated tracks to accommodate various types of nonrevenue equipment including crane cars and other specialized, rail-mounted equipment. Sufficient space should be allotted between these tracks for the movement of rubber-tired vehicles and for material storage.

Control centers or towers, supervisors offices, and communications systems should be provided to match yard operations and procedures. Yard and shop layout, equipment, and work environments must meet OSHA requirements. Facilities for yard and line operating personnel include locker, bathing, first-aid, toilet, and lounge facilities together with parking lots, lunchrooms, and classrooms. Suitable office space, work areas, and receiving and shipping areas must also be provided. Loading and unloading areas should be designed to handle large trucks.

3. Service and Inspection Shops

These shops are directly involved with the day-to-day operation of the transit system. The shops should be designed to accommodate intact trains and return them to operational readiness in the shortest time possible. Where feasible, these shops should be located at or near a route terminal to minimize nonrevenue car mileage.

Typically, depending on system operations and requirements and on major shop capabilities, service and inspection shops should provide the following:

- o A track for washing car exteriors. Washing facilities are usually separated from other facilities by full-height walls and may be enclosed.

- o A track for interior cleaning. Facility should allow easy access for personnel and cleaning equipment and should provide water service, electrical outlets, and a vacuuming capability.

- o Two-tracks for service and inspection with pits running full train length to facilitate undercar inspection and maintenance.

- o A blow-off pit located outside the shop building. This is for cleaning the trucks and under car equipment with compressed-air nozzles prior to inspection and servicing.

The arrangement of the shop should facilitate the following functions:

- o Inspection
- o Operational testing
- o Minor repairs
- o Component replacement
- o Lubrication
- o Car washing
- o Interior cleaning

Service and inspection facilities can be designed for conversion to major repair uses at a later stage in system development.

4. Major Repair Shops

The tasks of centrally located major repair shops are oriented toward overhaul and major repairs that require extensive periods of time. Consequently these shops are designed to service individual vehicles or units rather than complete trains. A frequent guideline for new HRT systems is to provide accommodations for servicing at least 3% of the total system vehicle fleet.

The major repair shops for some rail systems are designed to meet most of the equipment repair needs of the overall system except for such things as escalator equipment and traction motor repair which are performed by outside contract away from the shop area. Other systems may contract for repair of seats, complete truck assemblies, complete ATC units, fare collection machines, air-conditioning equipment, and other items. The shop should be equipped with an overhead crane system capable of handling car bodies and all car components including truck assemblies.

The following listing is representative of the functions that might be accommodated by a major shop with extensive facilities:

- Complete vehicle overhaul including all body and propulsion repairs (and painting if required).
- Exchange of trucks or bodies.
- Exchange, minor repair, and testing of components and subassemblies.
- Extensive modifications.
- Wheel truing.

- o Minor repair of miscellaneous equipment such as ATC components, fare collection machines, and maintenance-of-way vehicles.
- o New car acceptance and preparation.
- o Spare parts storage.
- o Designated areas for various maintenance tasks such as welding, sheet metal work, electronic repairs, and motor repairs.
- o An outdoor inventory storage area for wheels and other large parts.
- o Storage space for track maintenance supplies and for such things as flat cars or gondolas (for rails and ballast), crane cars, and subway cleaning and vacuuming equipment.

A major repair shop may be designed to incorporate service and inspection facilities in order to accommodate stage construction of a transit system.

5. Yards

Yard requirements for a system are a function of fleet size and vehicle utilization. Storage capacity must be sized and designed for two basic functions: to store cars for current operations and to store cars in support of service and repair shops.

Yards designed as support facilities for shops should be designed to accommodate the specific functional requirements of the particular shop. Even though transit systems are to be constructed on a staged-growth basis, storage tracks should be designed to handle the portion of the ultimate car fleet anticipated to be stored at a particular location.

The location and design of storage facilities seek to minimize nonrevenue car mileage, to optimize introduction and removal of trains from revenue service, and to facilitate changes in train consist during different operating periods. These objectives can often best be met by providing evening and off-peak storage at route terminals.

In summary, in order to provide necessary services for the system, yards should include appropriate lead tracks, storage tracks, transfer tracks, wash tracks, inspection pits, shop buildings, offices, control facilities, lighting facilities, parking areas, and employee facilities. Yards must have suitable access and adequate security.

Design criteria and clearance requirements for yard turnouts and other trackwork are given in Sections 4-3 and 4-4. Criteria for horizontal alignment and vertical alignment in yards are covered in Sections 4-6 and 4-7, respectively.

6. Operational Considerations and Layout Guidelines

Yard and shop facilities should be laid out so that cars or trains can be put into and removed from revenue service with minimum effort, dead-head time, and confusion. Transfer tracks should be convenient to both mainline and yard access. Yard entry tracks must be arranged for convenient switching of incoming trains to storage tracks, to repair tracks, or to a switching section for cutting out defective cars and making up trains.

In support of mainline operations, the yard arranges for proper train consists to be dispatched to revenue service on the proper headway. The yard must also be aware of when and from which direction trains will enter the yard.

Track arrangements must be such that routes and proper yard areas are clear.

Maximum flexibility is desirable within the constraints imposed by yard location, shape, and size. Yards should be double ended, with redundant trackage where feasible, to provide as many access routes to the mainline tracks as possible. Intra-yard movements should not occupy the mainline and at least one track leading directly to the mainline should always be available. Yard layout should minimize congestion for movements within the yard and lead tracks should remain clear except during immediate movement. Lead tracks to key facilities should be long enough to provide temporary train storage without blocking adjacent tracks or crossings. Run-around tracks to bypass yard or shop facilities can improve circulation where space permits. The number of reverse movements should be reduced to a minimum. A "Y" or a loop should be provided where trains need to be turned end for end.

B. Other Maintenance Facilities

In addition to shops for vehicle maintenance, facilities must also be provided for maintenance of the trackway and appurtenances such as stations, parking lots, offices, and loading areas. These facilities may be dispersed throughout the system for operating efficiency, but should also provide for employee needs, comfort, and security. Requirements for maintenance facilities for the electrical system are contingent upon agreements with utility companies.

C. Test Tracks

Some new systems may require a test track accessible from the mainline or yard tracks. The test track, located alongside or at the end of a mainline segment, should provide a level 2-mile (3.2-kilometer) tangent section plus typical and extreme examples of horizontal curvature and vertical alignment. The track should be suitable for testing vehicle performance, train controls, power collection, and special trackwork.

D. Emergency Storage and Turnback Tracks

Emergency storage tracks should be provided at critical intermediate points. These tracks are used for the temporary storage of disabled trains or cars so that they minimize delays to other operations. By locating the track between the through tracks (in the median) this track can, in addition to being used for both directions, also be used to turn back trains which for a number of reasons are ordered not to run to its normal terminal point and to proceed in the opposite direction.

E. Yard and Shop Construction Costs

Storage yards and maintenance shops and their related control and administrative facilities are major support facilities for rail transit systems. Principal construction cost items include site preparation, grading, drainage and utilities, buildings and shops, shop equipment, parts storage, staff facilities, trackwork, electrification, landscaping, and fencing. Approximate quantities can be estimated from the conceptual layouts for a specific facility. Based on 1975 prices for these items, the approximate construction cost of a typical vehicle storage or maintenance facility, for both LRT and HRT systems, is given by:

Storage Yards

- 60 vehicle capacity: $70,000 per vehicle.
- 300 vehicle capacity: $55,000 per vehicle.

Repair Shops and Support Yards

- 60 vehicle capacity: $135,000 per vehicle.
- 300 vehicle capacity: $100,000 per vehicle.

3-8 ENVIRONMENTAL CONCERNS

A. Introduction

Heightened environmental awareness and concern are reflected in legislation, in decisions regarding transportation and land use alternatives, and in measures taken to identify and mitigate impacts. The National Environmental Protection Act (NEPA) and the California Environmental Quality Act (CEQA) apply to rail-transit systems and projects in much the same manner as they apply to highway proposals.

B. Scope

This section focuses mainly on the noise and vibration impacts and related criteria that directly affect rail-transit planning, design, and operations. It mentions only briefly major environmental considerations such as energy consumption and air pollution which affect basic transportation decisions to develop rail-transit alternatives to the automobile. This section does not deal with the full range of social, economic, and environmental effects and implications of rail-transit proposals and alternatives.

C. Energy Consumption and Air Pollution

There are several issues related to energy consumption and smog relief which are important considerations in multimodal transportation policy and planning decisions. Although they are essentially beyond the scope of this manual, some issues warrant mentioning for background and perspective purposes:

- A number of analytical studies, various predictive and comparative methods, and differing assumptions and points of view have been put forth regarding energy and air pollution. They are informative, but they do not appear to be definitive, conclusive, or widely accepted.

- Transit and other transportation proposals are not intended or designed to reduce energy consumption or air pollution in absolute terms. Different system-balance scenarios, alternative project proposals, and changes in modal splits are usually considered in relative terms. However, equitable comparisons of energy consumption are clouded by the assumptions that are made regarding the extent of total direct and indirect energy requirements and by the conversion of petroleum fuels and other exhaustible or renewable energy sources into BTUs (joules) or other common units. Comparisons of relative efficiency are further dependent upon the validity of such things as vehicle-, seat-, or passenger-miles (kilometers) as a common basis for expressing system effectiveness or productivity.

- It seems unlikely that measurable (and desirable) incremental improvements in rail vehicle and system efficiency will alter the energy and pollution picture on a regional scale.

- Although marked increases in transit ridership are possible and discernible, it is not clear that they will result in significant modal shifts or will reduce air pollution or overall transportation energy consumption in the absence of travel restraints or changes in land use, living, and travel patterns.

- Given present and foreseeable technology, there are more direct, more cost-effective ways than rail transit to reduce the air pollution and energy consumption attributable to the automobile. All such measures are not necessarily desirable or feasible.

D. Noise and Vibration Overview

The acoustical performance of a rail transit system depends on the consideration given to noise and vibration problems during planning and design phases.

1. Control Goals

The basic goals of a rail transit noise and vibration control efforts are:

- To provide patrons with an acoustically comfortable environment by maintaining noise and vibration levels in vehicles and stations within acceptable limits.

- To reduce any adverse effects on the community by minimizing transmission of noise and vibration to adjacent properties.

Community acceptance requires control of airborne noise and vibration from surface and aerial operations and from yard operations. The design may also need to control groundborne noise and vibration from subway operations.

2. Sources

Noise and vibration generators may be subdivided into four general categories:

- Vehicles - Running noise, including wheels rolling and sliding on rails, flange restraint, and collector shoes.

  Undercar equipment noise radiating from trucks, wheels, drive gear, traction motors, compressors, blowers, and brake shoes and discs.

  Car interior noise from ventilating, air conditioning, and other auxiliary equipment.

  Rattling noise from doors, seats, couplings, louvres and windows.

Car noise emanating from subway vent shafts may also be a concern.

- o <u>Trackwork</u> - Noise sources include special trackwork, curves, restraining rails, joints of various types and quality, and rail irregularities and corrugations.

- o <u>Line Structures</u> - Airborne noise and vibration from bridge or aerial girders and decks. Groundborne radiation, particularly from subways.

- o <u>Equipment</u> - Noise and vibration radiated by ventilating fans, escalators, panels, ducts, transformers, emergency generators, and from maintenance facilities.

3. <u>Perspective</u>

Railway and highway noise are much alike with respect to methods for predicting and attenuating wayside noise that is generated by vehicles moving along a fixed path. There are also significant differences. Railway noise is intermittent and its effects on the wayside community are related to the recurrence of similar events, while highway noise tends to be continuous, but of variable intensity. Transient noises, such as occur during a train passby, are acceptable at higher levels than are steady-state noises, such as those characterized by fans or electrical substations, particularly if the steady state noises contain pure tones.

It is common practice in both rail transit and highway design to describe noise levels in dBA-weighted decibels.

Sound levels should not exceed 70 dBA in the interests of passenger comfort and ease of conversation. This value, which is reasonable for normal operating conditions on ballasted CWR track in the open, is considered a "bench mark" value for establishing noise design goals for a rail transit system.

Under these basic (bench mark) trackbed conditions, new vehicles such as the SOAC and SLRV should achieve interior noise levels comparable to the midrange for automobiles. Although well designed and well maintained LRT and HRT systems can be superior to buses and some automobiles with respect to interior and exterior (roadside) noise levels, noise can be bothersome on a poorly maintained rail system.

4. Noise Variations and Mitigations

Track and wheel conditions are major factors in determining noise levels for both LRT and HRT systems. Wheel squeal is the most serious exterior noise problem for steel wheeled vehicles on track curves with radii up to 700' (215 m). On tight radius curves, wheel screech increases noise by 15 to 30 dBA. Tests with various resilient wheels indicate noise reductions of 15 to 30 dBA can be achieved. Reductions of 20 to 25 dBA on a 140' (43 m) radius curve are typical. Various oil and water lubricating systems have proved effective on critical sections of curved track.

Interior and exterior noise levels for vehicles and trains also depend on speed. Noise levels measured 50' (15 m) from the centerline of a tangent track typically increase by 5 to 10 dBA as speed is increased from 20 to 50 mph (32 to 80 km/hr). This increase can be critical in terms of community impact. Reduced speed is an effective mitigation technique in noise sensitive areas. Providing acoustic barriers 4' to 6' (1.2 m to 1.8 m) high adjacent to aerial or at-grade trackage is also effective in sensitive areas. This can reduce rail system noise by 8 to 12 dBA. Tracks constructed with CWR instead of jointed rail reduce the noise level about 5 dBA.

Two types of noise abatement measures may be used to reduce the extreme noise levels of high speed operations in subways. An acoustical absorption treatment may be added to the subway structure or extra sound insulation may be added to the car bodies, or both. Subway sound absorption can provide a 5 dBA or more reduction inside the vehicles and will also improve the acoustical environment for system employees. Insulation of car walls and roofs adds to the weight and cost of vehicles and is not required for interior noise control for surface operations where floor insulation will suffice. The relative length of subway and above-ground tracks may influence the choice of insulation.

5. Groundborne Noise and Vibration

Groundborne vibration levels are below the threshold of perception in most cases. However, the low frequency rumbling noise produced by steel wheels on steel rails may be radiated with sufficient loudness to be annoying in nearby buildings. Noise intrusion depends on train speed, type of line structure, special trackwork, geologic strata, and on building type and use. Where buildings are not more than 100' to 200' (30 m to 60 m) from a subway structure there may be need to use a floating slab for trackbed construction. Low level noises generated by groundborne vibrations should be unobtrusive, but need not be undetectable.

Table 3-8.1 includes guidelines for acceptable limits for groundborne noise for various buildings and community environments. Groundborne noise from passing trains should be held to maximum levels in the 25 to 50 dBA range for concert halls, auditoriums, churches, theaters, hospitals, courtrooms, and libraries.

6. Shop Equipment Noise

Equipment specifications and shop construction should be directed toward keeping employee noise exposure within OSHA standards and limiting community noise impacts to acceptable levels. Shop equipment noise should not exceed 85 dBA at operators' stations or 90 dBA at any point 3' (1 m) from the equipment.

E. Guidelines for Noise Control and Measurement

The most critical vehicle noise source can change with speed. At medium speeds, wheel-rail noise usually predominates, while at higher speeds, propulsion motor and gear noise predominate. At low speeds, service brakes may predominate.

High speed trains using maximum acceleration and braking rates can enter and leave stations at about 50 mph (80 km/hr), depending on platform length, grades, station spacing, and other factors. See Section 3-9, Subsection G. Environmental control criteria for allowable noise levels on station platforms are summarized in Section 3-6, Subsection I.

Immediately following are acoustical design goals and several noise measurement procedures that are related to vehicle interior noise, to exterior noise levels near the vehicle, and to wayside noise at some distance from the vehicle.

1. Vehicle Interior Noise

The following criteria represent realistic interior noise levels obtainable in modern, insulated LRVs and HRVs with resilient wheels operating over tangent CWR trackage. Desirable maximum noise levels are:

- In open, on ballasted track, at maximum speed — 70 dBA

o In open, on concrete trackbed, at maximum speed	74 dBA
o In subways, at maximum speed	80 dBA
o Car stationary, all auxiliaries operating	68 dBA
o Car stationary, one auxiliary operating	65 dBA
o Door Operation	72 dBA

The preceding noise limit guidelines apply to measurements taken along the centerline of an empty vehicle at a height of 4.0' (1.2 m) above the car floor.

2. Vehicle Exterior Noise

Exterior noise levels are checked in an open environment free of reflective or shielding surfaces. Test measurements are made 15' (4.5 m) from the car centerline, but the noise limits for stationary cars should not be exceeded anywhere on a station platform.

The exterior noise limits that follow are applied to all on-board auxiliary equipment and to the "dumping" of air brakes in stations. The full application of service brakes should not increase the noise levels on platforms substantially above the total noise from auxiliary equipment, propulsion equipment, and wheel-rail interaction.

Propulsion motor and gear box noise are checked with the car free-wheeling on jacks at the rpm equivalent of specified speeds. These measurements are taken at the level of the truck axles.

Some typical design goals for exterior noise are:

- o Car stationary, all auxiliary equipment operating — 65 dBA
- o Full-service braking — 75 dBA
- o Propulsion system with ducted ventilation to motors
  - At 60 mph (96 km/hr) rpm equivalent — 78 dBA
  - At 80 mph (128 km/hr) rpm equivalent — 84 dBA
- o Propulsion system with self-ventilated motors
  - At 60 mph (96 km/hr) rpm equivalent — 84 dBA
  - At 80 mph (128 km/hr) rpm equivalent — 90 dBA

3. Wayside Noise

Wayside noise levels are measured at 50' (15 m) from track centerline in the open with no reflective surfaces within 100' (30 m) of the test location.

The noise limits for moving vehicles, in the typical design goals that follow, are based on 4-car train operations over tangent CWR track. Values for 2-car trains would be 2 dBA lower and for 6- or 8-car trains, 1 dBA higher.

- o Ballast and ties at-grade in open
  - At 60 mph (96 km/hr) — 82 dBA
  - At 80 mph (128 km/hr) — 86 dBA

- o Concrete trackbed at-grade or aerial
  - At 60 mph (96 km/hr) — 87 dBA
  - At 80 mph (128 km/hr) — 90 dBA
- o Car Stationary, all auxiliaries operating
  - At any point along either side of car, 4.0' (1.2 m) above grade or at axle height, whichever gives higher reading — 60 dBA

F. Guidelines for Community Noise Levels and Effects

This subsection provides a general guide to typical ambient noise levels for five categories of community development and presents noise limit guidelines for three types of buildings in each category. Table 3-8.1 summarizes these values. The noise limit goals apply to all sources of wayside noise intrusion, whether caused by passing vehicles above or below ground or by ancillary facilities.

Predicting the acceptability of transient noises from transit operations is especially difficult because the operations usually represent a new noise nuisance in the community. Nevertheless, Table 3-8.1 suggests single event maximum noise levels for trains and shows both transient and continuous values for ancillary systems. These guideline values should be reasonably acceptable where the indicated ambient noise levels prevail.

The design goals shown in Table 3-8.1 for ancillary facilities should be applied at 50' (15 m) from the source or at the nearest building or occupied area, whichever is the shorter distance. The higher set of values for transient noise goals applies to short duration events such as train noise transmitted from a vent shaft opening. The lower values for continuous noise goals apply to such things as fans and cooling towers. Transformer hum, containing pure tones, should be 5 dBA less than the values given in the table.

G. Mitigation Costs

The costs of specific noise and vibration mitigation measures are weighed in the selection and design of vehicles, trackwork, line structures, and stations and they are included in the costs of these features in much the same manner as aesthetic considerations and operational criteria are reflected in such costs.

TABLE 3-8.1
COMMUNITY NOISE LEVELS AND DESIGN GUIDELINES

COMMUNITY CATEGORIES		TYPICAL (L 50) AMBIENT NOISE LEVELS (dBA)		NOISE LEVEL DESIGN GOALS — MAXIMUM dBA							
				TRAIN OPERATIONS — SINGLE EVENTS						ANCILLARY FACILITIES	
				AIRBORNE			GROUNDBORNE				
				DWELLINGS		COMMER BLDGS	DWELLINGS		COMMER BLDGS		
NO.	AREA DESCRIPTION	DAY	NIGHT	Single Family	Multi Family		Single Family	Multi Family		Transient Noises	Continuous Noises
I	LOW DENSITY URBAN RESIDENTIAL Quiet, openspace, suburban. No nearby highways.	40-50	35-45	70	75	80	30	35	40	50	40
II	AVERAGE URBAN RESIDENTIAL Quiet apartments & hotels, openspace, suburban residential or occupied outdoor areas near busy streets.	45-55	40-50	75	75	80	35	40	45	55	45
III	HIGH DENSITY URBAN RESIDENTIAL Semi-residential/commercial areas, parks, and noncommercial public buildings.	50-60	45-55	75	80	85	35	40	45	60	50
IV	COMMERCIAL AREAS Office buildings, retail stores, etc. Primarily daytime occupancy.	55-70	OVER 55	80	80	85	40	45	50	65	55
V	INDUSTRIAL AREAS OR HIGHWAY FREEWAY CORRIDORS Commercial or residential areas adjacent.	OVER 60	OVER 60	80	85	85	40	45	55	75	65

SOURCES: SCRTD (Tables II – 2, II – 3, II – 5 & II – 7)
BRRTS (Pp. VI – N5 & VI – N6)

3-9 SYSTEM OPERATING CHARACTERISTICS AND CONSIDERATIONS

This section presents factors, data, and relationships that are major determinants of system performance. A number of the elements mentioned here in an operational context are presented in more detail in other sections that cover system comparisons, vehicles, rights of way, controls, stations, and track design. Appendix A-11 contains CPUC rules and regulations that cover many of these elements with respect to LRT system operations.

This discussion first reviews some general relationships and then examines the effects of a number of interacting factors. Much rail system analysis is based on fundamental operational relationships which are valid in both theoretical and practical systems. The effects of real system constraints and conditions are applied to theoretical performance in order to approximate actual performance potential.

The Divison of Mass Transportation (DMT) may be contacted for assistance in assessing scheduling/vehicle requirements.

A. Service Policies and Physical Limitations

In a broad sense, system performance is determined by planning concepts and design criteria which are influenced heavily by routing and service philosophies, by policy decisions, by funding limitations, and by needs for future expansion to an "ultimate" system.

Actual system performance should lie somewhere between the upper absolute limits set by physical capabilities and the lower limits established by service policies. If these limits do not meet or overlap, the physical limitations prevail. This is why, as discussed in Section 2-5, criteria for planning and designing new systems must evolve from policy determinations regarding the type, extent, frequency, duration, and nature of service to be provided.

Severe physical and scheduling limitations are imposed when a rail system is extended in kind, is inserted in a freeway right of way, or shares trackage with an operating railroad freight line. These limitations may be acceptable, but their implications should be recognized and understood at the outset.

Track sharing represents an extreme condition which may afford a number of advantages for LRT development in terms of costs, community impacts, lead time, and accessibility to railroad equipment. However, it also imposes limitations with respect to track conditions, location, and clearance requirements, as well as intersection and scheduling problems. These limitations must be acceptable and be outweighed by the advantages of joint usage.

Another extreme is represented by the BART system which selected a wide gauge track for ride stability and quality and to eliminate some potential jurisdictional and operational conflicts. BART also acquired specially designed vehicles and control equipment as the best way to fulfill service and performance goals. Where BART shares a freeway right of way, the line was designed concurrently with the freeway in order to avoid undue restrictions.

B. Performance Objectives and Criteria

System operational goals, performance objectives, and achievement criteria depend in large measure on perceptions of system boundaries, purpose, and external relationships. Regional transportation needs differ and various elements of a multimodal, region-wide system perform different functions. Although each element performs its function well, it has inherent shortcomings in terms of total system requirements. Therefore, it is unlikely that a single criterion or set of criteria can be used satisfactorily to measure and compare performance of all elements in a valid, equitable manner, except for a limited specific function. Since high-capacity line haul, feeder, and distribution elements are interdependent, one element should not be optimized without regard for total system scale and balanced usage.

By the time an HRT or LRT system is operating or under development, there must be a strong presumption that these considerations have been evaluated and reconciled adequately in some fashion. At this point, performance objectives and achievement criteria usually relate solely to the limited purpose of the specific system and its function in support of the total transportation system.

C. Routing and Service Concepts

A rail system and feeder service may be thought of as a series of independent lines or as a much more complex, integrated network.

1. Single Lines

In some instances, such as radial HRT suburban commuter service, a zone concept for scheduling appears to be appropriate. For high-volume, single-line operations, it should improve running time and schedule dependability and provide added benefits by simplifying fares, reducing equipment requirements, and utilizing train crews more effectively.

2. Networks

In the network concept, the user is offered a wide variety of destinations, either via a single line or by transfers. This may be done through a grid layout approach that might utilize a combination of HRT, LRT, and bus service to cover all routes.

A theoretical 0.5-mile (0.8-km.) grid with frequent service could offer service between any two points with no more than one transfer and minimal waiting time. It would appear to be applicable in relatively high density areas.

A timed-transfer approach has been used successfully in several locations in Canada to reduce waiting times and improve regional mobility. In this scheme, radial routes are connected by crosstown routes in a cobweb pattern. The key to effective operation is to limit the number of nodes or focal points, and to control route lengths, so that all services arrive at a given node at the same time.

D. Scheduling and Control

For any given system, two basic aspects of transit operations are the movement and control of vehicles. Schedules are made up by reviewing fundamentals. The physical nature of the route and the operating characteristics of the vehicles or trains govern running time. The overall round trip time for any vehicle includes the running time for each direction, the dwell times at intermediate passenger stops, and any layover or turn-around time required at the ends of the route.

The frequency of service during peak periods is usually based on the number of passengers to be handled past a maximum load point. During off-peak periods, headway is often a policy determination based on desirable frequencies and economics. A common rule for the effective use of on-board personnel is to have them all work at least one peak period. Service levels and capacities can be maintained by using the maximum number of cars per train during peaks and shorter trains or basic units during day and evening off-peak periods.

Control systems are important in maintaining schedules and headways safely and effectively. Various degrees of control for LRT and HRT systems are discussed in Section 3-4, Subsection C.

E. Capacity

The passenger carrying capacity of a rail transit line (and alternatives) is often the operational parameter of most interest to planners.

A common definition of capacity is the number of people that can be moved past a fixed point per unit of time per track. This may be expressed:

$$C = \frac{3600\ p}{h}$$

Where:

C = Capacity in passengers per hour
p = Number of passengers per train
h = Headway in seconds

Table 2-3.1, summarizing Appendixes A-2 and A-3, contains passenger capacity figures, fleet sizes, and other information about operating LRT and HRT systems. Table 3-9.1 summarizes related operational data from Appendixes A-9 and A-10 for such factors as schedule speed, headways, and dwell times.

1. Factors and Relationships

Line capacity is a complex function involving:

- vehicle size
- Number of passengers (seated and standing) per vehicle
- Number of vehicles per train
- Vehicle speed
- Track curvature and grade limitations
- Acceleration and deceleration rates
- Braking distance
- Frequency of station stops

- o Dwell time at stations
- o Right-of-way restrictions
- o System reaction time
- o Practical allowance for operational tolerances

Restated in simplistic terms, the passenger capacity of a rail line depends on train size and frequency. Operational factors and their relationships are discussed in the balance of this section.

2. Critical Speed: Theoretical Minimum Headway/Maximum Capacity

Maximum rail capacity occurs at a moderate, critical speed as does maximum highway capacity. For any given train length, the critical speed permits minimum headway and maximum capacity. The longer the train, the higher its critical speed. As speed increases beyond the critical value, headway increases and capacity decreases.

If 500' (150m) long HRT trains with typical performance characteristics were running on a grade-separated right of way without station stops, the theoretical critical speed would be about 40 mph (64 km/hr) and the corresponding minimum headway would be about 23 seconds. If a 20-second station stop were introduced, the critical speed would drop to 25 mph (40 km/hr) and the headway would increase to 48 seconds.

Achieving greatest possible capacity is not a practical operational goal. It is outweighed by a desire to provide comfortable, high-speed service with minimum fleet size, dependable scheduling, and an adequate margin of safety.

3. Train Consist and Fleet Requirements

For a given number of cars, the problem of optimizing maximum practical capacity may be approached by providing many short, slow trains with short headways, or by providing fewer long, fast trains with longer headways. These alternatives may have different requirements for platform lengths, traction power, and control systems. LRT train consists are usually limited to short lengths in order to minimize intersection blockage and platform requirements.

The following formula may be used to estimate the approximate number of vehicles needed for route operations during the peak hour, based on constant headway without lay-up:

$$N = \frac{60ntL}{VH}$$

Where:

N = Number of cars required for peak hour
n = Number of cars per train
t = Number of tracks operated at the same headway
L = Length of line in route miles (kilometers)
V = Average schedule speed in mph (km/hr.)
H = Headway in minutes

Allowing for 3 trains at terminals and 10% for lay-up, the approximate number of cars required becomes: 1.1N + 3n.

Figure 3-2.3 shows typical ranges for the relationship between the size of vehicle fleets and the track mileage of operating LRT and HRT systems.

4. Headways

Headway is the interval of time between successive trains measured from the front end of the leading train to the front end of the following train as they pass a point.

The number of trains operating on a particular line is limited by the number that can pass through the limiting station. Station time consists of braking, dwell, and acceleration time. Acceleration and deceleration rates are not constant for all speeds and vary with the type of vehicle. The distance between trains must provide not only for braking distance, but for the distance the following train would travel during the reaction time between the sighting of a signal and the full application of brakes or for the system response time between the transmission of a command and the actual beginning of deceleration. A safety factor of 35% is added to the stopping distance for the worst condition that could occur on the system in order to allow for variations in wheel-rail adhesion and equipment performance.

Minimum achievable headways depend on such factors as vehicle speed, braking rates, degree of safety, system response time, train length, station dwell time, and random influences where right of way is not exclusive or controlled. Station stops are often the major physical factor in limiting minimum headways on rail transit systems.

Headways for LRT lines vary widely. Short headways in the range of 30-60 seconds can be achieved with low-speed, manual operations under visual rules. These short headways are usually employed for limited periods of 15 to 30 minutes and require effective dispatching to prevent irregular operation.

Speed has a major impact on headways. With wayside signals, speed can be increased safely, but this requires a greater braking distance. A headway of 60 seconds might be achieved with moderate top speeds on the order of 30 to 40 mph (48 to 64 km/hr), but minimum headways are usually limited to the 90 to 120 second range with block signalling systems.

Headways of 120 seconds are typical for HRT and high-speed LRT lines operating on reserved, protected rights of way. Wayside signals with automatic stop enforcement generally allow headways of 120 seconds with speeds in the 45 to 60 mph (72 to 96 km/hr) range.

On a few suburban LRT lines, speeds of 60 to 70 mph (96 to 112 km/hr) have been attained where wayside signals permitting 3- to 5-minute headways could satisfy passenger traffic requirements.

The Muni SLRVs, operating with automated cab signals at speeds up to 55 mph (88 km/hr) in the Market Street Subway, are expected to run with headways as close as 60 seconds.

Some LRT systems operate off-peak with headways of 10, 12, 15, or 20 minutes or more. With headway requirements above 15 minutes, limited sections of single track are sometimes used.

A number of LRT systems maintain near-constant 2- to 4-minute standard headways and provide safe, delay-free service during the rush hour by increasing train length to 3 or 4 cars.

F. Vehicle Operating Profile

Figure 3-9.11 illustrates some of the basic relationships that govern vehicle running time between station stops. It also includes dwell time so that the full cycle from one station departure to the next station departure is shown. Figure 3-9.11 serves to set the stage for presenting some basic speed-time-distance relationships and for subsequent discussion of the nature and relative magnitude of the effects of some performance variables on schedule speeds and headways. These interactions represent trade-off areas in vehicle/system performance.

Figure 3-9.10 shows time and distance relationships resulting from typical acceleration and deceleration rates for representative LRT or HRT vehicles on a level tangent track. It illustrates the times and distances required to attain a series of top speeds ranging from 40 to 80 mph (64 to 128 km/hr) and the corresponding times and distances required to brake to a stop. Over the whole range of speeds, braking requires one-half the time and about one-third the distance required for acceleration.

Figure 3-9.6 compares schedule speeds attainable by two different vehicles operating over a range of station intervals. Each vehicle has a different combination of assumed average acceleration/braking rates and top cruising speed. The curves indicate that when LRVs are operating with frequent starts and stops, the acceleration/deceleration rate may have more effect on schedule speed than does maximum speed. It also shows that when stations are over a mile apart, high cruise speed becomes more important in boosting schedule speed. However, the relative overall benefits and disadvantages and the operational implications of high-speed vehicles require careful consideration for any given system. The increase in station spacing required to take advantage of a significantly higher top speed may reduce the accessibility and usefulness of the system to potential users.

G. Acceleration and Braking

Acceleration and deceleration rates are limited by wheel-rail adhesion. Other factors which affect desired characteristics are passenger comfort and safety, the traction motor, and power demand and consumption.

Characteristics and ranges of typical service levels for acceleration and deceleration are shown in Figure 3-2.1.

The characteristics of the DC traction motor which make it well suited for transit operations are mentioned in Section 3-4, Subsection A. Articulated LRVs, having relatively fewer powered axles, are somewhat limited in the tractive effort they can deliver.

The braking capabilities of a vehicle are usually based on stopping with a crush load of passengers on a level tangent track. Section 9 of Appendix A-11 contains CPUC requirements for LRV braking capabilities.

Modern rail transit vehicles have a three-level braking system consisting of electrodynamic, friction disc, and magnetic track brakes.

The service braking system provides both dynamic and friction brakes which are continuously blended and jerk limited over the entire operating speed range.

The dynamic brake system alone should be capable of providing full service.

The friction brake system is the reserve as well as the final stopping system. It performs the following basic functions:

- o Supplements dynamic brake system to provide full service blended braking rates.
- o Provides emergency braking with assistance of track brakes.
- o Provides full service braking in the event of dynamic brake failure.
- o Acts as a parking brake.

Emergency braking is not jerk limited and can be interlocked to provide an irretrievable stop.

The magnetic track brakes operate from a low voltage auxiliary power supply. They can be controlled to provide "roll-back" protection as needed when the vehicle is starting on steep grades. Magnetic track brakes are not considered fail-safe since they depend on electric power. This must be allowed for if it becomes a critical factor in establishing minimum headways. LRVs can operate comfortably in mixed traffic when using track brakes for emergency stops because they can stop more quickly than automobiles.

Figure 3-9.1 shows a series of curves that indicate how vehicles with different speed capabilities achieve their top speed and the distance required to achieve it on a level tangent track.

Figure 3-9.2 illustrates the distance required for rail vehicles to brake to a stop from any speed up to 75-mile per hour (120 km/hr) on a level tangent track. The band width shown includes the performance of most HRT and LRT vehicles. It indicates that the approach speed at the beginning of a 600' (183 m) station platform might be as high as 40 or 50 mph (64 or 80 km/hr).

H. Performance Effects of Curves and Grades

The horizontal and vertical alignment of the track can have rather pronounced effects on vehicle acceleration, deceleration, and speed.

Figure 3-9.3 illustrates the effect of plus and minus grades on the acceleration of two representative vehicles with top speeds of about 50 mph (80 km/hr) and 80 mph (128 km/hr). For example, the faster vehicle would reach 55 mph (88 km/hr) in just under 1,000' (305 m) on a 4% down-grade, but it would take about 4,500' (1,370 m) on a 4% up-grade. In the latter instance, no further acceleration would take place since the vehicle performance capabilities and the grade are in balance.

Figure 3-9.4 shows the effects of plus 5% and minus 5% grades on the braking distance required by a typical LRT or HRT vehicle. From any speed, the stopping distance on a minus 5% grade is slightly more than twice the distance required on a plus 5% grade. This is one reason why design standards for modern high-speed HRT systems often limit maximum grades to 3%. It should be noted that the distance traveled during response time is not a function of grade, but of speed only. The response distance would be the same as on a level track. The grade effect applies to actual braking distance only.

Taken together, Figures 3-9.3 and 3-9.4 indicate graphically why the concept of rolling the grade line up at station stops is an attractive notion for aiding vehicle performance and conserving energy.

Figure 3-9.7 illustrates the speed-limiting effect of horizontal curvature and superelevation. For example, operating speed would be limited to 30 mph (48 km/hr) on a 3,000' (915 m) radius curve with 2" (5.1 cm) superelevation. See Section 4-6, Subsection D, for superelevation standards.

I. Effects of Station Spacing and Dwell Time

The frequency and duration of station stops are major factors in system operations as noted in the preceding discussions of headways and vehicle operating profiles.

Figure 3-9.5 illustrates how station spacing, dwell time, and schedule speed are related to one another. Their sensitivity is indicated in terms of typically performing vehicles with top cruise speeds of 50 mph (80 km/hr) and 80 mph (128 km/hr).

The difference in vehicle top speed capability makes little difference for station intervals less than 0.4 mi (0.6 km). At that interval, a reduction in dwell time from 30 seconds to 10 seconds could increase schedule speed for either vehicle from about 18 mph (29 km/hr) to 25 mph (40 km/hr). Viewed another way, in order to maintain a 30 mph (48 km/hr) schedule speed with a 20-second dwell time, the station interval would need to be 0.6 mi (1.0 km) for the faster vehicle and 0.8 mile (1.3 km) for the slower one. To keep a 40 mph (64 km/hr) schedule speed, the required station spacings differ markedly from 1.0 mile (1.6 km) for the high speed vehicle to 2.1 mile (3.4 km) for the slower one.

Platform heights, vehicle door widths, and fare collection techniques can all affect dwell time. These factors warrant careful consideration where short dwell times are critical to achieving system operating and service objectives.

J. Right-of-Way Effects on LRT Operations

Various types of non-exclusive rights of way are distinguishing features of LRT systems. There is a potential for great savings in capital costs, but problems may be introduced with respect to to pedestrian safety, automobile cross traffic and signal preemption, and schedule speeds. Basic decisions regarding the type and extent of right-of-way categories for LRT systems are among the most important in determining vehicle and system performance. It should be recognized, however, that in many situations, mixed-traffic rights of way are the most favorable environments for attracting riders and serving the public. Passenger stops on pedestrian malls are more visible and accessible than subway stations.

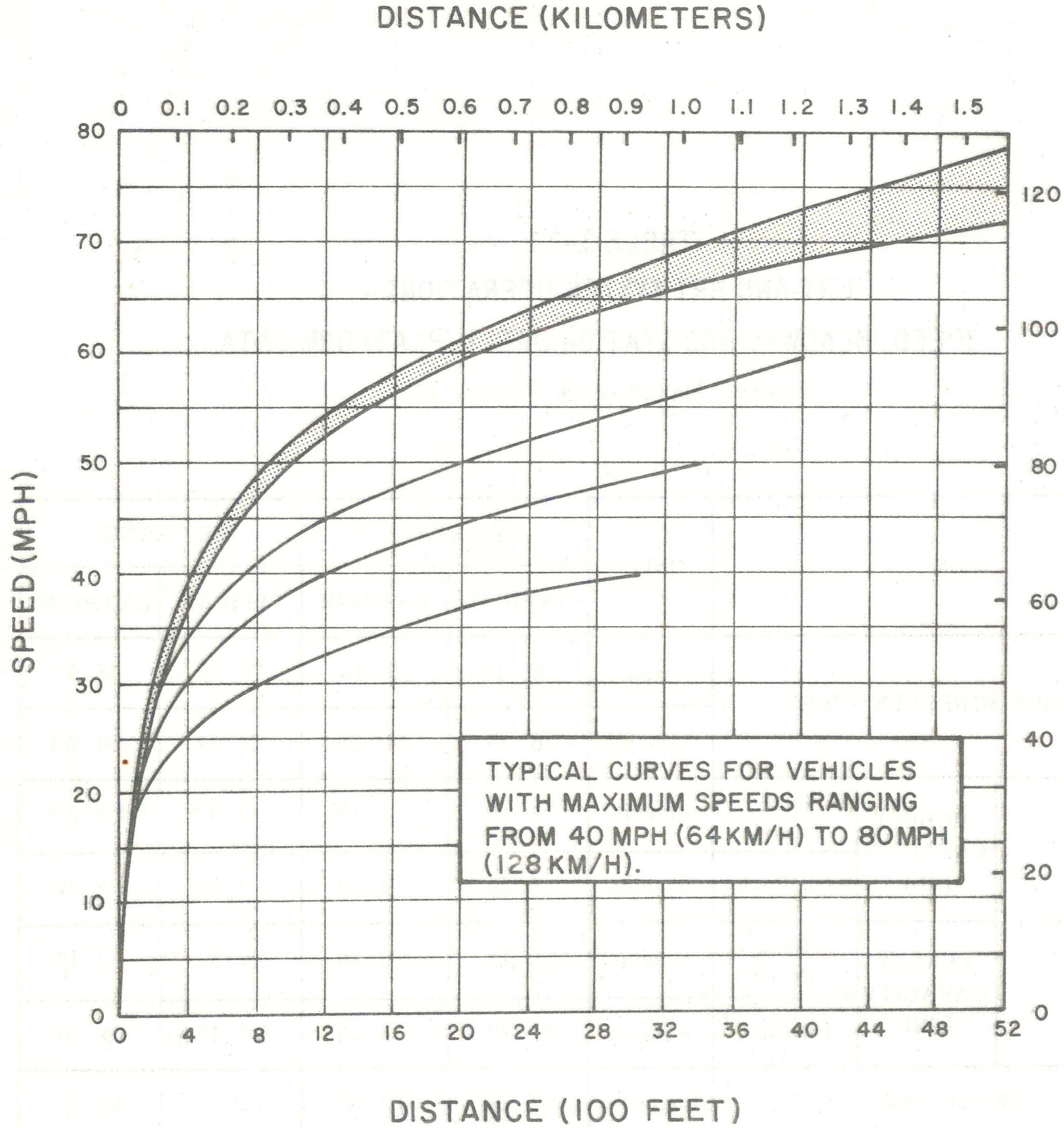
Figure 3-9.9 shows the effects of four representative right-of-way conditions on the schedule speeds associated with various station intervals and typical system operational assumptions. The figure indicates that schedule speed will be limited to about 10 mph (16 km/hr) regardless of the interval between stops when rail vehicle movement is governed by mixed traffic flow. The other extreme, shown as a basis for comparison, represents operational expectations for a completely grade-separated (Category A) right of way. The other right-of-way conditions shown represent two of the many possible conditions that might be assumed. Perhaps most importantly, Figure 3-9.9 shows that regardless of right-of-way condition, for the usual LRT station intervals of less than 0.4 mile (0.6 km), the schedule speed is apt to lie between 10 and 20 mph (16 and 32 km/hr).

