RTD
LIGHT RAIL
DESIGN CRITERIA

Regional Transportation District
November 2005

Prepared by the
Engineering Division of the Regional Transportation District

Regional Transportation District

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The RTD Light Rail Design Criteria Manual has been developed as a set of general guidelines as well as providing specific criteria to be employed in the preparation and implementation of the planning, design and construction of new light rail corridors and the extension of existing corridors. This 2005 issue of the RTD Light Rail Design Criteria Manual was developed to remain in compliance with accepted practices with regard to safety and compatibility with RTD's existing system and the intended future systems that will be constructed by RTD. The manual reflects the most current accepted practices and applicable codes in use by the industry.

The intent of this manual is to establish general criteria to be used in the planning and design process. However, deviations from these accepted criteria may be required in specific instances. Any such deviations from these accepted criteria must be approved by the RTD's Executive Safety & Security Committee.

Coordination with local agencies and jurisdictions is still required for the determination and approval for fire protection, life safety, and security measures that will be implemented as part of the planning and design of the light rail system. Conflicting information or directives between the criteria set forth in this manual shall be brought to the attention of RTD and will be addressed and resolved between RTD and the local agencies and/or jurisdictions.

This manual will be updated periodically either in part or in whole as deemed appropriate by RTD. Any updates or modifications to the manual will take precedence over previous versions or criteria at the time of approval of the updated material or sections of the manual.

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SECTION 1 – GENERAL INFORMATION

1.1.0 PURPOSE

This manual establishes basic criteria to be used in the design of the Regional Transportation District's (RTD) Light Rail Transit (LRT) system. In addition, drafting standards, directive or sample drawings and management procedures have been prepared to standardize and guide the design activities and the preparation of contract documents. See separate design criteria for Commuter Rail.

Design is to be directed toward minimum feasible costs for design, construction, capital facilities and operation; minimum energy consumption and minimum disruption of local businesses and communities. It should be consistent with system reliability, passenger comfort, mode of operation, type of light rail vehicle (LRV) to be used and maintenance. Safety for passengers, workers and the public is of primary importance.

1.2.0 SCOPE

The Design Criteria will take precedence over all other standards referred to herein except those fixed by legislation.

Specific attention should be given to the Americans with Disabilities Act (ADA), the ADA Accessibility Guidelines for Building and Facilities (ADAAG), the ADA Accessibility Guidelines for Transportation Vehicles and to any succeeding modifications that may be issued. The applicability of those documents is noted in several sections of this manual where it appears to be particularly appropriate. However, the regulations must be adhered to in all areas, whether or not mentioned herein.

The Design Criteria in this manual relates to the following elements of the LRT systems:

- Civil and Structural Engineering
- Track Geometry and Trackwork
- Utilities
- Landscaping
- Stations
- Operations Facility
- Traction Electrification System
- Signal System
- Communications and Central Control
- Stray Current/Corrosion Control
- Fare Collection Equipment
- Light Rail Vehicles
- System Safety

1.3.0 PROCEDURES

Design Engineers shall prepare drawings and technical specifications for each contract of the project in accordance with their design contract (if applicable) and the following RTD documents:

- Design Criteria Manuals
- CADD Standards
- Contract Requirements
- All other applicable requirements including codes, regulatory standards and environmental impact statements

Deviations may be made within the framework of the Design Criteria to meet the requirements of a particular problem. However, any deviation, discrepancy or unusual solution must be approved by RTD before it can be included in the design. It is the responsibility of the Design Engineer to identify, explain and justify any deviation from the established criteria and to secure the necessary approvals from RTD. Any variation from these Design Criteria must be submitted to and approved by RTD's Executive Safety and Security Committee.

All proposed deviations to these criteria shall be approved by RTD in writing.

1.4.0 DESIGN CODES AND MANUALS

In addition to this Design Criteria Manual, the Design Engineer must comply with all other applicable engineering codes and standards, including those of the various Federal, State, and local jurisdictions.

If codes and/or manuals