TABLE 3–9.1
LRT AND HRT SYSTEM OPERATIONS – SPEED, HEADWAY AND STATION DWELL/PLATFORM DATA

(Sources: Appendixes A–9 and A–10)

ITEM			UNITS	LRT RANGE *		HRT RANGE	
				TYPICAL	EXTREME	TYPICAL	EXTREME
AVERAGE SCHEDULE SPEED			mph	10 12	9 16	15 21	15 37
			(km/h)	16 19	14 26	24 34	24 60
HEADWAY	HIGHEST CAPACITY LINE	Peak Period	minutes	3 12	2 15	2 3 5	1 5 8.5
		Off-Peak	minutes	6 20	4 30	3 10	2 5 30
	LOWEST CAPACITY LINE	Peak Period	minutes	6 12	2 30	2 5	2 15
		Off-Peak	minutes	12 30	6 60	3.5 15	3 30
DWELL TIME			seconds	15 30	10 60	20±	10 33
PLATFORM LENGTH			feet	130 330	98 377	300 600	131 738
			(meters)	40 100	30 115	90 180	40 225

* GROUP 1 VALUES, APPENDIX A–9



SOURCES:

BART	(Fig. 2.1.1)
TTC	(D.S. 3.1.2.A)
WMATA	(Fig. II.7)
BRRTS	(Fig. IV.2)
SCRTD	(Fig. IV-1)
ASME	(Fig. 2)

RAIL TRANSIT CRITERIA

TYPICAL SPEED-DISTANCE CURVES
HRV & LRV OPERATIONAL ACCELERATION
-LEVEL TANGENT TRACK-

FIGURE 3-9.1

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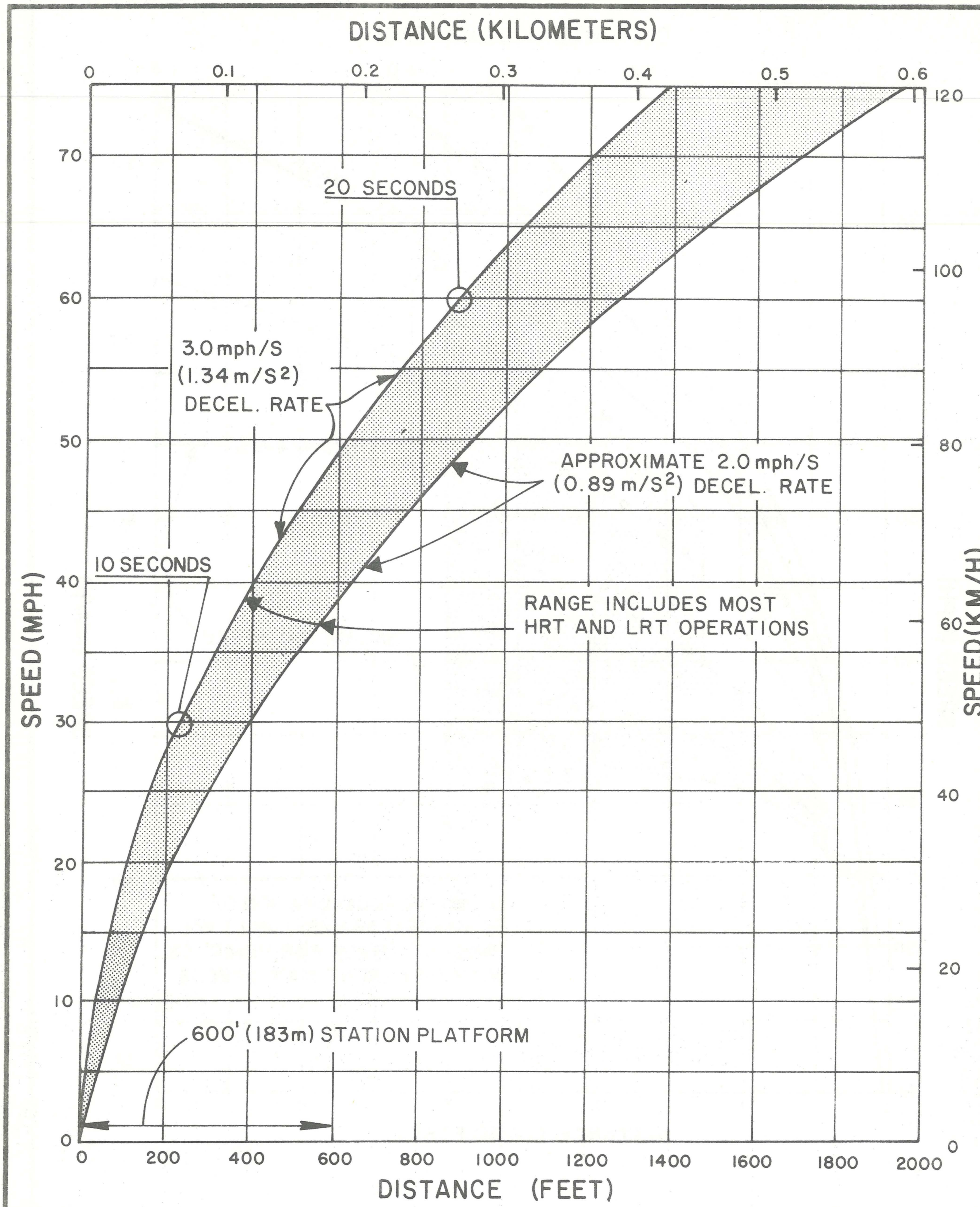

SOURCES:

WMATA	(Fig. II.8)
TTC	(D. S. 3. 1. 2. B.)
BRRTS	(Fig. IV.3)
SCRTD	(Fig. IV-2)
NYCTA	(Table 5.04) P. TP-5-32

RAIL TRANSIT CRITERIA

TYPICAL SPEED-DISTANCE CURVES HRV & LRV OPERATIONAL DECELERATION -LEVEL TANGENT TRACK-

FIGURE 3-9.2

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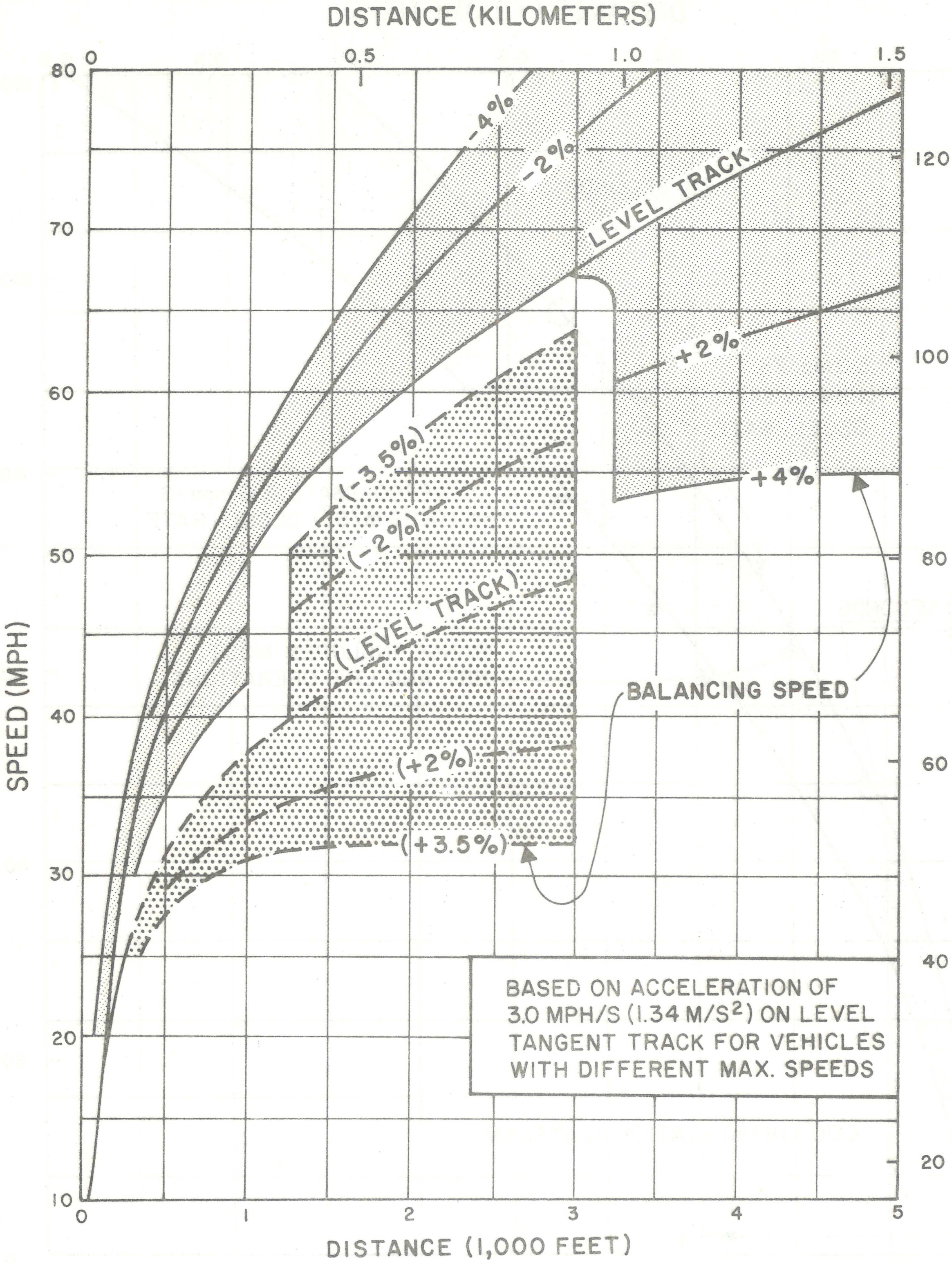

SOURCES:

TTC (DS 3.1.2.A)

BART (Fig. 2.1.1)

RAIL TRANSIT CRITERIA

TYPICAL SPEED-DISTANCE CURVES EFFECT OF GRADES ON HRV & LRV ACCELERATION

FIGURE 3-9.3

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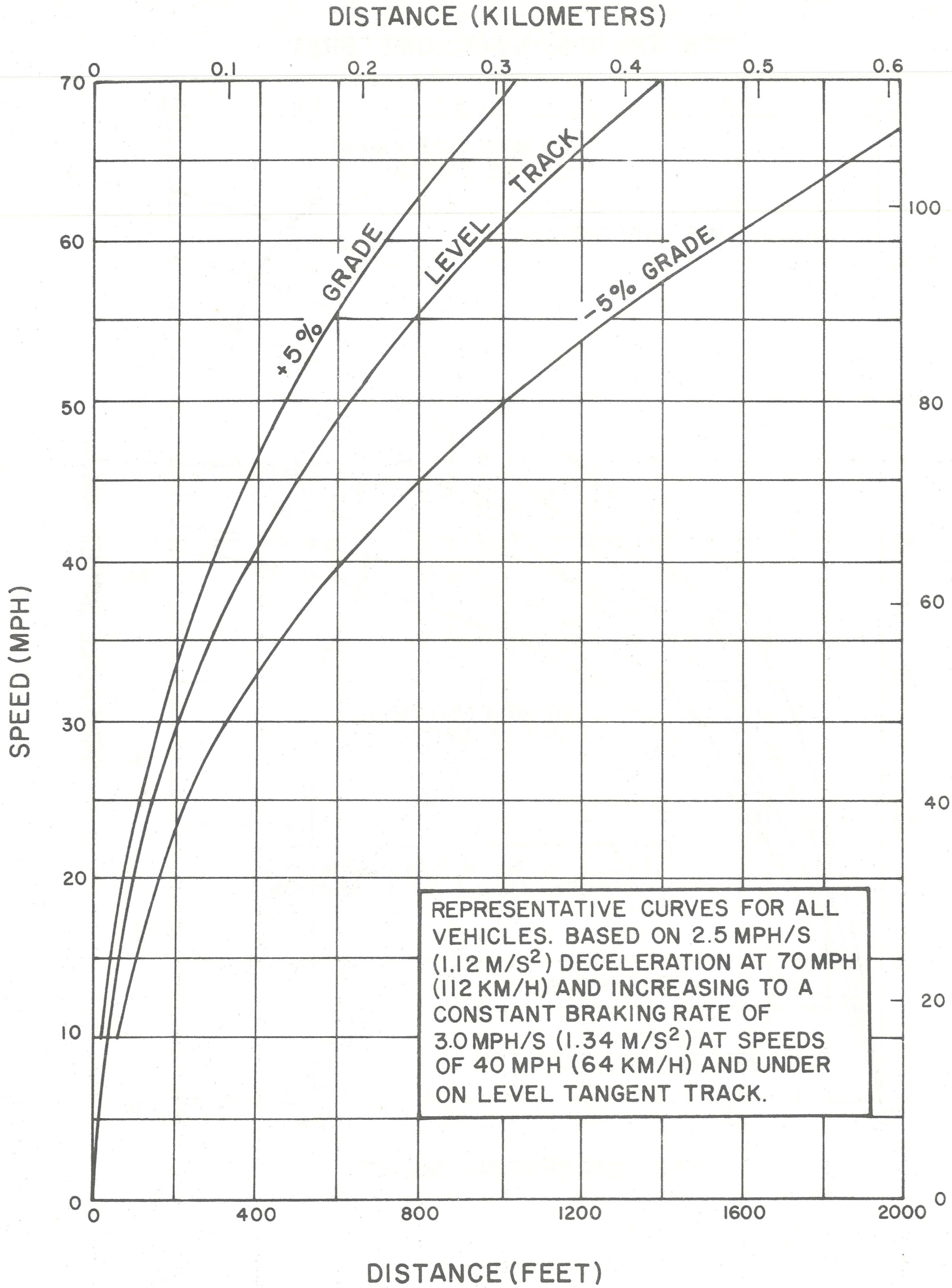

SOURCES:

NYCTA (Table 5.04 & Fig. 5.08)
TTC (D. S. 3. 1. 2. B)

RAIL TRANSIT CRITERIA

TYPICAL SPEED-DISTANCE CURVES
EFFECT OF GRADES
ON HRV & LRV DECELERATION
FIGURE 3-9.4

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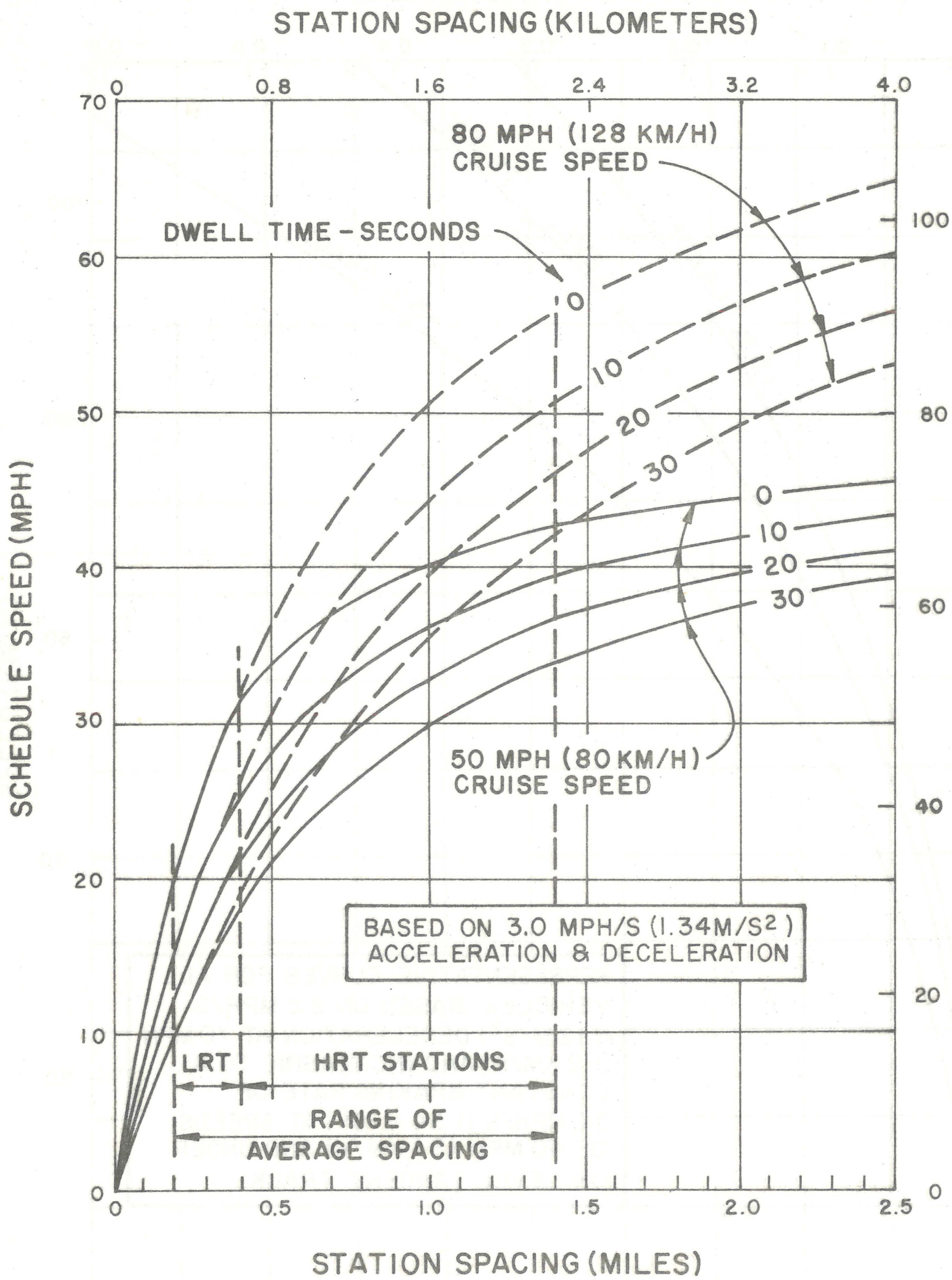

SOURCES:

CUTS (Figs. B-3 & B-6)
SOAR (Fig. 92)
APPENDIXES (A-2 & A-3)

RAIL TRANSIT CRITERIA

EFFECT OF STATION SPACING AND DWELL TIME ON SCHEDULE SPEED

FIGURE 3-9.5

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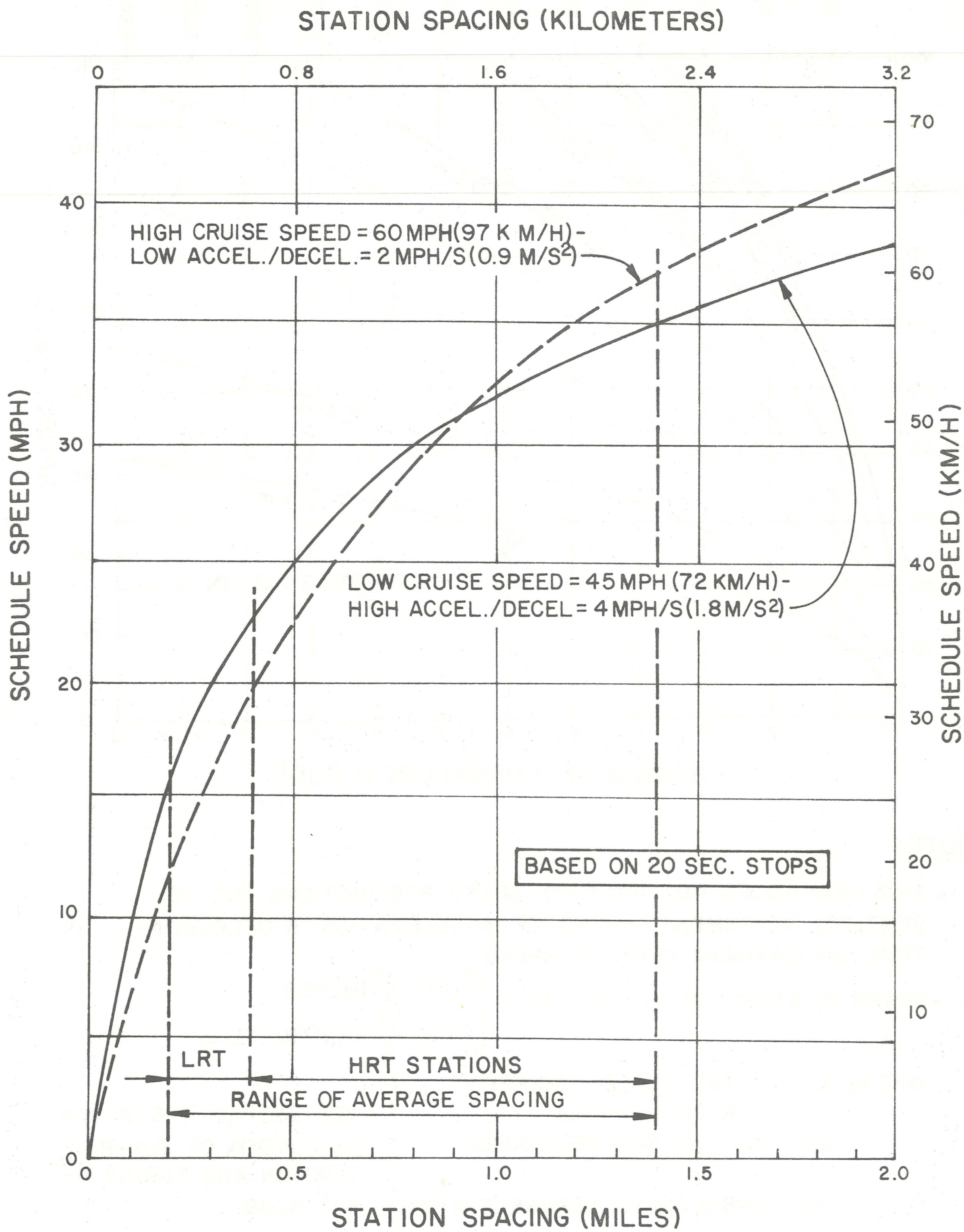

SOURCES:

SOAR (Fig. 91)

APPENDIXES (A-2 & A-3)

RAIL TRANSIT CRITERIA

EFFECT OF ACCELERATION, BRAKING & MAXIMUM SPEED ON SCHEDULE SPEED

FIGURE 3-9.6

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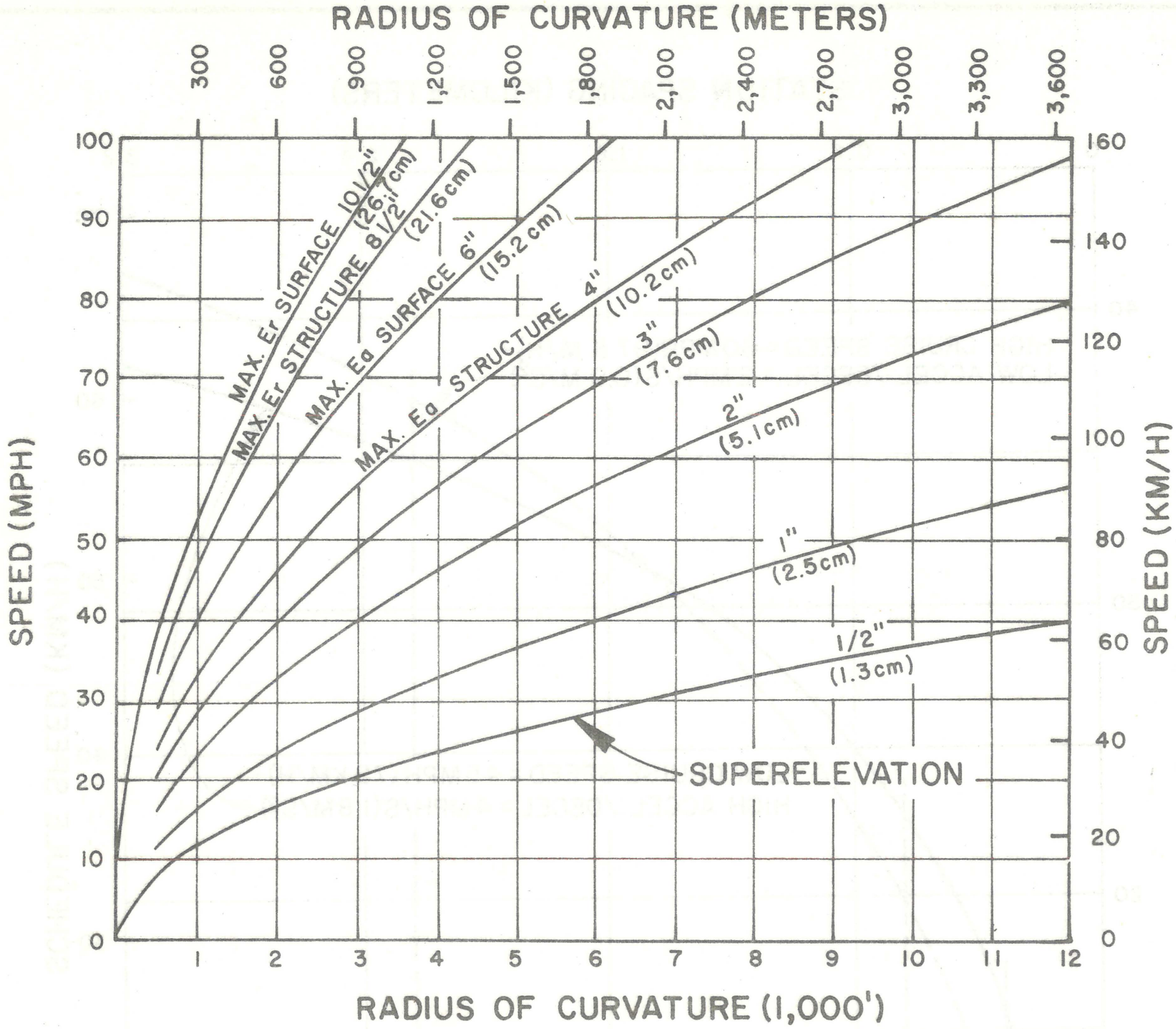

NOTE:

- THIS GRAPH DOES NOT INDICATE SPEED RESTRICTIONS DUE TO VERTICAL ALIGNMENT, RATES OF ACCELERATION & DECELERATION, OR MAXIMUM VEHICLE SPEED.
- GRAPH IS BASED ON $Er = Ea + Eu = \begin{cases} 3.775 \frac{V^2}{R} \text{ INCHES} \\ 1.128 \frac{V^2}{R} \text{ CENTIMETERS} \end{cases}$

WHERE Er = TOTAL SUPER. REQUIRED FOR EQUILIBRIUM
Ea = ACTUAL SUPERELEVATION
Eu = UNBALANCED SUPERELEVATION

SEE SECTION 4-6 (D) FOR DISCUSSION OF SUPERELEVATION AND FIGURE 4-6.2 ALSO.

SOURCES:

TTC (DS 4.1.3B)

RAIL TRANSIT CRITERIA

EFFECT OF HORIZONTAL CURVES ON SPEED

FIGURE 3-9.7

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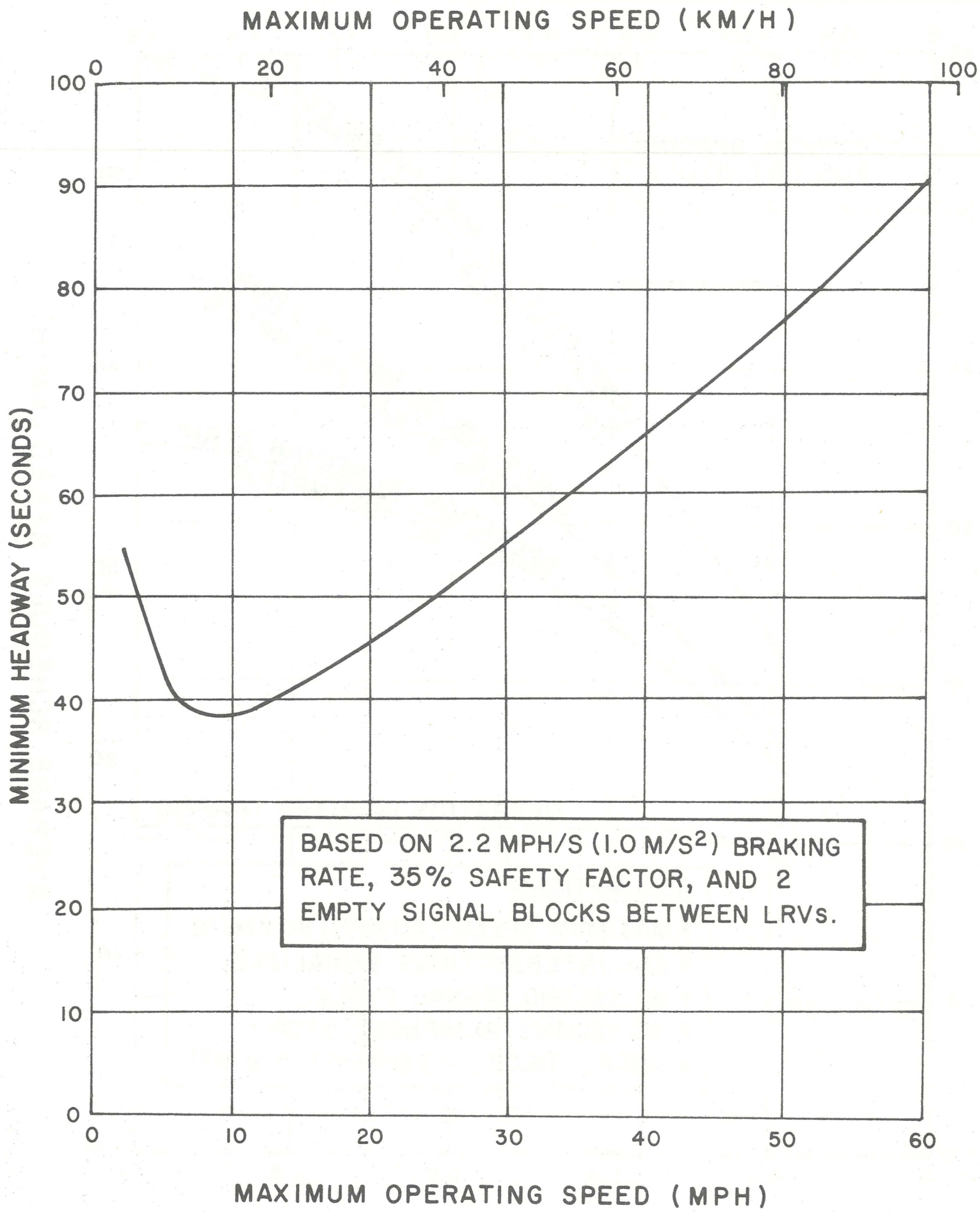
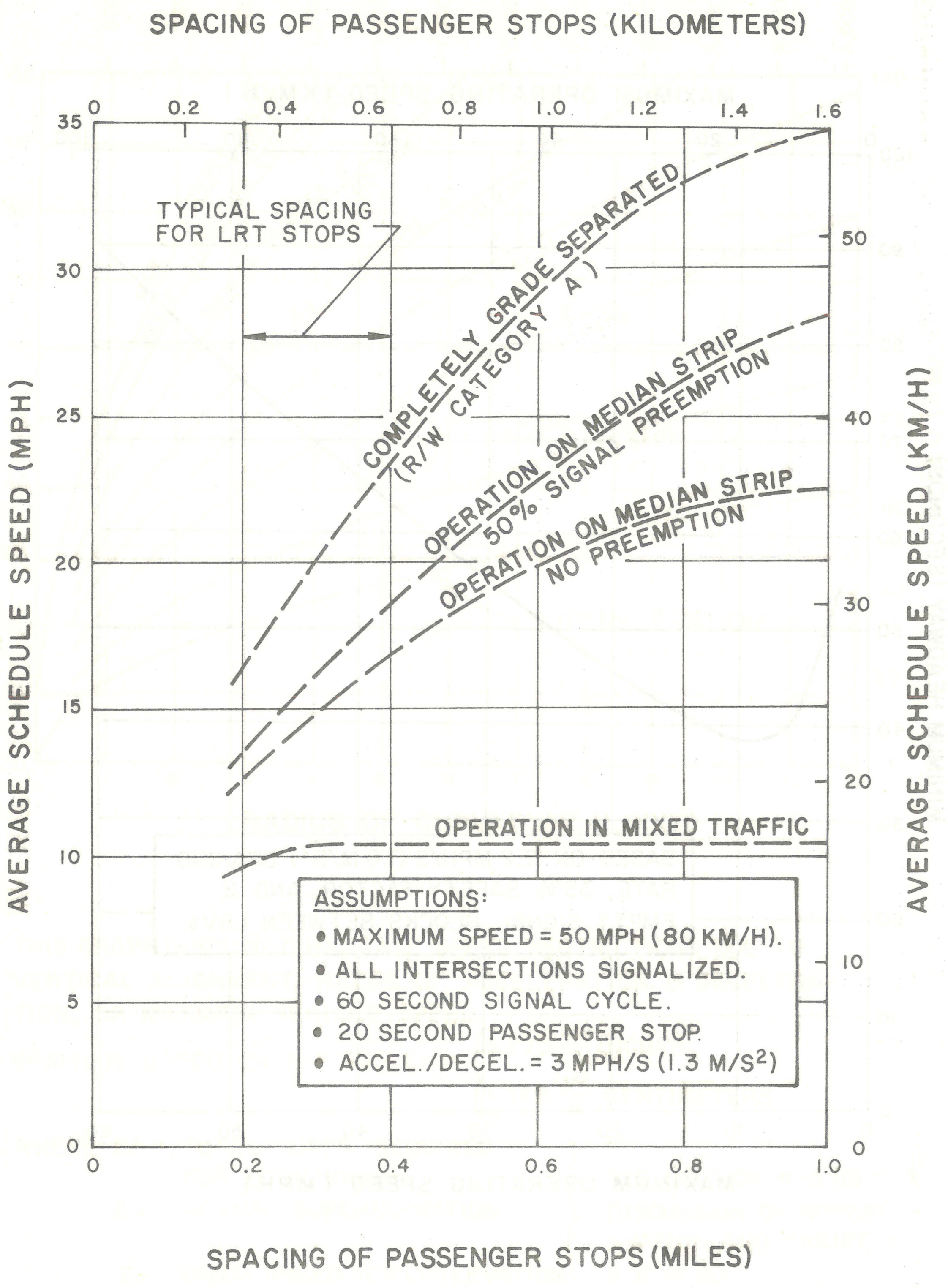


SOURCES:	RAIL TRANSIT CRITERIA	
SOAR (Fig. 96) NYCTA (Fig. 5.03 P. TP-5-12)	THEORETICAL LRT HEADWAY—OPERATING SPEED RELATIONSHIP FIGURE 3-9.8	Caltrans JUN 77



SOURCES:

SOAR (Fig. 93)
APPENDIX (A-2)

RAIL TRANSIT CRITERIA

EFFECT OF DEGREE OF GRADE SEPARATION ON RELATIONSHIP BETWEEN STATION SPACING AND SCHEDULE SPEED

FIGURE 3-9.9

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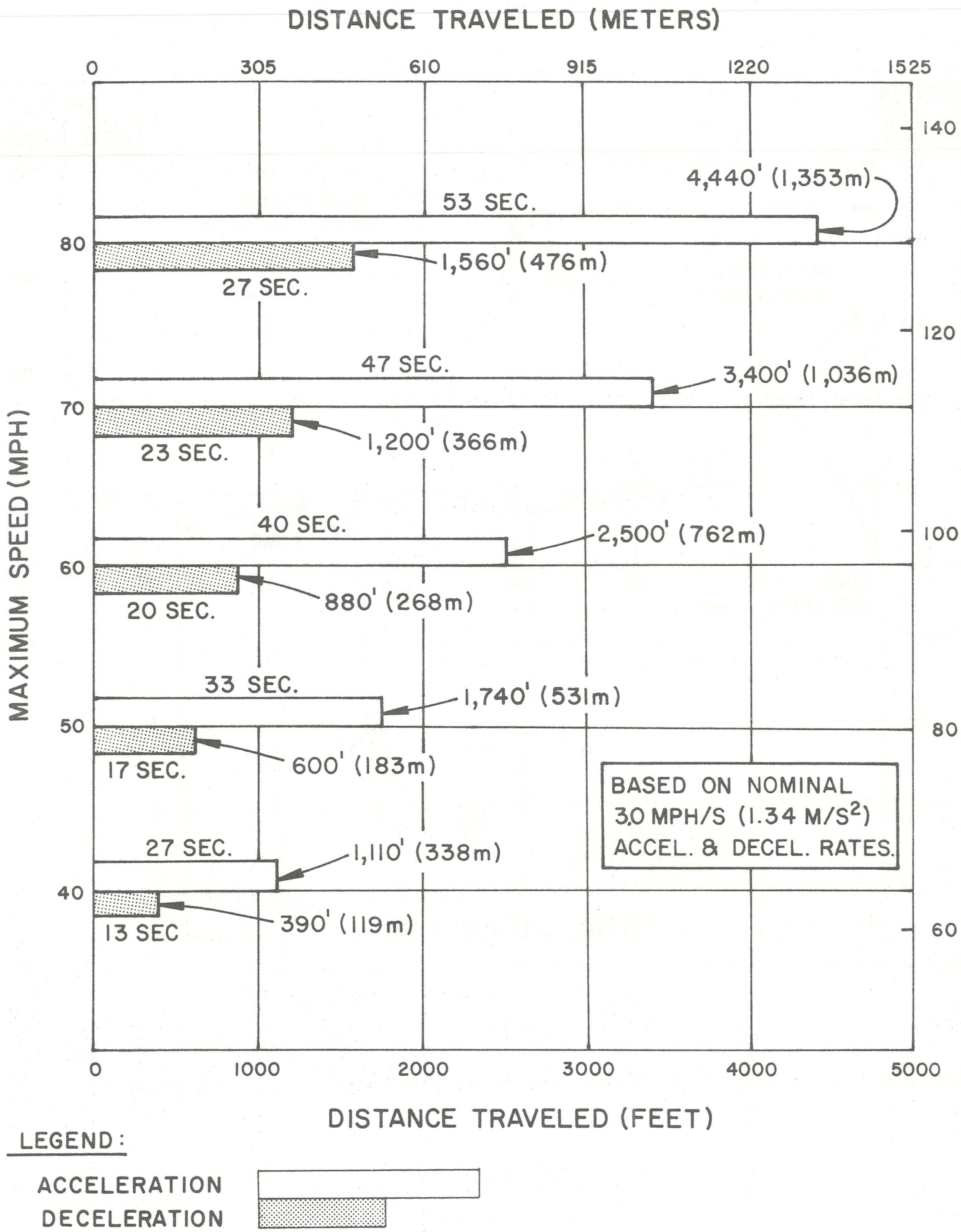

SOURCE:
SEDH (Fig. 3.3)

RAIL TRANSIT CRITERIA

TYPICAL SPEED-TIME-DISTANCE RELATIONSHIPS

FIGURE 3-9.10

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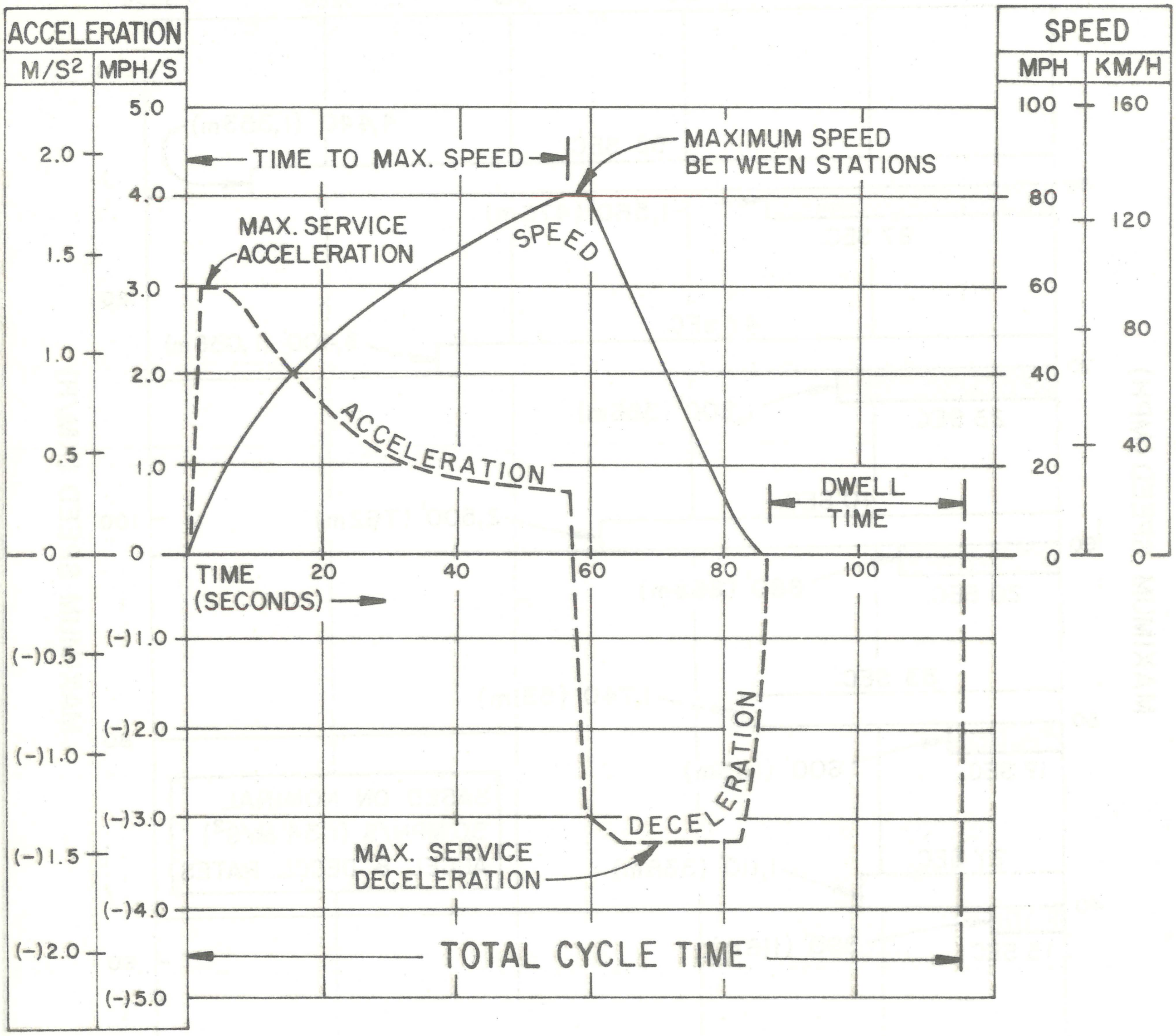

NOTE: See also Figures 3-2.1, 3-9.1, 3-9.2, 3-9.5 and 3-9.10

SOURCE:

SCRTD (Fig. IX-1)

RAIL TRANSIT CRITERIA

VEHICLE OPERATING PROFILE BETWEEN STATIONS

FIGURE 3-9.11

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3-10 SYSTEM COSTS

This section presents a summary of the basic elements of LRT and HRT system costs that may be used as a guideline for preparation, analysis, and comparison of preliminary cost estimates.

Table 3-10.1 shows typical cost ranges that give a good indication of the relative importance of basic elements of cost. Larger cost ranges are shown for elements that tend to vary most with system concept or site or both. 1975 is the base year for tabulated cost figures. It should be noted that the average California Construction Cost Index was relatively stable during 1974, 1975 and 1976, but that transit vehicle and operating costs have been rising steadily since the mid-1960s. Some cost elements are more volatile than others and the cost guidelines herein should be used with caution and judgment.

The January, 1976, Rail Transit System Cost Study (Reference R-7) is a comprehensive analysis of the costs of constructing, operating, and maintaining rail transit systems and is a helpful estimating guide. The Division of Mass Transportation (DMT) may be contacted regarding current, more detailed cost information.

A. Capital Costs

This subsection reviews the elements of capital expenditures shown in Table 3-10.1, defines them briefly, and refers to previous sections for cost figures developed earlier in this chapter. The top of the tabulation summarizes the elements of right-of-way costs and construction costs that can reasonably be expressed on a route-mile (kilometer) basis. These elements are subtotaled at mid-table. The next group of capital cost elements shows cost ranges for facilities and equipment on an individual basis. The land acquisition costs for these facilities are shown separately on a unit-area basis and are not otherwise included in the costs for such facilities or for mainline rights of way. Facility and vehicle costs, however, do include built-in environmental control and mitigation features.

1. Right of Way

As noted in Section 3-3, Subsection E, right-of-way costs are extremely site specific and variable. The cost range shown indicates relative order of magnitude and how influential right of way considerations might be in LRT and HRT system location, design, and operation.

2. Route Construction

Route construction includes line structures and covers the work necessary to prepare the roadbed for installation of trackwork. The cost ranges shown for the route construction element embrace the costs associated with the basic trackway and structure alternatives tabulated immediately below it. The costs for each alternative include applicable costs for demolition, utility relocation, excavating and grading, drainage, traffic handling, and fencing. Any given rail line may, of course, involve several of these basic types of construction.

The graded trackway item includes at-grade trackbed construction or trackways in open cuts or on embankments. The range of costs reflects such things as the amount of grading, the circumstances under which grading is to be done, and the varying requirements for retaining walls, bridges, and grade-separation structures.

The cost ranges shown for aerial and subway structures are derived from Tables 3-5.1 and 3-5.3. The conditions that produce the cost variations are discussed in Section 3-5, Subsections E and G. Underground construction costs per unit of length are also affected by discontinuity and the frequency of costly portal structures. A typical portal transition structure, estimated to cost $1.2 million, is shown in Figure 3-5.1.

3. Trackwork

Trackwork is described in some detail in Section 4-4. It includes ballast or concrete pads, ties, rails, fastenings, and special trackwork. It is inherently well defined, predictable work that is relatively independent of the method of track support. It is subject to little variation within a system or from system to system. The cost to upgrade existing trackage to transit standards might be estimated at about one third of the tabulated costs.

4. Electrification and Control

The tabulated cost ranges embrace overhead and third-rail electrification systems and the control signals and communication systems described in Section 3-4. A more detailed breakdown of cost elements is shown in Table 3-4.1. The item for LRT grade crossing protection is shown explicity in Table 3-10.1, but the item for on-board equipment is included in the range of vehicle costs. The potentially sizeable item for yard control is included in the cost range for storage yards shown in Table 3-10.1.

5. Subtotal per Unit of Length

Many combinations and tradeoffs are possible among the elements listed. This is reflected in the maximum cost figures shown for route-mile (kilometer) subtotals which indicate that all of the maximum values for elements are not additive.

6. Stations

LRT and HRT station characteristics and features are discussed at some length in Section 3-6 and cost ranges for stations associated with various profile grade conditions are given in Subsection K.

7. Parking Lots

Parking facilities are discussed in Section 3-6, Subsection J, and parking lot costs are given in Subsection K. The cost figures in Table 3-10.1 are for lots with up to 1,000 parking spaces and provide for internal circulation roadways, pedestrian pathways, and limited landscaping. They do not include lighting or make allowances for improvements in external access or for parking structures.

8. Storage Yards

As described in Section 3-7, Subsection D, yard construction cost items include site preparation, grading, drainage, utilities, buildings and staff facilities, trackwork, electrification, landscaping, and fencing. The upper limits of yard costs in Table 3-10.1 are based on a storage capacity for 300 rail cars and also include an allowance for the control systems costs shown in Table 3-4.1. The $23 million cost for the HRT yard includes $10 million for a full ATC system. Less sophisticated controls would range from $1 million for push button control up to $4 million for a fully interlocked control system. Other major cost items in the upper range are a $5 million allowance for trackage in LRT and HRT yards, $9 million for LRT power supply system, and $6 million for HRT power distribution.

9. Shops

Repair shop and support yard costs are discussed in Section 3-7, Subsection D. The costs are based on the same items as storage yard costs with the addition of shop buildings, shop equipment, and parts storage facilities. The cost ranges reflect fleet sizes that vary from 60 to 300 vehicles. Power distribution costs for shops are about one-half as much as for storage yards, and control costs are nominal. The major items include a $5 to $16 million cost range for shop facilities and $1 to $5 for shop and yard tracks.

10. Land

Land acquisition costs are site-specific and time-specific. The tabulated costs, ranging from $11,000 to $65,000 per acre ($27,000 to $160,000 per hectare), represent the extremes of lower cost suburban land and expensive central city sites. These figures are intended to indicate relative orders of magnitude only. In this connection, small parking lots might require 1 to 3 acres (0.4 to 1.2 hectares) and large lots, 5 to 10 or 15 acres (2 to 4 or 6 hectares). For preliminary estimating purposes, storage yards may be considered to range from 3 to 10 acres (1.2 to 4 hectares) and shop areas, from 4 to 12 acres (1.6 to 4.8 hectares).

11. Vehicles

The tabulated vehicle costs are derived from Figure 3-2.2 and the discussion in Section 3-2, Subsection F. There is only a marginal cost distinction between modern LRVs and HRVs.

The selection of a vehicle with standardized modules and components is worth careful consideration. Such a vehicle can be modified significantly within standard limits and subcomponents are designed for easy access and replacement. These features can minimize vehicle developmental, production, and testing costs, improve reliability, and reduce down time. This can not only reduce the purchase price and maintenance costs for each vehicle, but may also reduce fleet size and facility requirements.

12. Grade Crossing Protection

This element of cost is unique to LRT operations as described in Sections 3-3 and 3-4 and as shown in Table 3-4.1. It is included in Table 3-10.1 as part of the overview of cost elements and their relative magnitude.

B. Miscellaneous Costs

These factors are introduced here because they are significant in anticipating the total cost of planning, designing, and constructing new systems and in implementing revenue service. They are somewhat less critical elements in upgrading or extending existing systems and service.

An allowance for inflation is not included in these miscellaneous factors. However, the effects of inflation must be considered separately and in an appropriate manner.

The generalized rates shown for "contingencies" and "management" are typical of the factors in use. The higher rates are applied to early order-of-magnitude cost estimates. The rates to be used, their application sequence, and the capital cost base (right of way, construction, and equipment) to which they are applied, are matters of judgment and discretion at any particular point in project development.

1. Contingencies

This allowance is to provide for unknown and unanticipated conditions and for unpredictable items of cost.

2. Management, Engineering, and Design

This factor represents the anticipated cost of administration during project development and the costs to be incurred for planning, engineering design, PS&E, control surveys, soil investigations, construction contract management and inspection, procurement, and related activities.

3. Pre-Operation Expenses

The considerable lead time and costs required for service start-up on new systems should not be underestimated. Early planning and explicit funding for this effort should help reduce and control both time and cost.

This phase provides for the selection and training of operating and maintenance personnel and for the establishment of personnel policies. See Section 8, Appendix A-11. This phase includes such things as the development of operational and maintenance policies and manuals and the establishment of operating management and control systems. It also includes testing computer hardware, debugging software, and inspecting and testing vehicles.

The suggested allowance for pre-operation expenses provides an amount on the order of 25% to 65% of the increase in annual operating and maintenance expenditures estimated to be required for each increment of the system as it is readied for revenue service. This guideline is intended to suggest the approximate significance of this cost element which appears to warrant thorough analysis and validation.

C. Operating and Maintenance Costs

Cost studies and estimates of LRT and HRT operations generally break labor and materials costs down into the five categories shown in Table 3-10.2. The costs included in these categories are as follows:

- Maintenance of Way and Structures

  Covers costs involved in the maintenance of tracks, subways, aerial structures, bridges, power supply and signal systems, stations, and maintenance facilities themselves.

- Maintenance of Equipment

  Includes rolling stock and miscellaneous equipment.

- Power

  Identifies the costs involved in the production or purchase (or both) of electrical traction and auxiliary power.

- Transportation

  Identifies the costs involved in day-to-day system operations. The costs are nearly 100% labor related and include motormen, conductors, station attendants, dispatchers, switchmen, signalmen, and on-line supervisors.

- Administrative and General

  The costs involved in administering the system, include executives, accounting, public relations, and other administrative and support functions.

  The general expense portion includes miscellaneous left-over items such as public liability insurance and operating taxes. General expenses usually amount to somewhere between 30% and 60% of this category.

Maintenance and operating cost categories and totals have commonly been expressed in terms of car-miles (kilometers) as shown in Tables 3-10.1 and 3-10.2. This is most appropriate for the cost categories related to track usage and car usage. It has been suggested that the cost of conducting transportation might better be related to car-hours, but this information has not generally been available. Studies have also suggested that administrative costs should be related to the number of vehicles in peak-hour use and that miscellaneous general expenses should be related to the number of annual revenue passengers.

Despite shortcomings, internal accounting systems have nevertheless provided a reasonable basis for monitoring trends and forecasting changes in the operating costs of any given system. However, even with the apparent commonality of cost accounting categories, the accounting systems of the various properties have not yielded information such that operating costs and efficiencies could be compared in a satisfactory and equitable manner. There are mixed opinions as to the desirability, relevance, and ultimate validity of such comparisons. Some of the difficulties to be reconciled have to do with such things as regional differences in power costs and wage rates; differences in hours of operation, levels of service, and potential patronage; differences in the ages of facilities and rolling stock; differences in train crew requirements and the need for station attendants and maintenance crews; differences in vehicle preventive maintenance policies; and the varying difficulties associated with severe climates or maintaining extensive aerial or underground structures under traffic.

In an attempt to resolve these issues, UMTA and APTA have been collaborating on Project FARE to develop Uniform Financial Accounting and Reporting Elements to be used by 440± federally aided transit properties for reporting operating and cost information. The objectives of FARE are to improve management and control systems at the local level and to provide uniform financial and operating data at the national level. FARE reporting begins in 1978. Reporting on only 132 mandatory items will satisfy minimum requirements, but UMTA will accept voluntary reporting of all 708 FARE items.

TABLE 3-10.1

SUMMARY OF COSTS FOR DOUBLE TRACK SYSTEMS

TYPE EXPEND.	COST ELEMENT		COST RANGE — 1975 DOLLARS			
			LRT		HRT	
			$ Millions Per Mile	$ Millions Per Kilometer	$ Millions Per Mile	$ Millions Per Kilometer
CAPITAL COSTS	RIGHT OF WAY		0 - 10	(0 - 6.3)	0 - 10	(0 - 6.3)
	ROUTE CONSTRUCTION		0.7 - 30	(0.4 - 19)	1.2 - 75	(0.8 - 47)
	Graded Trackway		0.7 - 15	(0.4 - 9)	1.2 - 15	(0.8 - 9)
	Aerial Structure		8 - 20	(5 - 13)	8 - 20	(5 - 13)
	Cut and Cover Box		12 - 30	(8 - 19)	12 - 30	(8 - 19)
	Rock Tunnel		— — —	— — —	10 - 30	(6 - 19)
	Earth Tunnel, Dry		— — —	— — —	15 - 40	(9 - 25)
	Earth Tunnel, Wet		— — —	— — —	40 - 70	(25 - 44)
	Tube		— — —	— — —	50 - 75	(31 - 47)
	TRACKWORK		0.8 - 1.1	(0.5 - 0.7)	0.8 - 1.1	(0.5 - 0.7)
	ELECTRIFICATION & CONTROL		0.3 - 1.8	(0.2 - 1.1)	1.5 - 4.7	(0.9 - 2.9)
	SUBTOTAL - $ Millions /Mi (Km)		1.8 - 30+	(1.1 - 19+)	3.5 - 75+	(2.2 - 47+)
	STATIONS	$ Millions Each	0.02 - 8		0.5 - 14	
	PARKING LOTS	$ Millions Each	0.3 - 1.6		0.3 - 1.6	
	STORAGE YARDS	$ Millions Each	4 - 17		4 - 23	
	SHOPS	$ Millions Each	8 - 29		8 - 29	
	LAND (Yards, Lots, etc.)	$ Millions/Acre	0.01 - 0.65		0.01 - 0.65	
	VEHICLES	$ Millions Each	0.30 - 0.55		0.33 - 0.60	
	GRADE XING PROTECT'N.	$ Millions/Xing	0.03 - 0.06		— — —	
MISC.	Contingencies	% Cap. Cost	10 - 25		10 - 25	
	Project Mgt., Eng. & Des.	% Cap. Cost	10 - 20		10 - 20	
	Pre-Operation Expenses	% Ann. Maint. & Oper. Cost	25 - 65		25 - 65	
OPER.	ANNUAL MAINT. & OPER. COST (See Table 3-10.2)	$/Car-mi ($/Car-km)	1.85 - 2.40 (1.15 - 1.50)		1.15 - 1.70 (0.72 - 1.06)	

(SOURCES : References R-2, R-5, R-6, R-7, R-9, CP-2 & as noted on other cost summaries)

TABLE 3-10.2

MAINTENANCE AND OPERATING COSTS

COST CATEGORY	CATEGORY % OF TOTAL		LABOR (DIRECT + INDIRECT COSTS)
	LRT	HRT	% OF CATEGORY
1. MAINT. OF WAY & STRUCTURES	10	18	70 — 80
2. MAINT. OF EQUIPMENT	14	16	75 — 85
3. POWER	8	11	0 — 20
4. TRANSPORTATION	42	38	90 — 99
5. ADMINISTRATIVE & GENERAL	26	17	35 — 55
TOTAL PERCENT	100%	100%	65%— 80%

TOTAL MAINT. & OPERATING COST		
* COST GUIDELINE BASIS	COST RANGE 1975 DOLLARS	
	LRT	HRT
$ PER CAR – MILE	1.85-2.40	1.15-1.70
($ PER CAR – KILOMETER)	1.15-1.50	0.72-1.06

* Assumptions:

- ° LRVs average 21,000 mi/yr (34,000 km/yr) $\pm$ 5%
- ° HRVs average 34,000 mi/yr (55,000 km/yr) +60% −30%

(SOURCES: References R-7, P-9, P-15, M-20, CP-2)

3-11 PROJECT DEVELOPMENT TEAMS, CONTRACTS, AND PLANS

The purpose of this section is to illustrate in a general way the nature and sequence of project development efforts, stages, and products. This will be done by discussing patterns typical of recent or current HRT projects.

A. Design Roles and Expertise

A number of governmental and quasi-public authorities have been created to establish policy and to be responsible for the management and administration of transit programs, and for the construction of new rail systems. The transit authorities are empowered to acquire rights of way. Some also prepare design criteria and administer construction contracts, but more often they engage consultants to perform specialized and coordinating roles somewhat as follows:

1. General Consultant

The general consultant is responsible for preparation of design criteria, general plans, directive plans, and guide specifications for the system. A project engineer is assigned to each design contract to be responsible for scheduling and reviewing final design work. He assists the final designer in coordinating with outside parties and public agencies affected by the work. The general consultant advises the transit authority on all engineering and architectural matters and ensures that the system is designed and constructed in accordance with approved criteria, plans and specifications.

2. Architectural Consultant

A consultant is engaged to determine the architectural requirements of the system and to prepare conceptual designs, general plans, directive drawings and specifications, and to coordinate and review architectural work during final design.

3. Soils Consultant

This consultant performs soils and geologic investigations for the system, recommends design loadings and underpinning requirements affected by subsurface conditions, and reviews the soils assumptions made by the final designers.

4. Noise and Vibration Consultant

This consultant prepares design criteria for minimizing noise and vibration transmission, determines where controls are required, and makes recommendations to the final designers for implementing these criteria.

5. Final Designer

Engineering or architectural-engineering firms are retained by the transit authority to prepare contract plans, specifications, and cost estimates for specific elements or certain portions of the system. The final designer is responsible for coordinating his work with others, for maintaining schedules, for making design assumptions, and for preparing final designs in accordance with established design criteria unless deviations are approved by the general consultant.

6. Construction Inspector

Engineerng or architectural-engineering firms may also be retained by the transit authority to inspect the work of construction contractors.

7. Contractor

Construction contractors bid on and construct portions of the system.

B. Construction Contracts

The basic types of contracts prepared by final designers of a rail transit system usually fall into the four categories described below.

1. Preparatory Contracts

The following preparatory contracts may be carried out in order to prepare the site in advance of major construction:

- Underpinning Contracts involving the shoring or support of affected structures along the route.

- Utilities Contracts involving the relocation of major utilities impacted by the system. More routine utility relocation work is performed in the major construction contracts.

- Demolition Contracts involving the removal of buildings and structures to clear the right of way.

2. Major Contracts

Major contracts primarily involve heavy construction work such as grading and tunneling, underground and aerial line structures, vent shafts, and integral large scale station and parking facilities. The basic structures and trackbed constructed under this type of contract are to be ready for the application of finish materials or the installation of trackwork and equipment throughout a system or an operational portion thereof.

3. Finish Contracts

Finish contracts are let subsequent to major contracts and include such things as wall finish, flooring, lighting, and electrical and mechanical items. For certain portions of the system, it may be necessary or desirable to combine major and finish work under one contract.

4. System Contracts

System contracts include the procurement and installation of trackwork, traction power equipment, traffic control and communications equipment, escalators, and other major features which must be in place throughout an entire system or an operating portion.

C. Construction Drawings

Contract drawings are typically 22 x 36 inches (56 x 91 cm) and should be suitable for half-scale reproduction. Details are combined or superimposed on base mapping as appropriate.

Plan sheets vary from project to project, but the following headings outline the nature and general sequence of drawings that may be required.

o General Information

- Site/Key Plan
- Index of Drawings
- General Notes and Abbreviations
- Traffic and Construction Staging
- Payment Limits

o Geological, Hydrological, and Soils

- o <u>Civil Engineering</u>
  - Horizontal and Vertical Control
  - Survey Plots of Contours and Planimetry
  - Rights of Way
  - Plan and Profile
  - Cross Sections
  - Grading and Paving
  - Earthwork
- o <u>Utilities</u>
- o <u>Structural</u>
- o <u>Architectural</u>
- o <u>Mechanical</u>
  - Heating and Air Conditioning
  - Plumbing and Piping
- o <u>Electrical</u>
  - Lighting
  - Propulsion Power
  - Train Control
  - Communications
- o <u>Fare Collection</u>
- o <u>Landscaping</u>

CHAPTER 4

TRACK DESIGN CRITERIA

CHAPTER INDEX

CHAPTER 4 - TRACK DESIGN CRITERIA

CHAPTER 4

TRACK DESIGN CRITERIA

4-1 GENERAL

This chapter sets forth principles and basic design criteria for vehicle loads and clearances, trackwork and trackways, and track alignment. The criteria are based on the practices of operating transit systems, and on the standards proposed for the development of new systems in accordance with current AREA practices.

The criteria herein can be applied directly to HRT systems. They can also be applied with discretion, and in accordance with Appendix A-11, to LRT systems which embrace a wide range of operating conditions and characteristics. When used in conjunction with an assumed HRT or LRT "design vehicle," the criteria are suitable for system planning and preliminary design studies.

While design principles are constant, certain criteria, such as those related to superelevation, are affected by track gauge. The criteria herein are based on the standard gauge of 4 feet 8 1/2 inches (1,435 mm).

4-2 AXLE LOADS

As noted in Section 3-5, Subsection F, all transit structures are designed for the dead loads (DL) and live loads (LL) to which they might be subjected, including construction loads. Section 3-5 covers dead loads and seismic forces to be considered in the design of aerial and subway line structures and other transit structures. This section discusses the transit vehicle or train live load elements that affect the design of trackways and line structures. Vehicles or trains are placed on one or more tracks to produce maximum stress conditions for structural design. Figures 4-2.1 and 4-2.2 show axle loads and spacings for the four typical"design vehicles" identified in Table 3-2.1.

The following live load elements are typical of the design forces applied by transit properties and by the Caltrans Transit and Structural Design Section in conformance with AREA specifications. The indicated applications of loads and forces are combined according to current engineering practice with appropriate increases in allowable basic unit stresses.

A. Distribution of Wheel Loads

On open deck structures, wheel loads are distributed longitudinally over three ties or 4' (1.2 m) of rail.

On ballasted decks, wheel loads may be assumed as uniformly distributed longitudinally over 3' (0.9 m) of rail plus twice the depth of ballast under the tie plus twice the effective depth of slab, but the sum of the above may not exceed the axle spacing. The axle loads are distributed normal to the track for the length of the tie plus the depth of ballast under the tie, but the sum of the two may not exceed the width of the bottom surface of the ballast.

On rail mountings placed directly on the slab, wheel loads may be assumed to be uniformly distributed over 3' (0.9 m) of rail longitudinally and a transverse width of 14" (36 cm) centered on the rail.

B. Impact Factor (I)

Impact formulas and design practices vary. In the absence of a vehicle-guideway interaction analysis to determine the impact factor, a factor of 30% of the wheel load is applied vertically to each track up to a maximum of two tracks for a multiple track structure.

C. Centrifugal Force (CF)

Centrifugal force takes curve geometry and design speed into account. A percentage of the total vehicle load is applied horizontally 5.0' (152 cm) above the top of the low rail on all tracks. The percentage of the load to be applied is given by:

	$CF = 6.8755\frac{V^2}{R}$	$CF = 0.80914\frac{V^2}{R}$
Where:		
CF = Centrifugal force,	%	%
V = Velocity,	mph	kmph
R = Radius of curve,	feet	meters

D. Rolling Force (RF)

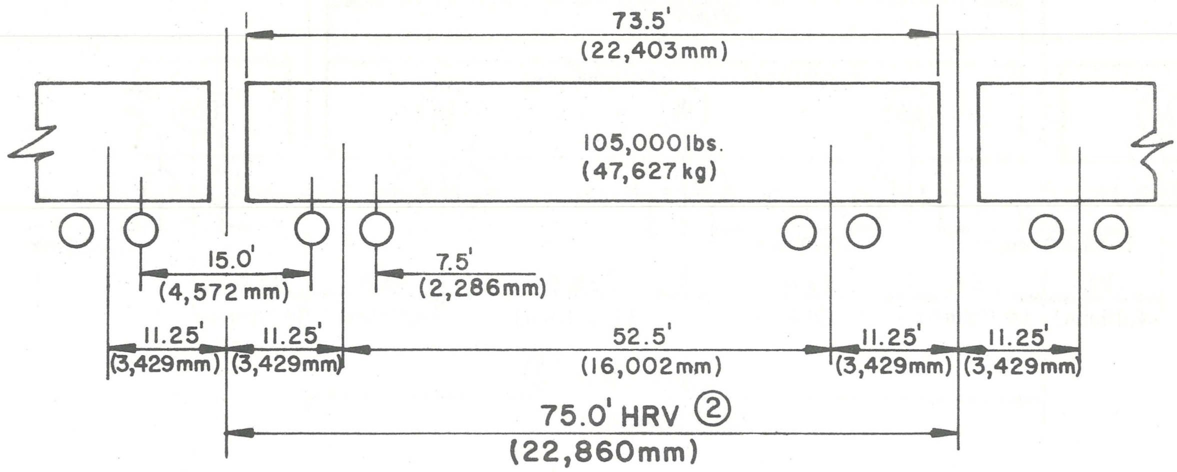
A force equal to 10% of the total vehicle load per track is applied downward on one rail and upward on the other, on all tracks.

E. Longitudinal Force (LF)

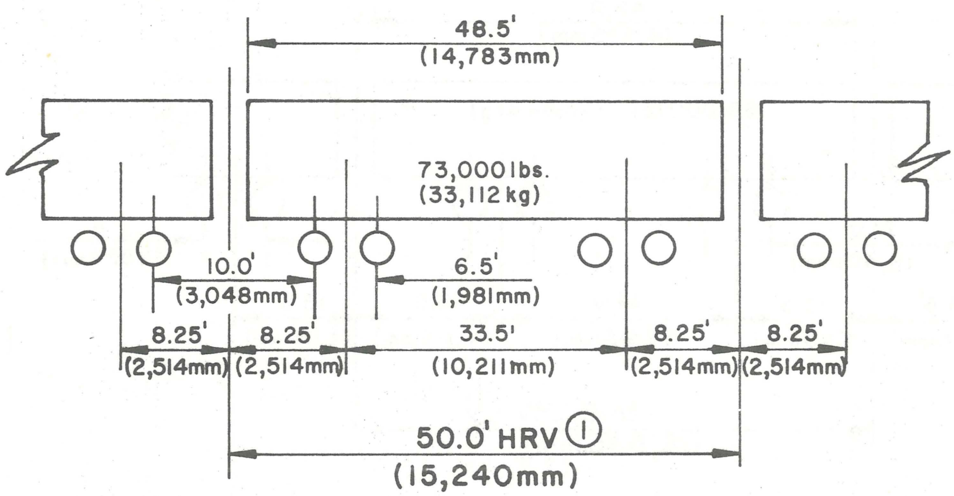
A longitudinal braking or tractive force equal to 15% of the total vehicle load per track is applied horizontally 5.0' (152 cm) above the rail on all tracks. Consideration is given to combinations of acceleration and deceleration forces where more than one track occurs.

F. Wind Load on Live Load (WL)

In addition to the wind load values specified by AASHTO on the structure itself, a wind load (WL) on the live load is to be applied. A transverse horizontal wind load of 300 lb/lf (446 kg/m) of train and a longitudinal horizontal wind load of 75 lb/lf (112 kg/m) of train are applied simultaneously. The transverse wind load is applied to the train as concentrated loads at the axle locations in a plane 7' (2.1 m) above the top of the low rail and normal to the track. The horizontal force component, transmitted to the rails and superstructure by an axle, is concentrated at the rail having direct wheel-flange contact. The longitudinal wind load is applied to the rails and superstructure as a uniformly distributed load over the length of the train in a horizontal plane at the top of low rail.



DESIGN LOADS: Vehicle (Empty) -------- 72,000 lbs. (32,659 kg)
Passengers ----------- 33,000 lbs. (14,968 kg)
Total Vehicle Load ------ 105,000 lbs. (47,627 kg)
AXLE LOADS (all axles) --------------- 26,250 lbs. (11,907 kg)



DESIGN LOADS: Vehicle (Empty) -------- 50,000 lbs. (22,680 kg)
Passengers ----------- 23,000 lbs. (10,432 kg)
Total Vehicle Load ------ 73,000 lbs. (33,112 kg)
AXLE LOADS (all axles) --------------- 18,250 lbs. (8,278 kg)

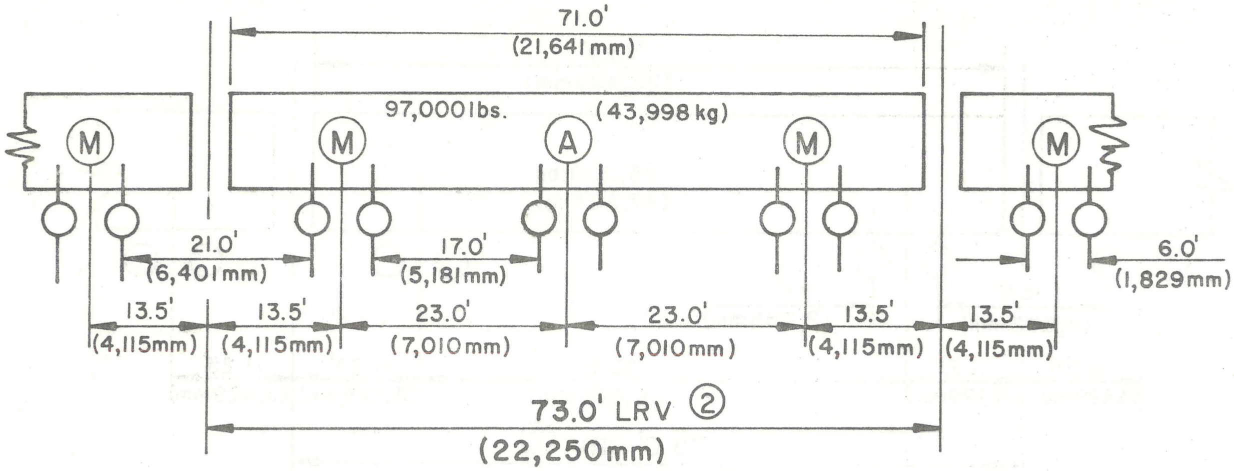
SOURCES
WMATA (Fig. V-1)
TTC (DS 4.3.3.B)
BRRTS (Fig. V.1)
SCRTD (Fig. V-1)
NYCTA P. SD-3-2
TABLE 3-2.1

RAIL TRANSIT CRITERIA

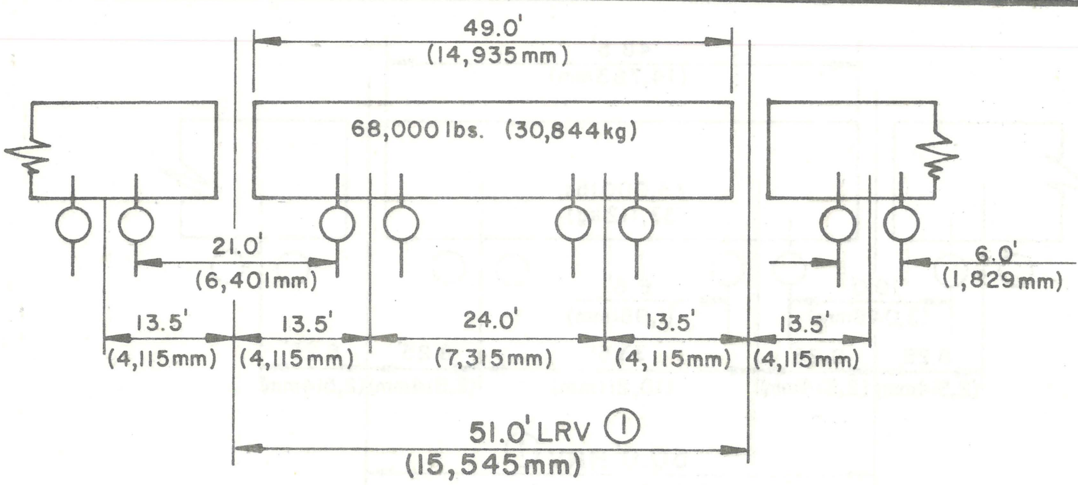
HRV AXLE LOADS

FIGURE 4-2.1

Caltrans
JUN 77



DESIGN LOADS: Vehicle (Empty) -------- 65,000 lbs. (29,483 kg)
Passengers ----------- 32,000 lbs. (14,515 kg)
Total Vehicle Load ------ 97,000 lbs. (43,998 kg)
AXLE LOADS: Motorized Trucks (M) -------- 18,350 lbs. (8,320 kg)
Center Truck (Artic. Joint) (A) --- 11,800 lbs. (5,350 kg)



DESIGN LOADS: Vehicle (Empty) ------- 42,000 lbs. (19,051 kg)
Passengers ----------- 26,000 lbs. (11,793 kg)
Total Vehicle Load ------ 68,000 lbs. (30,844 kg)
AXLE LOADS (all axles) ------------ 17,000 lbs. (7,711 kg)

SOURCES:

TTC (DS 4.3.3B)
ASME (P.9)
BRRTS (Fig. V.1)
SCRTD (Fig. V-1)
TABLE 3-2.1

RAIL TRANSIT CRITERIA

LRV AXLE LOADS

FIGURE 4-2.2

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4-3 VEHICLE CLEARANCES

Appropriate clearance must be provided to assure:

- Safe passage of vehicles and trains.
- Access to all areas of bad-order cars.
- Walkways for passenger evacuation.
- Normal passenger exchange at station platforms.

This section discusses the basic factors to be considered in assuring the necessary clearance between vehicles and transit structures. The approach is generalized to provide a basis for determining clear space requirements external to vehicles of various shapes and sizes. However, since line structures and high platforms are most characteristic of HRT system operations, a typically modern HRV has been used in some instances for illustrative purposes. CPUC clearance requirements governing LRT systems are contained in Section 5 of Appendix A-11.

A. General

Clearance determinations begin with the cross sectional shape of a specific vehicle (as shown in Figure 4-3.1) and then make allowances for the vertical, lateral, and rotational car body movements that occur when the car is operating on a tangent section of track. These body movements are due to spring action, bolster and truck suspension movements, allowable wheel and rail wear, and permitted tolerances in vehicle and track construction. A static car outline is used as a point of departure for illustrating body movements relative to track centerline and profile grade and for defining the cross sectional shape required to provide desired horizontal and vertical clearances for the rail vehicle in motion. Figure 4-3.1 illustrates the dynamic outline and the clearance envelope generated when allowances for body movement are added to the static outline.

In addition to body movement on tangent track, the effects of track curvature must also be considered. The dynamic outline must be modified to allow additional room for vehicle overhang on curves and for vehicle lean when the curves are superelevated.

Other factors external to the vehicle clearance envelope are needed to size structures. As indicated on Figure 4-3.6, an overall minimum clearance is required between the clearance envelope and the finished faces of structures. This minimum clearance provides for construction tolerances, chorded construction and for lateral and vertical running clearances.

In the balance of this section, the considerations, figures, and relationships referred to thus far will be presented in more detail and should form an adequate basis for determining clearance dimensions for specific vehicles and systems. Once vehicle characteristics are known, appropriate tables, graphs, and templates can be prepared to assist this design process.

Where railroads are involved, clearances must, of course, satisfy railroad requirements and be acceptable to the property concerned. Minimum clearances involving highways should be in accordance with Section 7-309, "Structure Clearances", as shown in the Caltrans Highway Design Manual. Both railroad and highway clearances must also satisfy CPUC requirements.

B. Vehicle Configuration and Dynamics

This subsection describes the clearance considerations that are related primarily to the size and shape of vehicles and to transverse movement with respect to track centerline and profile. It discusses the progression from static to dynamic outlines on tangent alignment as shown on Figures 4-3.1 and 4-3.2 and the manner in which dynamic outlines are modified for the effects of track curvature as shown on Figure 4-3.6. Short radius curves are not used for HRT mainline tracks and structures, but LRT systems may include alignment with severe curvature. In either type of system, however, vehicle overhang and lean on curves are significant design factors in providing adequate clearances for vehicles on mainline tracks or in yards and shops.

1. Static Car Outlines

Clearance determinations start with the attributes of a specific vehicle. Figures 4-3.1 and 4-3.2 contain three basic car outlines that represent the usual range of body cross sectional shapes. These shapes were selected to illustrate the similarities and differences in dynamic outlines that result when all shapes are subjected to identical limits of car body movement.

2. Car Body Movements

Table 4-3.1 summarizes the nature and extent of the typical lateral, vertical, and rotational car body movements that affect vehicle position relative to a section of tangent track. These are the body movements used to derive the dynamic outlines shown for the three representative vehicles depicted in Figures 4-3.1 and 4-3.2.

At station platforms, car body movements are assumed to be controlled within narrower limits. Guidelines for use at platforms only are:

- Vertical Downward.......................... 3" (7.62 cm)
- Lateral Movement....................... 2 5/8" (6.67 cm)
- Roll... 2 degrees (0.035 radians) after lateral movement of 1 1/2" (3.81 cm)

3. Dynamic Outlines

Dynamic outlines represent the extreme car displacement that can occur for any combination of lateral, vertical, and rotational movements. The dynamic outlines shown in Figures

4-3.1 and 4-3.2 are for vehicles on tangent track. In contrast, the dynamic outline in Figure 4-3.6 has been modified to allow for vehicle overhang on curves and for the lean caused by track superelevation.

4. Superelevation Effects

The application of superelevation is discussed at some length in Section 4-6, Subsection D, and a superelevation chart is presented in Figure 4-6.2. However, for purposes of discussing vehicle clearance, the effects of superelevation can be limited to the predictable vehicle lean induced by a specified difference in elevation between the rails of a standard gauge track. This superelevation effect on the dynamic outline is usually considered independently of other effects. The shape of the dynamic outline is not altered, it is simply tipped to a superelevated position as shown in Figure 4-3.6. When superelevation is 2" (5.1 cm) or more, the point of maximum lateral displacement for the three representative vehicle shapes occurs about 9.5' (2.9 m) above the top of rail. At this height, each 1" (2.5 cm)increment of superelevation adds about 2" (5.1 cm) to the lateral clearance required on the low-rail side.

Figure 4-3.3 combines vertical, lateral, and rolling body movements with superelevation effects on the dynamic outlines of the three illustrative vehicles. This combined effect may be thought of as representing (very closely) the total of all effects that define the dynamic outline for a cross section that is cut through a car body at the pivot point of a truck. This concept is valid because inswing and outswing reach maximum values midway between trucks and at car ends respectively, but are negligible at truck positions. Inswing and outswing are major clearance considerations, especially for LRT systems, and are covered in the next topic in this subsection.

The "Base Line" plot on Figure 4-3.3 is at zero superelevation and represents the width of dynamic allowance between the static outline and the dynamic outline for any car shape at any height above the top of rail (profile grade) up to the point of roof rounding. This "Base Line" is, therefore, a generalized depiction of the shaded areas and dynamic outlines of the three vehicles as shown in Figures 4-3.1 and 4-3.2. Fanned out on either side of the "Base Line" are lines representing 1" (2.5 cm) increments of superelevation up to the usual 6" (15.2 cm) maximum for constructed superelevation. The normal 4" (10.2 cm) limit for superelevation in or on line structures (where clearances are most critical) is also noted. The superelevation lines fanned to the right represent the condition on the low side of superelevation where vehicle lean toward the center of the curve is added to the "Base Line" allowance for dynamic lateral movement and roll. The lines to the left represent the high side where lean is subtracted from the dynamic allowance on the outside of the curve.

Superimposed on Figure 4-3.3 are lines representing the position of the critical point on the dynamic outline of each of the three illustrative vehicles at each increment of superelevation. The plots, developed by constructing and superelevating dynamic-outline templates, illustrate the range of location characteristics exhibited by the points of maximum displacement of the dynamic outline from centerline. It is evident that rounding the sides of a vehicle smooths out and dampens the combined effects of dynamic lateral movement, roll, and lean. At the other extreme, the plot shows that for a vehicle with flat, vertical sides, the critical point remains at the roof line on the low side of superelevation. On the side away from the curve center, the critical point stays at roof elevation until lean overcomes the 3.5 degree (0.06 radian) roll and the critical point drops suddenly to a lower position on the vehicle. Design clearances must allow for lateral body movement and roll to the outside of each curve as well as to the inside.

The plots on Figure 4-3.3 also evidence some similarities in the patterns and magnitudes of displacements for the three vehicles. For example, at 4" (10.2 cm) of superelevation, the point of low-side, maximum displacement for all vehicles occurs between 8' and 10' (2.4 m and 3.0 m) above the rail and the magnitude of displacement from the static outline of each car ranges from approximately 15" to 18" (38 cm to 46 cm). At the same 4" (10.2 cm) superelevation, all vehicles show a corresponding displacement of about 1.5" to 2" (4 cm to 5 cm) away from the center of curvature.

5. Inswing/Outswing

In addition to the dynamic body movements and the superelevation effects which represent total lateral displacement at the trucks, body overhang on horizontal curvature also increases the lateral displacement of dynamic outlines relative to track centerline. This effect is commonly illustrated by means of a split dynamic outline as shown in Figure 4-3.6.

The amounts of mid-car inswing and end-of-car outswing depend primarily on the truck spacing and end overhang of the vehicle and on the severity of track curvature as shown by the diagram on Figure 4-3.4. The inswing and outswing displacements graphed below the diagram give preliminary design values for the two typical LRVs presented in Table 3-2.1. These values are for track curves with radii from 45' (14 m) to 1400' (425 m) and show that displacements become progressively more critical below a curve radius of 500' (150 m). This is especially true of outswing. To emphasize how critical the length and shape of end overhangs can be in designing LRT systems, rectangular vehicles without tapered ends or rounded corners have been used for illustrative purposes in

Figure 4-3.4. Additional body shape and clearance considerations are discussed in Subsection D under "Vehicle Characteristics".

Figure 4-3.5 shows inswing displacements for the two HRVs and two LRVs selected as representative vehicles for preliminary design. Within the limits of curvature shown for each HRV, and without considering rounded vehicle corners, outswing displacements are nearly the same as the graphed inswing values and may be used interchangeably. The difference is 1/4" (0.6 cm) or less for radii above the 755' (230 m) preferred mainline minimum. At the 300' (91 m) minimum turning radius for the HRV(2), outswing is about 5/8" (1.6 cm) less than graphed inswing. At the 90' (27.4 m) lower limit for the HRV(1), outswing exceeds inswing by less than 1.5" (3.8 cm). For curve radii larger than 1400' (425 m), the outswing for both "square-cornered" LRVs exceeds the plotted inswing values by less than 1.5" (3.8 cm).

6. Turnouts

Figure 4-3.8 gives the maximum horizontal limits of a typical HRV dynamic outline as it moves through AREA standard turnouts numbered 6, 8, 10, and 15. Turnouts are discussed in Section 4-4, Subsection D, and are further illustrated in Figures 4-4.3 through 4-4.6.

The horizontal offsets given in Figure 4-3.8 were determined graphically and assume that the design vehicle approaches and leaves the turnouts on a tangent track and that the track is not superelevated within turnout limits. If a turnout is from a curved or superelevated track, the dynamic clearance values shown must be increased. Also, outside the dynamic outlines, additional allowances for running clearances to structures and other objects must be provided.

C. Running Clearance Allowances and Criteria

This subsection describes the clearance factors to be considered in providing adequate separation between dynamic outlines and adjacent structures, obstructions, or facilities.

Figure 4-3.6 illustrates a number of running clearances and shows their relationship to allowances for vehicle envelopes and construction tolerances. Figures 1 and 2 in Appendix A-11 illustrate some minimum LRT clearances required by the CPUC.

1. Clearance Envelope/Installation Allowance

The clearance envelope is a standard 2" (5.1 cm) clearance allowance enclosing the dynamic outline as illustrated by Figures 4-3.1 and 4-3.6. No fixed objects should violate this space. This is the absolute minimum separation required between the dynamic outline and fixed installations such as pipes, pipe hangers and supports, signals, lighting fixtures, and air conditioning equipment. This 2" (5.1 cm) clearance applies only to non-structural elements: greater clearances are required for permanent structural elements.

2. Construction Tolerances

As indicated on Figure 4-3.6, a tolerance of ± 1" (2.5 cm) is the usual allowance made for permissible construction variations in the finished surfaces of line-structure walls and roofs and for other critical facilities. A design tolerance of ± 2" (5.1 cm) may be assumed for segmented linings in circular tunnels in contrast to the usual allowance for cast-in-place construction.

3. Chorded Construction

An extra allowance for lateral clearance must be made when subway walls, retaining walls, and the like are constructed in chords adjacent to curved track alignment. The maximum lengths of chords to be used, measured along the trackside face of wall nearest the curve center, are:

- o 50' (15.2 m) chords for curve radii 2,500' (762 m) or longer.

- o 25' (7.6 m) chords for curve radii less than 2,500' (762 m)

Figure 4-3.7 illustrates the chord allowance (Ac) with a diagram and gives additional width requirements for 25' (7.6 m) chords and 50' (15.2 m) chords in conjunction with curve radii ranging from 150' (45.7 m) to 35,000' (10,670 m). Figure 4-3.6 relates the chord allowances (Ac) to other elements of the cross sectional clearance diagram.

4. Clearance Criteria for Mainline Structures

The criteria presented here represent guidelines for the minimum running clearances to be tolerated between the clearance envelope and the face of structures, exclusive of the construction tolerance and, where applicable, an allowance for chord construction. The criteria are most relevant to HRT system operations and line structures, but are applicable as well to LRT systems where design is not governed by conflicting joint-occupant or CPUC regulations or by clearance requirements for overhead electrification.

Some examples of the following minimum clearances are indicated on Figure 4-3.6:

- o 4" (10.2 cm) - Clearance to flat or curved roof surfaces of subways or to any point on the lining of a circular tunnel or the curved surface of a horseshoe tunnel section.

- 6" (15.2 cm) - Lateral clearance (where no safety walk is provided) to vertical sidewalls of underground structures, to parapets on aerial structures and retained embankments, and to retaining walls in open cuts.

5. Intermittent Structures and Point Restrictions

The following circumstances and minimum clearance guidelines should be reviewed on an individual basis and adjusted where appropriate:

- 6" (15.2 cm) - Lateral clearance from vehicle clearance envelope to intermittent columns, miscellaneous structures, and other point restrictions.

- 24" (61.0 cm) - Lateral clearance from vehicle clearance envelope to parallel bridge abutments and piers and vertical clearance to overhead separation structures. Preferred lateral clearance to new intermittent columns and point restrictions.

6. Light Standards

- 6" (15.2 cm) - Minimum lateral distance from clearance envelope to pole, exclusive of construction tolerance.

7. Poles for Overhead Electrification

- 16" (40.6 cm) - Minimum lateral distance from clearance envelope to pole, exclusive of construction tolerance.

8. Safety Walks

A minimum clear space 6.5' (2.0 m) high and 2' (0.6 m) wide should be provided in most situations where safety walks are required. Safety walk space 2.5' (0.8 m) wide is desirable on aerial structures, on elevated sections retained by full-height walls, and where walks are located between double tracks.

As shown by the shaded portions of Figure 4-3.6, vehicle dynamic outlines should not encroach into the safety walk envelope and allowances should be made for construction tolerances and chorded construction where walk width is confined by structural elements.

9. Platforms

The clearance gap between car floors and high-level platforms should be held to a practicable minimum horizontally and vertically. However, even when body movement is limited, the car threshold may move as much as 3.5" (8.9 cm) laterally and a like amount downward.

In Section 5 of Appendix A-11, the CPUC calls for a 3" (7.6 cm) minimum clearance between LRVs and high-level platforms. Other aspects of this gap are mentioned in Section 3-2, Subsection E, and Section 3-6, Subsection F.

10. Acoustical Treatment

An additional allowance for acoustical treatment on the order of 1.5" (3.8 cm) may be required in areas where car clearance would be critically diminished.

D. Clearance Adjustments and Options

This subsection reviews several ways in which clearance requirements may be met or modified.

1. Structure Working Points

In order to place the vehicle clearance envelope most advantageously in variously shaped subway sections, it may be desirable to shift the centerline or working point of the structure relative to the centerline of track. This may be done to accommodate such things as safety walk clearance envelopes and vehicle lean and overhang on curves. With a maximum superelevation of 4" (10.2 cm) on a 755' (230 m) radius curve, the relative shift of tunnel centerline toward the center of curvature might be as much as 12" (30.5 cm) for a vehicle with a truck spacing of 52.5' (16.0 m). Figure 4-3.6 illustrates working point locations.

2. Superelevation Rotation

As discussed in Section 4-6, Subsection D, it may be advantageous, especially in circular tunnels, to rotate the track about its centerline instead of raising the outside rail to achieve superelevation in the usual manner. This compensating adjustment may be done in conjunction with a centerline shift.

3. Track Separation

The spacing of track centerlines and the additional separation needed to accommodate clearance on curves are discussed in Section 4-5, Subsection B, and typical dimensions are shown in Tables 4-5.1 and 4-5.2. Appendix A-6 illustrates the geometry of a change in the spacing of double tracks for a typical, short-radius LRT curve. When vehicles meet in a curve, the critical point for inswing-outswing interference may occur in the spiral transitions.

4. Width Adjustment Transitions

Where structures must be widened or other lateral adjustments made through a curve, the change in width should be applied and removed over a distance equal to the spiral transition length, beginning at a point 25' (7.6 m) prior to the spiral point. Full width required on the circular curve should be reached on the spiral 25' (7.6 m) before the SC point and maintained 25' (7.6 m) after the CS point.

5. Vehicle Characteristics

As noted throughout this section, the shape, dimensions, suspension systems, and tracking characteristics of a vehicle have a pronounced effect on clearance envelopes.

Roof and side shapes of the static car outline can do much to compensate for the effects that body roll and lean have on the vertical and lateral dimensions of the dynamic outline.

The manner of electrification may be of concern with respect to clearance and safety requirements; some cars have been equipped for both overhead and third-rail electrification.

Particularly on LRT systems with short radius curves, truck spacings must be matched against acceptable limits of mid-car inswing. Outswing can also be matched to inswing.

The length and shape of LRV end overhangs are important considerations in street operations. Tapered or rounded vehicle ends reduce track separation and other lateral clearance requirements and can be shaped to suit the semi-circular swing of radial couplers so that coupled cars can better negotiate short radius curves.

Although tapering and rounding were not considered in developing the outswing displacements graphed in Figure 4-3.4, the difference of 3.1' (0.9 m) shown between the inswing and outswing displacements for a curve radius of 45' (13.7 m) is an indication of the half-width reduction required in shaping the vehicle nose to reduce outswing displacement to match inswing. The shorter the end overhand, the less the need for end tapering and corner rounding to reduce outswing.

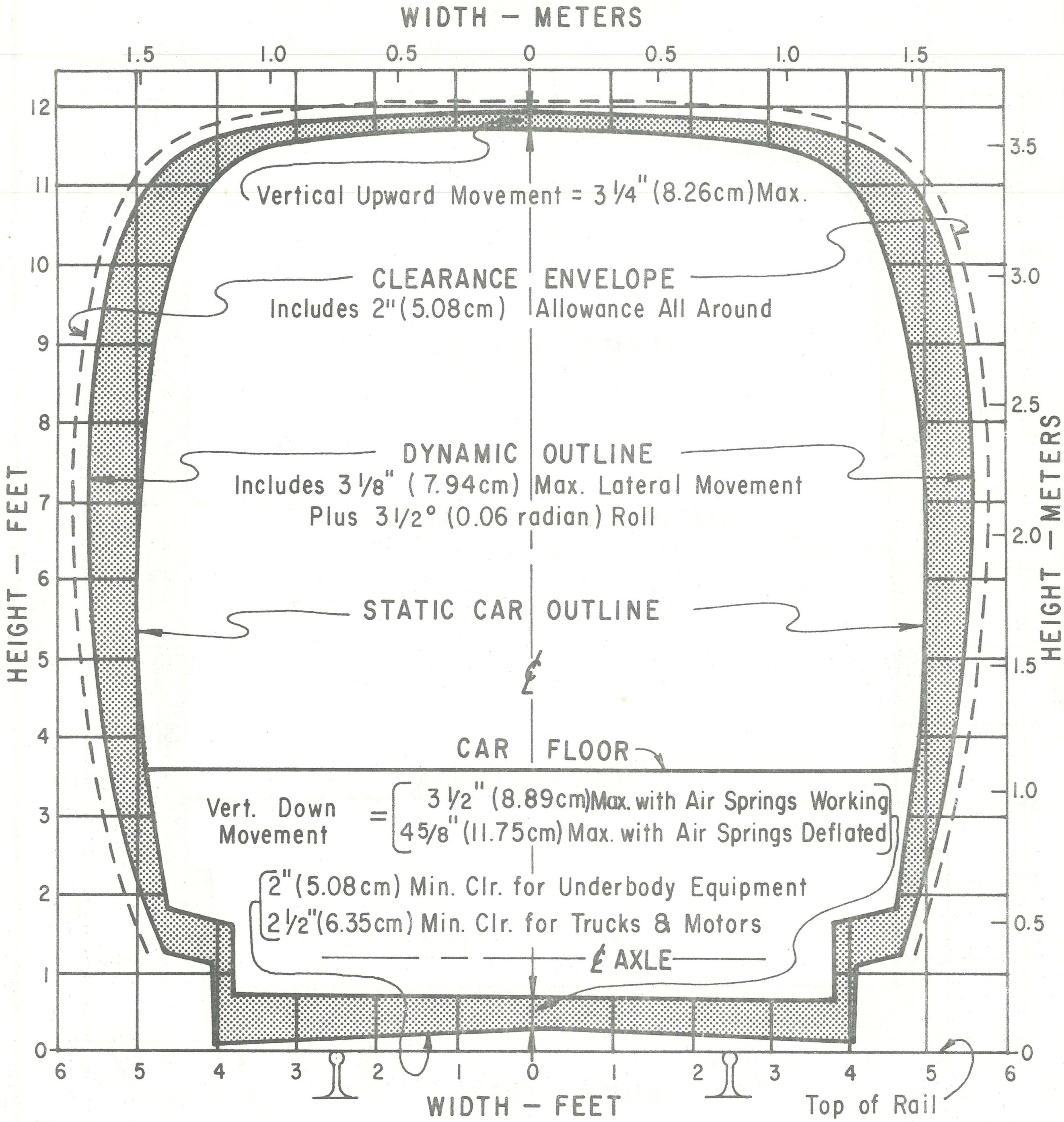
TABLE 4-3.1

CAR BODY MOVEMENTS INCLUDED IN DYNAMIC OUTLINES

(See Figures 4-3.1, 4-3.2, and 4-3.6)

NATURE OF MOVEMENT	AMOUNT	
	Inches	Centimeters
VERTICAL UPWARD		
Non-Suspension Items – Includes construction tolerances for track and car, car body camber, and vertical track curvature	1 5/8	4.13
Suspension Items – Includes primary springs unloaded and bounce against up stops	1 5/8	4.13
TOTAL	3 1/4	8.26
VERTICAL DOWNWARD		
Non-Suspension Items – Includes wheel wear, rail wear, vertical track curvature, and car body deflection	2 3/8	6.03
Suspension Items – Includes primary spring deflection to stops and air (secondary) spring deflection to stops:		
◦ with air springs deflated	2 1/4	5.72
◦ with air springs working	1 1/8	2.86
TOTAL WITH AIR SPRINGS DEFLATED	4 5/8	11.75
TOTAL WITH AIR SPRINGS WORKING	3 1/2	8.89
LATERAL		
Non-Suspension Items – Includes wheels relative to rail, rail and wheel wear, car and track construction tolerances, and truck assembly tolerances	1 5/8	4.13
Suspension Item – Car body against stops	1 1/2	3.81
TOTAL	3 1/8	7.94
ROLL		
Based on 3 1/2° (0.061 radian) of body lean occurring above axle after lateral movement of	1 1/2	3.81

SOURCES: TTC, ASME, CTA, BART, WMATA, BRRTS, and SCRTD



NOTES:

- See Table 4-3.1 for components of vertical and lateral movement.
- See subsequent Figures 4-3.2, 4-3.3, 4-3.4, 4-3.5, 4-3.6, 4-3.7 and 4-3.8 for other vehicle shapes and clearance considerations.

SOURCES
TTC (Part 3.3)
CTA (Part II-A
ASME (P.1)
BART (Sect. 2)
NYCTA (Struct. Des. Chap. 2)
BRRTS (III-B)
SCRTD (IV-F)
WMATA (Sect. II)

RAIL TRANSIT CRITERIA

DYNAMIC OUTLINE AND CLEARANCE ENVELOPE FOR A VEHICLE WITH ROUNDED SIDES ON A TANGENT TRACK

FIGURE 4-3.1

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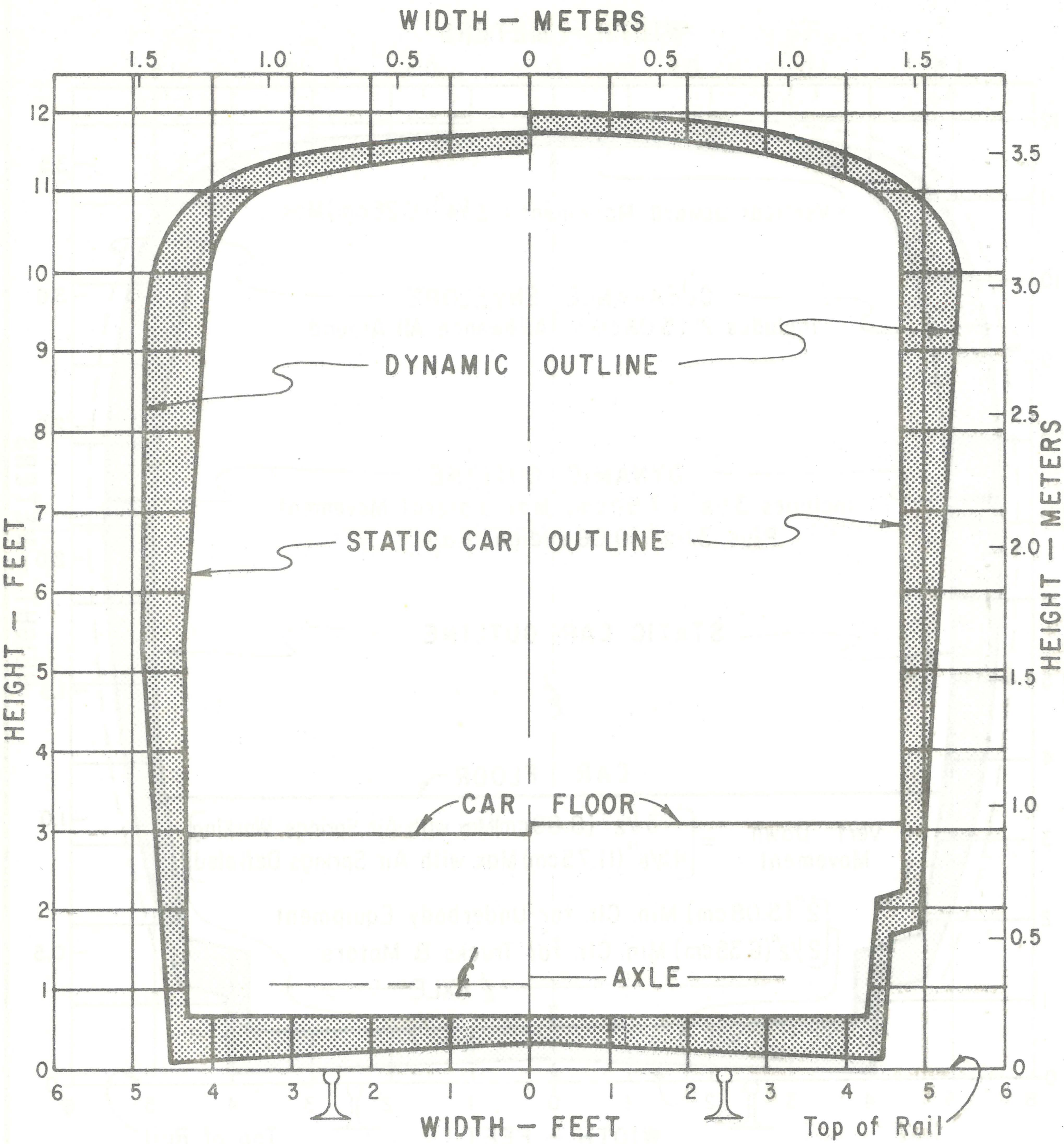

NOTE:

- These two half-sections, together with Figure 4-3.1, typify basic vehicle shapes.
- See Figure 4-3.1 for additional notes and details.

SOURCES	RAIL TRANSIT CRITERIA	
SEE Fig. 4-3.1	TYPICAL DYNAMIC OUTLINES FOR VEHICLES WITH SLANTED OR VERTICAL SIDES RUNNING ON A TANGENT TRACK FIGURE 4-3.2	Caltrans JUN 78

RAIL TRANSIT CRITERIA

BODY MOVEMENT PLUS LATERAL DISPLACEMENT OF DYNAMIC OUTLINES DUE TO SUPERELEVATION

FIGURE 4-3.3

SOURCES
FIGS. 4-3.1 and 4-3.2
TABLE 4-3.1

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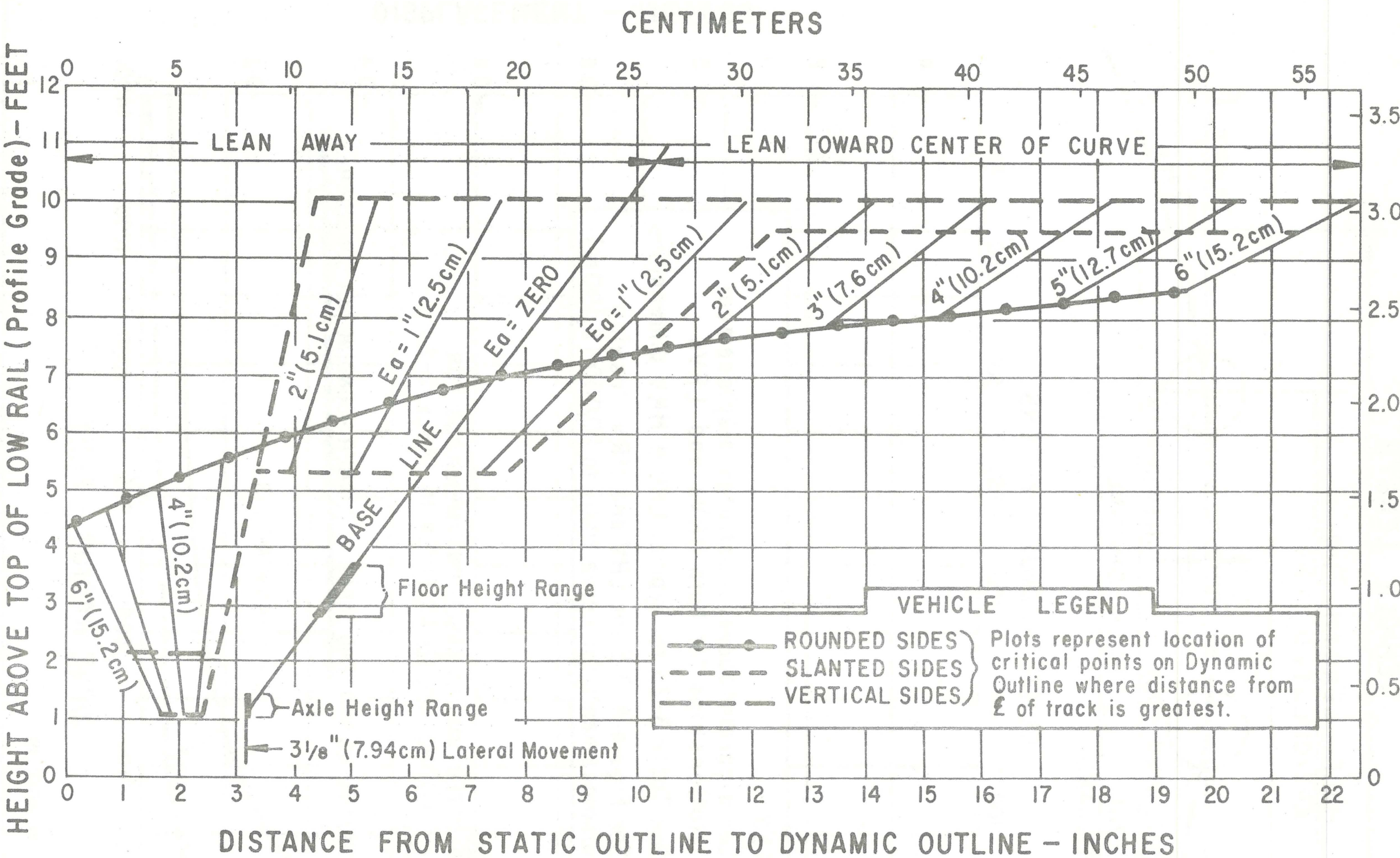
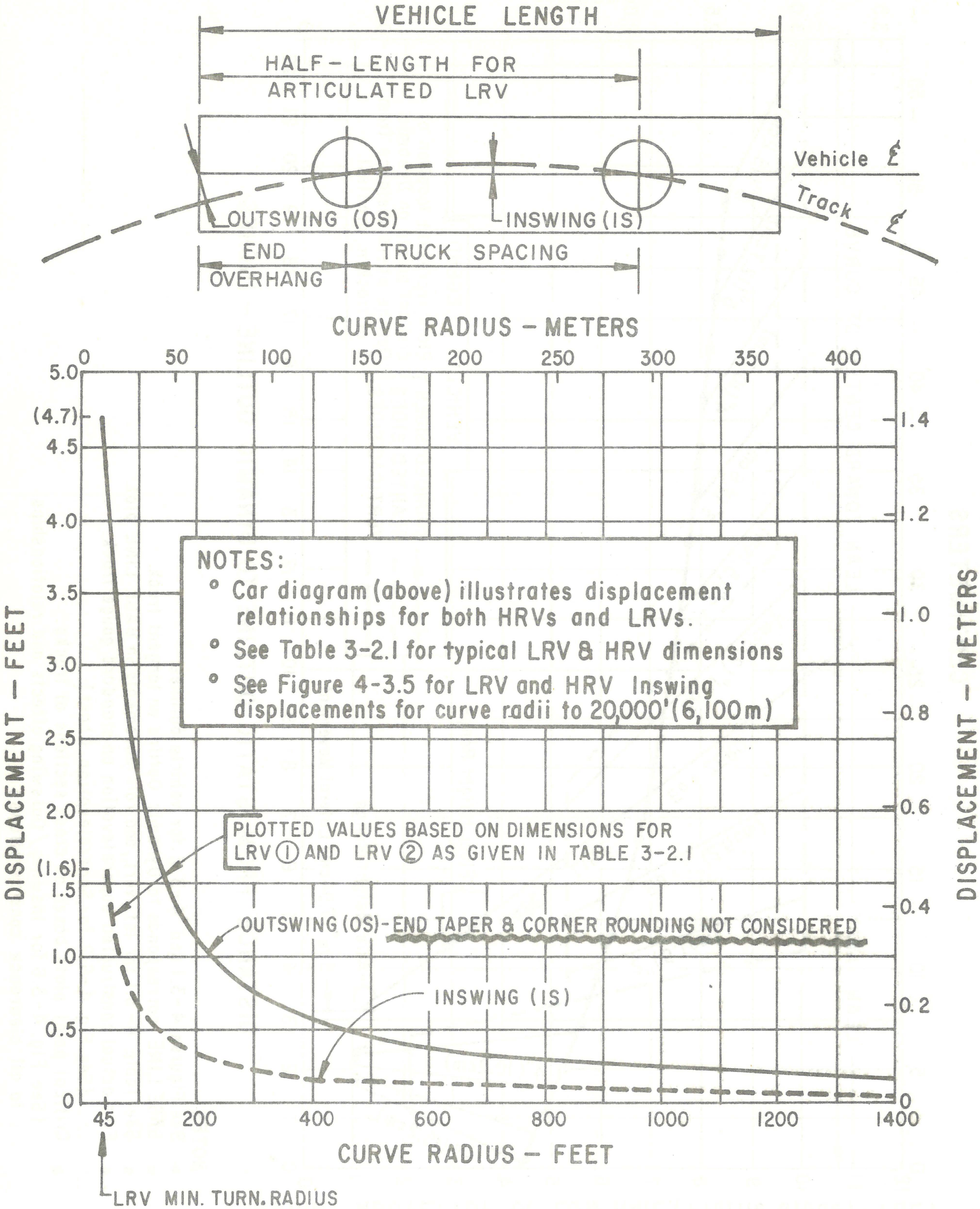


NOTES

- See Figures 4-3.1 and 4-3.2 for vehicle outlines.
- BASE LINE corresponds to Dynamic Outline on tangent track.
- See Table 4-3.1 for lat., vert., and roll movements in BASE LINE plot.
- Ea = actual constructed superelevation on standard gauge track. (See Fig. 4-6.2 for Superelevation Chart)
- Critical point plots based on cross sections at trucks. (See Fig. 4-3.6 for Inswing / Outswing effects and relationships to all clearance considerations.)



SOURCES

SEE FIGURE 4-3.1 Re: BART, WMATA, CTA, BRRTS, SCRTD, TTC

RAIL TRANSIT CRITERIA

TYPICAL LRV INSWING AND OUTSWING DISPLACEMENTS ON CURVES

FIGURE 4-3.4

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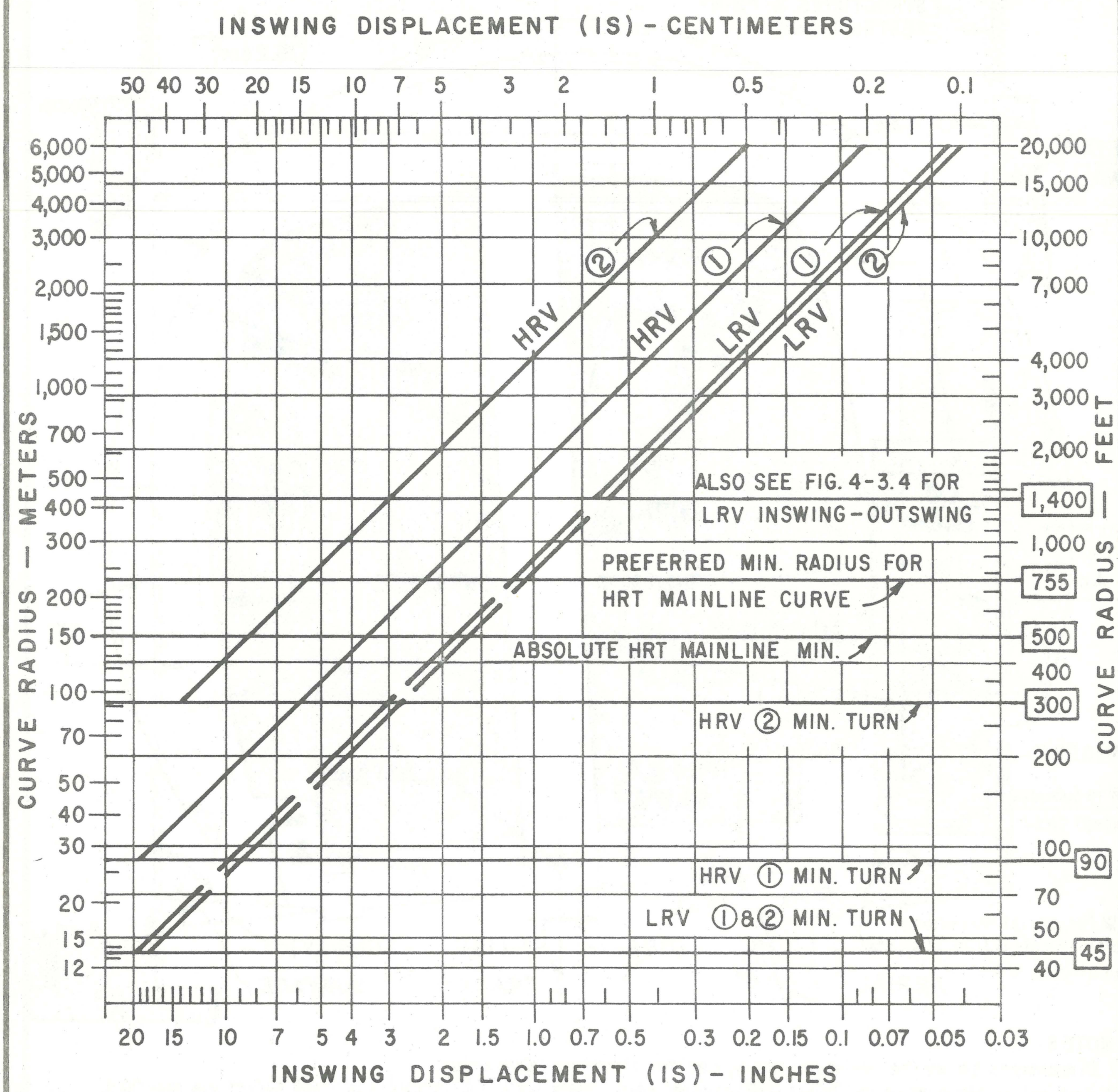
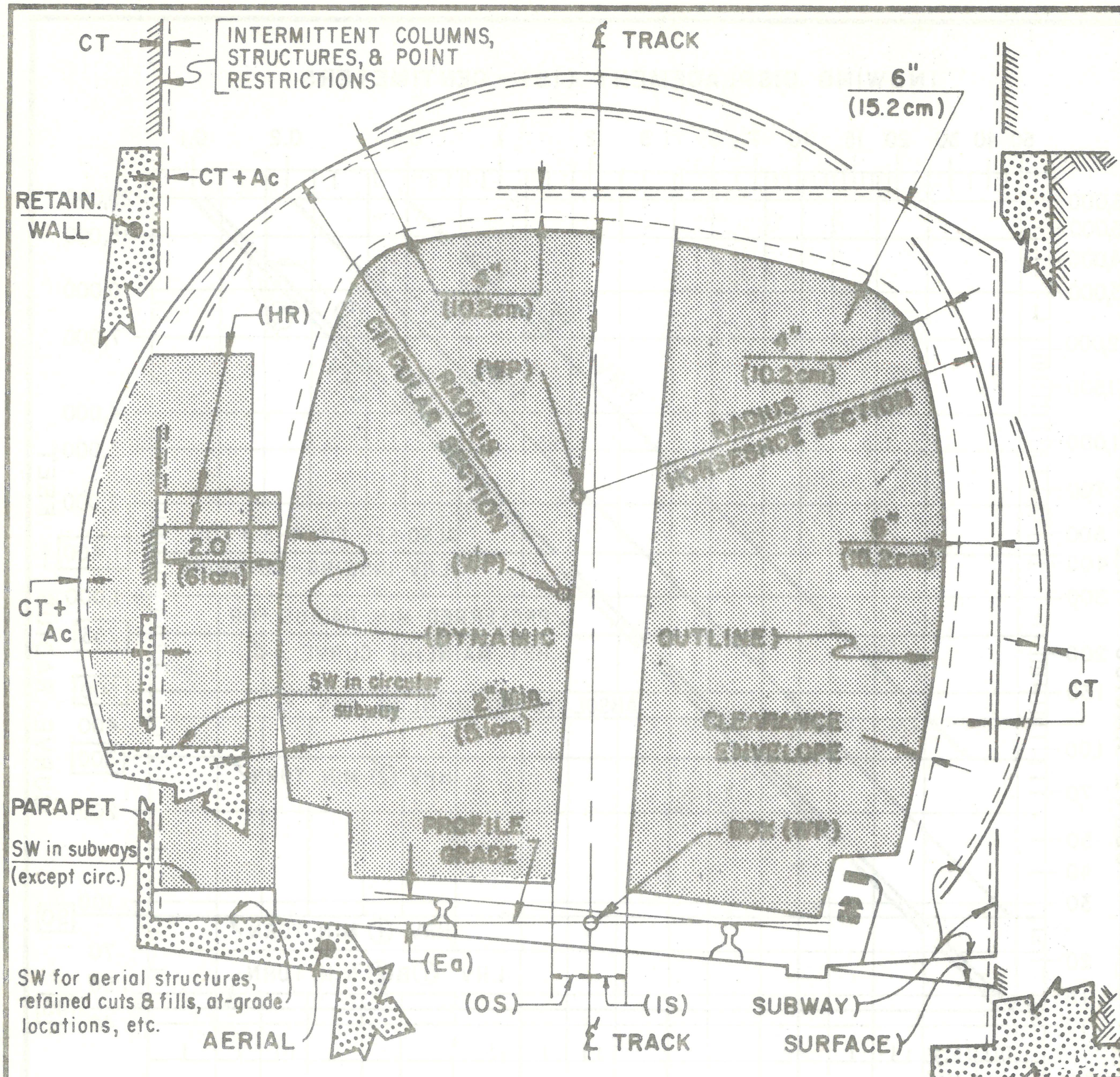


NOTES:
- See vehicle diagram on Figure 4-3.4
- See Table 3-2.1 for vehicle dimensions and min. turning radii.
- For HRVs ① & ②, OUTSWING (OS) values may be considered equal to the INSWING (IS) values shown above.
- For LRVs ① & ②, OS displacements may be considered equal to IS values except for the range shown on Figure 4-3.4
- OS values or IS equivalents do not consider tapering or corner rounding.

SOURCES	RAIL TRANSIT CRITERIA	
BART (Fig. 2.4.2) BRRTS (Figs. III.2,.3, & .4) SCRTD (Figs. IV-8,-9, & -10) WMATA (Figs. II.2,.3, & .4) TTC (D5 3.3.3A, B, & C) CTA (A1.5)	INSWING DISPLACEMENTS ON CURVES FOR TYPICAL HRVs AND LRVs **FIGURE 4-3.5**	Caltrans JUN 78



NOTES:

1. Dimensions shown are minimum clearances for structural elements.
2. Critical points & Working Points (WP) change when Safety Walk (SW) locations or track curves are reversed.
3. Clearance Envelope provides 2" (5.1cm) minimum clearance to installations.
4. Construction Tolerance (CT) = 1" (2.5cm) except = 2" (5.1cm) for segmental circular tunnel construction.
5. Headroom (HR) = 6.5' (198cm) over full 2.0' (61cm) width of SW (or at ℄ of SW in circular tunnel only).
6. For Dynamic Outline see Figure 4-3.1.
7. For displacement of Dynamic Outline due to Superelevation (Ea) see Figure 4-3.3.
8. For Inswing (IS) and Outswing (OS) values see Figures 4-3.4 and 4-3.5.
9. For Additional Width (Ac) for chorded construction see Figure 4-3.7.
10. For general dimensions at HRT station see Figures 3-6.1, 3-6.2, and 3-6.3.

SOURCES
WMATA (Figs. II-12 thru 53)
BRRTS (Figs. III-11 thru 39)
CTA (Dgms. A-1.2 thru 1.4)
TTC (Dgms. 3.3.2. A thru E)
NYCTA (SD-2-18, -19, & -21)
SCRTD (Figs., IV-17 thru 45 & P. IV-70)
SOAR (Fig. 36)
CPUC (G.O. 26-D)

RAIL TRANSIT CRITERIA

CLEARANCE DIAGRAM

FIGURE 4-3.6

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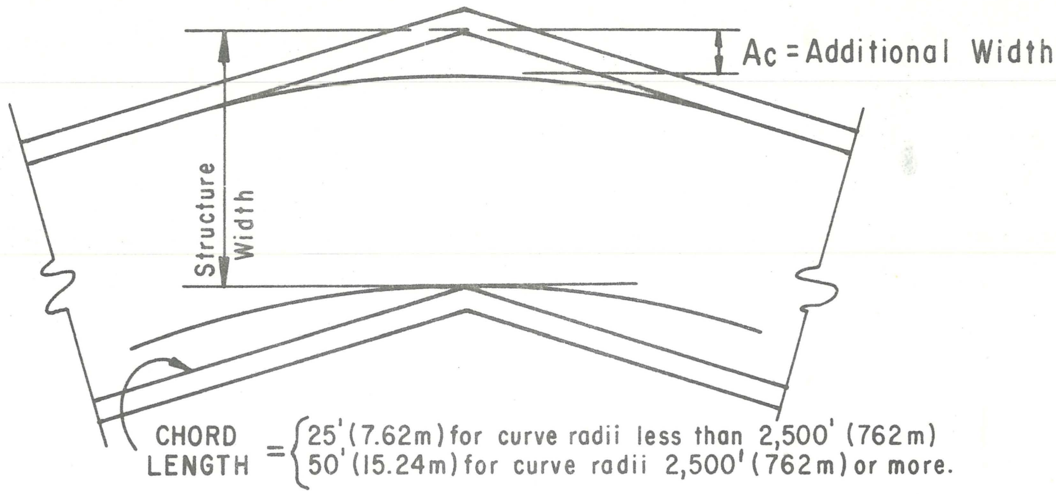

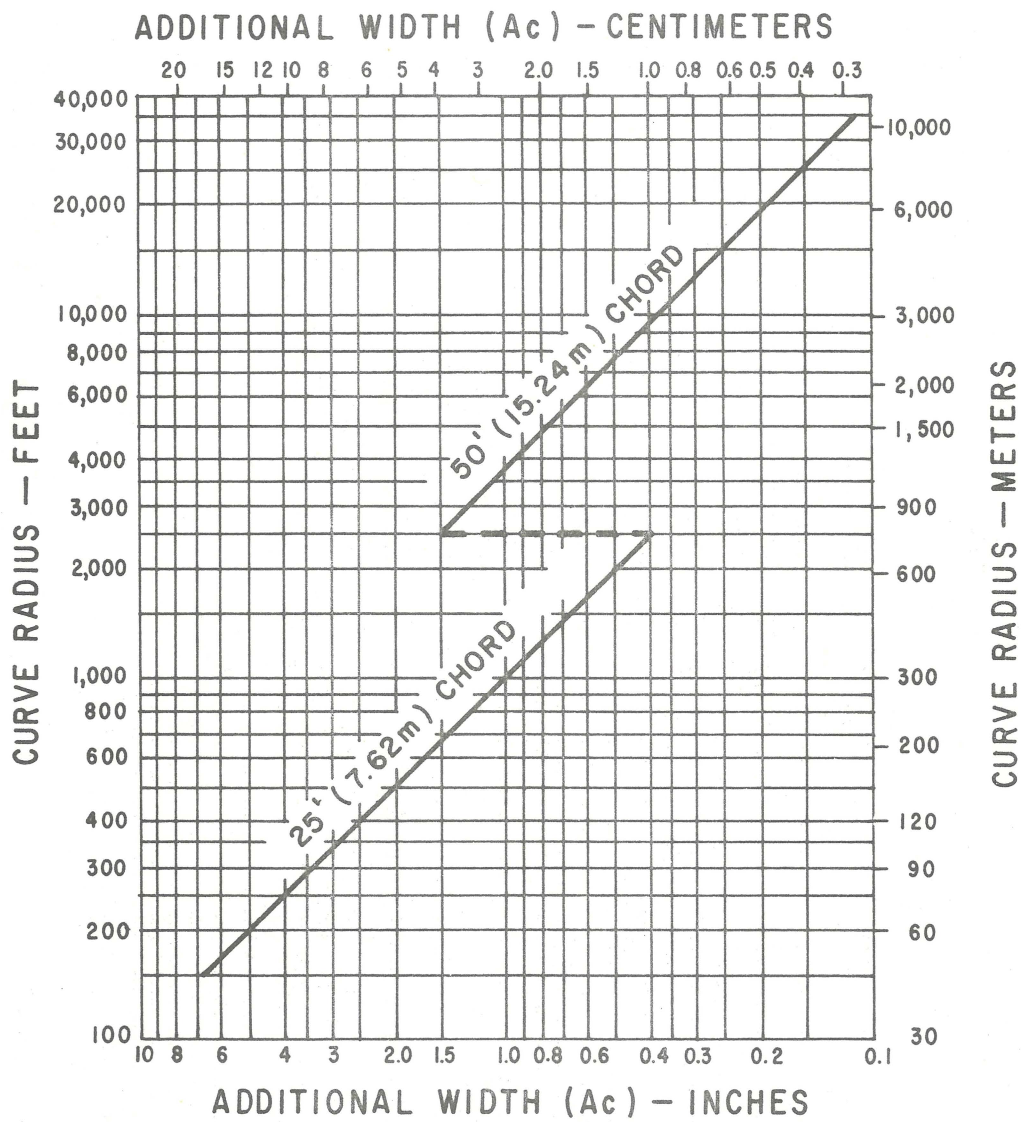

SOURCES

SCRTD	(Figs. IV-15 & IV-16)
WMATA	(Figs. 11.9 & 11.10)
BRRTS	(Figs. III-7 & III-8)
TTC	(3.4.1.b)
BART	(2.4.9)

RAIL TRANSIT CRITERIA

ADDITIONAL WIDTH FOR CHORDED CONSTRUCTION

FIGURE 4-3.7

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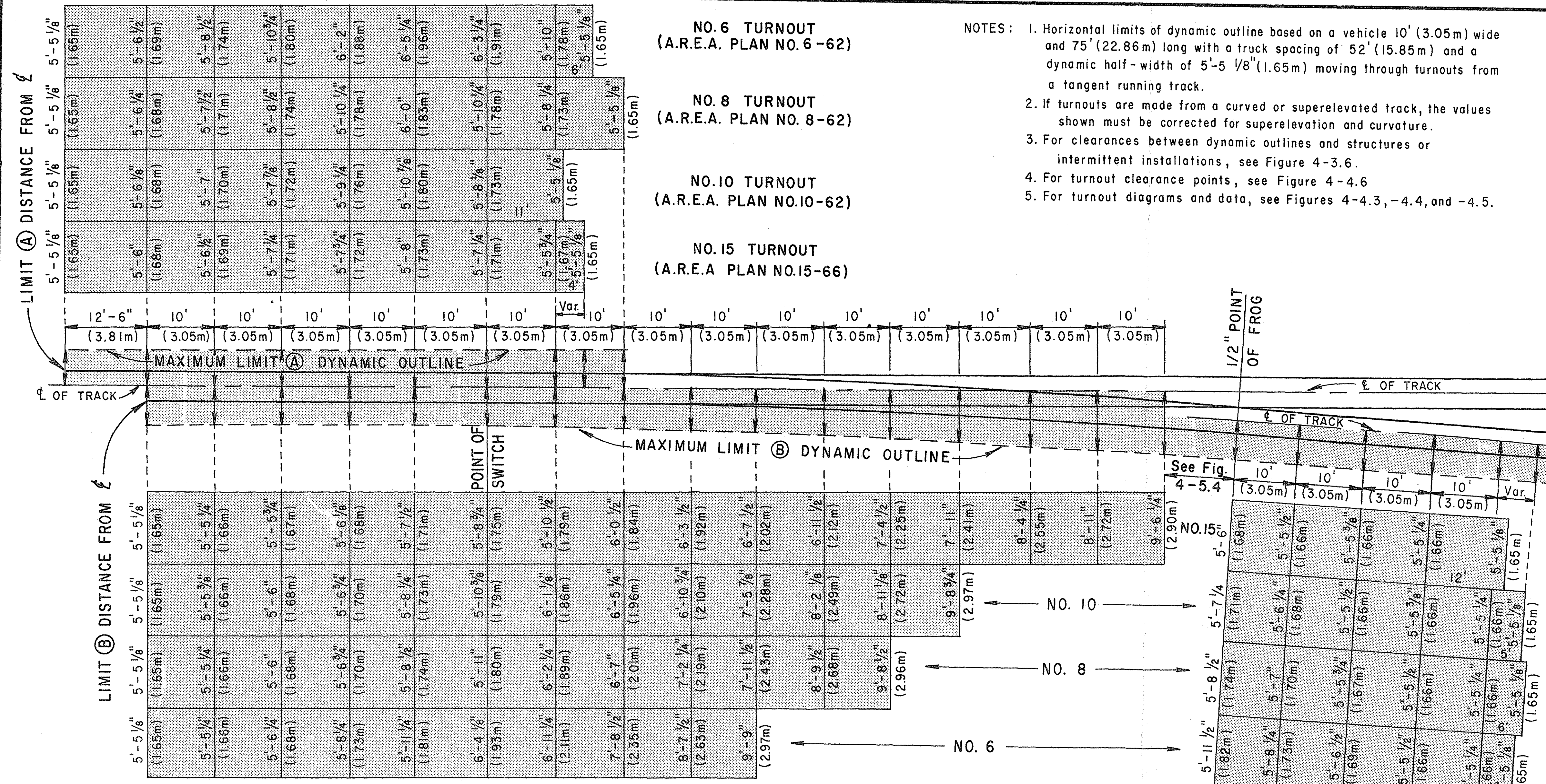

NOTES:

1. Horizontal limits of dynamic outline based on a vehicle 10' (3.05m) wide and 75' (22.86m) long with a truck spacing of 52' (15.85m) and a dynamic half-width of 5'-5 1/8" (1.65m) moving through turnouts from a tangent running track.
2. If turnouts are made from a curved or superelevated track, the values shown must be corrected for superelevation and curvature.
3. For clearances between dynamic outlines and structures or intermittent installations, see Figure 4-3.6.
4. For turnout clearance points, see Figure 4-4.6
5. For turnout diagrams and data, see Figures 4-4.3, -4.4, and -4.5.

SOURCES

WMATA (Figs. II.46, .47, .48, and .49)
SCRTD (Figs. IV-40, -41, and -42)
BRRTS (Figs. III.34, .35, and .36)

RAIL TRANSIT CRITERIA

DYNAMIC OUTLINE MAXIMUM LIMITS FOR TURNOUT NOS. 6, 8, 10 and 15

FIGURE 4-3.8

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4-4 TRACKWORK

A. General

Trackwork includes ballast, pads, ties, rails, switches, frogs, crossings, fastenings, etc.; in essence, all track hardware and the structural section above the trackbed or subgrade as shown on Figure 4-4.1.

This section of the manual presents a general description of various materials and typical uses rather than detailed specifications for all trackwork materials.

Most transit properties in the United States refer to and substantially comply with the AREA "Manual for Railway Engineering" and folio of "Trackwork Plans and Specifications", latest revisions.

There are contractors who specialize in the installation of conventional rail trackwork, and it is common practice for this phase of the work to be done under a separate contract. (See Section 3-11.)

B. Track Fastening Systems

Although there are a number of variations in construction and usage, there are four basic track fastening systems for trackwork: direct fixation to a concrete trackbed, ties in a concrete trackbed, ties on open-deck bridges and trestle structures, and ties and ballast. The track fastening system can influence and be influenced by the design of subways, aerial structures, and other situations where trackside space may be restricted. If tie replacement will be required, trackside clearance should allow for the insertion of new ties.

1. Direct Fixation

A typical direct fixation scheme consists of connecting the rails to combination steel and elastomeric fasteners which are secured to a deck or slab by anchor bolts. There are several techniques and stages for placing, supporting, and adjusting the rails to precise horizontal and vertical alignment. The procedure may involve grouting or placing a separate concrete pad over the structural concrete base followed by horizontal adjustment of the connecting devices. The separate pad is placed as late as possible to allow initial creep and deflection to occur.

Direct fixation is used primarily in stations and for aerial or underground line structures. Rail fastener spacing is typically 30" (76.2 cm) for main tracks and 33" (83.8 cm) for yard and secondary tracks.

2. Ties in Concrete

This system can utilize either concrete or wood ties embedded in concrete. When rails are fastened to precast concrete ties, the ties (which may be encased in rubber boots) are grouted into formed depressions in the slab after precise horizontal and vertical alignment have been attained. This type of construction is sometimes used in subway structures and stations.

The use of wood ties embedded in concrete is usually limited to stations and to special work on unballasted tracks, but is sometimes designated for subways and portal areas with floor slabs. The rails and hold-down fastenings are mounted on cross ties at 30" (76.2 cm) centers for main tracks and on longer switch ties in special work locations. Rails and special items are secured in position before the supporting and surrounding concrete is placed.

3. Open-Deck Structures

This track system is designed for use on steel open-deck bridge and trestle structures where the track is fastened to structural members. Wood ties spaced at 18" (45.7 cm) centers are secured to wood joists with full bearing on girder flanges. Superelevation is obtained by installing beveled elevation blocks on ties under the high rail.

4. Ties and Ballast

Tie and ballast systems are used for yard tracks and for main tracks at grade, on decked bridges, and in subways with adequate dimensions and suitable concrete trough flooring.

Ties may be either concrete or wood. The ties used for relatively short structures are usually the same as those used on adjacent at-grade sections. The usual center-to-center spacing for wood ties in ballast is 24" (61.0 cm) on mainline tracks and in yards; for concrete ties, 30" (76.2 cm). Joint ties are spaced at 18" (45.7 cm).

An example of a special type of track that has been used in river tunnels is one in which the outer ends of wood ties are embedded in concrete and the space between and under the ties in the center of the track is filled with stone ballast.

C. Track Materials

1. Rails

Rail sections are selected on the basis of structural adequacy, economy, continuing availability, and compatibility with existing systems. The dimensions of a typical rail section are shown on Figure 4-4.2. Rail sections are designated on the basis of pounds per yard (kilograms per meter).

In the absence of specific criteria, a 115 lb./yd. (57 kg/m) section may be assumed for mainline HRT operations and a 100 lb./yd. (49.5 kg/m) section for LRT. A 90 lb./yd. (44.5 kg/m) section is an appropriate selection for all yard and secondary tracks.

Conventional jointed rail sections are manufactured in 39' (11.9 m) lengths, but modern transit systems often often specify continuously welded rail (CWR) with insulated joints at interlocking locations. However, CWR is not generally used on aerial structures where thermal movement is anticipated and provided for.

Specially hardened rails are used in portions of track where heavy wear is expected, such as on curves with a radius of 1000' (305 m) or less, or at points of repeated rapid acceleration or deceleration, or on heavy grades.

2. Wood Ties

Wood cross ties 6" (15.24 cm) thick and 8" (20.32 cm) wide, AREA Size 3, are appropriate for HRT and LRT main tracks. An 8' (2.44 m) tie length is typical for LRT trackwork and 9' (2.74 m) for HRT. Switch ties, which vary in length as required, may be assumed as 7" x 9" (17.78 cm x 22.86 cm), AREA Size 5.

HRT contact rail ties are AREA Size 3, and are usually 10' (3.05 m) in length. The ends of ties are lined on the side of the track opposite the contact rail so that the contact rail ties extend 1' (30.5 cm) beyond the ends of cross ties.

All wood ties are treated with a preservative except where used for temporary track.

3. Concrete Ties

Concrete ties are typically 6" x 10" (15.24 cm x 25.40 cm) in cross section. For HRT trackwork, ties 9' (2.74 m) in length can be provided with inserts for holding contact rail support arms.

4. Concrete Slabs

When rails and rail fastening systems are mounted within a supporting concrete layer or slab, specified concrete strength should be 4,000 lb./in.^{2} (280 kg/cm^2). Concrete track construction calls for $\pm$ 1/8" ($\pm$ 3.2 mm) tolerances for cross level, profile, and horizontal lines. Track gauge tolerance is plus 1/8" (3.2 mm).

When subgrade conditions require it, an appropriate foundation course is used to provide drainage and minimize settlement of the slab.

Concrete subballast slabs (approach slabs) are constructed to support an 8" (20.3 cm) minimum depth of ballast at the ends of all ballast-less tracks. They usually call for 3,000 lb./in.^{2} (210 kg/cm^2) concrete.

5. Ballast

Ballast is usually crushed stone, varying in size from 3 1/2" (88.9 mm) down to 3/4" (19.1 mm). Ties are embedded in ballast which serves to:

- Support the load and distribute it to the subgrade.
- Hold the track to line and grade.
- Provide drainage for the track structure.

- Facilitate adjustment of line and grade.
- Minimize dust and inhibit weeds.
- Provide a measure of electric insulation for running rails.

The specified minimum depth of ballast, measured from the base of tie at any rail to the top of subballast or subgrade, is usually 6" (15.2 cm) for yard and secondary tracks, and 12" (30.5 cm) for mainline tracks, assuming acceptable subgrade conditions. An 8" (20.3 cm) minimum depth of ballast is used over concrete floors in subways and on ballasted bridge decks. In these instances, the structures are designed to accommodate an additional 4" (10.2 cm) of ballast to permit future correction of track profile. Subways must provide for extra vertical clearance over and above vehicle clearance diagram requirements, and ballasted bridges are designed for the additional dead load.

The absolute minimum depth of ballast called for under ties is usually 6" (15.2 cm). An allowable maximum is often set at 24" to 30" (61.0 cm to 76.2 cm) for total ballast depth. Subgrade stabilization or some form of subballast is preferred to increasing the required depth of ballast to more than 12" (30.5 cm).

The top of ballast is specified to be either flush with the tops of ties or to be 1" (2.5 cm) below the base of rail and neatly trimmed. Transit properties designate the circumstances under which each is to be used. Space is sometimes left between ballast and rail to accommodate signal wires or special track hardware.

Top of ballast width is usually carried 12" (30.5 cm) beyond the ends of ties on mainlines and 6" (15.2 cm) beyond for yard tracks. When curve radii drop below 1,000' (305 m) or so, the 12" (30.5 cm) width extension is often retained. Ballast is continuous between structure walls and should provide a 6" (15.2 cm) minimum cushion between the ends of ties and confining concrete faces.

Where the trackbed is unconfined, ballast side slopes are 2:1 as a rule.

6. Subballast

Subballast is placed on the finished subgrade below the ballast to improve drainage and load distribution over the subgrade. A wide range of subballast may be selected from jobsite materials, but more often subballast is specified, imported material. It is placed 6" (15.2 cm) or more in depth and its top surface extends 2' (61.0 cm) beyond the toe of ballast where it daylights full depth with a 2:1 downslope as in Figure 4-5.4.

7. Track Hold-Down Fastenings

There are a number of different rail hold-down fastenings. The combinations of plates, pads, clamps, braces, spikes, and bolts vary for timber ties, concrete ties, and slabs. Other variations are used for different mainline track alignments and for yard tracks.

8. Rail Joints

Rail joints are fastenings designed to unite the abutting ends of contiguous rails. The fastening consists of two joint bars plus bolts, spring washers, and nuts for splicing the rail webs. A standard mainline joint uses six hole, 36" (91.4 cm) long joint bars; yard rail joints use four hole, 24" (61.0 cm) bars. Compromise joints are used to align and hold rail heads and gauge where rails of different height or section meet in track. Insulated joints are designed to insulate the flow of electric current between abutting rails. The preceding joints are detailed in Chapter 4 of the AREA Manual of Recommended Practice.

9. Track Guard Rails

Steel emergency guard rails are installed at locations where it is critically important to keep derailed cars from traveling more than a few inches (centimeters) away from the running rails. Such locations include retained fills with close-by wall tops, aerial structures, and approaches to obstructions such as piers, platforms and bridges. Used rails and structural angles are placed parallel to, and on the gauge side of running rails beginning 50' or 60' (15 m or 18 m) before the obstruction and carrying 10' (3 m) beyond. Guard rails are carried across bridges. On open deck bridges with wood ties, longitudinal 6" x 8" (15.2 cm x 20.3 cm) timbers are installed on the top of the ties continuously along the field side of each running rail.

Guard rails are also placed in front of switches and opposite frogs which are not self-guarded. Restraining guard rails are installed adjacent to the gauge side of the low (inner) rail to provide guidance for the wheels around short radius curves and to hold the wheel flanges from the outer rail. Typically they are installed on main tracks with a radius of 1,000' (305 m) or less, and on yard or secondary tracks with a radius of 500' (152 m) or less.

10. Derails

Derails are installed on yard and secondary tracks used for the storage of unattended vehicles when these tracks are on a descending grade to a main track connection. Derails are located:

- o At the downgrade end of yard and secondary tracks.

- o To derail equipment away from main tracks.

- o To derail equipment away from contact rails.

The locations of derails are shown on Figure 4-4.6.

11. Bumping Posts

Steel or concrete bumping posts are installed a minimum of 12' (3.7 m) from the end of each stub track.

D. Special Work

1. General

Special work includes switches, turnouts, and crossings. Figure 4-4.3 illustrates various turnouts and components.

Turnouts and crossovers are located on tangent track and constant profile grade where possible. Since superelevation is not usually applied through the switch or turnout, speed reductions may be necessary. Double (scissors) crossovers are located where tracks are parallel and are used when there is insufficient space for two single crossovers. The desired minimum tangent length between a point of switch and the end of a station platform is 70' (21 m). The desired minimum tangent distance preceding a point of switch is 10' (3 m).

To facilitate adaptable construction and adjustments, special trackwork is usually placed on wood tie and ballast sections which extend a minimum of 15' (4.6 m) beyond the switch point. Ties of varying lengths as required are carried through the switch at turnouts. Tie and ballast sections may be terminated when the separation of diverging track center-lines exceeds 8' (2.4 m) or so. Where avoidable, special work is not located within 200' (60 m) of a transition between direct fixation and ballasted track construction. Wood ties may be encased in concrete when slab construction is employed. The placement of special work on nonballasted aerial structures is avoided when practical because special structure and track designs are required to prevent misalignment of the special trackwork due to thermal stresses.

2. Turnouts and Frogs

A turnout is an arrangement of a switch and a frog with closure rails for diverting cars from one track to another as shown in Figure 4-4.3. The turnout number is the number of the frog used in the turnout. The frog is a track structure used at the intersection of two running rails to permit wheels on either rail to cross the other. The frog number is the number of units of centerline length in which the spread is one unit (or one-half the cotangent of one-half the frog angle formed by the intersecting gauge lines of the frog). The "half-inch point of frog" is a point at which the spread between gauge lines is 1/2" (1.27 cm). It is located at a distance behind the theoretical point equal in inches to one-half the frog number, or in centimeters, to 1.27 times the frog number. It is the origin from which measurements are usually made. Figure 4-4.4 gives AREA trackwork plan reference numbers and some dimensional and operating speed data for five representative turnouts. Typical HRT turnout usage is as follows:

- No. 6 - Low speed turnouts for use on yard tracks.
- No. 8 - Low speed turnouts for yard tracks and secondary tracks, for center storage tracks, main track emergency crossovers, service track connections to mainline, and for turnbacks and yard track connections to mainline where higher numbers (10 or 15) are not practical.

- o <u>No. 10</u> - Intermediate speed turnouts for use on transfer tracks and maintracks and for turnback crossovers at terminal stations.

- o <u>Nos. 15 and 20</u> - High speed, maintrack turnouts for intermediate turnbacks and junctions of mainline routes.

Figure 4-4.6 illustrates some typical turnout clearance and layout relationships.

3. <u>Crossovers</u>

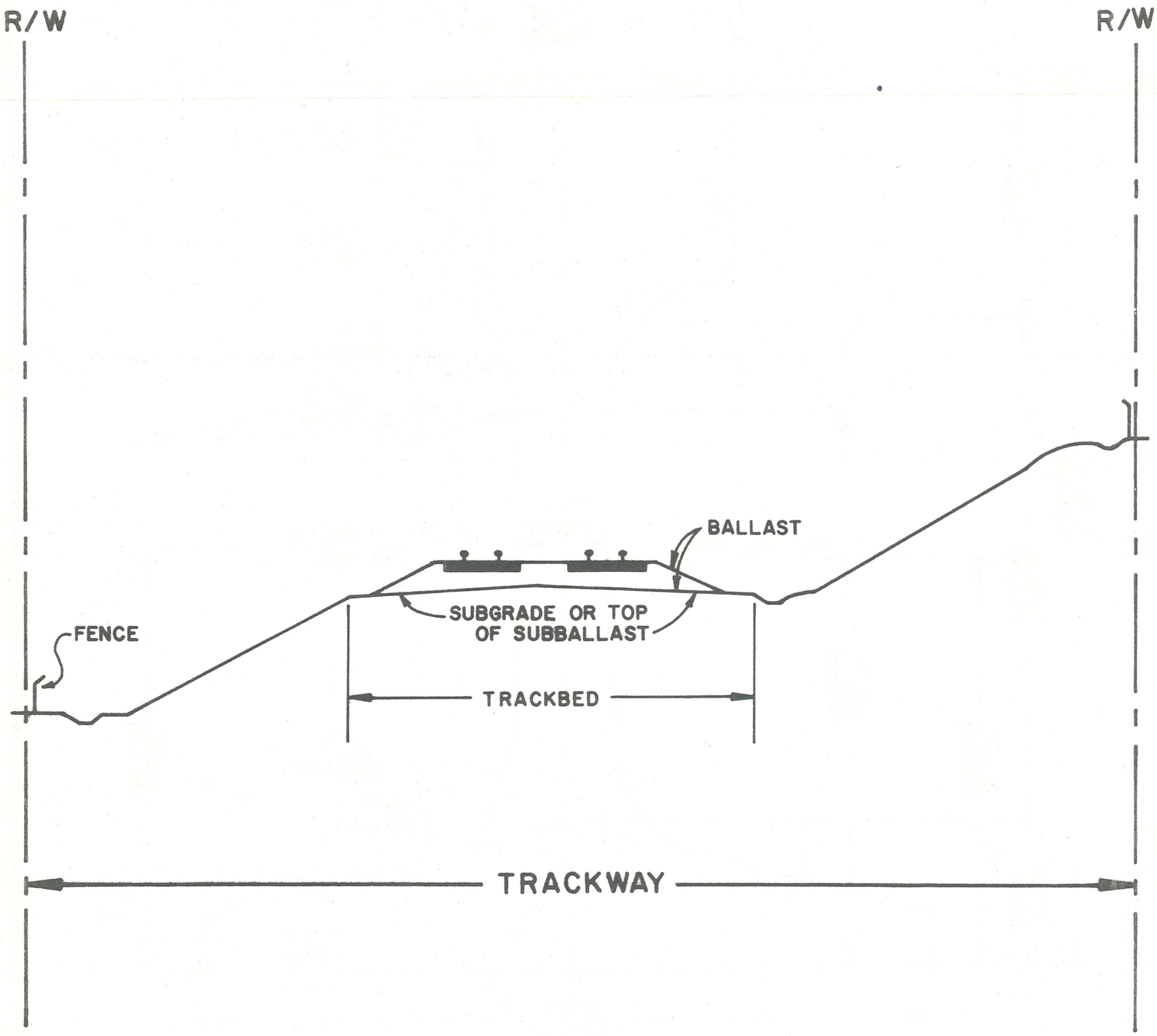
A crossover consists of two turnouts with tracks between frogs arranged to provide a connection between two nearby, usually parallel tracks. Figure 4-4.5 illustrates crossover geometry and gives dimensions for five turnouts and five track centerline spacings ranging from 12' (3.7 m) to 30' (9.1 m). The length of a crossover and the speed through it are dependent upon the turnouts used. For double crossovers, contact rail configuration may control geometry so that traction power can be provided to all trains operating through the crossings. There is no traction power restriction with No. 8 double crossovers, but No. 10s require 28' (8.5 m) or more between the centerlines of the tracks to be cross-connected.

4. <u>Switches</u>

Switches divert rolling stock from one track to another. The actual "point of switch" is the end of the switch rail (straight or curved) most distant from the frog. The switch point operates against the "stock rail". The "throw of switch", the distance the points of switch rails are moved sidewise (measured along the centerline of the "switch rod" connecting one rail to the opposite rail), is standardized at 4 3/4" (12.1 cm). Space for switch rods to operate below the rails is provided in ballast or slab construction. The "heel spread" of the switch, the distance between the gauge lines of the switch rail and its stock rail, is standardized at 6 1/4" (15.9 cm) for straight switches. Switch point and stock rail fabrication requirements are given in AREA Detail 5100.

5. Track Crossings

A track crossing is a structure used where one track crosses another track at grade. It consists of four connected frogs which can accommodate a wide range of angles of intersection. Track crossings should be located on straight grades and tangent alignment if possible. Special foundations and fastenings may be required.



SOURCES

RAIL TRANSIT CRITERIA

GENERAL TRACKWAY SECTION

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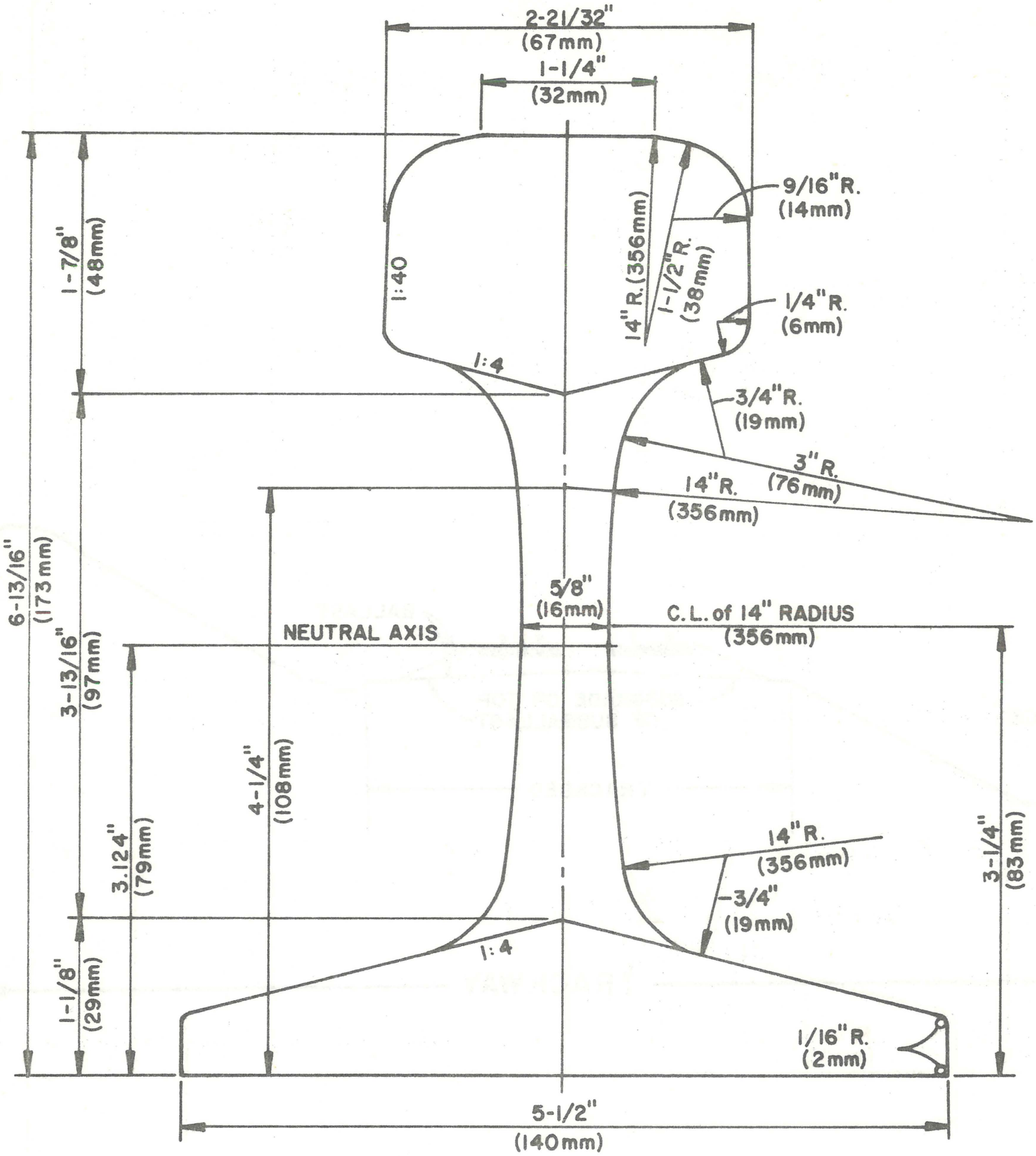
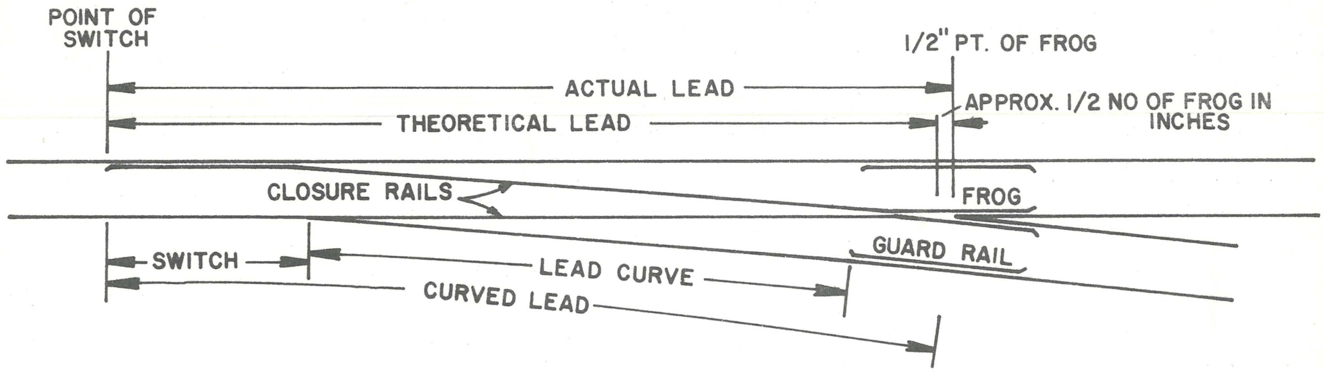
FIGURE 4-4.1



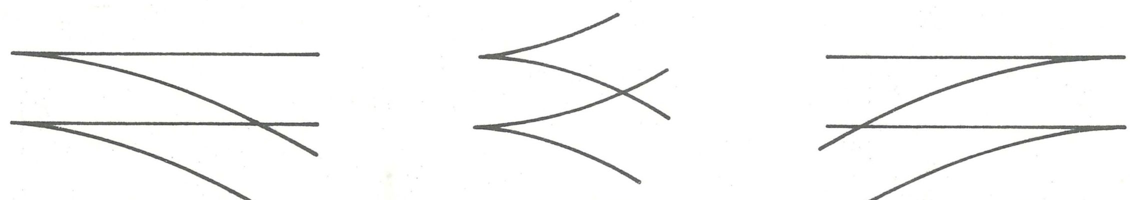
RAIL SECTION 119 CF & I

Total Area = 11.65 sq. in (75.16 cm^2) Weight = 118.8 lb/yd. (59 kg/m)

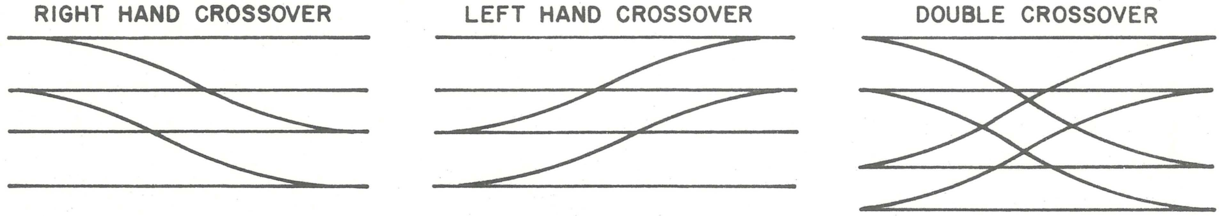
SOURCES	RAIL TRANSIT CRITERIA	
BART (Fig. 4.6.1)	**TYPICAL RAIL CROSS SECTION** FIGURE 4-4.2	Caltrans JUN 77



LATERAL TURNOUT COMPONENTS



TURNOUT DIAGRAMS



CROSSOVER DIAGRAMS

SOURCE:

BART (Fig. 4.9.1)

RAIL TRANSIT CRITERIA

TURNOUT DIAGRAMS AND COMPONENTS

FIGURE 4-4.3

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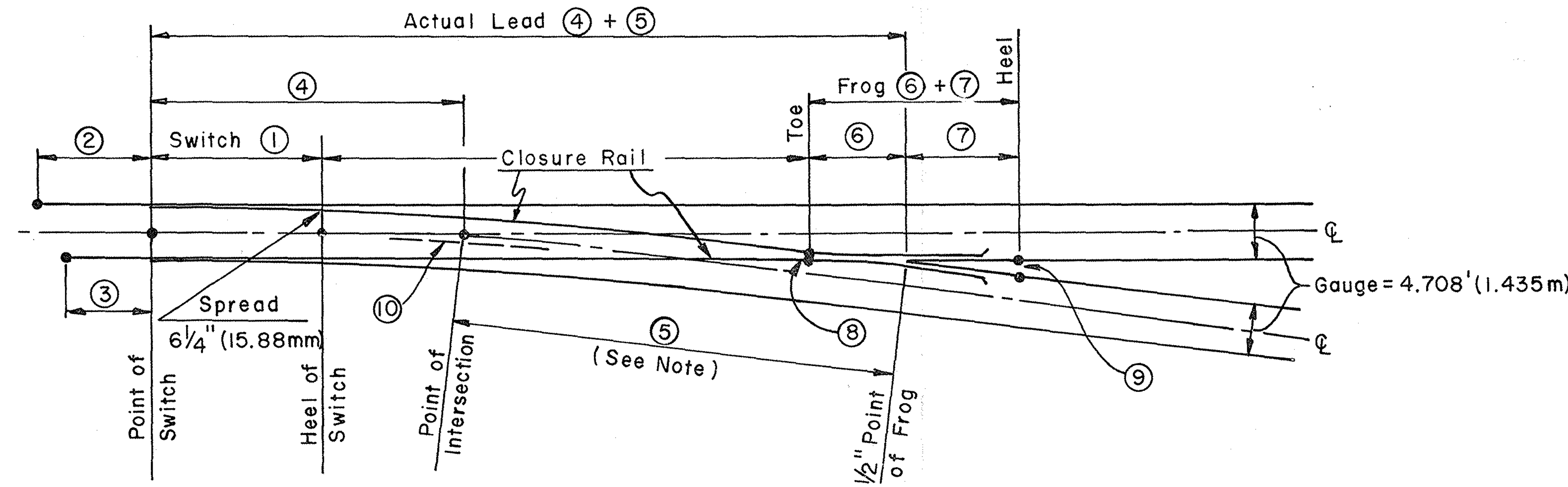

TURNOUT DATA											
FROG No.	SWITCH			ACTUAL LEAD		FROG				RADIUS OF CURVED CENTERLINE	SPEED THROUGH TURNOUT
	LENGTH & TYPE [AREA Plan No.]	STOCK RAIL JOINT			(SEE NOTE)	LENGTH		SPREAD			
						TOE	HEEL	TOE	HEEL		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(SEE NOTE)
6	11.0' (3.35 m)-Straight [6 - 62]	6.17' (1.88 m)	4.50' (1.37 m)	21.74' (6.63 m)	28.50' (8.69 m)	5.08' (1.55 m)	7.42' (2.26 m)	9 5/8" (244 mm)	15 5/16" (389 mm)	327.06' (99.69 m)	14 mph (23 km/h)
8	16.5' (5.03 m)-Straight [8 - 62]	6.17' (1.88 m)	4.50' (1.37 m)	32.95' (10.04 m)	38.00' (11.58 m)	6.25' (1.91 m)	9.42' (2.87 m)	8 13/16" (224 mm)	14 9/16" (370 mm)	576.46' (175.71 m)	21 mph (34 km/h)
10	19.5' (5.94 m)-Curved [10-62 & 124 - 55]	13.92' (4.24 m)	12.25' (3.73 m)	34.98' (10.66 m)	47.50' (14.48 m)	7.42' (2.26 m)	11.33' (3.45 m)	8 3/8" (213 mm)	14 1/8" (359 mm)	973.34' (296.67 m)	28 mph (45 km/h)
15	26.0 (7.92 m)-Curved [15 - 62 & 125-62]	13.92' (4.24 m)	12.25' (3.73 m)	47.36' (14.44 m)	71.25' (21.72 m)	10.33' (3.15 m)	16.33' (4.98 m)	7 3/4" (197 mm)	13 9/16" (344 mm)	2278.10 (694.36 m)	40 mph (64 km/h
20	39.0' (11.89 m)-Curved [20 - 62]	13.92' (4.24 m)	12.25' (3.73 m)	68.22' (20.79 m)	95.00' (28.96 m)	13.08' (3.99 m)	21.08' (6.43 m)	7 3/8" (187 mm)	13 1/8" (333 mm)	4066.48' (1239.46 m)	50 mph (80 km/h

NOTES:

- In feet, (5) = Frog No (Gauge + 0.0417), approximately.
  In meters, (5) = Frog No (Gauge + 0.0127), approximately.
- Values in Column (5) are based on standard gauge of 4.708' (1.435 m)
- Speeds shown are normal operating speeds. Critical speeds (maximum safe speeds), based on unbalanced superelevation (E_u) of 6" (15.24 cm), are 25% higher.
- For Crossover Data see Figure 4-4.5

SOURCES

BART (ST 401-A)
WMATA (Figs. III.22 & II.7)

RAIL TRANSIT CRITERIA

STANDARD TURNOUT DATA

FIGURE 4-4.4

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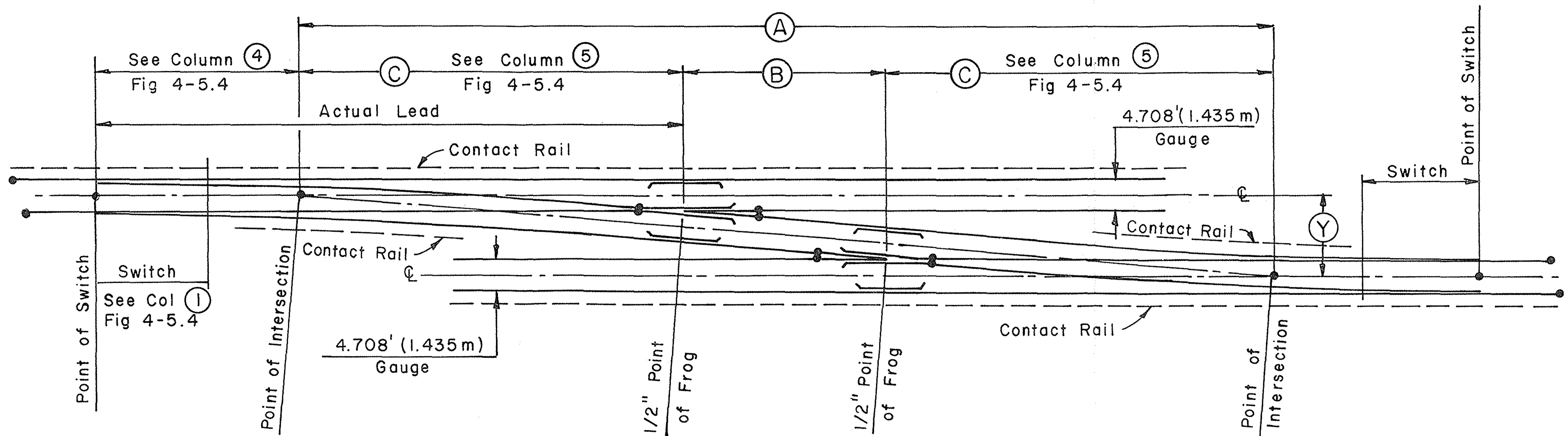

CROSSOVER DATA

TRACK CENTERS	No 6 TURNOUTS		No 8 TURNOUTS		No 10 TURNOUTS		No 15 TURNOUTS		No 20 TURNOUTS		UNITS
Y	A	B	A	B	A	B	A	B	A	B	
12.0 (3.66)	71.50 (21.79)	14.50 (4.42)	95.62 (29.15)	19.62 (5.98)	119.70 (36.49)	24.70 (7.53)	179.80 (54.80)	37.30 (11.37)	239.85 (73.11)	49.85 (15.19)	feet (meters)
13.0 (3.96)	77.46 (23.61)	20.46 (6.24)	103.59 (31.57)	27.59 (8.41)	129.68 (39.53)	34.68 (10.57)	194.78 (59.37)	52.28 (15.94)	259.84 (79.20)	69.84 (21.29)	feet (meters)
14.0 (4.27)	83.42 (25.43)	26.42 (8.05)	111.56 (34.00)	35.56 (10.84)	139.65 (42.57)	44.65 (13.61)	209.77 (63.94)	67.27 (20.50)	279.83 (85.29)	89.83 (27.38)	feet (meters)
18.0 (5.49)	107.25 (32.69)	50.25 (15.32)	143.44 (43.72)	67.44 (20.55)	179.55 (54.73)	84.55 (25.77)	269.70 (82.20)	127.20 (38.77)	359.78 (109.66)	169.78 (51.75)	feet (meters)
30.0 (9.14)	178.75 (54.48)	121.75 (37.11)	239.06 (72.87)	163.06 (49.70)	299.25 (91.21)	204.25 (62.26)	449.50 (137.01)	307.00 (93.57)	599.63 (182.77)	409.63 (124.86)	feet (meters)

NOTES

1. $A = Y\left(\frac{\text{Cos of frog angle}}{\text{Sin of frog angle}}\right)$ Precisely

   $= Y\left(\text{Frog No.} - \frac{0.25}{\text{Frog No}}\right)$ Closely

   $= Y\,(\text{Frog No.})$ Approx.

2. $B = A - 2C$ Precisely

   $= \left[Y\left(\text{Frog No.} - \frac{0.25}{\text{Frog No.}}\right)\right] - 2\left[\text{Frog No.}(\text{Ga.} + 0.0417)\right]$ Closely in feet

   $= \left[Y\left(\text{Frog No.} - \frac{0.25}{\text{Frog No.}}\right)\right] - 2\left[\text{Frog No.}(\text{Ga.} + 0.0127)\right]$ Closely in meters

   $= (Y - 2 \cdot \text{Gauge})(\text{Frog No.})$ Approx.

3. Tabulated values of B based on Standard Gauge of 4.708' (1.435 m)

4. For turnout data see Fig 4-4.4

SOURCES
BART (ST 403-A)

RAIL TRANSIT CRITERIA

STANDARD CROSSOVER DATA

FIGURE 4-4.5

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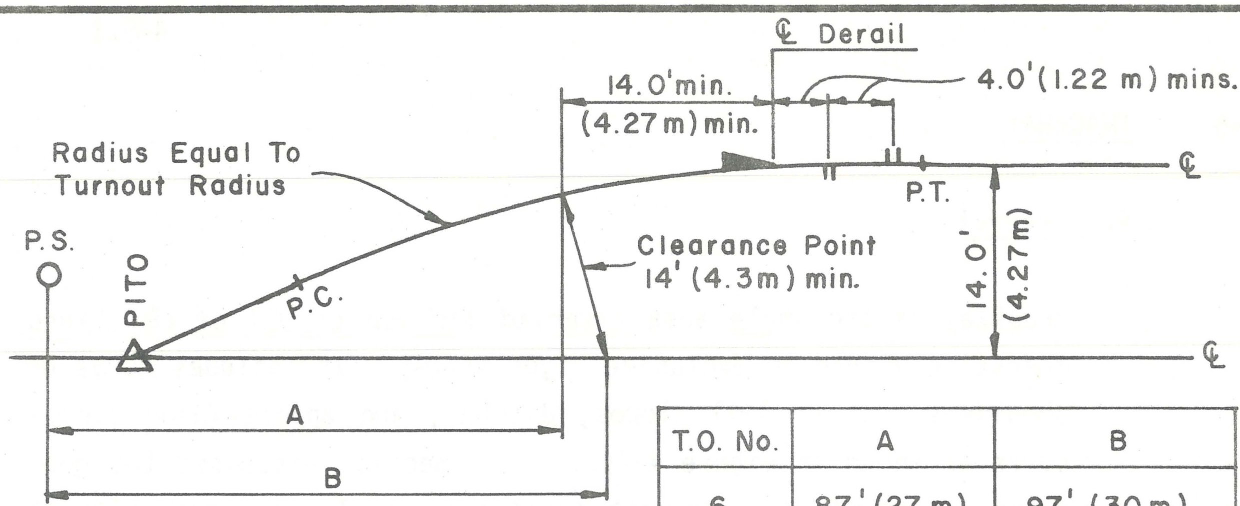
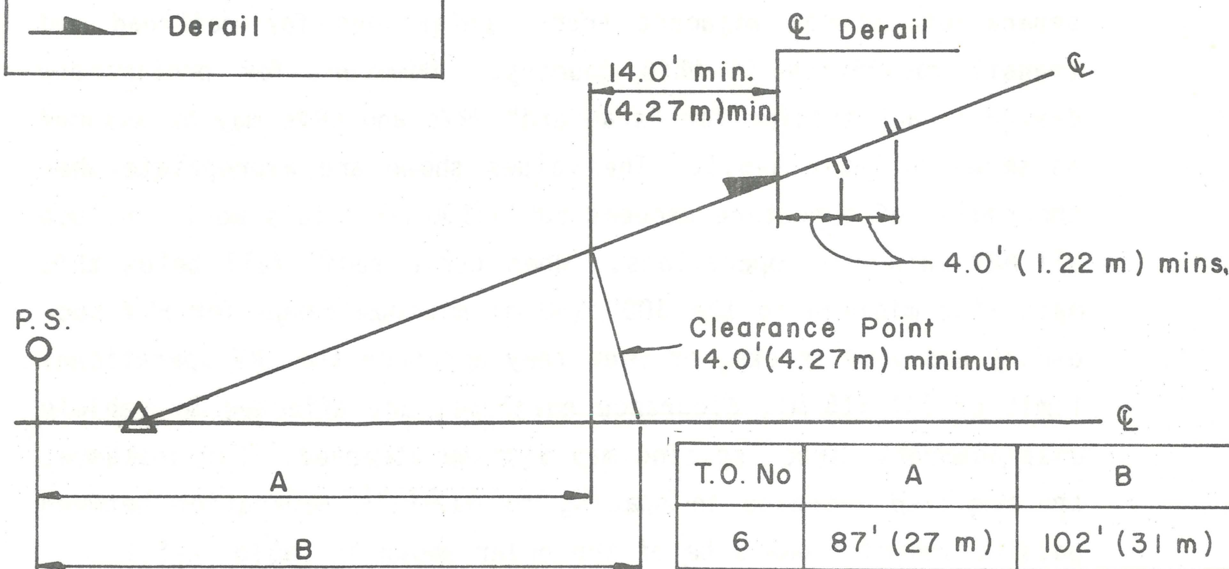


T.O. No.	A	B
6	87' (27 m)	97' (30 m)
8	120' (37 m)	127' (39 m)
10	143' (44 m)	148' (45 m)
15	210' (64 m)	213' (65 m)

CLEARANCE TO PARALLEL SIDINGS ON 14' TRACK CENTERS

LEGEND

- Insulated Joint
- Derail



T.O. No	A	B
6	87' (27 m)	102' (31 m)
8	120' (37 m)	131' (40 m)
10	142' (43 m)	142' (43 m)
15	208' (63 m)	208' (63 m)

CLEARANCE FOR TURNOUTS WITH TANGENT TRACKS BEYOND THE FROG

NOTE:
If derail is not required, first insulated joint is 14.0'(4.27m) min. behind clearance point. The second, if required, is in opposite rail 4.0'(1.22 m) behind the first. Values of A and B are based on clearance envelope for 75'(22.86m) HRV, 10'(3.05m) wide and truck spacing of 52'(15.85 m).
See FIGURE 4-3.8 for dynamic outline limits at turnouts.

SOURCES

SCRTD (Figs. VIII - 2 & -3)
WMATA (Figs. III. 19 & .20)
BRRTS (Figs. IV. 9 & .10)

RAIL TRANSIT CRITERIA

CLEARANCE FOR TURNOUTS

FIGURE 4-4.6

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4-5 TRACKWAY

A. General

Trackway is the whole area reserved for use of HRT or LRT lines operating within an exclusive right of way. It includes curbs or shoulders, cut or fill slopes, ditches, and appertaining structures as shown in Figure 4-4.1. This section discusses the geometric standards dealing with cross section elements exclusive of trackwork.

B. Track Spacing

A distance of 14' (4.27 m) is the most commonly specified minimum separation between adjacent track centerlines for railroad and transit facilities in this country. However, for preliminary design, track spacing for "standard" HRVs and LRVs may be assumed as shown in Table 4-5.1. The values shown are appropriate when the radius of curvature exceeds 500' (150 m). This would include all HRV main line operations. When curve radii fall below this main line minimum to the 300' (90 m) minimum range for HRV secondary and yard tracks, or when they approach the LRV operational limit of 50' (15 m), clearance envelopes are affected by vehicle displacement. Track spacing may also be affected. For instance, the required increase in spacing to maintain separation between passing vehicles would be of the order shown in Table 4-5.2

C. Track Gauge

Most HRT and LRT systems in this country employ a standard gauge of 4'-8 1/2" (1,435 mm) or close to it. The gauge is the distance between the inner sides of the heads of rails measured 5/8" (15.9 mm) below the tops of rails.

Most systems specify that the track gauge used for tangent alignment be increased in increments of 1/4" (6.35 mm), as curvature becomes more severe. The point at which adjustments begin, and the number of increments to be applied, differ markedly from system to system depending on permitted degrees of curvature, vehicle characteristics, and operational considerations.

Some HRT and LRT systems make only one adjustment to accomodate the range of their horizontal alignment. Table 4-5.3 illustrates a rather extreme example of curve widening criteria representative of current HRT practice. Such gauge widening is applied symmetrically about the track centerline by some properties or only to the rail nearest the center of the curve by others.

D. Trackbed

Trackbed is defined as the finished surface of the subballast or subgrade between outside edges of the shoulders. Standards relating to trackbed width call for strict adherence in contrast to the criteria which apply to the portion of the trackway between the edge of trackbed and the right of way limit. The intent of the latter is is to provide general design guidance.

1. General Standards and Assumptions

Trackbed width is affected by the following:

- Track gauge.
- Distance between track centerlines.
- Rail height.
- Superelevation.
- Depth of tie, slab or beam supporting the rails.
- Minimum ballast depth under the tie at the rail.

- o Distance from track centerline to top of slope of ballast.

- o Ballast side slope.

- o Walkway requirements.

- o Tie length and replacement.

Figures 4-5.1 and 4-5.2 and the trackbed standards which follow are based on the standard track gauge of 4'-8 1/2" (1,435 mm) and on a tie thickness of 6" (15.24 cm). Also, for HRTs, a minimum spacing of 13'-0" (3.96 m) between track centerlines and a tie length of 9'-0" (2.74 m) have been assumed; for LRTs, the corresponding dimensions are 12'-0" (3.66 m) and 8'-0" (2.44 m).

As shown in Figures 4-5.1 and 4-5.2, the trackbed is characteristically cross sloped to drain at 24:1. Also, a walkway is provided adjacent to one side of every track. Where the trackbed is unretained, a 2'-0" (0.61 m) walkway is provided by extending the trackbed past the toe of ballast. In retained locations, such as shown by Figure 4-5.3, the walkway is at least 2'-6" (0.76 m) wide.

2. Unretained Trackbed

Figures 4-5.1 and 4-5.2 show typical trackbed cross sections for tangent and superelevated HRT and LRT double tracks. The cross sections are applicable to track spacings up to 4' (1.22 m) wider than the minimum distances shown, and for mainline curve radii greater than 755' (230 m).

In addition to the previously stated general standards, the cross sections are based on the following assumptions:

- o Grade and superelevation are approximately identical for each track.

- o Superelevation (E) does not exceed 6" or 15 cm.

- o Minimum depth of ballast under ties at any rail is 12" (30.5 cm).

- o Top of ballast is flush with top of tie and extends 1'-0" (0.30 m) beyond the end of tie.

- o Ballast side slope is 2:1.

- o Track centerline passes through a point which is midway between the rails and which lies in the plane of the top of the rails.

- o Profile grade is carried on the low rail.

- o Superelevation is achieved by rotation about the low rail.

The trackbed slopes each way from a high point located between the tracks 6.5' (1.98 m) from the "R" (right) track centerline for HRTs, and 6.0' (1.83 m) for LRTs. These values are such that the trackbed is symmetrical about the high point when track spacings (S) are the designated minimum values. For single track LRT operations, the trackbed high point would be located at track centerline.

Figure 4-5.2 gives changes in trackbed width to compensate for increasing the distance between track centerlines and for the effects of track superelevation for curves to the right and to the left.

In all cases shown, the trackbed high point is 16" (40.6 cm) below the top of tie at the nearest low rail.

Trackbed geometry in spiral transitions is determined by assuming a linear variation of width dimensions through the transition.

HRT contact ("third") rails are usually carried on 10' (3.05 m) long ties spaced at about 10' (3.0 m) intervals. Contact rails are normally located between double tracks, and the longer ties do not extend beyond the standard 9' (2.74 m) ties on the outside of the track. When contact rails are located outside, the ties extend 1' (30.5 cm) beyond the standard ties to the top of ballast hinge point.

At switch points where switch and lock movements are located outside the track, the trackbed is widened so that the top of ballast can be extended 2.5' (0.76 m) beyond the end of ties, 4' (1.22 m) each side of the point of switch.

3. Retained Trackbed

Figure 4-5.3 illustrates a trackbed embankment confined by a wall on each side. Walls are placed as close together as clearances will allow.

The retained trackbed cross section is based on essentially the same set of assumptions as the unretained trackbed. One difference is that the trackbed high point is inverted so that the subgrade slopes to an underdrain. As noted, track-side walkways next to the inside face of wall are widened to 2'-6" (0.76 m) and should be at least 2'-10" (0.86 m) wide when the contact rail is located on the outside.

4. Other Trackbed Cases

In instances where the number and spacing of tracks or other conditions differ from the previous assumptions and illustrations, trackbed design should be modified appropriately in a manner consistent with basic criteria.

Trackwork for yard tracks often calls for a minimum of 6" (15.2 cm) rather than 12" (30.5 cm) of ballast under ties, and yard drainage requires special attention where profile grades are flat.

E. Trackway in Cut or Fill

Figure 4-5.4 shows trackway sections in cut and on fill. The sections illustrates some of the conditions that may be encountered and are intended as general guides.

1. Side Slopes

Side slopes are generally 2:1 or flatter. Steeper slopes are considered where earthwork or right-of-way costs are high and where materials are suitable.

2. Benches

Where cuts require benching, benches should be at least 10' (3 m) wide and properly drained. In some cuts it may be advisable to create a catchment area by providing extra width at subgrade level to retain material that might fall from the slope above.

3. Ditches

Side ditches are located in conventional positions within the trackways as shown in Figure 4-5.4. The dimensions given are for minimum ditch sizes.

4. Right-of-Way Lines

Right-of-way lines are shown relative to slope, drainage, and fencing requirements for typical cut and fill situations.

F. Earthwork

Earthwork quantities for trackway design estimates are determined by cross sections and average end areas in the manner of highway estimates. Centerline curvature is ignored. Earthwork quantities are computed and tabulated separately for each trackway prism.

Cross sections are at 50' (15 m) intervals or at breaks in terrain. Longer intervals are used where linear relationships exist. Cut and fill volumes are computed separately and shrink/swell factors are applied to cut volumes to develop mass diagram ordinates.

TABLE 4-5.1
Track Spacing (℄-℄) for Tangents and Curve Radii Over 500' (150 m)

Condition	HRT		LRT	
	Feet	Meters	Feet	Meters
Surface	13.0	3.962	12.0	3.658
Aerial	13.0	3.962	12.0	3.658
Cut and Cover	16.0	4.877	14.0	4.267
Tunnel	30.0	9.144	30.0	9.144

TABLE 4-5.2
Nominal Increase in Track Spacing (℄-℄) for Curve Radii Less Than 500' (150 m)

Radius		Increase Distance	
Feet	Meters	Feet	Centimeters
400	120	0.2	6
300	90	0.5	15
200	60	1.0	30
100	30	2.0	60
50	15	4.0	120

TABLE 4-5.3
Track Gauge Criteria

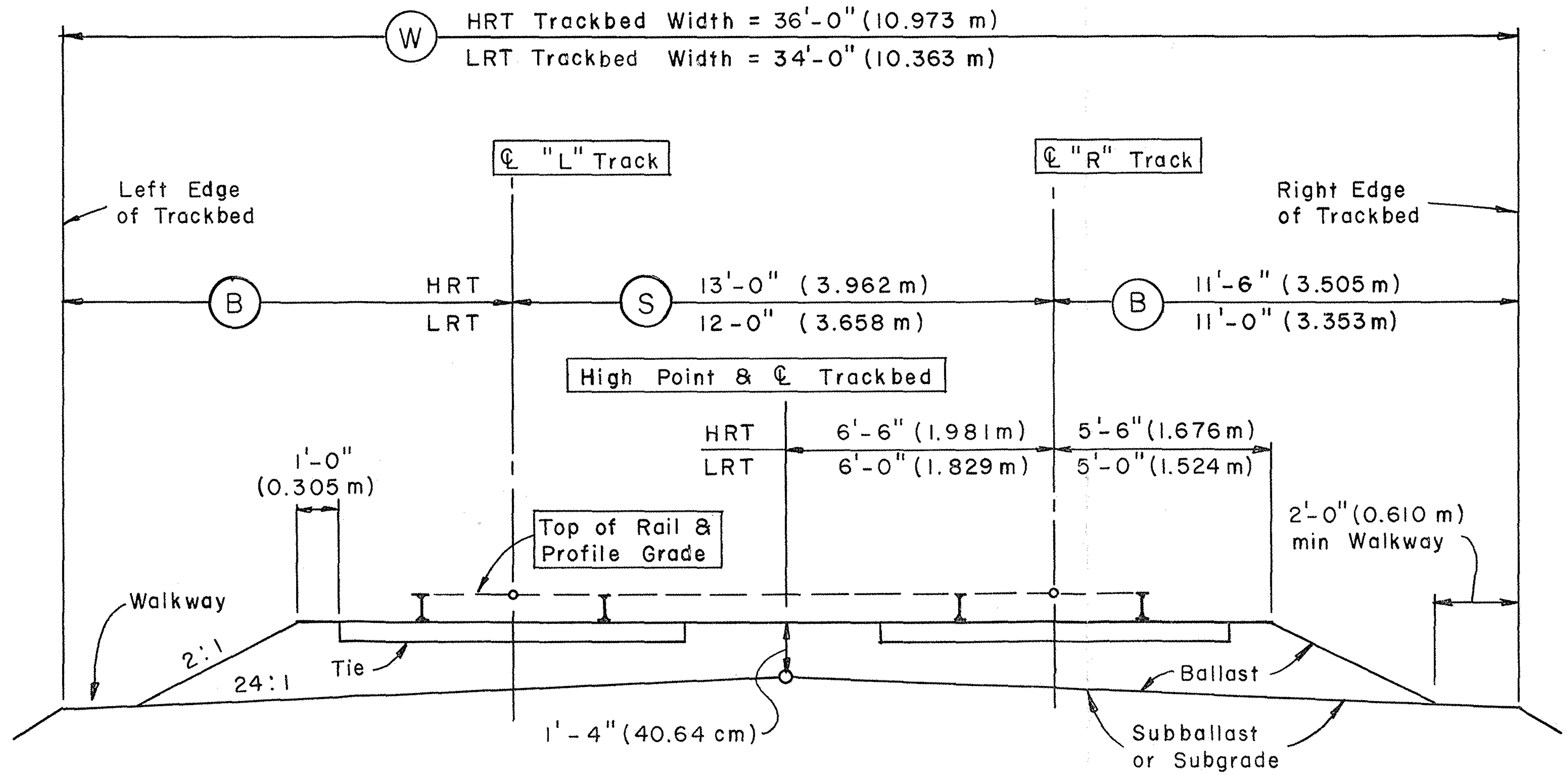
HORIZONTAL TRACK ALIGNMENT	TRACK GAUGE
Tangent Main Line Track	4'–8¼" (1,429 mm)
Curve Radius Over 1,425' (435 m)	4'–8¼" (1,429 mm)
Radius 755' to 1,425' (230 m to 435 m)	4'–8½" (1,435 mm)
Radius 500' to 755' (150 m to 230 m)	4'–8¾" (1,441 mm)
Radius 400' to 500' (120 m to 150 m)	4'–9" (1,448 mm)
Radius 225' to 400' (70 m to 120 m)	4'–9¼" (1,454 mm)

NOTES: 1. Track gauge criteria apply only with standard AAR wheel gauges of 4'–7 11/16" (1,414 mm) and axle spacing between 7'–0" (2,134 mm) and 8'–6" (2,591 mm) inclusive.

2. Transition length to be not less than 31' (9.45 m) nor more than 62' (18.90 m) for each ¼" (6.35 mm) change in gauge.

3. For yard and secondary track, the basic gauge is 4'–8½" (1,435 mm) for tangents and for curves with radii greater than 755' (230 m).

SOURCES: WMATA (Fig. III.9)
BRRTS (Fig. IV.8)
SCRTD (Fig. VIII.5)



NOTE: Dimension (B) should allow for tie replacement as needed.

SOURCES
BART (Figs. 5.2.3:3)
MARTA (Fig. 5-1)

RAIL TRANSIT CRITERIA

TYPICAL TANGENT TRACKBED
CROSS SECTION

FIGURE 4-5.1

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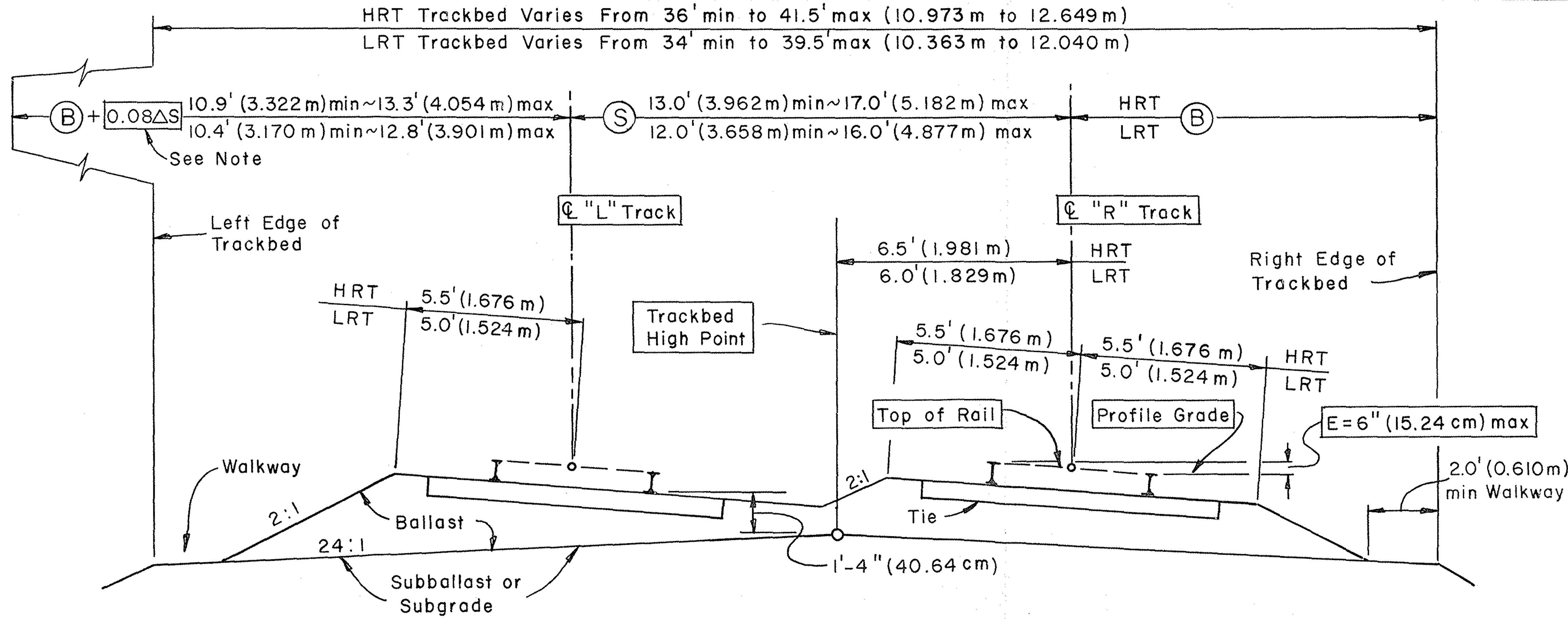

NOTE: When (S) is increased, left edge of trackbed moves out from ℄ "L" a distance equal to 0.08ΔS, where ΔS equals the increment of widening in feet or meters above minimum (S) distances shown

SYSTEM	DIMENSION (B) ADJUSTMENTS FOR CURVES WITH A RADIUS OF 755' (230 m) OR MORE			
	ON OUTSIDE OF CURVE (B) EQUALS		ON INSIDE OF CURVE (B) EQUALS	
	FEET	METERS	FEET	METERS
HRT	11.5 + 0.3E	3.505 + 0.036E	11.5 − 0.1E	3.505 − 0.012E
LRT	11.0 + 0.3E	3.353 + 0.036E	11.0 − 0.1E	3.353 − 0.012E
Where: E = Actual Super	INCHES	CENTIMETERS	INCHES	CENTIMETERS

SOURCES

BART (Fig. 5.2.3.2.)
MARTA (Fig. 5-2)

RAIL TRANSIT CRITERIA

TYPICAL SUPERELEVATED TRACKBED CROSS SECTION

FIGURE 4-5.2

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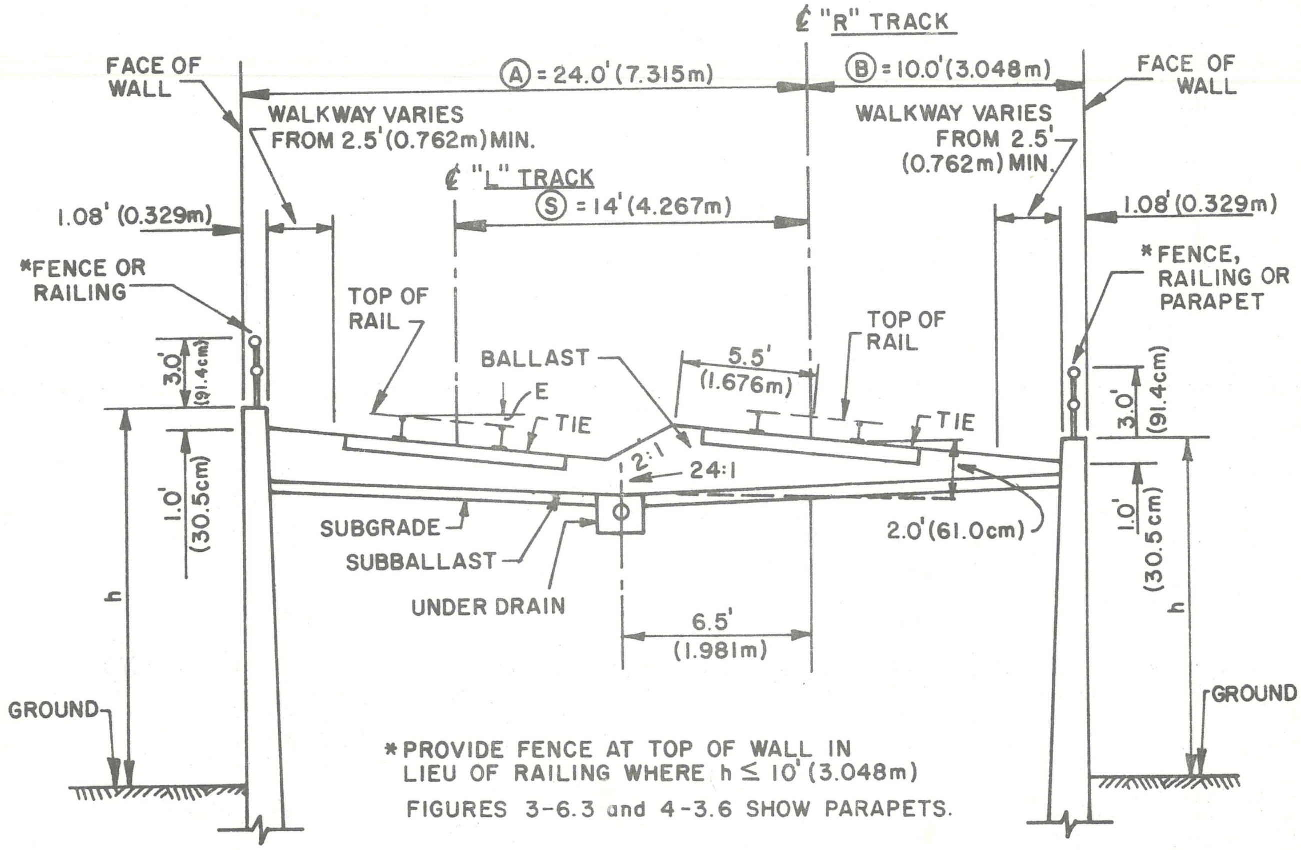


*PROVIDE FENCE AT TOP OF WALL IN LIEU OF RAILING WHERE h ≤ 10' (3.048m)

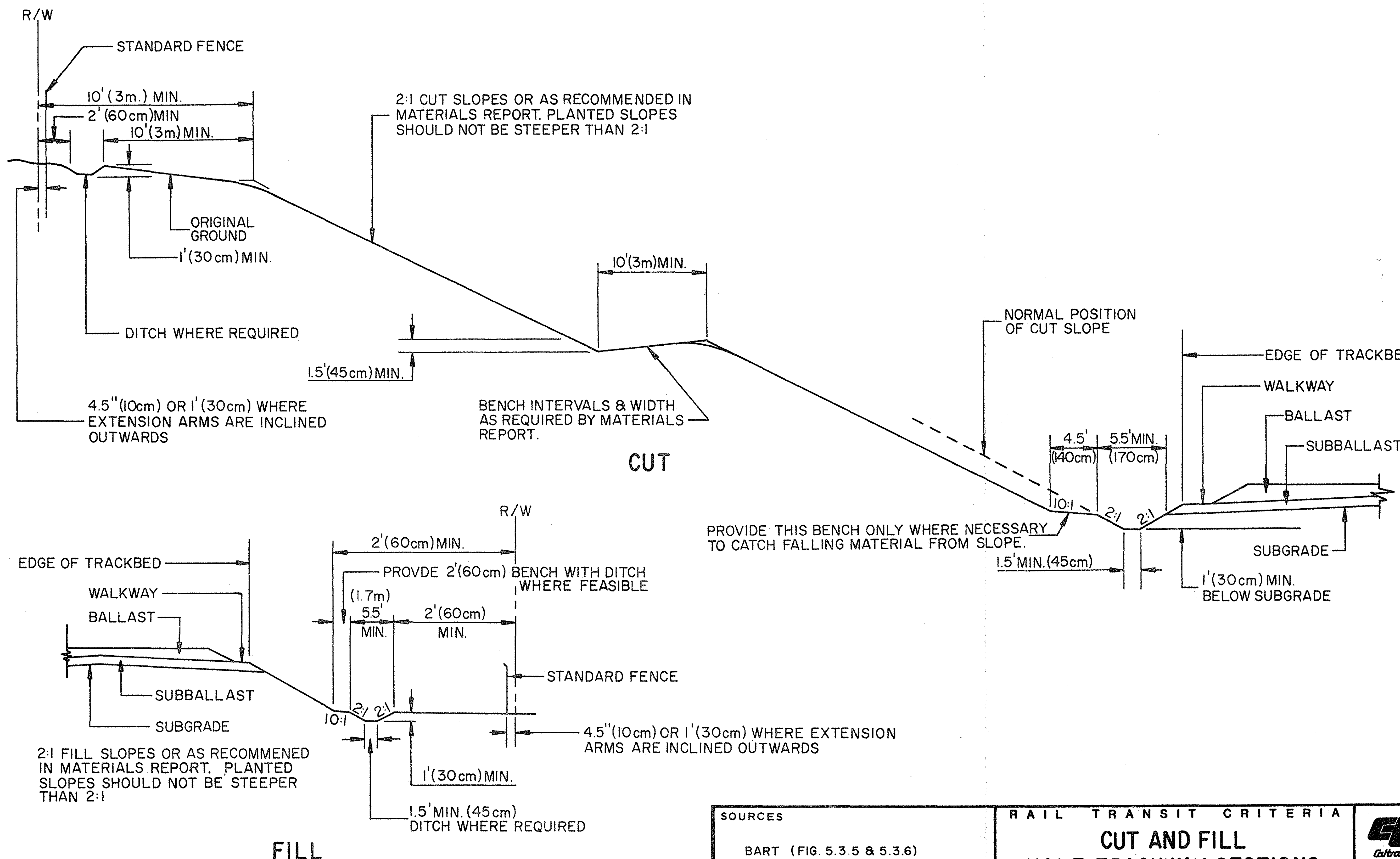
FIGURES 3-6.3 and 4-3.6 SHOW PARAPETS.

NOTES: 1 - Ⓐ & Ⓑ DIMENSIONS SHOWN ARE APPROPRIATE FOR RIGHT OR LEFT CURVES WITH "R" TRACK RADIUS OF 755' (230m) OR MORE WHEN:

- Ⓢ = 14' (4.267m)
- E = 6" (15.24cm) MAX. SUPERELEVATION
- TIES ARE 9' (2.743m) LONG.

2 - Ⓐ, Ⓑ OR Ⓢ SHOULD ALLOW FOR TIE REPLACEMENT AS NEEDED.

SOURCES	RAIL TRANSIT CRITERIA	
BART (Fig. 5.2.4) MARTA (Fig. 5-3)	**RETAINED EMBANKMENT TRACKBED** CROSS SECTION FIGURE 4-5.3	Caltrans JUN 77



SOURCES

BART (FIG. 5.3.5 & 5.3.6)
MARTA (FIG. 5-4 & 5-5)

RAIL TRANSIT CRITERIA

CUT AND FILL HALF-TRACKWAY SECTIONS

FIGURE 4-5.4

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APPENDIXES

4-6 HORIZONTAL ALIGNMENT

The horizontal alignment of mainline tracks consists of tangents joined to circular curves by spiral transition curves. Spirals are generally not used in yards and service areas.

Curvature and superelevation are related to design speed and to the acceleration and deceleration characteristics of the design vehicle as discussed in Section 3-2, Subsection B. Wherever possible, track geometry is designed for maximum vehicle operating speed considering vehicle performance characteristics, station spacing, and vertical and horizontal alignment. These relationships are described in Section 3-9.

A. Control

Routes are stationed throughout their length along the centerline of the mainline track in the direction of travel.

B. Minimum Tangent Length

The tangent length often specified as an absolute minimum is 75' or 100' (23 m or 30 m). A preferred minimum is 200' (60 m). An acceptable minimum above the absolute limit is usually determined by the following formula:

	L=3V	L=0.6V
Where:		
L=Min. tangent length,	feet	meters
V=Design velocity through tangent,	mph	kmph

At stations employing platforms, it is desirable to extend tangent alignment 75' (23 m) beyond the platform in each direction. The introduction of curvature into or through a station may be considered in locations such as freeway medians. A radius on the order of 3,000' (915 m) is sometimes designated as an acceptable minimum in station areas. Curves with lesser radii at station approaches should not encroach more than 40' (12 m) on platforms or future extensions, and superelevation should not exceed one inch (2.5 cm) within the platform area. Vehicle inswing-outswing on curves and clearance gaps at high-level platforms are discussed in Section 4-3.

C. Circular Curves

Circular curves are defined by the arc definition of curvature and specified by their radii.

1. Minimum Radius

The desirable minimum radius for HRT mainline track curvature is often specified as 1,000' (305 m), but is sometimes as low as 755' (230 m). Stated absolute minimum mainline values range from 750' (229 m) down to a radius of 500' (152 m). The absolute minimum specified for secondary tracks and for yard tracks ranges from 350' to 250' (107 m to 76 m).

LRT systems can employ similar alignment standards where they approach HRT operational standards at one extreme, but they may also employ radii on the order of 50' (15 m) where appropriate for street operation.

2. Minimum Length

The desirable minimum length of a circular curve is given by the same formula as for tangent length:

	L=3V	L=0.6V
Where:		
L=Min. tangent length,	feet	meters
V=Velocity through curve,	mph	kmph

The usual absolute limit for a circular curve length is 100' (30 m), although circumstances may occasionally require that a curve be transitional throughout its length. Tracks are placed on concentric curves for multitrack alignments. Figure 4-6.1 shows circular curve functions and abbreviations.

D. Superelevation

Superelevation is the height difference between the high and low rail and is divided into the following elements:

$$E_r = E_a + E_u$$

Where:

E_r = Total superelevation required for equilibrium.

E_a = Actual superelevation to be constructed.

E_u = Unbalanced superelevation (difference between E_r and E_a).

Allowable values for superelevation (actual and unbalanced), and the manner in which they are applied, are similar for different HRT systems, but do show some variation. One representative set of values and a typical methodology have been selected for the sake of consistency and continuity in the presentation of superelevation immediately following. These values are shown in Figure 4-6.2.

1. Maximum

For running tracks in tunnels or in cut and cover structures, the absolute maximum actual superelevation (E_a) is limited to 4 inches or 10 centimeters.

For running tracks on surface construction and on aerial structures, the desirable maximum actual superelevation (E_a) is 4" or 10 cm. In instances where an increase in actual superelevation would permit an increase in the design speed of a section of alignment, an absolute maximum of 6" or 15 cm may be used.

The maximum unbalanced superelevation (E_u), which is applied throughout a system, is typically 4 1/2" (11.5 cm) for HRT, although 3" (7.5 cm) or less is cited as a preferred value.

For LRT operations in San Francisco, MUNI follows the AAR recommended allowance of 3" (7.5 cm) for unbalanced superelevation.

2. Amount

Superelevation may be determined by the following formula:

	$E_a=3.775\frac{V^2}{R}-E_u$	$E_a=1.128\frac{V^2}{R}-E_u$
Where:		
V=Velocity,	mph	kmph
R=Radius of curve,	feet	meters
E_a=Actual super.,	inches	centimeters
E_u=Unbal. super.,	inches	centimeters

When E_u equals zero, E_a is the equilibrium superelevation. Calculated values of actual superelevation (E_a) are rounded to the nearest one-quarter inch (one-half centimeter). The relationship between superelevation, curvature, and design speed is shown on Figure 4-6.2.

3. Application

Yard and secondary tracks are usually not superelevated.

Superelevation is specified and applied in 1/4" or 0.5 cm increments. For a calculated superelevation (E_r) of 1/2" or 1.5 cm (or less), no actual superelevation (E_a) need be provided.

Unbalanced superelevation (E_u) varies from a desirable zero to an absolute maximum of 4 1/2" (11.5 cm). Unbalance is held at zero until E_a reaches the preferred maximum of 4" (10 cm) or the absolute maximum of 6" (15 cm). Actual superelevation (E_a) is then maintained at these values until the total $E_a + E_u$ is equal to the preferred 8 1/2" (21.5 cm) or the absolute maximum of 10 1/2" (26.5 cm) for surface construction. At this point a limit is placed on speed of operation.

Actual superelevation is attained or removed linearly throughout the full length of the spiral transition curve. This is normally done by raising the rail farthest from the curve center while maintaining the top of the inside rail at profile grade.

There are exceptions to the general rule that superelevation is held constant through the circular curve and is attained and removed in spiral transitions by raising the outer rail. These special cases are discussed in Parts 4 and 5 immediately following and in subsequent Subsections F, G, and H.

4. Subways

In some subways, superelevation is obtained by raising the outer rail and lowering the inner rail 1/2 of the total amount of required superelevation. In circular tunnels this may be done by rotating the track about the axis of the tunnel and adjusting the centerline of the tunnel to compensate for the resulting vertical and horizontal offsets.

5. Variations in Operating Speeds

A variation in vehicle or train operating speed through a curve will result wherever a curve lies in an acceleration or deceleration zone. In such a case, the superelevation is varied along the curve so that a more or less uniform unbalanced superelevation (E_u) will be maintained. If reasonably uniform values cannot be obtained, use of a compound curve or an extra long transition spiral should be considered.

"Non-design" operating speeds through a curve can also result from running through a station in skip-stop, express operation. Since such run-throughs should occur only occasionally, all curves adjacent to stations are designed for station-stop operations and maximum run-through speeds are limited by the maximum allowable unbalanced superelevation.

In curves immediately adjacent to stations, and in other curves which have wide speed variations, the superelevation between the head and tail ends of a maximum length train must be checked. The difference in unbalanced superelevation between train ends should not exceed the limits defined by plus to minus values for allowable unbalanced superelevation.

F. Spiral Transition Curves

Spiral transitions are used in mainline tracks to connect curves and tangents and to provide superelevation transition length. For multitrack layout, where tracks follow the same general alignment, and where the distance between track centers in the circular curve is the same as for adjacent tangents, the tracks are placed on parallel spirals. If the distance between track centers in the circular curve is different from that in the tangents, each spiral is a "true" spiral and its geometry is defined individually.

Figure 4-6.3 shows functions and abbreviations for the Barnett spiral used in this manual.

1. Minimum Length

The absolute minimum length for a mainline spiral is 100' (30 m). The minimum length for spirals more than 100' (30 m) long is the greater of the lengths given by the following formulas:

	$L_s=50E_a$	$L_s=6E_a$
	$L_s=1.22E_uV$	$L_s=0.091E_uV$
Where:		
L_s=Min. spiral length,	feet	meters
E_a=Actual superelevation,	inches	centimeters
E_u=Unbalanced super.,	inches	centimeters
V=Design velocity,	mph	kmph

The relationship between superelevation and spiral length is shown on Figure 4-6.4.

In instances where available space is insufficient for the length of spiral required to maintain $E_u=0$ until maximum E_a is reached, E_a is reduced and E_u is increased in order to achieve maximum design speed. In such cases, maximum speed is achieved for a given length of spiral by adjusting E_u as follows:

	$E_u = \frac{41E_a}{V}$	$E_u = \frac{66E_a}{V}$
Where:		
E_u=Unbalanced super.,	inches	centimeters
E_a=Actual superelevation,	inches	centimeters
V=Design velocity,	mph	kmph

2. Right-Angle Turns

Appendix A-6 shows a curve solution for a minimum radius, double-track, right-angle turn appropriate for LRT street running. The geometry will accommodate SLRV operation and permit two vehicles to meet and pass on the curve.

3. Curves Without Spirals

As a practical consideration, transition spirals for simple curves are omitted where the length for spiral (L_s) divided by the radius of circular curvature (R) using either feet or meters, is less than 0.01. Where the spiral is not provided, the superelevation is attained over equal lengths of tangent and curve throughout the greater of the lengths given by the formulas in preceding Part 1.

G. Compound Circular Curves

Where compound circular curves are required, a spiral is inserted between the circular curves. The minimum length of such a spiral is the greater of the lengths as determined by the earlier formulas, modified as follows:

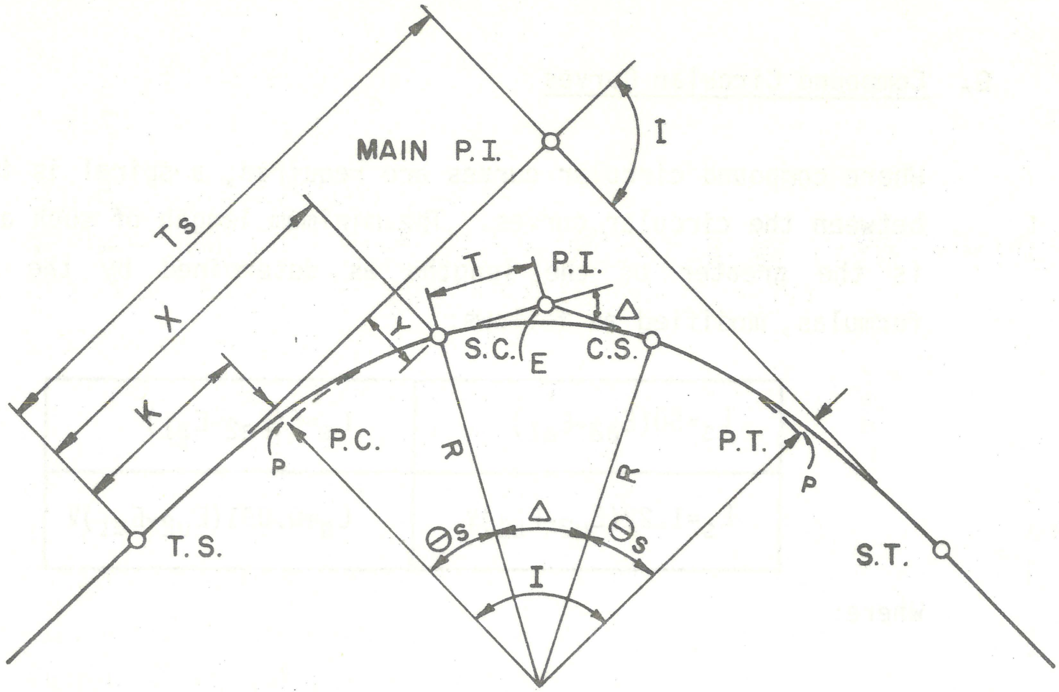
$L_s=50(E_{a2}-E_{a1})$	$L_s=6(E_{a2}-E_{a1})$
$L_s=1.22(E_{u2}-E_{u1})V$	$L_s=0.091(E_{u2}-E_{u1})V$

Where:

L_s=Minimum length of spiral in feet or meters as before, and the added subscripts 1 and 2 denote the first and second circular curves.

H. Reverse Curves

If circumstances do not permit the minimum tangent length to be accommodated between reversing curves, the transition spirals may meet at the point of reverse curvature and the superelevation transition may be accomplished as shown in Figure 4-6.5. This situation is to be avoided if at all possible, because at Point A both rails are above profile grade through the transition (a maximum at Point A) and this creates problems with respect to vehicle clearance and ballasting. Clearances must be based on actual rail elevation.



I = TOTAL INTERSECTION ANGLE

Θs = SPIRAL ANGLE = $\frac{LsDc}{200}$ IN U.S. UNITS = $\frac{LsDc}{60.96}$ IN METRIC UNITS

Δ = CENTRAL ANGLE OF CIRCULAR CURVE = $I - 2\Theta s$

R = RADIUS OF CIRCULAR CURVE

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

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

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

Ts = TANGENT LENGTH FROM T. S. TO MAIN P. I. = $(R + P) \tan \frac{I}{2} + K$

P.C. = POINT OF CURVATURE

P.T. = POINT OF TANGENCY

T.S. = TANGENT TO SPIRAL

S.C. = SPIRAL TO CURVE

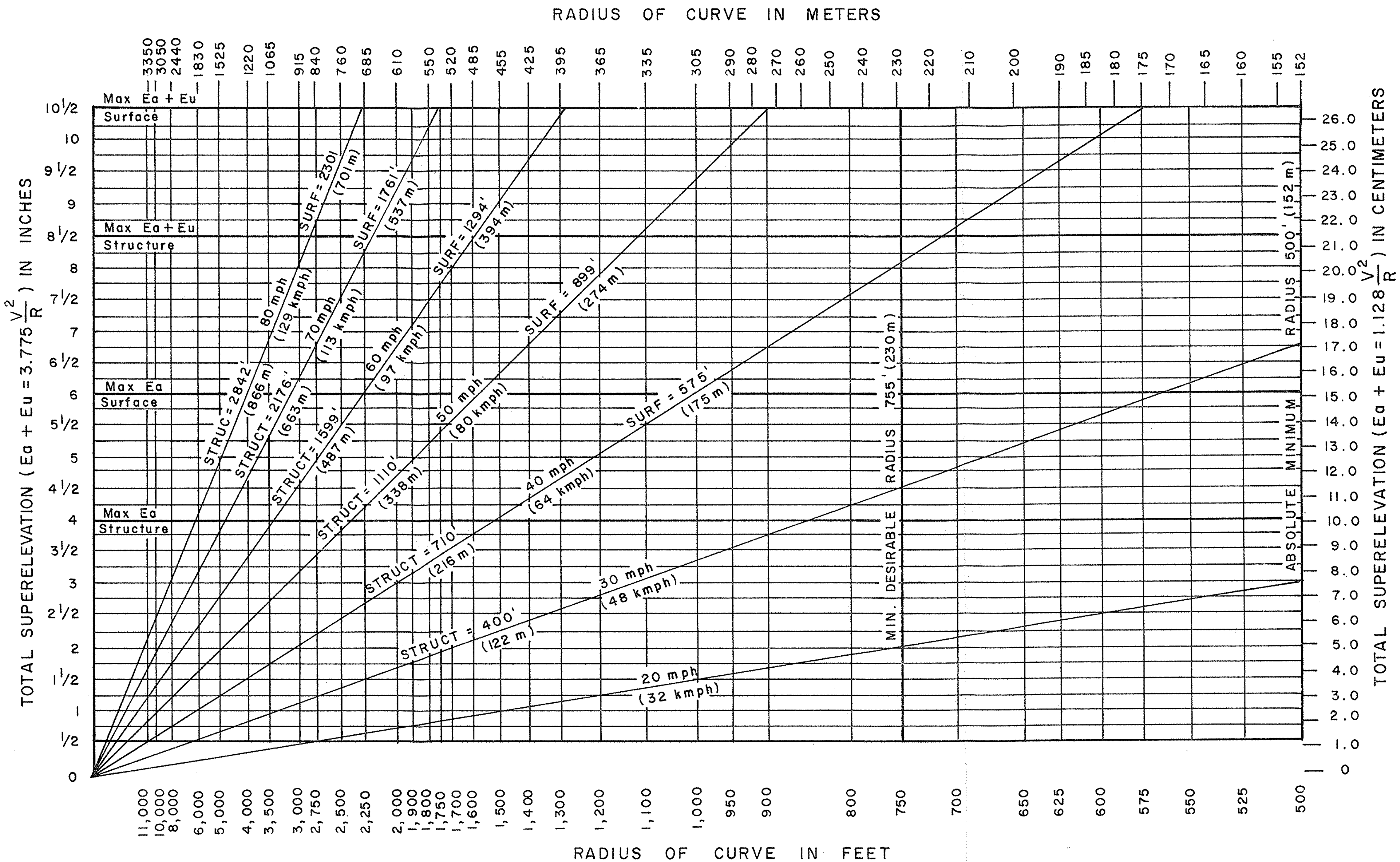
C.S. = CURVE TO SPIRAL

S.T. = SPIRAL TO TANGENT

P.I. = POINT OF INTERSECTION

NOTE: SEE FIG. 4-6.3 FOR SPIRAL CURVE FUNCTIONS & ABBREVIATIONS

SOURCES:	RAIL TRANSIT CRITERIA	
WMATA (Fig. III . 5) BRRTS (Fig. IV . 4) SCRTD (Fig. IV - 3)	CIRCULAR CURVES FUNCTIONS AND ABBREVIATIONS FIGURE 4-6.1	Caltrans JUN 77



NOTE: Superelevation unbalance equals zero until maximum Ea is reached. Then unbalanced superelevation is added until maximum Ea + Eu is reached. At this point a limit is placed on speed of operation.

SOURCES

BRRTS (Fig. IV.5)
WMATA (Fig. III.8)
SCRTD (Fig. IV-4)

RAIL TRANSIT CRITERIA

SUPERELEVATION CHART

FIGURE 4-6.2

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	U.S. UNITS	METRIC UNITS
Θs = SPIRAL ANGLE =	$\frac{Ls \cdot Dc}{200}$	$\frac{Ls \cdot Dc}{60.96}$
Dc (DEGREE OF CURVE-ARC DEFINITION) =	$\frac{5,729.578}{R}$	$\frac{1,746.3753}{R}$

U. S. or METRIC UNITS

Ls = LENGTH OF SPIRAL

$$X = Ls\left(1 - \frac{\delta s^2}{10} + \frac{\delta s^4}{216} - \frac{\delta s^6}{9360} + \frac{\delta s^8}{685440} - \frac{\delta s^{10}}{76204800} + \frac{\delta s^{12}}{11975040000}\right)$$

$$Y = Ls\left(\frac{\delta s}{3} - \frac{\delta s^3}{42} + \frac{\delta s^5}{1320} - \frac{\delta s^7}{75600} + \frac{\delta s^9}{6894720} - \frac{\delta s^{11}}{91808640} + \frac{\delta s^{13}}{168129561600}\right)$$

Ts = TANGENT LENGTH FROM T. S. TO MAIN P.I. = $(R+P)\,TAN\,\frac{I}{2} + K$

P = $Y - R\,(1 - COS\,\Theta s)$

K = $X - R\,SIN\,\Theta s$

ST = $Y / SIN\,\Theta s$

LT = $X - Y / TAN\,\Theta s$

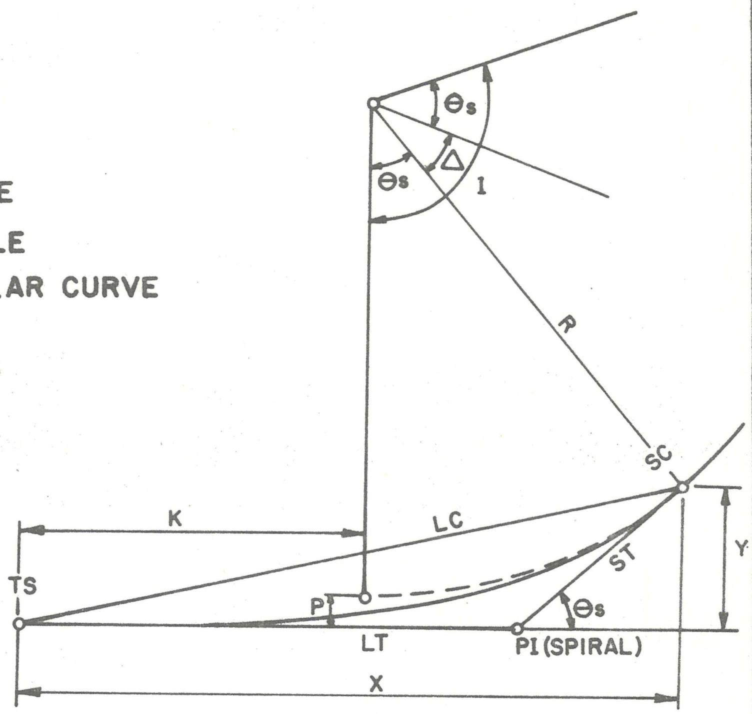
LC = $\sqrt{X^2 + Y^2}$

R = RADIUS OF CIRCULAR CURVE

I = TOTAL INTERSECTION ANGLE

Δ = CENTRAL ANGLE OF CIRCULAR CURVE

- Dc, Θs, Δ & I ARE IN DEGREES
  δs = Θs EXPRESSED IN RADIANS.
- ALL OTHER DIMENSIONS ARE IN FEET WHEN USING U. S. UNITS OR IN METERS WHEN USING METRIC SYSTEM.



NOTES: 1 - ACTUAL SUPERELEVATION (Ea) IS ATTAINED & REMOVED LINEARLY THROUGHOUT THE FULL LENGTH OF THE SPIRAL TRANSITION.

2 - SEE FIG. 4-6.1 FOR CIRCULAR CURVE FUNCTIONS & ABBREVIATIONS.

SOURCES:

SCRTD	(Fig. IV - 5)
BRRTS	(Fig. IV - 6)
WMATA	(Fig. III - 6)
MARTA	(Fig. 3 - 2)

RAIL TRANSIT CRITERIA

SPIRAL CURVES (BARNETT'S SPIRAL) FUNCTIONS AND ABBREVIATIONS

FIGURE 4-6.3

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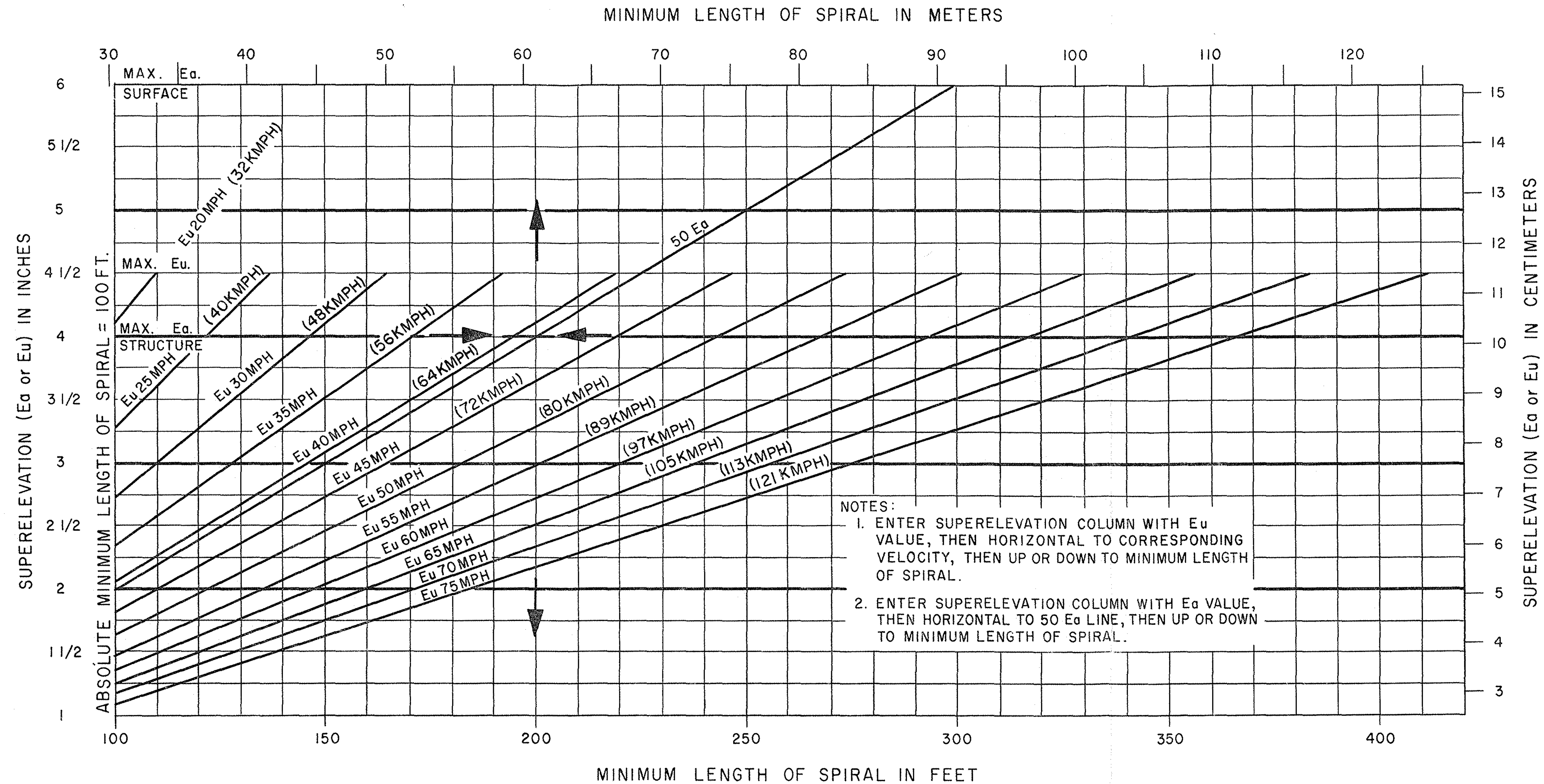

SOURCES

SCRTD (Fig. IV-6)
WMATA (Fig. III.7)
BRRTS (Fig. IV.7)

RAIL TRANSIT CRITERIA

SPIRAL LENGTH CHART

FIGURE 4-6.4

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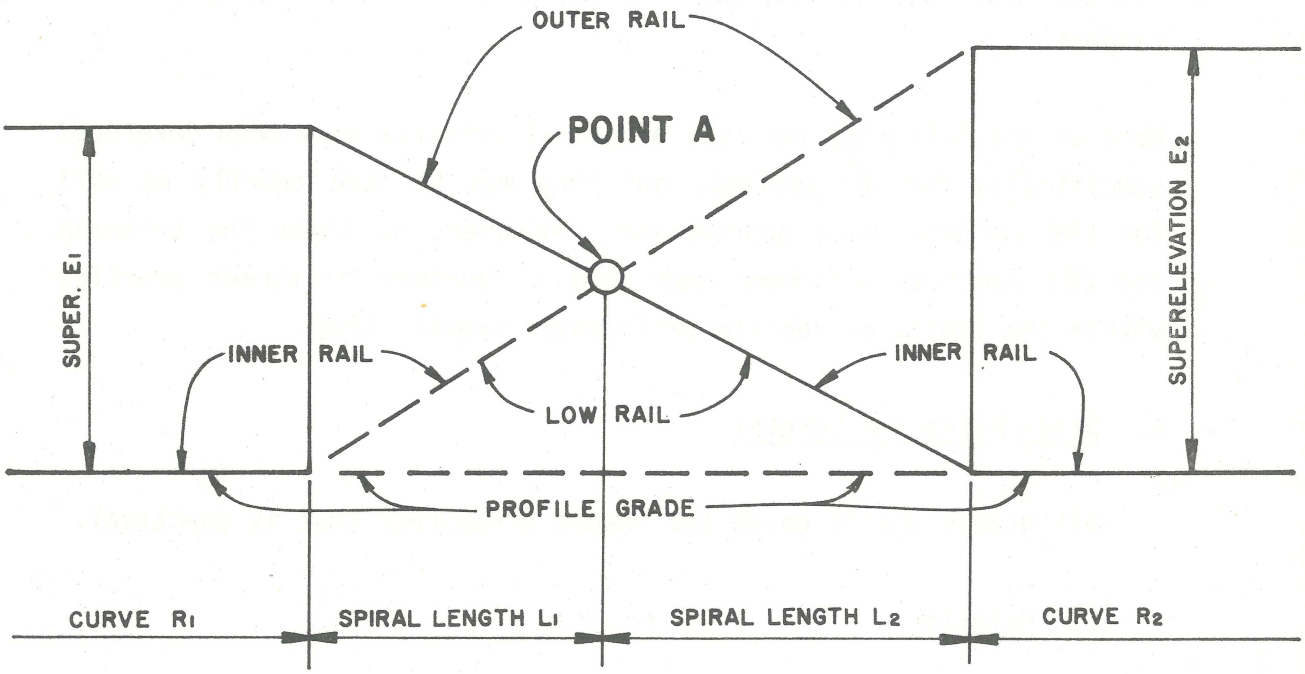

SOURCES:

MARTA (Fig. 3-3)
BART (Fig. 3.4.3)

RAIL TRANSIT CRITERIA

SUPERELEVATION TRANSITIONS FOR REVERSE CURVES

FIGURE 4-6.5

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4-7 VERTICAL ALIGNMENT

Profile grade represents the elevation of the low rail. When only one track profile is given for curved alignment, the profile of the second track is adjusted uniformly to accommodate the difference in length through the curve. No compensation of grades is required for horizontal curvature.

All changes in grade are connected by parabolic vertical curves.

Stations and special trackwork such as turnouts and crossovers are located preferably where both horizontal and vertical alignment are tangent.

Most of the following vertical alignment criteria have been developed specifically for HRT systems, but they may be used equally as well for LRT systems where appropriate. However, at times the criteria for LRT vertical alignment may need to conform to street profiles within the limits of vehicle performance capabilities.

A. Grade Rates and Lengths

All grades should be at the lowest percentage that is practical.

1. Mainline

The desirable maximum grade specified for mainline track between stations on systems is usually 3 percent; 4 percent is often allowed, but seldom more. In exceptional circumstances, such as split-level junctions, the maximum 4 percent grade may be increased to 5 percent on down grades only.

A minimum grade of zero percent is acceptable for at-grade construction. A minimum grade of 0.25 percent should be maintained for underground and aerial structures to accommodate drainage.

As noted in Section 3-2, Subsection B, plus 6 percent and minus 8 percent might be considered desirable maximum grades for LRVs, with plus 8 percent and minus 10 percent being allowable under some circumstances. These values are fairly representative for modern LRVs generally, but if LRT system design (or vehicle selection) is to be directly influenced by vehicle capabilities and desired performance, then specific vehicle information must be matched against system policies. Appendix A-4 shows some significant differences in LRV performance characteristics.

The minimum length of constant profile grade between vertical curves on mainline HRT track is often determined by the familiar formula:

	L=3V	L=0.6V
Where:		
L=Min. length of grade,	feet	meters
V=Design velocity through tangent,	mph	kmph

The absolute minimum length of constant grade is sometimes set at 75' (23 m), but more often at 100' (30 m) on new and proposed HRT systems in this country.

2. Stations

The maximum grade permitted through stations on modern HRT systems is frequently in the 0.30 to 0.50 percent range, but 1.0 percent is also prevalent where stations are not used for vehicle storage.

A minimum grade of zero percent is usually permissible in all station areas if drainage can be accommodated.

As with horizontal tangents, it is desirable to extend constant grade tangents 75' (23 m) beyond the limits of station platforms.

3. Yard and Secondary Tracks

For yard and secondary tracks in general, the minimum grade is usually specified as 0.20 or 0.30 percent and the maximum grade is commonly 1.0 percent.

For storage tracks, a level grade is often permissible and 0.30 percent is a frequently stated maximum. Stub-end storage tracks should slope away from the turnout, and through storage tracks should have a sag in their profiles where feasible.

Turnback and center pocket tracks to be used for train storage and train consist changes should also be limited to a maximum grade of 0.30 percent.

Tracks located within shop buildings should be held to a level grade.

B. Vertical Curves

All changes in grade are connected by parabolic vertical curves at crests and sags. Figure 4-7.1 illustrates vertical curve types and the elements of a standard vertical curve.

1. Mainline

For mainline track the absolute minimum length of vertical curve is usually established at 100' (30 m). The preferred minimum length is 200' (60 m). The length of mainline vertical curves above the minimum is most often determined by:

Where:	$L=100(G_1-G_2)$	$L=30(G_1-G_2)$
L=Length of vert. curve,	feet	meters
(G_1-G_2)=Algeb. diff. in grades,	%	%

Under normal operating conditions, this formula limits centripetal acceleration to less than one foot (0.3 m) per second which has been found to be an acceptable rate of change for passenger comfort.

Where vertical and horizontal curves are combined and unbalanced superelevation (E_u) exceeds 1" (2.5 cm), the length of vertical curve should be increased to 200 $(G_1 - G_2)$ feet or 60 $(G_1 - G_2)$ meters.

2. Stations

It is desirable to extend a constant profile grade 75' (23 m) beyond platform limits where feasible. It is also desirable, where feasible, to roll profile grade up and down at station stops. As mentioned in Section 3-2, Subsection B, this helps braking and acceleration. It saves energy and permits underground stations to be constructed at a lesser depth. With grades ascending to and descending from stations employing platforms, the PVIs should be located so that not more than one-fourth of the vertical curves will encroach on the platform.

If a grade of more than 1.0 percent ascends from a station, the PVI should be located at a distance of 50 $(G_1 - G_2)$ feet or 15 $(G_1 - G_2)$ meters beyond the end of platform.

3. <u>Yard and Secondary Tracks</u>

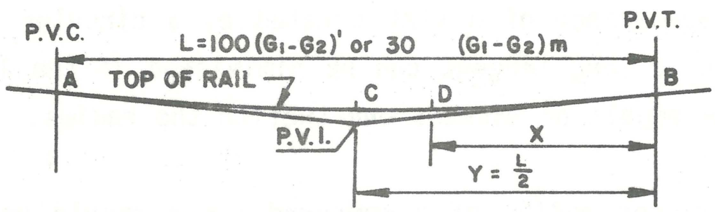
Some transit systems do not establish minimum vertical curve lengths for yard and secondary tracks. Suggested minimum lengths for vertical curves at critical locations off the mainline are shown in Figure 4-7.1.

Where branch track joins mainline track from a different grade, the vertical curve should end sufficiently clear of the actual point of switch to provide for common track ties.

CREST TYPE VERTICAL CURVES

SAG TYPE VERTICAL CURVES

STANDARD VERTICAL CURVE



PREFERRED MINIMUM L = 200' (60m)

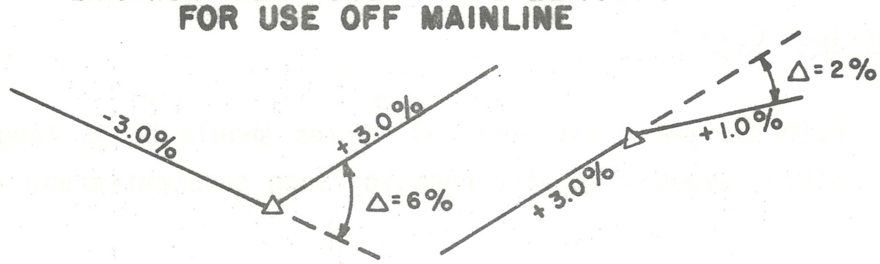
EL. C = $\frac{2\text{ EL. P.V.I.} + \text{EL. A} + \text{EL. B}}{4}$

OFFSET AT C = DIFFERENCE BETWEEN EL. C & EL. P.V.I.

OFFSET AT D = OFFSET AT C$\left(\frac{X}{Y}\right)^2$

T/R AT D = OFFSET AT D ± GRADIENT EL. AT D.

MINIMUM VERTICAL CURVE LENGTHS FOR USE OFF MAINLINE



IF GRADE DIFF. (Δ) IS:	CAN REDUCE V.C. LENGTH (L) TO:
7%	160' (48m)
6%	140' (42m)
5%	120' (36m)
4%	100' (30m)
3%	80' (24m)
2%	60' (18m)
1%	40' (12m)

SOURCES:

TTC (DS 4.1.2.A.1 & DS 4.1.2.A.2)

RAIL TRANSIT CRITERIA

VERTICAL CURVES

FIGURE 4-7.1

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4-8 ALIGNMENT AESTHETICS

Aesthetics of alignment are considered where horizontal or vertical curves, or combinations thereof, create disturbing visual effects in sensitive areas where at-grade or aerial construction can be observed from off the right of way or from a station platform.

The following criteria should be considered where applicable:

A. Horizontal Curves

- The appearance of a kink created by a circular curve at the end of a long tangent can be diminished if the length of the curve equals or exceeds one-twelfth the radius.

- The longer radius of a compound curve should not exceed the shorter by more than 50 percent.

- Broken-back curves (in the same direction) should be separated by a tangent at least 1,500' (450 m) in length.

B. Vertical Curves

- Both sag and crest vertical curves should be as long as possible, especially if connecting long constant-grade lines.

- Broken-back vertical curves should be avoided.

- The tops of rails and edges of aerial structures should be checked to avoid a roller-coaster appearance. Profiles plotted to a distorted scale are helpful in this analysis.

C. Combined Horizontal and Vertical Curves

- Preferably, vertical control points (PVC, PVT) should lie either completely inside or completely outside of horizontal control points (TS, SC, CS, ST).

- Short horizontal curves at sags and crests should be avoided.

- If a horizontal curve begins or ends in a vertical curve, especially a sag curve, great care should be taken to produce a pleasant visual effect.

DEFINITIONS

A-Car -- Rail car with operating cab and controls.

Articulated Car -- A rail car consisting of two or more units free to swivel with the inner ends usually carried on a common truck at the articulated joint.

Balancing Speed -- A speed, less than cruise velocity, that a vehicle maintains when neither accelerating or decelerating on an upgrade.

Ballast -- Specified material, usually crushed stone, placed on the trackbed to hold track in line and elevation. (Material should distribute load, drain well, and resist plant growth.)

B-Car -- Rail car without attendant's cab and complete operating controls.

Block -- A defined length of track.

Block Signal System -- Standard railway signaling system for controlling headways using a fixed signal at the entrance of a block to govern the trains entering the block.

Bolster -- A cross member of the underside of a car body and in the center of a truck, through which the weight is transmitted.

Broad Gauge -- A railway track gauge more than 4 feet 8 1/2 inches (1,435 mm).

Cab -- The space in a self-propelled rail car containing the operating controls.

Catenary -- A suspended contact wire for electric power supply. (The current is gathered by the vehicle using either a pantograph or trolley.)

Center Pin -- A large bolt which passes through the center plates of the body bolster and truck bolster.

Center Plates -- A pair of plates which fit one into the other and which support the car body on the trucks, allowing them to turn freely under the car. (The center pin passes through both, but does not really serve as a pivot.)

Center Platform Station -- A transit station with one platform located between two tracks.

Center Sill -- The central longitudinal (backbone) member of the underframe of a car.

Chopper -- A solid-state electronic device used to control traction motors. Chopper equipment supplies DC energy to the propulsion motors by very rapidly turning the motor current on and off in a controlled pattern.

Clearance Envelope -- The cross sectional shape required to provide specified horizontal and vertical clearances for a rail vehicle in motion.

Clearance Point -- The point where the minimum distance between converging/-diverging tracks is sufficient to meet clearance envelope requirements when vehicles are on both tracks.

Consist -- The makeup or composition of a train of vehicles, their number and specific identity.

Contact Rail -- See "Third Rail".

Continuous Welded Rail (CWR) -- Railway track with welded joints providing a smoother running surface and thereby a smoother ride.

Conventional Rail (CR) -- Transportation utilizing trains of steel wheeled vehicles operating on duo-rail steel tracks.

Cruise Velocity -- The forward speed that a vehicle normally maintains when it is not accelerating or decelerating.

Crush Capacity -- The maximum passenger capacity of a vehicle considering that the spacing between standing passengers is zero and one more passenger cannot enter without causing serious discomfort.

DC/AC System -- DC pickup from electrified line, AC propulsion system.

Dwell Time -- The time a vehicle or train requires to discharge and take on passengers at a station (including opening and closing doors) and time spent standing in station.

Dynamic Braking -- Electromagnetic braking using the motors as generators.

Effective Velocity -- The speed that a vehicle travels, including dwell times at stations and acceleration and deceleration. (Calculated by dividing trip distance by total elapsed time to complete trip.)

Electrified Rail System -- Rail operations in which vehicle propulsion is provided by electric power picked up by a shoe from a third rail or by pantograph or trolley from an overhead contact wire.

Electronic Coupling -- Very close headway between vehicles to form trains without physical contact between cars.

Electropneumatic Brake -- Used on long, high-speed electric trains (such as in a subway). Provides means for applying and releasing air brakes on each car instantaneously and simultaneously, eliminating any tendency to surge.

Emergency Braking -- Irretrievable, unmodulated braking usually at higher retardation rate than obtained with a maximum service braking. (Once initiated, the brake application cannot be released until the train has stopped.)

Equilibrium Superelevation -- When the centrifugal (outward) force is totally resisted by the component of the weight of vehicle parallel to the plane of superelevation.

Exclusive Right of Way -- Land area or other space devoted to the exclusive use of a transit system.

Fixed Block System -- An automatic train control system maintaining a fixed headway using a fixed block with track circuits to detect train presence and to supply some or all of the commands to the trains. Uses block signal system or some other means of controlling train.

Flange -- The inside rim of a rail car wheel which projects below the tread.

Friction Braking -- Braking by use of shoes against wheels.

Frog -- A track structure used at the intersection of two running rails to provide support for wheels and passageways for their flanges, thus permitting wheels on either rail to cross the other rail.

Gauge (Track) -- Distance between the inside face of rails, usually measured 5/8 of an inch (1.59 cm) below the top of the centerline of heads of running rails and at a right angle thereto.

Guard Rail (Track) -- A rail or other structure laid parallel with the running rails of a track to prevent wheels from being derailed, or to hold wheels in correct alignment to prevent their flanges from striking the points of turnout or crossing frogs or the points of switches.

<u>Headway</u> -- The interval between vehicles or trains expressed either in units of time or in distance, measured from nose-to-nose (not tail-to-nose) at a stated speed.

<u>Interface</u> -- Transfer activity and the facilities required for transfers between transportation modes, e.g., bus to rapid transit, etc.

<u>Jerk</u> -- Rate of change of acceleration or deceleration (measured in feet or meters per second per second per second, for example).

<u>Joint (Rail)</u> -- A fastening designed to unite the abutting ends of contiguous rails.

<u>Lateral Motion</u> -- Side-to-side movement of a transit vehicle.

<u>Line Capacity</u> -- The hourly volume that could be carried if every vehicle operated at the minimum headway which the control system permits.

<u>Load Factor</u> -- Ratio of total passengers to number of seats.

<u>Magnetic Coupling</u> -- Coupling by energized electromagnets.

<u>Manual Train Control</u> -- Train movement completely controlled by the operator.

<u>Married Pair</u> -- Two rail cars which are operated as a unit.

<u>Maximum Service Braking</u> -- The normal maximum unmodulated braking effort employed to stop a train. (The brake can be released and reapplied.)

<u>Mechanical Coupling</u> -- Coupling by railroad car knuckle couplers, for example.

Moving Block System -- An automatic train control system permitting trains to be spaced on a track according to relative velocity as well as train location.

Narrow Gauge -- A railway track gauge less than 4 feet 8 1/2 inches (1435 mm).

Off-line Station -- A station in which vehicles are diverted off the main-line track for loading and unloading.

On-line Station -- A station in which vehicles stop on the main track for loading and unloading.

Overpass -- Any structure where the transit system tracks pass over a street, highway, railroad, etc.

Pantograph -- An overhead current collector device usually consisting of two parallel, hinged, double diamond frames.

Pitch -- Rise and fall "porpoising" motion about the transverse axis of the vehicle.

Pneumatic Coupler -- An automatic connector which links pneumatic trainlines together between rail cars.

Property -- The general term given to a transit system.

Regenerative Braking -- Dynamic braking where the power generated by the traction motor is returned to the system.

Resilient Wheel -- Wheel with impact absorbing material between the tread and axle to reduce noice, vibration and wear.

Restraining Rail -- A rail placed parallel to the inside running rail on a curve to restrain the wheel flange and reduce wear on the outside running rail.

Ride Quality -- A measure of the comfort level experienced in a moving vehicle. Partially defined by vibration frequency, acceleration, jerk, pitch, yaw, and roll.

Roll -- Motion about the longitudinal axis of a vehicle.

Running Time -- The elapsed travel time between points along a route.

Shoulder (Track) -- That portion of the subgrade or subballast, lying between the ballast covered portion and the ditch in cuts and the top of slope on embankments, serving as a walkway.

Shops -- Structures which shelter transit vehicle construction and repair activities.

Siding -- A length of track adjacent or parallel to the main track connected by switches at each end. (Used for meeting or passing trains.)

Special Trackwork -- All rails, track structures and fittings (including switches and turnouts) other than plain unguarded track that is neither curved nor fabricated before laying.

Spiral -- A form of easement (transition) curve in which the rate of change of curvature is uniform throughout its length.

Standard Gauge -- A railway track gauge that measures 4 feet 8 1/2 inches (1435 mm).

Subballast -- Specified material placed above the finished subgrade and below the ballast to provide better drainage and better load distribution to the subgrade.

Subgrade (Track) -- The finished surface of the basement material below the ballast or subballast.

Superelevation (Track) -- The vertical distance that the outer rail of a curved track is above the inner rail.

Suspension -- The system of wheels and axles which support the vehicle on the track and the springs and dampers which further isolate it from shocks and vibration.

Sway -- A side-to-side oscillation or fluctuation of a transit vehicle.

Switch -- A track structure used to divert rolling stock from one track to another.

Terminal -- An area or building which serves for the pick up, transfer or discharge of passengers or goods.

Third Rail -- An electric conductor (contact rail) located alongside the running rail from which power is collected by means of sliding contact shoe attached to the truck of an electric vehicle.

Third-Rail Shoe -- An insulated metallic sliding contact mounted on the truck of an electric transit vehicle for collecting current from an insulated third-rail located alongside the running rails. (Positive contact between shoe and rail is maintained by gravity, a spring or by pneumatic pressure).

Tie Plate -- A metal plate at least 6 inches wide (and long enough to provide a safe bearing area on the tie) with a shoulder to restrain outward movement of the rail.

<u>Top of Rail Profile</u> -- The profile line representing the elevation of the top of the running surface of rails. (Where superelevation occurs, the top of rail profile represents the inside or lowest running rail unless otherwise indicated.)

<u>Trackbed</u> -- The finished surface of the subballast or subgrade between outside edges of the shoulders.

<u>Trackway</u> -- That portion of a transit system line included between the outside lines of curbs or shoulders, cut or fill slopes, ditches, channels, waterways, and including all appertaining structures.

<u>Trackwork</u> -- The rails, switches, frogs, crossings, fastenings, pads, ties, and ballast or track support slab over which transit cars are operated.

<u>Trolley</u> -- A pole-type current collector operating in connection with an overhead contact wire.

<u>Truck</u> -- A general term for the complete four-wheel assembly which supports each end of the car body. (It is attached to the body by a pair of center plates which function as a pivot.)

<u>Turnout</u> -- An arrangement of a switch and a frog with closure rails by means of which rolling stock may be diverted from one track to another.

<u>Unbalanced Superelevation</u> -- The amount (vertical distance) that the actual superelevation is less than that required for equilibrium superelevation for vehicles traveling at maximum authorized speed.

<u>Underpass</u> -- Any transit system structure, regardless of structure type, where the transit system tracks pass under a street, highway, railroad, etc.

Vehicle Capacity -- The normal maximum number of passengers that the vehicle is designed to accommodate comfortably, but which may be exceeded under crush load conditions.

Wayside Control -- A system of electronic or mechanical devices alongside the track for controlling the vehicles.

Yard -- A system of tracks within defined limits provided for making up trains, storing cars, and other purposes.

Yaw -- Veering motion as vehicle heading deviates from track alignment.

APPENDIX A-2

LRT SYSTEMS
DEMOGRAPHIC and GENERAL STATISTICS
(Source: Lea LRT Compendium, Vol. II No. 5, 1975)

CITY	Area Served		System Mileage		Stations		Total Annual Passengers (Millions)	No. of Vehicles	Single Direction Line Capacity (Passengers/Hr)			
									Highest Capacity Line		Lowest Capacity Line	
	Square Miles	Population (Millions)	Total	Above or Below Grade *	No.	Ave. Spacing (Miles)			Peak Period Oper.	Off-Peak Oper.	Peak Period Oper.	Off-Peak Oper.
Antwerp	35	0.54	49.3	1.0	146	0.16-0.25	42.2	166	—	—	—	—
Basel	37	0.36	38.0	—	146	0.25-	132.2	375	5,220	2,610	4,080	2,040
Bern	13	0.21	10.9	—	42	0.22	33.4	76	3,520	1,056	1,760	880
Bochum	179	1.06	103.2	—	209	0.42	46.0	133	1,810	535	712	356
Braunschweig	202	0.37	17.0	—	101	0.25	44.5	53	1,518	306	1,518	306
Bremen	169	0.62	42.3	2.0	113	0.29	44.3	279	5,433	1,148	2,508	836
Brussels	96	1.20	178.1	3.1	—	0.30	118.3	546	3,160	2,370	670	540
Charleroi	58	0.35	81.4	—	274	0.39	13.9	125	1,800	1,200	400	200
Dortmund	123	0.72	128.5	0.1	160	0.31	52.2	114	2,061	458	1,374	372
Frankfurt	238	1.11	136.4	—	506	0.29	99.5	415	—	—	—	—
Ghent	413	0.25	15.5	—	71	0.19	27.9	149	2,000	1,000	500	400
Goteborg	172	0.45	45.9	—	154	0.22	87.5	358	1,920	720	1,440	480-960
Hamburg	1,158	2.50	32.3	0.1	84	0.30	35.2	140	2,736	218	654	218
Hannover	199	0.85	114.7	—	146	0.35	86.5	427	1,200	900	500	400
Heidelberg	91	0.25	18.0	—	106	0.25	17.2	57	2,535	1,014	468	234
Hong Kong	317	3.49	19	—	112	0.23	147.8	184	9,000	—	—	—
Kassel	—	0.24	56.2	0.1	158	0.26	46.0	101	1,040	480	640	480
Kiel	56	0.34	7.1	—	26	0.27	11.2	42	—	—	—	—
Koln	239	1.31	155	8	211	0.52	172.1	312	2,556	639	1,065	426
Melbourne	124	1.04	134.5	—	800	0.17	109.4	701	3,640	1,950	780	650
Milan (Urban)	—	—	116.9	—	1,280	0.18	436.3	661	40,000	18,000	—	—
Munchen	1,930	2.19	125.9	—	442	0.29	155.9	631	4,478	1,292	1,080	864
Nurnberg	127	0.79	94.4	1.3	129	0.29	88.9	351	1,820	—	840	—
Oslo	—	—	16.6	—	60	—	37.4	122	—	—	—	—
Rome (ATAC)	394	2.90	37.2	—	534	0.31	92.6	195	4,700	2,650	1,380	1,290
Stockholm (Rte 221)	—	—	5.6	0.4	14	0.44	3.0	24	1,690	320	—	—
Stuttgart	225	1.02	78.0	3.2	242	0.32	115.3	455	3,900	1,300	1,270	650
The Hague	30	0.70	52.5	—	351	0.26	76	234	2,000	440	600	220
Tokyo	223	8.74	7.6	—	29	0.27	34.2	62	2,112	1,536	—	—
Toronto	240	2.20	68.5	—	805	0.17	66	390	5,625	1,875	1,125	750
Wien	160	1.61	181.6	—	980	0.26	266.9	1,645	—	—	—	—
Wuppertal	—	0.56	29.1	—	110	0.28	8.9	39	720	480	—	—
Philadelphia (CTD)	—	1.04	82.0	13.0	—	—	37.5	382	4,900	980	1,176	588
Shaker Heights, O.	50	0.20	13.1	0 **	29	0.33-1.0	3.7	55	5,000	550	—	—
Extreme Range	15-2,000	0.20-9.00	5-180	0-13	15-1,300	0.16-1.0	3-440	25-1,600	700-40,000	200-18,000	400-4,100	200-2,000
Typical Range	50-400	0.20-2.50	10-140	(0)	30-500	0.20-0.40	9-150	90-650	1,200-5,500	450-2,600	500-1,500	200-900

* Utilizing structures only; cut or fill locations considered "at grade".
** 25 of 49 Crossings are grade separated.

HRT SYSTEMS
DEMOGRAPHIC and GENERAL STATISTICS
(Source: Lea HRT Compendium, Vol. II No. 6, 1975)

CITY	Area Served		System Mileage		Stations		Total Annual Passengers (Millions)	Number of Vehicles	Single Direction Line Capacity (Passengers/Hour)			
									Highest Cap. Line		Lowest Cap. Line	
	Square Miles	Population (Millions)	Total	Above or Below Grade*	No.	Ave. Spacing (Miles)			Peak Per. Oper.	Off-Pk. Oper.	Peak Per. Oper.	Off-Pk. Oper.
Athens	386	2.54	16.1	2.4	20	0.85	90.7	135	12,308	5,430	–	
Barcelona	16	1.1	25.7	25.1	63	0.42	253.9	283	20,400	19,200	12,480	12,480
Budapest	203	2	6.2	5.4	11	0.62	166.5	100	19,000	10,000	–	–
Frankfurt	238	1.1	38.7	5.2	52	0.34	45.8	101	–	–	–	–
Glasgow	13	–	13.1	13.1	15	0.44	14	43	3,160	2,980	3,160	2,980
Helsinki (1980)	19	0.13	6.5	2.1	8	0.93	39	45	–	–	–	–
Lisbon	5	0.20	7.5	7.5	20	0.39	84.6	70	12,000	4,800	6,000	2,400
London	630	7.35	280	99	278	0.16-3.9	644	4,379	–	–	–	–
Madrid	–	–	41.1	37.4	98	0.4	540	697	36,000	–	31,300	15,000
Milan	–	4.0	23.2	16.3	48	0.5	134.9	311	36,168	7,535	34,716	7,233
Montreal	144	1.9	13.7	13.7	26	0.55	130	369	37,440	15,840	12,480	4,800
Munchen	164	1.8	9.0	7.2	17	0.50	59.6	54	10,440	2,320	6,960	1,160
Nurnberg	127	0.79	3.5	1.7	9	0.43	10.2	14	10,032	1,672	–	–
Oslo	15	0.15	25.5	4.6	38	0.5	32	135	7,140	3,400	2,720	1,360
Paris (Regional)	70	3.0	46.7	3+	51	1.08	138.8	469	56,800	15,500	31,000	13,800
Rotterdam	–	–	11	–	12	1.0	–	71	23,200	3,500	–	–
Stockholm	–	1.49	55.8	33.0	89	0.69	169	863	36,600	14,400	9,360	3,120
Sydney	927	2.7	565	5.7	165	1.36	214.9	1,103	84,320	21,080	25,296	2,432
Tokyo	223	8.7	24.4	24.4	42	0.6	278.2	308	24,480	12,240	13,500	9,000
Toronto	–	–	26.6	23.5	49	0.55	185.9	470	77,000	25,000	51,500	23,000
Wien	160	1.61	27.5	–	25	0.59	66.7	328	–	–	–	–
Atlanta	799	1.0	52.8	26.3	39	1.5	83.6	100	9,000	1,200	5,000	600
Baltimore	700	1.79	28.0	20.0	21	1.4	76.5	160	19,800	5,280	19,800	5,280
Boston	977	2.17	28.4	13.8	42	0.7	–	338	17,280	–	16,200	–
Chicago	285	4.0	89.4	59.0	142	0.63	94.0	1,094	15,000	1,800	1,000	200
Cleveland	380	1.7	19.0	–	18	1.0	11.3	116	18,360	1,800	–	–
NY (PATH)	30	4.0	13.9	7.8	13	1.2	38.1	298	27,000	2,000	8,000	2,000
SF (BART)	1,528	2.4	71.0	44.0	34	2.2	31.1	450	14,400	5,760	7,200	2,880
Wash. DC	485	2.48	98.0	57.0	86	1.14	274	300	42,000	8,600	21,000	4,300
Extreme Range	5-1,000	0.1-9.0	4-560	0-100	8-280	0.33-2.2‡	10-650	14-4,400	3,000-84,000	1,200-25,000	1,000-35,000	200-23,000
Typical Range	15-1,000	1.0-4.0	7-100	5-60	10-100	0.4-1.4	10-275	40-1,000	10,000-40,000	1,700-20,000	2,700-31,000	1,200-15,000

* Utilizing structures only; cut or fill locations considered "at grade".

‡Range disregards London's spacing.

LRV DATA SUMMARY

	FEATURE	REPRESENTATIVE 50-FT (15 METERS) VEHICLES					
		CANADIAN LIGHT RAIL VEHICLE (CLRV)		P.C.C. TRAMCAR U.S.A		TATRA T5B	
BODY DIMENSIONS	Length (Body)	50.67 ft.	15.444 m.	47.0 ft.	14.326 m.	49.54 ft.	15.100 m.
	Width (Body)	8.33 ft.	2.539 m.	8.33 ft.	2.539 m.	8.53 ft.	2.600 m.
	Height Rail to Roof	10.67 ft.	3.252 m.	10.0 ft.	3.048 m.	10.37 ft.	3.160 m.
	Width, Center Aisle	37.44 or 22.08 in.	95.0 or 56.0 cm.	34.0/46.25 in.	86.4/117.5 cm.	40.95 in.	104.0 cm.
	Door-way Width	60 in.	152.4 cm.	Front - 52 in. Front - 24.0 in.	Front - 182.1 in. Rear - 61.0 cm.	51.18 in.	130.0 cm.
	Door-way Height	102 in.	259.0 cm.	78.0 in.	198.1 cm.	86.62 in.	220.0 cm.
	Number of Doors	2 ON ONE SIDE ONLY		2 ON EACH SIDE		3 ON ONE SIDE ONLY	
	Height Rail to Floor	3.02 ft.	0.920 m.	2.72 ft.	0.829 m.	2.95 ft.	0.900 m.
	Height of Steps	First Step 10 in.		15.0/8.84/8.84 in.		14.17/10.63/10.63 in.	
		First Step 25.4 cm.		38.1/22.5/22.5 cm.		36.0/27.0/27.0 cm.	
SUSPENSION & PROPULSION	Truck Spacing	25.0 ft.	7.620 m.	22.75 ft.	6.934 m.	24.61 ft.	7.500 m.
	Wheel Base	6.0 ft.	1.829 m.	6.00 ft.	1.829 m.	6.23 ft.	1.900 m.
	Wheel Diameter	26.0 in.	66.0 cm.	25.0 in.	63.5 cm.	27.6 in.	70.0 cm.
	Track Gauge	4.906 ft.	1.495 m.	4.708 ft.	1.435 m.	4.708 ft.	1.435 m.
	Number of Motors	2, ONE EACH TRUCK		4, ONE EACH AXLE		–	
	Rating per Motor	225 H P (168 Kw.)		55 H P (41 Kw.)		87 H P (65 Kw.)	
	Voltage per Motor	300 vdc		300 vdc		460 vdc	
	Line Voltage	600 vdc		600 vdc		600 + 120 - 200 vdc	
	Power Collection	Pantograph		Trolley		Pantograph	
VEHICLE PERFORMANCE	Maximum Velocity	50.00 mph	80.47 Km/h	40.0 mph	64.4 Km/h	49.7 mph	80.0 Km/h
	Maximum Grade	± 8%		± 6.5%		+8 - 10%	
	Service Acceleration	4.84 ft./s^2	1.48 m/s^2	4.6 ft./s^2	1.4 m/s^2	4.9 ft./s^2	1.5 m/s^2
	Service Deceleration	5.13 ft./s^2	1.57 m/s^2	4.6 ft./s^2	1.4 m/s^2	4.9 ft./s^2	1.5 m/s^2
	Emergency Deceleration	10.27 ft./s^2	3.13 m/s^2	9.5 ft./s^2	2.9 m/s^2	7.5 ft./s^2	2.3 m/s^2
	Service Maximum Jerk	3.67 ft./s^2	1.12 m/s^3	7.0 ft./s^3	2.2 m/s^3	–	–
	Min. Horiz. Turn Radius	Single - 30 ft. Coupled - 36 ft.	Single - 9.177 m. Coupled - 10.973 m.	Varies	Varies	65.6 ft.	20.0 m.
	Min. Vert. Curve - Sag	800 ft.	243.5 m.	Varies	Varies	984.1 ft.	300.0 m.
	Min. Vert. Curve - Crest	122 ft.	37.19 m.	Varies	Varies	984.1 ft.	300.0 m.
	Dual Directional	No		Single or Dual		No	
CAPACITY	Number of Seats	41 or 51		49		36	
	No. Design Capacity Standees	Up to 90		69		92	
	Area per Design Standee	–	–	–	–	2.1 ft.^{2}	0.2 m.^{2}
	No. Crush Capacity Standees	–		–		147	
	Area per Crush Standee	–	–	–	–	1.4 ft.^{2}	0.13 m.^{2}
WEIGHT	Vehicle (Empty)	52,480 lbs.	23,805 Kg.	39,360 lbs.	17,853 Kg.	39,690 lbs.	18,003 Kg.
	Vehicle (Gross)	71,660 lbs.	32,504 Kg.	55,880 lbs.	25,347 Kg.	67,914 lbs.	30,805 Kg.
MISC.	Noise (Inside/Outside)	65 dbA/75 dbA		–		–	
	Cost	(1975) $360 000 ± (1979) $500,000 ±		(?) $15,000 - $32,000		–	

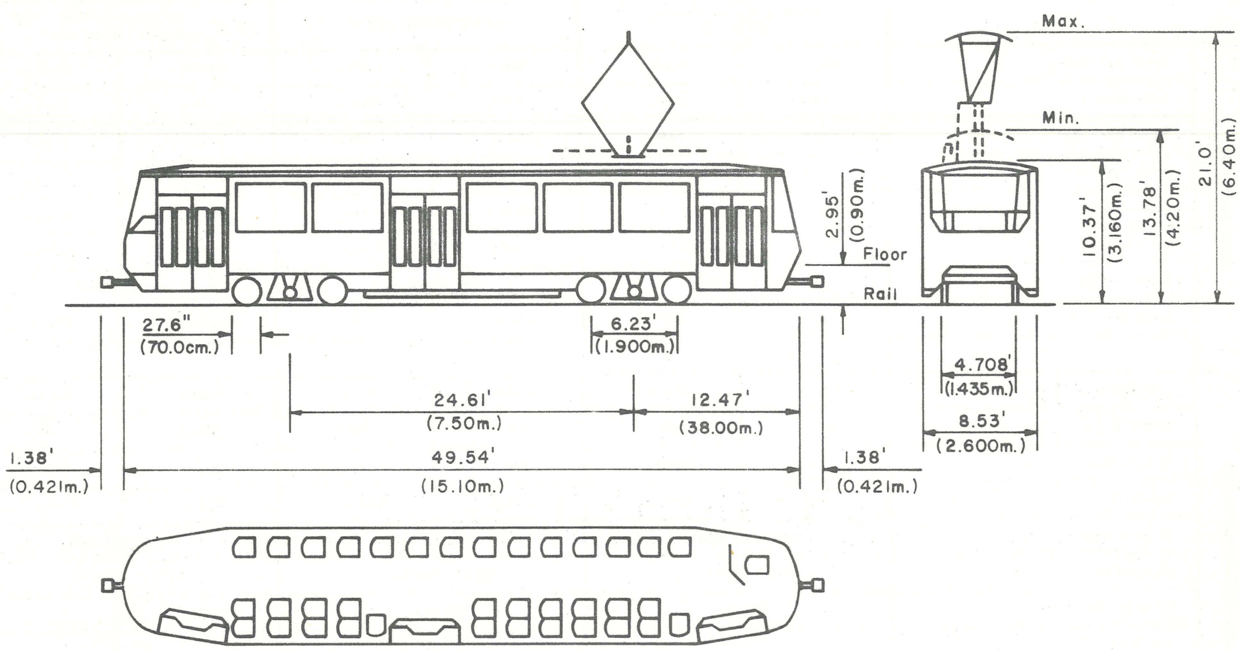
Source: Lea Transit Compendium Vol. II No. 5 1975
Vol. III No. 5 1976-77

LRV DATA SUMMARY

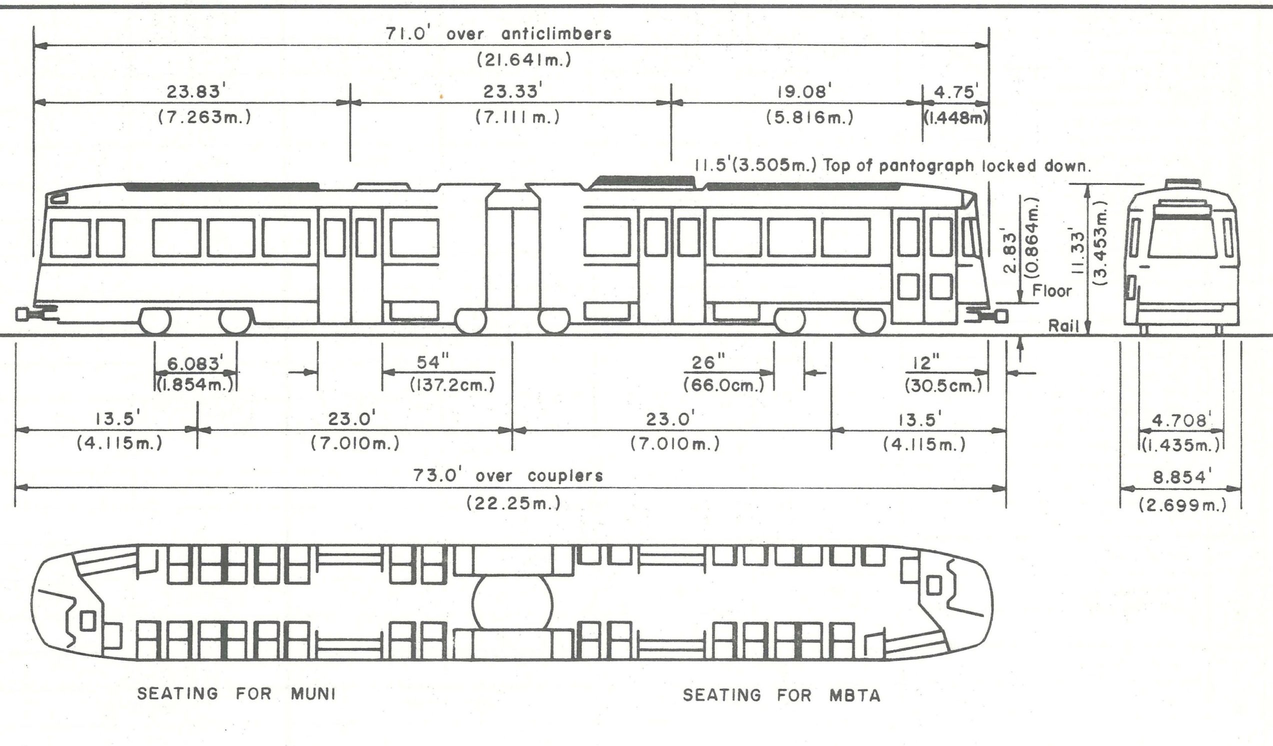
	FEATURE	REPRESENTATIVE 70-75 FT. (21-23 METERS) ARTICULATED VEHICLES					
		U.S. STANDARD LIGHT RAIL VEHICLE 6-AXLE		HANNOVER DUWAG 6-AXLE		HANNOVER L B 6-AXLE	
BODY DIMENSIONS	Length (Over Couplers)	73.0 ft.	22.25 m.	68.17 ft.	20.78 m.	70.01 ft.	21.34 m.
	Width (Body)	8.854 ft.	2.699 m.	8.203 ft.	2.500 m.	8.203 ft.	2.500 m.
	Height, Rail to Roof	11.33 ft.	3.453 m.	10.76 ft.	3.280 m.	10.76 ft.	3.280 m.
	Width, Center Aisle	29.04/44.76 in.	73.8/113.7 cm.	22.56 in.	57.2 cm.	22.52 in.	57.2 cm.
	Door-way Width	54 in.	137.2 cm.	63.04 in.	160.1 cm.	63.03 in.	160.1 cm.
	Door-way Height	75 in.	190.5 cm.	74.76 in.	190.0 cm.	76.77 in.	195.0 cm.
	Number of Doors	3 ON EACH SIDE		4 ON EACH SIDE		4 ON EACH SIDE	
	Height, Rail to Floor	2.83 ft.	0.864 m.	3.05 ft.	0.930 m.	3.05 ft.	0.930 m.
	Height of Steps	14/10/10 in.		15.35/10.79/10.47 in.		15.35/10.78/10.47 in.	
		35.6/25.4/25.4 cm.		39.0/27.4/26.6 cm.		39.0/27.4/26.6 cm.	
SUSPENSION & PROPULSION	Truck Spacing	23.0 ft.	7.010 m.	19.68 ft.	6.000 m.	20.08 ft.	6.120 m.
	Wheel Base	6.083 ft.	1.854 m.	5.906 ft.	1.800 m.	–	–
	Wheel Diameter	26 in.	66.0 cm.	25.6 to 28.7 in.	65.0 to 73.0 cm.	–	–
	Track Gauge	4.708 ft.	1.435 m.	4.708 ft.	1.435 m.	4.708 ft.	1.435 m.
	Number of Motors	2, ONE PER END TRUCK		2, ONE PER END TRUCK		2, ONE PER END TRUCK	
	Rating per Motor	210 H.P. (157 Kw.)		201 H.P. (150 Kw.)		201 H.P. (150 Kw.)	
	Voltage per Motor	600 vdc		600/750 vdc		600/750 vdc	
	Line Voltage	600 vdc		600/750 vdc		600/750 vdc	
	Power Collection	Pantograph		Pantograph		Pantograph	
VEHICLE PERFORMANCE	Maximum Velocity	50 mph	80.47 Km/h	50 mph	80 Km/h	43 mph	70 Km/h
	Maximum Grade	± 9%		± 5%		± 5%	
	Service Acceleration	4.55 ft./s^2	1.39 m/s^2	3.9 ft./s^2	1.2 m/s^2	3.9 ft./s^2	1.2 m/s^2
	Service Deceleration	5.14 ft./s^2	1.57 m/s^2	3.9 ft./s^2	1.2 m/s^2	3.9 ft./s^2	1.2 m/s^2
	Emergency Deceleration	8.8 ft./s^2	2.68 m/s^2	9.8 ft./s^2	3.0 m/s^2	9.8 ft./s^2	3.0 m/s^2
	Service Maximum Jerk	3.67 ft./s^3	1.12 m/s^3	–	–	–	–
	Min. Horiz. Turn Radius	42 ft.	12.80 m.	59.05 ft.	18.00 m.	59.05 ft.	18.00 m.
	Min. Vert. Curve - Sag	460 ft.	140.2 m.	Single - 492.06 ft. Coupled - 820.10 ft.	Single - 150.00 m. Coupled - 250.00 m.	492.1 ft.	150.0 m.
	Min. Vert. Curve - Crest	310 ft.	94.5 m.	Single - 492.06 ft. Coupled - 820.10 ft.	Single - 150.00 m. Coupled - 250.00 m.	492.1 ft.	150.0 m.
	Dual Directional	Yes		Yes		Yes	
CAPACITY	Number of Seats	68 or 52		44		52	
	No. Design Capacity Standees	151 or 167		134		138	
	Area per Design Standee	1.2 or 1.6 ft.^{2}	0.11 or 0.15 m^2	2.7 ft.^{2}	0.25 m^2	2.7 ft.^{2}	0.25 m^2
	No. Crush Capacity Standees	–		160		160	
	Area per Crush Standee	–	–	2.2 ft.^{2}	0.21 m^2	1.35 ft.^{2}	0.125 m^2
WEIGHT	Vehicle (Empty)	67,000 lbs.	30,391 Kg.	62,700 lbs.	28,440 Kg.	62,700 lbs.	28,440 Kg.
	Vehicle (Gross)	102,945 lbs.	46,695 Kg.	99,420 lbs.	45,096 Kg.	99,420 lbs.	45,006 Kg.
MISC.	Noise (Inside/Outside)	70 dbA/75 dbA		75 dbA/82 dbA		75 dbA/82 dbA	
	Cost	(1973) $300,000 ±		–		–	

Source: Lea Transit Compendium Vol. II No. 5 1975
Vol. III No. 5 1976-77

LRV EXAMPLES



TATRA T5B



S.L.R.V. ARTICULATED

HRV DATA SUMMARY

	FEATURE	REPRESENTATIVE 50-FT (15 METERS) VEHICLES					
		CHICAGO BOEING - VERTOL METROCAR		CHICAGO BUDD METROCAR		PATH PA-3 HAWKER SIDDELEY TRANSIT CAR	
BODY DIMENSIONS	Length (Anti-Climbers)	48.0 ft.	14.630 m.	48.00 ft.	14.630 m.	51.00 ft.	15.544 m.
	Width (Body)	9.33 ft.	2.844 m.	9.33 ft.	2.844 m.	9.23 ft.	2.813 m.
	Height, Rail to Roof	12.0 ft.	3.658 m.	12.00 ft.	3.658 m.	11.70 ft.	3.566 m.
	Width, Center Aisle	29.3 in.	74.4 cm.	29.26 in.	74.3 cm.	28.0 in.	71.12 cm.
	Door-way Width	50 in.	127.0 cm.	26.52 in.	67.4 cm.	54.0 in.	137.16 cm.
	Door-way Height	76 in.	193.0 cm.	75.82 in.	192.6 cm.	78.0 in.	198.12 cm.
	Number of Doors	2 ON EACH SIDE		2 ON EACH SIDE		2 ON EACH SIDE	
	Height, Rail to Floor	3.8 ft.	1.158 m.	3.802 ft.	1.159 m.	3.79 ft.	1.155 m.
SUSPENSION & PROPULSION	Truck Spacing	33.67 ft.	10.26 m.	33.67 ft.	10.26 m.	33.00 ft.	10.058 m.
	Wheel Base	6.5 ft.	1.98 m.	6.25 ft.	1.905 m.	6.833 ft.	2.083 m.
	Wheel Diameter	28 in.	71.12 cm.	28 in.	71.12 cm.	28 in.	71.12 cm.
	Track Gauge	4.708 ft.	1.435 m.	4.708 ft.	1.435 m.	4.708 ft.	1.435 m.
	Number of Motors	4, ONE PER AXLE		4, ONE PER AXLE		4, ONE PER AXLE	
	Rating per Motor	115 H P (86 Kw.)		100 H P (74.6 Kw.)		150 H P (111.9 Kw.)	
	Voltage per Motor	300 vdc		300 vdc		–	
	Line Voltage	600 vdc		600 vdc		650 vdc	
	Power Collection	Third Rail		Third Rail		Third Rail	
VEHICLE PERFORMANCE	Maximum Velocity	70 mph	113 Km/h	70 mph	113 Km/h	70 mph	113 Km/h
	Maximum Grade	–		–		± 4.8%	
	Service Acceleration	4.69 ft/s^2	1.43 m/s^2	4.69 ft./s^2	1.43 m/s^2	3.67 ft./s^2	1.12 m/s^2
	Service Deceleration	4.69 ft./s^2	1.43 m/s^2	4.69 ft./s^2	1.43 m/s^2	4.4 ft./s^2	1.34 m/s^2
	Emergency Deceleration	9.53 ft./s^2	2.90 m/s^2	9.53 ft./s^2	2.90 m/s^2	4.5 ft./s^2	1.37 m/s^2
	Service Maximum Jerk	–	–	–	–	–	–
	Min. Horiz. Turn Radius	85 ft.	25.9 m.	85 ft.	25.9 m.	90 ft.	27.4 m.
	Min. Vert. Curve - Sag	690 ft.	210.3 m.	–	–	900 ft.	274.3 m.
	Min. Vert. Curve - Crest	690 ft.	210.3 m.	–	–	900 ft.	274.3 m.
	Dual Directional	No		No		–	
CAPACITY	Number of Seats	A Car - 47, B Car - 51		A Car - 47, B Car 51		35	
	No. Design Capacity Standees	–		–		105	
	Area per Design Standee	–	–	–	–	–	–
	No. Crush Capacity Standees	A Car - 103, B Car - 99		A Car 103, B Car - 99		130	
	Area per Crush Standee	–	–	–	–	–	–
WEIGHT	Vehicle (Empty)	50,000 lbs.	22,680 Kg.	44,500 lbs.	20,185 Kg.	59,000 lbs.	26,762 Kg.
	Vehicle (Gross)	72,500 lbs.	32,885 Kg.	67,000 lbs.	30,391 Kg.	81,500 lbs.	36,968 Kg.
MISC.	Noise (Inside/Outside)	70 dbA/85 dbA		–		–	
	Cost	(1974) $316,000		(1967) $125,000		(1970) $184,000	

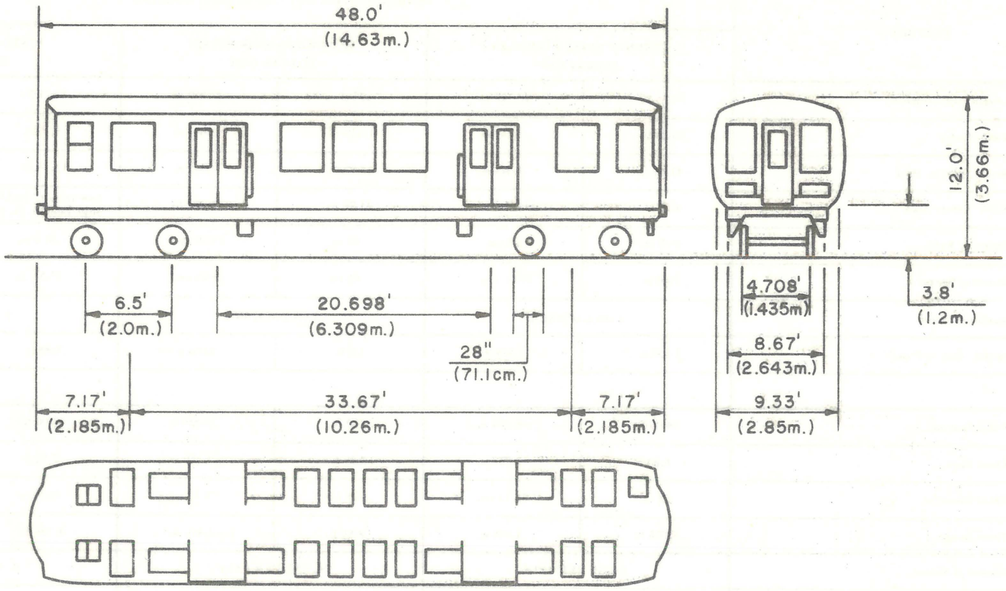
Source: Lea Transit Compendium Vol. II No. 6 1975

HRV DATA SUMMARY

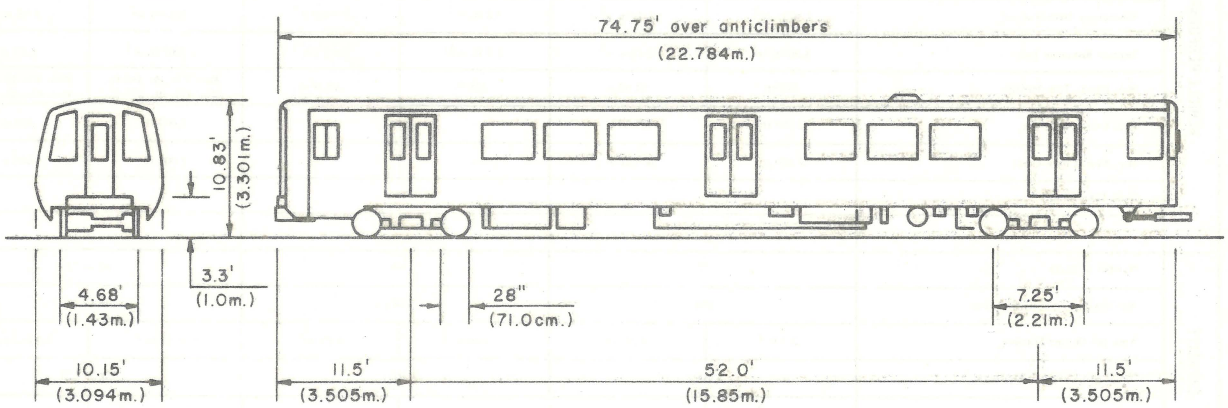
	FEATURE	REPRESENTATIVE 75–FT (23 METERS) VEHICLES					
		TORONTO HAWKER SIDDELEY SUBWAY CAR		WASHINGTON ROHR METRO TWO-CAR UNIT		STATE-OF-THE-ART-CAR (SOAC) U S A	
BODY DIMENSIONS	Length (over couplers)	74.76 ft.	22.787 m.	75 ft.	22.860 m.	74.71 ft.	22.772 m.
	Width (Body)	10.33 ft.	3.149 m.	10.15 ft	3.094 m.	9.75 ft.	2.972 m.
	Height, Rail to Roof	11.96 ft.	3.645 m.	10.83 ft.	3.301 m.	12.13 ft.	3.697 m.
	Width, Center Aisle	47.0 in.	119.4 cm.	33.96 in.	86.26 cm.	Low Density 50.55 in. High Density 25.6 in.	Low Density 128.40 cm. High Density 65.02 cm.
	Door-way Width	45.0 in.	114.3 cm.	50 in.	127.0 cm.	50.0 in.	127.00 cm.
	Door-way Height	76.0 in.	193.0 cm.	76 in.	193.0 cm.	75.55 in.	191.90 cm.
	Number of Doors	4 ON EACH SIDE		3 ON EACH SIDE		4 ON EACH SIDE	
	Height, Rail to Floor	3.625 ft.	1.105 m.	3.3 ft.	1.006 m.	3.88 ft.	1.183 m.
SUSPENSION & PROPULSION	Truck Spacing	54.00 ft.	16.459 m.	52 ft.	15.850 ft.	54.00 ft.	16.459 m.
	Wheel Base	6.83 ft.	2.082 m.	7.25 ft.	2.210 m.	7.50 ft.	2.286 m.
	Wheel Diameter	28 in.	71.12 cm.	28 in.	71.12 cm.	30.0 in.	76.20 cm.
	Track Gauge	4.906 ft.	1.495 m.	4.68 ft.	1.426 m.	4.708 ft.	1.435 cm.
	Number of Motors	4, ONE PER AXLE		4, ONE PER AXLE		4, ONE PER AXLE	
	Rating per Motor	110 H.P. (82 Kw)		175 H.P. (130 Kw)		175 H.P. (130 Kw)	
	Voltage per Motor	300 vdc		325 vdc		300 vdc	
	Line Voltage	600 vdc		760 vdc		600 vdc, optional-450-650 vdc	
	Power Collection	Third Rail		Third Rail		Optional-Third Rail or Pantograph	
VEHICLE PERFORMANCE	Maximum Velocity	55 mph	89 Km/h	75 mph	120 Km/h	80 mph	129 Km/h
	Maximum Grade	±3.5%		±4%		±3%	
	Service Acceleration	3.67 ft./s^2	1.12 m/s^2	3.0 ft./s^2	0.91 m/s^2	3.96-4.4 ft./s^2	1.21 - 1.34 m/s^2
	Service Deceleration	4.11 ft./s^2	1.25 m/s^2	3.0 ft./s^2	0.91 m/s^2	3.96-4.69 ft./s^2	1.21 - 1.43 m/s^2
	Emergency Deceleration	4.40 ft./s^2	1.34 m/s^2	3.2 ft./s^2	0.98 m/s^2	5.13 ft/s^2	1.56 m/s^2
	Service Maximum Jerk	8.80 ft./s^3	2.68 m/s^3	2.7 ft./s^3	0.82 m/s^3	3.67 ft./s^3	1.12 m/s^3
	Min. Horiz. Turn Radius	300 ft.	91.44 m	225 ft.	68.58 m	Max. Flr. Ht. 145 ft. Min. Flr. Ht. 295 ft.	Max. Flr. Ht. 4420 m. Min. Flr. Ht. 89.92 m.
	Min. Vert. Curve-Sag	2,000 ft.	609.60 m	–	–	2,000 ft.	609.6 m
	Min. Vert. Curve-Crest	2,000 ft.	609.60 m	–	–	2,000 ft.	609.6 m
	Dual Directional	No		Yes		–	
CAPACITY	Number of Seats	77		80		62 or 72	
	No. Design Capacity Standees	250		128		38 or 28	
	Area per Design Standee	2.5 ft.^{2}	0.23 m^2	2.69 ft.^{2}	0.25 m^2	8 or 11 ft.^{2}	0.74 or 1.02 m^2
	No. Crush Capacity Standees	300		160		158 or 228	
	Area per Crush Standee	2.08 ft.^{2}	0.19 m^2	2.19 ft.^{2}	0.20 m^2	1.9 or 1.35 ft.^{2}	0.18 or 0.13 m^2
WEIGHT	Vehicle (Empty)	A - Car - 55,814 lbs. B - Car - 55,369 lbs.	A - Car - 25,317 Kg. B - Car - 25,115 Kg.	72,600 lbs.	32,930 Kg.	90,000 lbs.	40,823 Kg.
	Vehicle (Gross)	A - Car - 100,814 lbs. B - Car - 100,369 lbs	A - Car - 45,728 Kg B - Car - 45,527 Kg	108,000 lbs.	48,988 Kg.	135,000 lbs.	61,235 Kg.
MISC.	Noise (Inside/Outside)	79 db A/87 db A		68 db A/84 db A		63 db A 78 db A	
	Cost	(1973) $288,665		(1972) $305,300±		(1974) Self Sufficient $351,673 Married Pair $331 115	

Source: Lea Transit Compendium Vol. II No. 6 1975

HRV EXAMPLES



CHICAGO BOEING-VERTOL METROCAR

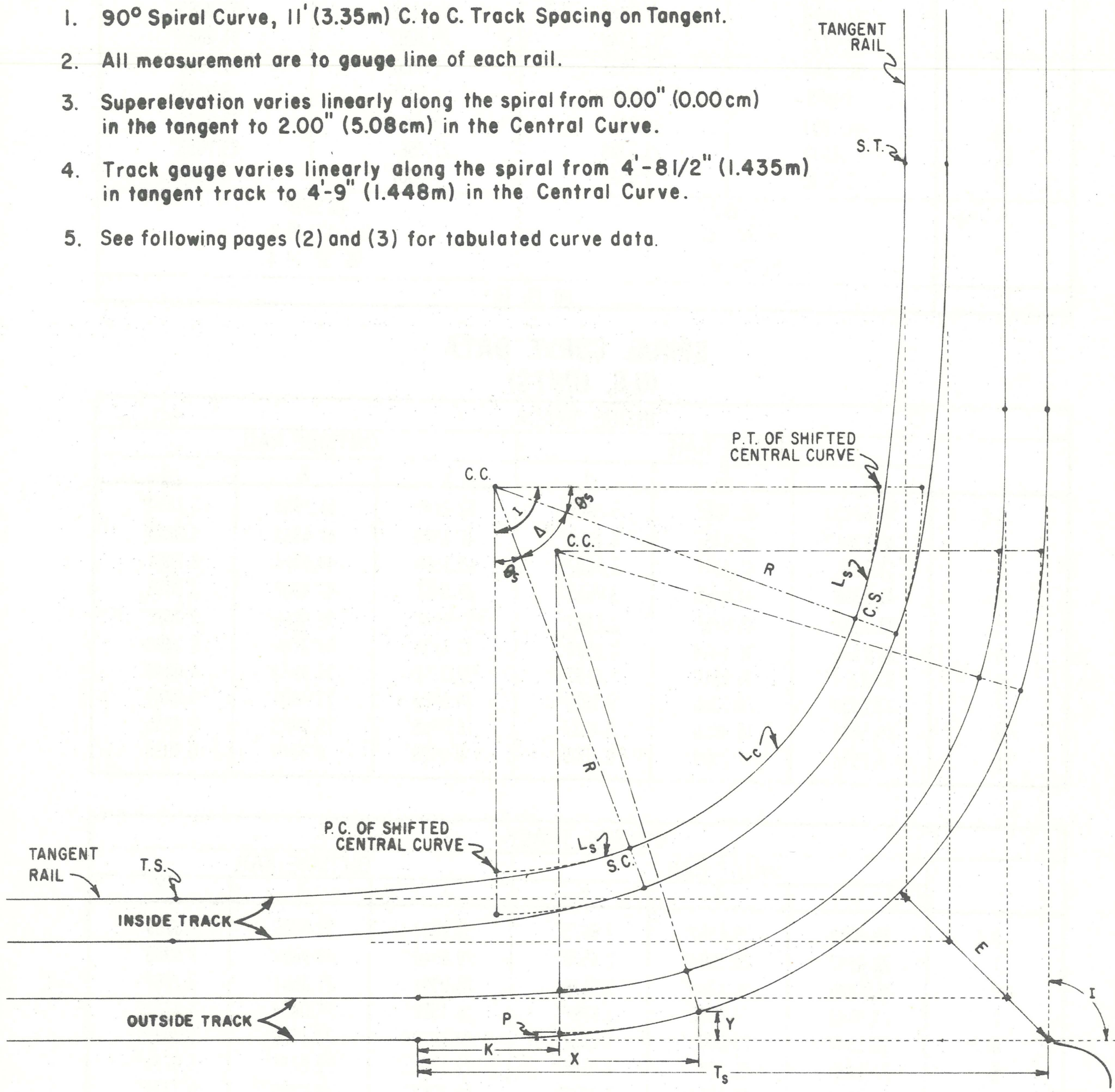


WASHINGTON (ROHR) METRO

LRT DOUBLE-TRACK, 90° TURN DIAGRAM AND DATA

NOTES:

1. 90° Spiral Curve, 11' (3.35m) C. to C. Track Spacing on Tangent.
2. All measurement are to gauge line of each rail.
3. Superelevation varies linearly along the spiral from 0.00" (0.00cm) in the tangent to 2.00" (5.08cm) in the Central Curve.
4. Track gauge varies linearly along the spiral from 4'-8 1/2" (1.435m) in tangent track to 4'-9" (1.448m) in the Central Curve.
5. See following pages (2) and (3) for tabulated curve data.



SOURCE

SAN FRANCISCO MUNICIPAL RAILWAY
Drawing No. CL-5587, CL-5588

90° TURN DATA
(U.S. UNITS)

RAIL	INSIDE TRACK		OUTSIDE TRACK	
	INSIDE RAIL	OUTSIDE RAIL	INSIDE RAIL	OUTSIDE RAIL
R	42.6250′	47.3750′	48.8259′	53.5759′
L_c	37.1973′	41.3425′	48.1812′	52.8685′
L_s	50.6731′	52.3140′	29.9092′	31.2883′
X	50.1687′	51.7933′	29.6552′	31.0226′
Y	5.5446′	5.7894′	2.8675′	3.0269′
T_s	81.1891′	85.8974′	65.2264′	69.9347′
E_s	21.8617′	23.7703′	21.3567′	23.2653′
P	2.9740′	2.9323′	0.8007′	0.7590′
K	35.5901′		15.5998′	
θ_s	20°00′00″		16°43′49.3″	
Δ	50°00′00″		56°32′21.4″	
I	90°00′00″			

SPIRAL CURVE DATA
(U.S. UNITS)

	INSIDE TRACK					
	INSIDE RAIL			OUTSIDE RAIL		
	L	X	Y	L	X	Y
S.C.	50.6731′	50.1687′	5.5446′	52.3140′	51.7933′	5.7894′
1	46.2396′	45.9455′	4.1995′	47.7370′	47.4333′	4.3849′
2	43.7396′	43.5217′	3.5877′	45.1560′	44.9311′	3.7461′
3	41.2396′	41.0765′	3.0679′	42.5751′	42.4067′	3.2033′
4	38.7396′	38.6158′	2.6267′	39.9941′	39.8663′	2.7427′
5	36.2396′	36.1444′	2.2500′	37.4131′	37.3149′	2.3493′
6	31.0071′	30.9510′	1.6137′	32.0112′	31.9533′	1.6849′
7	23.2553′	23.2316′	0.9081′	24.0084′	23.9839′	0.9482′
8	15.5035′	15.4965′	0.4037′	16.0055′	15.9983′	0.4215′
9	7.7518′	7.7509′	0.1009′	8.0028′	8.0019′	0.1054′

	OUTSIDE TRACK					
	INSIDE RAIL			OUTSIDE RAIL		
	L	X	Y	L	X	Y
S.C.	29.9092′	29.6552′	2.8675′	31.2883′	31.0226′	3.0269′
1	28.3852′	28.1894′	2.4539′	29.6940′	29.4892′	2.5903′
2	26.7745′	26.6283′	2.0616′	28.0091′	27.8561′	2.1762′
3	24.9993	24.8955′	1.6797′	26.1520′	26.0434	1.7731′
4	23.1544′	23.0835′	1.3357′	24.2220′	24.1479′	1.4099′
5	21.1490′	21.1040′	1.0185′	22.1242′	22.0771′	1.0751′
6	18.9324′	18.9065′	0.7311′	19.8054′	19.7783′	0.7717′
7	16.4193′	16.4066′	0.4771′	17.1764′	17.1631′	0.5036′
8	13.3300′	13.3255′	0.2553′	13.9446′	13.9399′	0.2695′
9	9.4257′	9.4249′	0.0903′	9.8603′	9.8595′	0.0953′
10	6.7789′	6.7787′	0.0336′	7.0915′	7.0913	0.0355′

90° TURN DATA (METRIC UNITS)

RAIL	INSIDE TRACK		OUTSIDE TRACK	
	INSIDE RAIL	OUTSIDE RAIL	INSIDE RAIL	OUTSIDE RAIL
R	12.9921 m.	14.4399 m.	14.8821 m.	16.3299 m.
L_C	11.3377 m.	12.6012 m.	14.6856 m	16.1143 m.
L_S	15.4452 m.	15.9453 m.	9.1163 m.	9.5367 m.
X	15.2914 m	15.7866 m.	9.0389 m.	9.4557 m.
Y	1.6900 m.	1.7646 m.	0.8740 m.	0.9226 m.
T_S	24.7464 m.	26.1815 m.	19.8810 m.	21.3161 m
E_S	6.6634 m.	7.2452 m.	6.5095 m.	7.0913 m.
P	0.9065 m.	0.8938 m.	0.2441 m.	0.2313 m.
K	10.8479 m.		4.7548 m.	
θ_S	20°00′00″		16°43′49.3″	
Δ	50°00′00″		56°32′21.4″	
I	90°00′00″			

SPIRAL CURVE DATA (METRIC UNITS)

INSIDE TRACK						
	INSIDE RAIL			OUTSIDE RAIL		
	L	X	Y	L	X	Y
S.C.	15.4452 m.	15.2914 m.	1.6900 m.	15.9453 m.	15.7866 m.	1.7646 m.
1	14.0938 m.	14.0042 m.	1.2800 m.	14.5502 m.	14.4577 m.	1.3365 m.
2	13.3318 m.	13.2654 m.	1.0935 m.	13.7635 m.	13.6950 m.	1.1418 m.
3	12.5698 m.	12.5201 m.	0.9351 m.	12.9769 m.	12.9256 m.	0.9764 m.
4	11.8078 m.	11.7701 m.	0.8006 m.	12.1902 m.	12.1512 m.	0.8360 m.
5	11.0458 m.	11.0168 m.	0.6858 m.	11.4035 m.	11.3736 m.	0.7161 m.
6	9.4510 m.	9.4339 m.	0.4919 m.	9.7570 m.	9.7394 m.	0.5136 m.
7	7.0882 m.	7.0810 m.	0.2768 m.	7.3178 m.	7.3103 m.	0.2890 m.
8	4.7255 m.	4.7233 m.	0.1230 m.	4.8785 m.	4.8763 m.	0.1285 m.
9	2.3627 m.	2.3625 m.	0.0308 m.	2.4393 m.	2.4390 m.	0.0321 m.

OUTSIDE TRACK						
	INSIDE RAIL			OUTSIDE RAIL		
	L	X	Y	L	X	Y
S.C.	9.1163 m.	9.0389 m.	0.8740 m.	9.5367 m.	9.4557 m.	0.9226 m.
1	8.6518 m.	8.5921 m.	0.7479 m.	9.0507 m.	8.9883 m.	0.7895 m.
2	8.1609 m.	8.1163 m.	0.6284 m.	8.5372 m.	8.4905 m.	0.6633 m.
3	7.6198 m.	7.5881 m.	0.5120 m.	7.9711 m.	7.9380 m.	0.5404 m.
4	7.0575 m.	7.0359 m.	0.4071 m.	7.3829 m.	7.3603 m.	0.4297 m.
5	6.4462 m.	6.4325 m.	0.3104 m.	6.7435 m.	6.7291 m.	0.3277 m.
6	5.7706 m.	5.7627 m.	0.2228 m.	6.0367 m.	6.0284 m.	0.2352 m.
7	5.0046 m.	5.0007 m.	0.1454 m.	5.2354 m.	5.2313 m.	0.1535 m.
8	4.0630 m.	4.0616 m.	0.0778 m.	4.2503 m.	4.2489 m.	0.0821 m.
9	2.8730 m.	2.8727 m.	0.0275 m.	3.0054 m.	3.0052 m.	0.0290 m.
10	2.0662 m.	2.0661 m.	0.0102 m.	2.1615 m.	2.1614 m.	0.0108 m.

Excerpts From

GENERAL ORDER NO. 26-D
(Superseding General Order No. 26-C)

PUBLIC UTILITIES COMMISSION OF THE
STATE OF CALIFORNIA

REGULATIONS GOVERNING CLEARANCES ON RAILROADS AND STREET RAILROADS WITH REFERENCE TO SIDE AND OVERHEAD STRUCTURES, PARALLEL TRACKS, CROSSINGS OF PUBLIC ROADS, HIGHWAYS AND STREETS.

Adopted January 19, 1948. Effective February 1, 1948

As Amended:
Decision No. 42925, April 20, 1954, Effective May 10, 1954;
Decision No. 80051 (A. 53108), May 16, 1972 effective June 6, 1972.

It Is Hereby Ordered by the Public Utilities Commission of the State of California that the minimum clearance requirements for railroads and street railroads hereinafter prescribed shall hereafter be observed in this state in all construction or reconstruction of tracks or structures adjacent to tracks.

It Is Hereby Further Ordered that no railroad or street railroad corporation shall operate any cars, trains, motors, engines, or other rolling equipment over its own or other tracks, except as hereinafter provided, on which overhead or side clearances, or clearances between tracks, are less than the minimum herein prescribed, if such tracks or structures adjacent to such tracks are constructed or reconstructed subsequent to the effective date hereof.

DEFINITIONS

Section 1

For the purposes of these regulations definitions as hereinafter prescribed will govern.

1. 4 *Overhead Clearance* is the vertical distance from the level of the top of the highest rail to a structure or obstruction above.

1. 5 *Side Clearance* is the shortest distance from the center line of track to a structure or obstruction at the side of track.

STANDARD GAUGE RAILROADS AND STREET RAILROADS TRANSPORTING FREIGHT CARS

Section 2–Overhead Clearances

2. 1 The minimum overhead clearance above railroad and street railroad tracks, which are used or proposed to be used for transporting freight cars, shall be twenty-two (22) feet six (6) inches. Structures constructed prior to the effective date of this order may be maintained at such clearances as was lawful at the time of construction.

Section 3–Side Clearances

3. 1 Minimum side clearances from center line of tangent standard gauge railroad and street railroad tracks, which are used or proposed to be used for transporting freight cars, except as hereinafter prescribed, shall be as shown below.

Description	*Minimum Side Clearance*
3. 2 All structures and obstructions above the top of the rail except those hereinafter specifically mentioned	8' 6"
NOTE: Posts, pipes, warning signs and similar obstructions should, where practicable, have a side clearance of ten (10) feet.	
3..3 Platforms eight (8) inches or less above top of rail	4' 6"
3. 4 Platforms four (4) feet or less above top of rail	7' 6"
3. 5 Platforms four (4) feet six (6) inches or less above top of rail when used principally for loading or unloading refrigerator cars	8' 0"
3. 6 Platforms previously constructed at clearance not less than seven (7) feet three (3) inches may be extended at such clearance unless such extension is in connection with the reconstruction of the original platform.	
NOTE: Combinations of platforms under subsections 3.4 and 3.5 will not be permitted. Combinations of platforms under subsection 3.3 with either of those under subsections 3.4 or 3.5 is permitted provided that the platform under subsection 3.3 presents a level surface from a point not more than four (4) feet eight (8) inches from center line of track to the face or wall of the platform with which it is combined.	
3. 7 Poles supporting trolley contact conductors supplying motive power to track affected, if of bracket construction, on either single or double main track	8' 3"
NOTE: In order to bring switch stand targets into clear vision where pole lines are or have been constructed at legal clearance on railroads operated by overhead trolley contact the clearance as applied to switch stands may be reduced to seven (7) feet six (6) inches.	
3. 8 Switch boxes, switch-operating mechanisms and accessories necessary for the control and operation of signals and interlockers projecting four (4) inches or less above the top of rail	3' 0"
3. 9 Signals and switch stands three (3) feet or less above top of rail and located between tracks where not practicable to provide clearances otherwise prescribed in this order	6' 0"
3.10 Through bridges supporting track affected, tunnels, water columns and oil columns	8' 0"

Section 4–Overhead and Side Clearances

Minimum overhead and side clearances as prescribed in Sections 2 and 3 of this order may be decreased to the extent defined by the half circumference of a circle having a radius of eight (8) feet six (6) inches and tangent to a horizontal line twenty-two (22) feet six (6) inches above top of rail at a point directly over the center line of track; provided, however, that for tunnels and through bridges such radius may be eight (8) feet, and provided further, that subsections 2.3 and 3.19 of this order shall apply hereto.

Section 5—Clearance Between Parallel Tracks

5. 1 The minimum distance between the center lines of parallel standard gauge tracks shall be fourteen (14) feet except as hereinafter provided.

5. 2 The center line of any standard gauge track, except a main track or a passing track, parallel and adjacent to a main track or a passing track, shall be at least fifteen (15) feet from the center line of such main track or passing track; provided, however, that where a passing track is adjacent to and at least fifteen (15) feet distant from the main track, any other track may be constructed adjacent to such passing track with clearance prescribed in subsection 5.1 of this order.

RAILROADS AND STREET RAILROADS NOT TRANSPORTING FREIGHT CARS

Section 9—Overhead and Side Clearances

9. 1 The minimum overhead clearance above railroad and street railroad tracks which are not used or proposed to be used for transporting freight cars shall be fourteen (14) feet.

9. 2 Minimum side clearances of railroad and street railroad tracks which are not used or proposed to be used for transporting freight cars shall be thirty (30) inches from the side of the widest equipment operated, except that for poles supporting trolley contact conductors between main line double tracks such distance may be decreased to twenty-four (24) inches.

9. 3 Minimum overhead and side clearances as prescribed in this section may be decreased to the extent defined by a line extending diagonally downward from a point fourteen (14) feet above the top of rail and four (4) feet distant laterally from the center line of track to a point eight (8) feet above the top of rail and distant laterally thirty (30) inches from the side of the widest equipment operated.

9. 4 Minimum side clearances as prescribed in this section may be decreased in bridges, tunnels or subways to the extent defined by a line extending diagonally upward from a point level with the top of rail and five (5) feet distant laterally from the center line of track to a point four (4) feet above the top of rail and distant laterally thirty (30) inches from the side of the widest equipment operated.

Section 10—Clearance Between Parallel Tangent Tracks

The minimum distance between the center lines of parallel tangent tracks shall be not less than the width of the widest car operated plus twenty-four (24) inches.

Section 11—Exceptions

11. 1 Minimum clearances prescribed in Sections 9 and 10 of this order may be reduced along passenger platforms subject to approval by the Commission.

11. 2 Minimum clearances prescribed in Sections 9 and 10 of this order may be reduced for trackage located in subways and tunnels or compartments thereof, which are used exclusively for railroad passenger traffic; provided that the passenger equipment operated thereon shall have all windows and other openings effectively barred.

PUBLIC ROADS, HIGHWAYS, AND STREETS CROSSING UNDER OR OVER RAILROADS AND STREET RAILROADS

Section 12–Public Roads, Highways, and Streets Crossing Under Tracks

12.1 Where a railroad or street railroad crosses above any public road, highway, or street, a minimum overhead clearance of fifteen (15) feet shall be provided above the surface of such road, highway or street.

12.2 Where a railroad or street railroad crosses above any public road, highway, or street on a single supporting span, a minimum width of twenty-four (24) feet shall be provided for the opening for such public road, highway or street. Where two or more supporting spans are used over the public road, highway or street, a minimum width of twelve (12) feet shall be provided for each opening.

12.3 When the public road, highway or street is occupied by one or more tracks, minimum clearance dimensions shall be determined by this Commission for the case under consideration.

Section 13–Public Roads, Highways, and Streets Crossing Over Tracks

13.1 Where a public road, highway, or street crosses above any railroad or street railroad track used or proposed to be used for transporting freight cars, the minimum clearances prescribed in this order for such tracks must be observed.

13.2 Where a public road, highway, or street crosses over a railroad or street railroad track which is not used or proposed to be used for transporting freight cars, minimum clearances as prescribed in this order must be provided, except that a minimum overhead clearance of nineteen (19) feet above top of rail shall be provided unless otherwise ordered by the Commission.

GENERAL REQUIREMENTS

Section 14–Electrical Construction

All clearances of electrical construction over, above, adjacent to, along or across railroads and street railroads shall conform to the requirements specified in General Order No. 95, or such other and further general orders covering similar requirements as may be currently effective.

Note: See Appendix A-8 for #95 excerpts

Excerpts From

Rules for

Overhead Electric Line Construction

GENERAL ORDER NO. 95

Prescribed by the

PUBLIC UTILITIES COMMISSION

of the

STATE OF CALIFORNIA

SECTION III

REQUIREMENTS FOR ALL LINES

31. APPLICATION

The following rules apply to all classes of overhead lines under all conditions.

37. MINIMUM CLEARANCES OF WIRES ABOVE RAILROADS, THOROUGHFARES, BUILDINGS, ETC.

Clearances between overhead conductors, guys, messengers or trolley span wires and tops of rails, surfaces of thoroughfares or other generally accessible areas across, along or above which any of the former pass; also the clearances between conductors, guys, messengers or trolley span wires and buildings, poles, structures, or other objects, shall not be less than those set forth in Table 1, at a temperature of 60° F. and no wind.

TABLE 1

Basic Minimum Allowable Vertical Clearance of Wires Above Railroads, Thoroughfares and Ground; Also Clearances from Poles, Buildings, Structures or Other Objects (nn)

(Letter References Denote Modifications of Minimum Clearances as Referred to in Notes Following this Table)

Case No.	Nature of clearance	Wire or conductor concerned						
		A	B	C	D	E	F	G
		Span wires (other than trolley span wires) overhead guys and messengers	Communication conductors (including open wire, cables and service drops), supply service drops of 0–750 volts	Trolley contact, feeder and span wires, 0–5000 volts	Supply conductors of 0–750 volts, and supply cables treated as in Rule 57.8	Supply conductors and supply cables, 750–22,500 volts	Supply conductors and supply cables, 22.5–300 kv	Supply conductors and supply cables. 300–550 kv (mm)
1	Crossing above tracks of railroads which transport or propose to transport freight cars (max. height 15 ft. 6 in.) where not operated by overhead contact wires. (a) (b) (c) (d)	25 ft.	25 ft.	22½ ft.	25 ft.	28 ft.	34 ft.	34 ft. (kk)
2	Crossing or paralleling above tracks of railroads operated by overhead trolleys. (b) (c) (d)	26 ft. (e)	26 ft. (e) (f) (g)	19 ft. (h) (i)	27 ft. (e) (g)	30 ft. (g)	34 ft. (g)	34 ft. (g) (kk)
3	Crossing or along thoroughfares in urban districts or crossing thoroughfares in rural districts. (c) (d)	18 ft. (j) (k) (ii)	18 ft. (j) (l) (m) (ii)	19 ft. (hh)	20 ft. (ii)	25 ft. (n) (o) (ii)	30 ft. (o) (ii)	30 ft. (o) (ii) (kk)
4	Above ground along thoroughfares in rural districts or across other areas capable of being traversed by vehicles or agricultural equipment.	15 ft. (k)	15 ft. (m) (n) (p)	19 ft.	16 ft.	25 ft. (n) (o)	30 ft. (o) (p)	30 ft. (o) (kk)
5	Above ground in areas accessible to pedestrians only.	7 ft.	10 ft. (m) (q)	19 ft.	12 ft.	17 ft.	25 ft. (o)	25 ft. (o) (kk)
6	Vertical clearance above buildings and bridges (or other structures, which do not ordinarily support conductors and on which men can walk) except generating plants or substations whether attached or unattached.	8 ft. (r)	8 ft. (r)	8 ft.	8 ft.	12 ft.	12 ft.	20 ft. (ll)
7	Horizontal clearance of conductor from buildings (except generating and substations), bridges or other structures (upon which men may work) where such conductor is not attached thereto. (s) (t)	----------------	3 ft. (u)	3 ft.	3 ft. (u) (v)	6 ft. (v)	6 ft. (v)	15 ft. (v)
8	Distance of conductor from center line of pole, whether attached or unattached. (w) (x) (y)	----------------	15 in. (s) (aa)	15 in. (aa) (bb) (cc)	15 in. (o) (aa) (dd)	15 or 18 in. (o) (dd) (ee) (jj)	18 in. (dd) (ee)	Not Applicable
9	Distance of conductor from surface of pole, crossarm or other overhead line structure upon which it is supported, providing it complies with Case 8 above. (x)	----------------	3 in. (aa) (ff)	3 in. (aa) (cc) (gg)	3 in. (aa) (dd) (gg)	3 in. (dd) (gg) (jj)	¼ pin spacing shown in Table 2 Case 15. (dd)	½ pin spacing shown in Table 2 Case 15. (dd)

References to Rules Modifying Minimum Clearances in Table 1

	Rule	Page
(a) Shall not be reduced more than 5% because of temperature or loading	37	42
1. Supply lines	54.4-B1	102
2. Communication lines	84.4-B1	206
(b) Shall be increased for supply conductors on suspension insulators, under certain conditions	37	42
(c) Special clearances are provided for traffic signal equipment	58.1-C	154
(d) Special clearances are provided for street lighting equipment	58.2-B	155
(e) Based on trolley pole throw of 26 feet. May be reduced where suitably protected.		
1. Supply guys	56.4-B2	144
2. Supply cables and messengers	57.4-B2	151
3. Communication guys	86.4-B2	223
4. Communication cables and messengers	87.4-B2	230
(f) May be reduced depending on height of trolley contact conductors.		
1. Supply service drops	54.8-C5	130
2. Communication service drops	84.8-D5	221
(g) May be reduced and shall be increased depending on trolley throw.		
1. Supply conductors (except service drops)	54.4-B2	103
2. Communication conductors (except service drops)	84.4-B2	206
(h) Shall be increased where freight cars are transported.		
1. Trolley contact and feeder conductors	74.4-B1	185
2. Trolley span wires	77.4-A	188
(i) May be reduced for trolley contact and span wires in subways, tunnels and under bridges.		
1. Trolley contact conductors	74.4-E	186
2. Trolley span wires	77.4-B	189
(j) May be reduced at crossings over private thoroughfares and entrances to private property and over private property.		
1. Supply service drops	54.8-B2	125
2. Supply guys	56.4-A	143
3. Communication service drops	84.8-C2	218
4. Communication guys	86.4-A	222
(k) May be reduced along thoroughfares where not normally accessible to vehicles.		
1. Supply guys	56.4-A1	143
2. Communication guys	86.4-A1	222
(l) May be reduced where within 12 feet of curb line of public thoroughfares.		
1. Supply service drops	54.8-B1	124
2. Communication service drops	84.8-C1	218
(m) May be reduced for railway signal cables under special conditions	84.4-A4	206
(n) May be reduced in rural districts.		
1. Supply conductors, 750-20,000 volts, crossing roads or driveways	54.4-A2a	102
2. Supply conductors, 750-20,000 volts, above agricultural areas and along roads	54.4-A2b	102
3. Communication conductors along roads	84.4-A2	205
(o) May be reduced for transformer regulator or capacitor leads.		
1. Transformer leads	58.3-B	157
2. Regulator or capacitor leads	58.4-B	164
(p) May be reduced across arid or mountainous areas.		
1. Supply conductors of more than 22,500 volts	54.4-A1	101
2. Communication conductors	84.4-A1	205
(q) Shall be increased or may be reduced under special conditions.		
1. Increased for supply service drops on industrial or commercial premises	54.8-B3a	125
2. Supply service drops on residential premises	54.8-B3b	125
3. Communication conductors	84.4-A3	206
4. Increased for communication service drops on industrial or commercial premises	84.8-C3a	218
5. Communication service drops on residential premises	84.8-C3b	218
(r) May be reduced above roofs of buildings under special conditions.		
1. Supply overhead guys	56.4-G	147
2. Supply service drops	54.8-B4	125
3. Communication overhead guys	86.4-F	226
4. Communication conductors and cables	84.4-E	210
5. Communication service drops	84.8-C4	219
(s) Also applies at fire escapes, etc.		
1. Supply conductors	54.4-H1	112
2. Supply service drops on industrial or commercial premises	54.8-B4a	125
3. Supply service drops on residential premises	54.8-B4b	126
4. Communication conductors	84.4-E	210
(t) Special clearances where attached to buildings, bridges or other structures.		
1. Supply conductors of 750-22,500 volts	54.4-H2	112
2. Trolley contact conductors	74.4-E	186
3. Communication conductors	84.4-F	211
(u) Reduced clearances permitted under special conditions.		
1. Supply service drops on industrial or commercial premises	54.8-B4a	125
2. Supply cables, grounded	57.4-G	153
3. Communication cables beside buildings, etc.	84.4-E	210
4. Communication conductors under bridges, etc.	84.4-F	211
5. Communication service drops	84.8-C4	219
(v) May be reduced under special conditions.		
1. Supply conductors of 750-7,500 volts	54.4-H1	212
2. Supply transformer lead and bus wires, where guarded	58.3-B2	158
(w) May be reduced at angles in lines and transposition points.		
1. Supply conductors	54.4-D1	107
2. Communication conductors	84.4-D5	210
(x) May be reduced for suitably protected lateral or vertical runs.		
1. Supply bond wires	53.4	99
2. Supply ground wires	54.6-B	114
3. Supply lateral conductors	54.6-C	114
4. Supply vertical runs	54.6-D	115
5. Supply risers	54.6-E	116
6. Communication ground wires	84.6-B	212
7. Communication lateral conductors	84.6-C	212
8. Communication vertical runs	84.6-D	212
9. Communication risers	84.6-E	213
(y) Increased clearances required for certain conductors.		
1. Unattached conductors on colinear and crossing lines	32.3	38
2. Unattached supply conductors	54.4-D3	108
3. Supply service drops on clearance crossarms	54.8-C2	129
4. Supply service drops on pole top extensions	54.8-C3	129
5. Unattached supply service drops	54.8-D	130
6. Communication lines, colinear, conflicting or crossing	84.4-D3	209
7. Communication conductors passing supply poles and unattached thereto	84.4-D4	210
8. Communication service drops on clearance crossarms	84.8-D2	220
9. Communication service drops on pole top extensions	84.8-D3	221
10. Unattached communication service drops	84.8-E	221
(z) Special provisions for police and fire alarm conductors require increased clearances	92.2	242
(aa) May be reduced under special provisions.		
1. Supply conductors of 0-750 volts in rack configuration	54.4-D5	108
2. Supply service drops from racks	54.8-F	131
3. Supply cables and messengers attached to poles	57.4-F	152
4. Communication conductors on communication poles	84.4-D	208
5. Communication conductors on crossarms	84.4-D1	208
6. Communication conductors attached to poles	84.4-D2	209
7. Communication service drops attached to poles	84.8-B	217
8. Communication cables and messengers	87.4-D	232
9. Supply or communication cables and messengers on jointly used poles	92.1-B	240
10. Communication open wire on jointly use poles	92.1-C	241
11. Multiconductor cables with bare neutral	54.10-B1	135
(bb) May be reduced for Class T conductors of not more than 750 volts and of the same potential and polarity	74.4-D	186
(cc) Not applicable to trolley span wires	77.4-E	189
(dd) Special clearances for pole-top and dead-end construction.		
1. Conductors dead-ended in vertical configuration on poles	54.4-C4	105
2. Conductors dead-ended in horizontal configuration	54.4-D7	109
3. Conductors in pole-top construction	54.4-D8	110
(ee) Clearance requirements for certain voltage classifications	54.4-D2	107
(ff) Not applicable to communication conductors	84.4-D	208
(gg) Clearance from crossarms may be reduced for certain conductors.		
1. Suitably insulated leads to protect runs	54.4-E	111
2. Leads of 0-5,000 volts to equipment	54.4-E	111
3. Leads of 0-5,000 volts to cutouts or switches	58.5-C	166
(hh) Reduced clearance permitted from temporary fixtures and lighting circuits 0-300 volts	78.3-A1	194
(ii) Special clearances required above public and private swimming pools:		
1. Supply line conductors	54.4-A4	102
2. Supply service drops	54.8-B5	127
3. Communication line conductors	84.4-A5	206
4. Communication service drops	84.8-C5	219
5. Supply guys, span wires	56.4-A3	143
6. Communication guys	86.4-A3	223
(jj) May be decreased in partial underground distribution	54.4-D2	107
(kk) Shall be increased by 0.025 ft. per kv in excess of 300 kv.		
(ll) Shall be increased by 0.04 ft. per kv in excess of 300 kv.		
(mm) Proposed clearances to be submitted to the CPUC prior to construction for circuits in excess of 550 kv.		
(nn) Voltage shown in the table shall mean line-to-ground voltage for direct current (DC) systems.		

NOTE: Revised February 1, 1948 by Supplement No. 1 (Decision No. 41134, Case No. 4324), January 2, 1962 by Resolution No. E-1109, February 7, 1964 by Decision No. 66707, August 9, 1966 by Decision No. 71094, September 18, 1967 by Decision No. 72984 and March 30, 1968 by Decision No. 73813.

Requirements for All Lines

38. MINIMUM CLEARANCES OF WIRES FROM OTHER WIRES

The clearance between any overhead line conductor or wire and any other conductor or wire over which the former crosses, the vertical clearance between wires on different crossarms on the same pole, the horizontal clearance between wires of the same voltage classification on the same crossarm and the clearances of line wires from vertical or lateral conductors or guy wires of the same line or of conflicting lines shall not be less than the values given in Table 2, at a temperature of 60° F. and no wind, except that conductors may be dead-ended at the crossarm or have reduced clearances at points of transposition, and shall not be held in violation of Table 2, Cases 8–15, inclusive.

The clearances of Table 2 shall in no case be reduced more than 10 per cent because of temperature and loading as specified in Rule 43 or difference in size or design of the supporting pins, hardware or insulators.

Where conductors, dead ends and metal pins are concerned in any clearance specified in these rules, all clearances of less than 5 inches shall be applicable between the surfaces of conductors (not including tie wires), dead ends, or metal pins, and other conductors, dead ends, metal pins, or other objects to which the clearances are applicable.

All clearances of 5 inches or more shall be applicable from the center lines of conductors concerned.

79. THIRD RAILS

79.1 General Provisions

Third rail construction or reconstruction shall be permitted only for rapid transit passenger lines located in subways, on elevated structures or within completely fenced rights of way, or a combination thereof.

In no event shall the third rail railroad cross at grade any other railroad, or public way, road, street, thoroughfare or highway, whether for use by pedestrians or vehicles.

Third rail construction shall be designed, installed and maintained in such manner as will secure safety to patrons and employees of the rapid transit line and to the public in general.

79.2 Protective Guards and Coverings

Every third rail, whether carried in subways, on elevated structures or on completely fenced rights of way, shall be protected by suitable guards and coverings made of insulating, impact resistant material and of such form as will present a minimum of third rail exposure.

79.3 Location

Third rails, whether in subways, on elevated structures or in fenced rights of way shall be located to the side of the running rail farthest from station or passenger loading platforms.

fc

CPUC GENERAL ORDER NO. 143

Decision No. 89022 June 27, 1978

BEFORE THE PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

Investigation on the Commission's own motion to adopt rules and regulations relating to safety appliances and procedures for rail transit services operated at grade and in vehicular traffic.	Case No. 10411 (Filed September 7, 1977)

Gregory Lee Thompson, for San Diego Metropolitan Transit Development Board; Daniel R. Paige and O. J. Solander, Attorney at Law, for California Department of Transportation; James P. Jones, for United Transportation Union; Gerald D. Fox and Peter Straus, for themselves; interested parties.
Richard D. Rosenberg, Attorney at Law, for the Commission staff.

ORDER ADOPTING GENERAL ORDER

California Public Utilities Code Section 778, enacted in 1976, requires the Public Utilities Commission to adopt rules and regulations relating to safety appliances and procedures for rail transit services operated at grade and in vehicular traffic.

In order to fulfill this responsibility, the Commission's Transportation Division staff established a Technical Advisory Committee consisting of representatives of transit agencies and others with knowledge and experience in the rail transit field. Several meetings were held during which the committee members made many valuable suggestions and recommendations. Using that information, the staff prepared a report titled "Proposed Rules and Regulations for the Design, Construction and Operation of Light Rail Transit Systems Including

Streetcar Operations". This report was offered and received as Exhibit 1 during a hearing in this matter held on November 3, 1977.

Due to certain objections which were raised at the hearing and not resolved during a recess, the matter was set over for further hearing on a later date. Subsequently, the staff revised its report which was offered and received as Exhibit 2 when the hearing was reconvened on February 10, 1978.

A representative of the United Transportation Union objected to the revised Section V.C in Exhibit 2 on the grounds that the minimum clearances required were too close for safety. He recommended that the Commission substitute in Section V.C, Subsections 3.a, 3.b, and 3.c on Page 4 a minimum of 24-inch clearance in each of those sections where either 12 inches or 6 inches now exist.

The clearance requirements in Exhibit 2, Section V.C were changed by the staff from those contained in Exhibit 1 in response to requests by Technical Advisory Committee members during a recess in the November 3, 1977 hearing. They were extracted from the German Association of Public Transport Operations standards by a member of the Technical Advisory Committee who testified that the German clearance requirements have been in effect for many years and that he has no knowledge of any accidents occurring as a result of those clearances. Further, he stated that had there been any problem because of those clearances, he believes the clearances would have been changed rather than retained for so many years.

The representative of the United Transportation Union did not have statistics or other evidence to substantiate his position that the clearances in Exhibit 2 could cause personal injuries or property damage.

The head of the Electric Safety Unit of the Utilities Division stated that the proposed General Order makes necessary a slight modification of the clearance provisions for trolley contact conductors in subways, tunnels, or bridges set forth in Rule 74.4E of this Commission's General Order No. 95, "Rules for Overhead Electric Line Construction." A reference to the proposed General Order was recommended.

Several further modifications of Exhibit 2 suggested during the hearing by interested parties were accepted by the staff. This matter was submitted on March 15, 1978 upon the receipt of a draft decision from the staff to implement modifying Exhibit 2 to include the suggestions made at the hearing with the exception of increasing minimum clearances.

Finding

We find that the rules and regulations contained in Exhibit 2, with modification as agreed upon during the hearing on February 10, 1978, are reasonable and necessary to fulfill the Commission's responsibility under Public Utilities Code Section 778.

Conclusion

The Commission concludes that the attached General Order should be adopted and that General Order No. 95 should be modified as hereafter ordered. The individual sections and subsections of Exhibit 2 have been renumbered to conform with the practice used in other Commission General Orders. The sequence of each part has not been altered.

IT IS ORDERED that:

1. General Order No. 143, attached hereto as Appendix A, is adopted to become effective on the effective date of this order.

2. Rule 74.4E of General Order No. 95, "Rules for Overhead Electric Line Construction" which reads:

"E. UNDER BRIDGES, ETC.

"A reduction of the clearances given in Table 1 to a minimum of 14 feet for trolley contact conductors is permitted for subways, tunnels or bridges, provided the railway does not operate freight cars where the vertical distance from the top of car or load to trolley contact conductor is less than 6 feet. This will require the grading of the trolley contact conductor from the prescribed construction down to the reduced elevation (see App. G, Fig. 64).

"No clearance is specified between the trolley contact conductor and the structure. Where the structure is of material which will ground the trolley current in the event the collector leaves the contact conductor, a properly insulated trolley trough or equivalent protection shall be installed to prevent contact between the collector and the structure. Where pantograph collectors are used, this protection is not required. See Rule 54.4-1 for provisions applicable to conductors other than trolley contact conductors."

is hereby modified to read as follows:

E. UNDER BRIDGES, ETC.

A reduction of the clearances given in Table 1 to a minimum of 14 feet for trolley contact conductors is permitted for subways, tunnels or bridges, provided the railway does not operate freight cars where the vertical distance from the top of car or load to trolley contact conductor is less than 6 feet, except that for light rail transit systems, the minimum height shall be that set forth in General Order No. 143, "Rules for the Design, Construction and Operation of Light Rail Transit Systems Including Streetcar Operations." This will require the grading of the trolley contact conductor from the prescribed construction down to the reduced elevation (see App. G. Fig. 64).

No clearance is specified between the trolley contact conductor and the structure. Where the structure is of material which will ground the trolley current in the event the collector leaves the contact conductor, a properly insulated trolley trough or equivalent protection shall be installed to prevent contact between the collector and the structure. Where pantograph collectors are used, this protection is not required. See Rule 54.4-1 for provisions applicable to conductors other than trolley contact conductors.

3. The Executive Director of the Commission shall cause a copy of this decision to be served upon the interested parties listed in Appendix B hereto.

The effective date of this order shall be thirty days after the date hereof.

Dated at San Francisco, California, this 27th day of June, 1978.

____
President

WILLIAM SYMONS, JR.

VERNON L. STURGEON

RICHARD D. GRAVELLE

CLAIRE T. DEDRICK

Commissioners

Commissioner Robert Batinovich, being necessarily absent, did not participate in the disposition of this proceeding.

APPENDIX A

General Order No. 143

PUBLIC UTILITIES COMMISSION OF THE STATE OF CALIFORNIA

RULES FOR THE DESIGN, CONSTRUCTION AND OPERATION OF LIGHT RAIL TRANSIT SYSTEMS INCLUDING STREETCAR OPERATIONS

Adopted June 27, 1978. Effective July 27, 1978.

Decision No. 89022 in Case No. 10411.

IT IS ORDERED by the Public Utilities Commission of the State of California that each public and private transit agency or authority operating in the State of California shall observe this general order in designing, constructing and operating light rail transit systems. The table of contents and rules are set forth below:

APPENDIX A

TABLE OF CONTENTS

APPENDIX A

1. Purpose:

To establish rules and regulations governing the design, construction and operation of light rail transit systems at grade and in vehicular traffic. It is intended that they be sufficiently flexible to enable transit agencies to apply them uniformly in meeting the varying conditions that exist on their respective properties. However, the safety of patrons, employees and the public is of primary importance in every consideration. It is recognized that advancement in technology and new experience may justify modification of the rules and regulations in the future and due consideration will be given at appropriate times toward updating them to meet the need.

2. Applicability:

These rules and regulations are applicable to all private light rail transit operators subject to the Commission's jurisdiction and to those public light rail transit operators designated by statutes to be subject to the Commission's regulations for safety. (Southern California Rapid Transit District, Section 30646, Public Utilities Code and Santa Clara County Transit District, Section 100168, Public Utilities Code.) Light rail transit operators not subject to the Commission's jurisdiction are encouraged to follow these rules and regulations.

3. Definitions:

3.1 *Light Rail Transit (LRT) - "A mode of urban transportation utilizing predominantly reserved but not necessarily grade-separated rights-of-way. Electrically propelled rail vehicles operate singly or in trains."

3.2 Light Rail Vehicles (LRV) - An electrically propelled passenger carrying rail vehicle capable of operating on each alignment classification described in Section 4. Passengers on light rail transit lines may be carried only in light rail vehicles (LRV).

3.3 Automatic Train Protection (ATP) - A system of train control devices including cab or wayside signals that automatically indicate the state of the track ahead and at junctions (interlocking).

*Definition adopted in 1976 by the Transportation Research Board Committee on LRT.

3.4 Automatic Train Stop (ATS) - A device that will automatically bring the train to a stop should the LRV operator disregard a stop indication or command of the Automatic Train Protection system.

3.5 Interlocking - An arrangement of signals and control apparatus so interconnected that functions must succeed each other in a predetermined sequence, thus permitting train movements over routes only if non-conflicting conditions exist.

3.6 Cab Signal System - A signal system whereby block conditions and speed commands are transmitted and displayed directly within the train cab. The cab signal system may be operated in conjunction with a system of fixed wayside signals or separately.

3.7 Deadman Control - A safety device that requires the operator's continuous pressure or activity to remain activated and used to detect the inattention or disability of a train operator.

The abbreviations LRT, LRV, ATP and ATS are used throughout these rules and regulations in conformance with the definitions described in this section and LRV is to be considered singular or plural as appropriate.

4. Alignment Classification:

4.1 Exclusive:

A fully exclusive right-of-way without at-grade crossings, also referred to as grade-separated or protected by a fence or substantial barrier, as appropriate to the location. (Includes subways and aerial structures.)

4.2 Semi-Exclusive:

4.2.1 Fully exclusive right-of-way with at-grade crossings, protected between crossings by a fence or substantial barriers, if appropriate to the location.

4.2.2 Within street right-of-way, but protected by six-inch high curbs and safety fences between crossings. The safety fences should be located outside the tracks.

4.2.3 Within street right-of-way, but protected by six-inch high curbs between crossings. A safety fence may be located between tracks.

4.2.4 Within street right-of-way, but protected by mountable curbs, striping or lane designation.

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4.3 Non-Exclusive:

4.3.1 Mixed traffic operation - surface streets.

4.3.2 LRT/Pedestrian Mall.

5. Construction Requirements:

5.1 Track Construction:

Light rail track shall be constructed to standards appropriate for the type and weight of LRV, speeds, grade, curvature, drainage, etc. and shall conform generally to practice in the LRT industry. Track materials shall meet the applicable American Railway Engineering Association (AREA) standards. Track shall be maintained in proper gauge, alignments, surface level and cross level.

5.2 Structures:

5.2.1 Buildings/Stations - Shall be designed and constructed to meet all California Occupational Safety and Health Act (OSHA), State and local engineering and construction standards and codes.

5.2.2 Civil Engineering Features - All bridges, viaducts, retaining walls and similar structures shall be designed in accordance with California Department of Transportation (CALTRANS) "Bridge Planning and Design Manual", adapted to light rail dimensions and loading where appropriate.

5.3 Clearances:

The provisions of General Order 26-D, Sections 9, 10 and 11, shall not apply to tracks used exclusively for rail passenger operations defined in Section 3.1 hereof as Light Rail Transit (LRT). The following clearance requirements shall govern LRT:

5.3.1 All clearances shall be measured from the surface of the largest vehicle stationary on tangent track. The spacing of tracks and structures shall be increased proportionately for curved track to provide the minimum clearances specified in Section 5.3.3 hereof at all locations. Minimum clearances shall be such that no contact can take place due to any condition of design wear, loading or anticipated failure such as air spring deflation or normal lateral vehicle motion.

5.3.2 The requirements of the applicable sections of General Order 26-D shall govern where LRT is operated: a) on or adjacent to tracks used for transporting freight cars; b) where LRT is operated with light rail vehicles not having all windows and other openings sealed or effectively barred.

*5.3.3 The minimum clearances for LRV that have all windows and other openings sealed or effectively barred and operated on tracks used exclusively for transit purposes shall be:

5.3.3.1 Between LRV's on parallel tracks - 12 inches.

5.3.3.2 Between LRV's and fixed wayside structures - 12 inches except center poles and pedestrian fences not having rigid horizontal members such as railings - 6 inches.

5.3.3.3 Between LRV's on medians and face of curb - 12 inches.

5.3.3.4 Between LRV's and high level platforms - 3 inches.

5.3.3.5 Between LRV's and low level platforms, horizontally from the widest equipment operated - 3 inches and sufficient vertically to avoid contact at all times. See 5.3.1 above. Subject to these conditions, low level platforms may extend beneath a Light Rail Vehicle.

Alignment Classifications 4.1 and 4.2.1 segments having minimum clearances may be subject to speed profile reduction.

5.3.4 Track installation and clearances shall provide sufficient room that in an emergency, passengers can leave a stalled train and reach a station or other exit point safely.

5.3.5 Overhead clearance shall conform to General Order 95 except that on Alignment Classifications 4.1 and 4.2.1, between crossings, and used exclusively for transit purposes the minimum contact wire clearance shall be 9 inches above the height of the LRV pantograph in the retracted position. Where LRT is operated on or across railroad tracks at grade, overhead clearances less than those specified in General Order 95 may be authorized at specific locations, provided warning signs, telltales and other safety devices appropriate to the location, are installed.

5.4 <u>Electrical and Communication Facilities</u>:

5.4.1 <u>Above Ground</u> construction of electrical and communication lines, including trolley contact and third rail conductors, shall comply with the provisions of General Order 95, except as provided in Subsection 5.3.5. Exemptions from trolley contact wire clearances for specific locations will be considered when requested in accordance with Section 12 herein.

5.4.2 <u>Underground</u> construction of electrical and communication lines shall comply with the provisions of General Order 128.

*See figures 1 and 2.

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In addition, the provisions of California OSHA, National Electrical Code, Electrical Safety Orders of California, Title 8 and local electrical safety codes shall apply.

In the event of conflict, the most stringent code shall apply.

5.5 <u>At-Grade Roadway Crossings</u>:

5.5.1 Roadway crossings of transit rails shall be designed and constructed in accordance with General Order 72-B.

5.5.2 All LRT crossings and intersections shall be equipped with a traffic control device and/or railroad-type warning device to clearly assign the right-of-way among the conflicting movements.

5.5.2.1 Railroad-type warning devices, where used, shall be installed in accordance with General Order 75-C. Where the same right-of-way is shared with other rail lines, such warning devices shall operate for both LRT and train movements on those lines.

5.5.2.2 Standard #10 (GO 75-C) pedestrian crossing warning devices shall be installed at pedestrian grade crossings in Alignment Classifications 4.2.1 and 4.2.2 which are not a part of vehicular crossings. Traffic signals or other approved devices may be used in Alignment Classifications 4.2.3 and 4.2.4.

5.5.2.3 Highway-type traffic control devices (traffic signals, stop signs) shall be installed in accordance with the Traffic Manual - State of California, Department of Transportation, current edition.

5.6 <u>At-Grade Railroad Crossings</u>:

At-grade crossings of railroad tracks shall be protected by interlocking, ATP, and ATS, except where the light rail track is in a street right-of-way, the Commission may authorize other protective measures.

6. <u>Operating Requirements</u>:

6.1 <u>Basic Speed Rule</u>:

The other provisions of this section notwithstanding, the operator of an LRV shall at all times operate at a safe speed that is consistent with weather, visibility, track conditions, traffic, traffic signal indications and the indications of ATP systems where used.

6.2 Speed Profile:

LRV shall be operated at all times within the maximum speed profiles established for the system. System speed profiles shall be contained in the Transit Authority's Operating Rules and Procedures (Section 8). Speed limit signs which are visible from the operator's cab shall be posted in advance of critical locations.

6.3 Maximum Speeds:

The maximum speeds permitted on an LRT system shall be established in accordance with Table 1. Refer also to Section 7.

6.4 Hand Signaling Devices:

Colored flags and lights, fusees (flares) shall be used where appropriate to control LRV movements.

6.5 Audible Warning:

The LRV operator shall sound an audible warning at public crossings and in traffic as required by local regulations.

6.6 Headways:

Minimum headways shall be governed by:

6.6.1 ATP where used.

6.6.2 Operating Rules.

7. Public Utilities Commission Review:

All orders, rules and speeds as proposed by the transit authority for LRT operations, regardless of alignment classification, shall be subject to PUC review.

8. Operating Rules and Procedures:

Each transit authority shall adopt and enforce operating rules and procedures governing its employees whose duties affect the safety of LRT operations. Copies of such rules and procedures shall be filed with the Commission not less than twenty working days before the rules and procedures are implemented. Any subsequent amendments thereto shall be submitted to the Commission not less than twenty working days prior to implementation. Such employees shall:

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8.1 Receive training in the proper application of the operating rules and procedures in performing their duties.

8.2 Be required to pass an examination to determine their knowledge and understanding of the rules and procedures. Employees transferred to positions of different responsibility shall be required to pass an examination appropriate for the new position. Employees shall be certified by the transit authority as to their qualifications for their respective positions as they relate to the employee's knowledge and understanding of the operating rules and procedures, hereto.

8.3 Be required to pass an examination to determine their knowledge and understanding of all applicable Federal, State, and local regulations and ordinances which shall be included in the operating rules and procedures.

8.4 Be given refresher training at appropriate intervals to assure their continued qualifications for their respective duties per Section 8.2 above.

8.5 Possess a valid Class 2 California Vehicle Driver's License.

9. Light Rail Vehicles:

New vehicles contracted and constructed after January 1, 1978, intended for passenger operation on LRT lines shall conform to the requirements of this section.

9.1 Construction:

9.1.1 Vehicles shall be designed and constructed according to the technology that will insure their crashworthiness in case of a collision. Anti-Climbers and other devices shall be installed to reduce the likelihood of one car overriding the frame of another car during collision and intruding into the body of the other car. Under-frame construction, collision posts and end frame construction shall be capable of passing the following test:

> Under a combined vertical load representative of a maximum design passenger load and a horizontal load of 2G (empty car) applied at the end sills, the stress (unrelieved by permanent strain) in the principal framing members shall not be greater than the yield of the material.

9.1.2 Windshields, window and partition glazing materials shall be of shatterproof construction capable of resisting shock and penetration by foreign objects that may strike the material during normal operation.

9.1.3 Vehicles shall be provided with manual operating capability including, but not limited to, manual control of propulsion, braking and doors and visual/audio indications needed for manual monitoring of vehicle performance and vital functions. Additionally, vehicles shall be equipped with a speed indicator which shall be maintained to indicate actual speed within 3 mph and a Deadman Control as defined in Section 3.7. Vehicles operating on Alignment Classifications 4.1 and 4.2.1 where ATP plus ATS is required as depicted in Table 1 shall be equipped with ATS control. Cab Signal equipment as defined in Section 3.6 is optional.

9.2 Brakes:

LRV shall have, as a minimum, a service braking system consisting of dynamic/regenerative and friction brakes, an independent emergency magnetic track brake system and a parking brake system.

9.2.1 The service braking system shall provide braking capability for all vehicle weights up to a full passenger load utilizing both dynamic/regenerative and friction brakes continuously blended and jerk-limited to attain the desired braking rate over the entire operating speed range up to overspeed cutoff.

9.2.2 All LRV's shall be capable of the following dry-track braking rates under all loading conditions:

Maximum full braking rate	4.0 mphps
Nominal full braking rate	3.5 mphps
Minimum full braking rate	3.0 mphps
Emergency braking rate	
from max to 30 mph	4.0 mphps minimum
from 30 mph to 20 mph	6.0 mphps minimum
from 20 mph to 10 mph	5.0 mphps minimum
from 10 mph to zero	3.5 mphps minimum

9.2.3 In the event of dynamic brake failure, the friction brake system shall have the capability of providing an average braking rate of not less than the minimum rate established by the Transit Authority over the entire operating range.

9.2.4 The emergency braking system shall utilize the capabilities of the service brake plus the application of magnetic track brakes and sand as required. Emergency braking rates shall be available for vehicle weights up to a maximum design passenger load. Emergency brake application shall not be jerk-limited. Slip/spin protection, where used, shall be designed for fail-safe operation such that the normal system failure mode will cause a by-pass of the slip/spin protection.

9.2.5 All braking systems shall be monitored continuously for any detectable failures by a fail-alarm checking system. Should an impending failure of either the dynamic or friction braking system or components thereof be detected, a visual and audible warning shall be annunciated followed by a manual application of the magnetic track braking system by the LRV operator and the train brought to a stop at the earliest possible moment. The train may then proceed at a reduced speed to the closest station stop where the passengers shall be off-loaded. The train shall then be moved out-of-service to the nearest dead track, yard or terminal for repairs.

9.2.6 A parking brake function, which may be an integral part of the service brake, shall be provided on each vehicle. The parking brake/hand brake shall have the capability to hold a fully loaded car on the maximum grade to be encountered without power available. Design shall be such that the parking/hand brake function can be utilized from each cab with no power source available. It shall also be semi-automatic in that it shall be applied when the vehicle is placed in the lay-up mode and the cab transfer key has been removed from the master controller. Parking brake shall be interlocked with propulsion control to prevent application of power when the parking brake is set on a single car or train.

9.3 Doors:

9.3.1 The side door operating function shall be interlocked with the propulsion and brake control to prevent a vehicle from moving whenever the operator has enabled the door interlock function and a door is open.

9.3.2 All side doors that are not directly within the operator's sight and under his supervision shall contain an obstruction protection device which shall operate only when the operator has enabled the door interlock function. When activated, by an obstruction, this device shall cause the door to release and remain released for an adjustable time period, then the door will attempt to close again.

9.4 Lights - Exterior:

9.4.1 Headlights, taillights, clearance lights and turn signals shall comply with the provisions of Division 12, Chapter 2 of the California Vehicle Code. Other or brighter headlights may be installed, but may not be operated when the light would conflict with the Code concerning approaching motor vehicles.

9.4.2 Curb and platform illumination lamp(s) shall be located at each doorway and will provide not less than two-foot candles of illumination measured on the street and platform 24 inches (61 cm) away from the vehicle in a horizontal direction. This light shall be on when the door is opened and extinguished when the door is closed.

9.5 Lights - Interior:

9.5.1 The lighting intensity at each seat shall have an overall average of not less than 20-foot candles measured at a plane 36 inches (92 cm) above the floor.

*9.5.2 All stepwells and floor level exits shall be entirely illuminated without shadows. The lighting intensity on the surface of the step tread shall be not less than 5-foot candles.

9.6 Warning Devices:

The lead unit of every light rail train shall be equipped with an audible warning device such as a horn, whistle, or bell capable of emitting sound audible under normal conditions from a distance of not less than 500 feet.

10. Train Protection:

It is intended that an LRV operator will normally maintain visual/manual control of a vehicle or train. In addition, Automatic Train Protection as defined in Section 3.3 may be required at locations with restricted visibility or other special operating conditions. In accordance with Table 1, Automatic Train Protection shall be required wherever speeds in excess of 45 mph are permitted. Automatic Train Protection and Automatic Train Stop shall be required wherever speeds in excess of 55 mph are permitted and wherever interlocking is provided at railroad crossings in accordance with Section 5.6.

*Applies to vehicle equipped to serve curb level and floor level passenger platforms.

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11. Safety Implementation:

Any California transit authority subject to the jurisdiction of the Commission wishing to build a new LRT system or expand, renew or improve its existing LRT facilities shall file with the Commission its plans to implement the safety provisions of Sections 5, 6, 9 and 10 herein, not less than thirty working days prior to letting a contract for construction.

12. Exemptions:

Requests for exemptions from these rules shall contain a full statement of the reasons justifying the requested exemptions and demonstrating that safety is not reduced thereby. Any exemption so granted shall be limited to the particular case covered by the request.

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MINIMUM CLEARANCES DESCRIBED IN SECTIONS 5.3.3.1 TO 5.3.3.5 INCL.

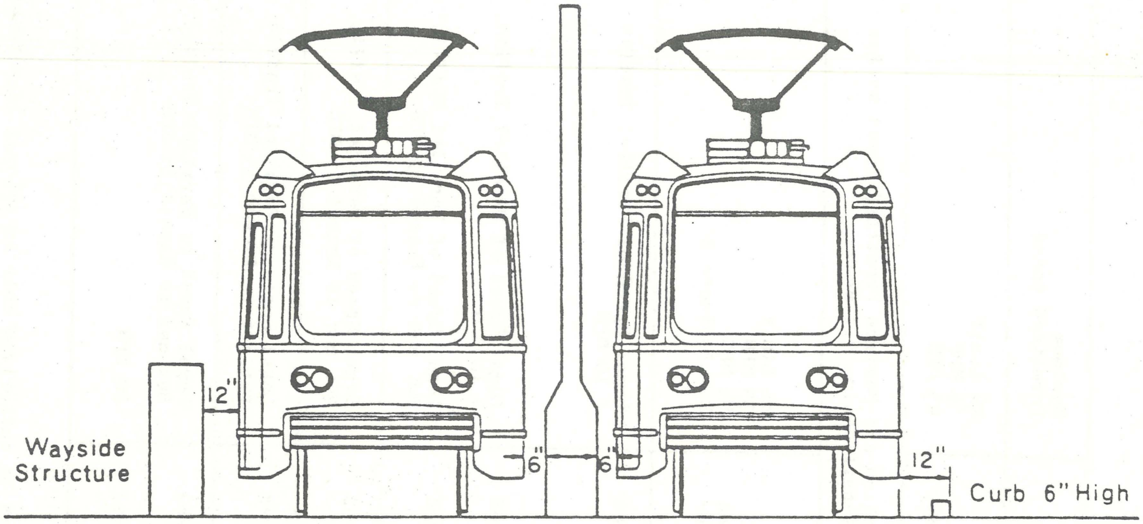

Figure 1

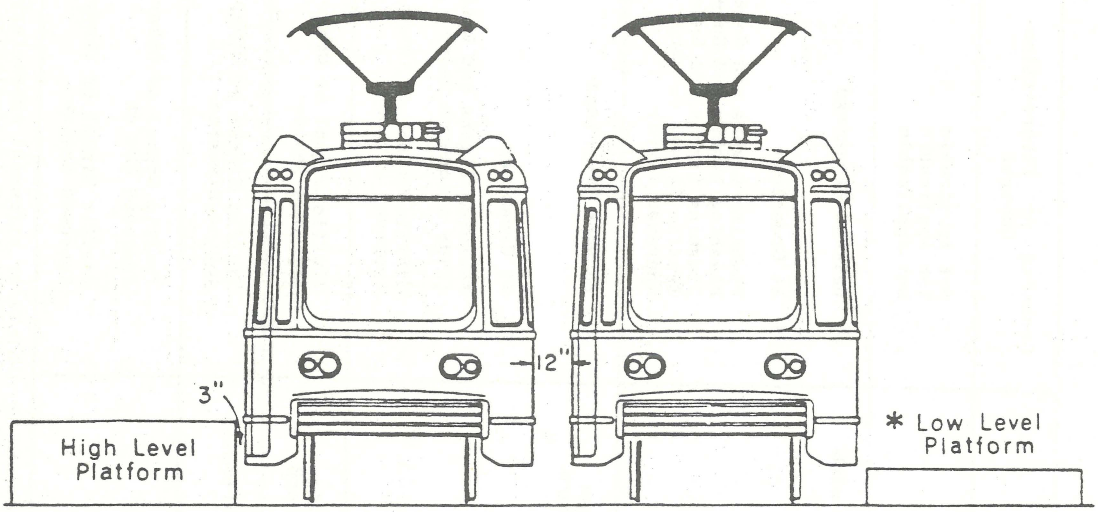

Figure 2

* Low level platforms may extend beneath a light rail vehicle, provided the minimum horizontal and vertical clearances specified in Section 5.3.3.5 are maintained.

Table 1
MAXIMUM PERMITTED SPEEDS ON LRT SYSTEMS

Alignment Classification	Crossing or Intersection Control	Train Protection	Maximum Permitted Speed	Notes
4.1 Exclusive	Not Applicable	ATP & ATS	No Limit	1
	Not Applicable	ATP Only	55 MPH	
	Not Applicable	None Required	45 MPH	2
4.2.1 Fenced Right-of-Way with At-Grade Crossings	1) Between Crossings	Train Protection and Maximum Permitted Speed as for Alignment Classification 4.1 above		
	2) At Crossings			
	Flashing Lights and Gates	ATP & ATS	No Limit	1
	Flashing Lights and Gates	ATP Only	55 MPH	
	Flashing Lights and Gates	None Required	45 MPH	2
	Traffic Signal or Other Approved Device	None Required	See Footnote 3	2,3
4.2.2 Street Median or Side Alignment with 6" Curb and Fence	1) Between Crossings	None Required	Legal Speed of Parallel Traffic + 10 MPH	2,5
	2) At Crossings			
	Flashing Lights and Gates (Side Alignment Only)	None Required	Legal Speed of Parallel Traffic + 10 MPH	2,5
	Traffic Signal or Other Approved Device	None Required	Legal Speed of Parallel Traffic But not to Exceed 35 MPH	2
4.2.3 Street Median or Side Alignment with 6" Curb	Traffic Signal or Other Approved Device	None Required	Legal Speed of Parallel Traffic But not to Exceed 35 MPH	2
4.2.4 Mountable Curb or Transit Lane	Traffic Signal or Other Approved Device	None Required	Legal Speed of Parallel Traffic But not to Exceed 35 MPH	2
4.3.1 Mixed Traffic	Traffic Signal or Other Approved Device	None Required	Legal Speed of Parallel Traffic But not to Exceed 35 MPH	2
4.3.2 Pedestrian Mall	Traffic Signal or Other Approved Device	None Required	20 MPH	4

Notes:
1) Speed is limited only by vehicle or alignment characteristics.
2) Provided adequate stopping sight distance is available.
3) Traffic signal or other approved device at crossings on 4.2.1 right-of-way may be authorized only in special locations, where speeds do not exceed 25 MPH (such as at stations).
4) Lower speed may be required for malls paved flush with the tracks.
5) Maximum speed 55 MPH unless ATP & ATS are provided. Maximum speed 45 MPH unless ATP is provided.

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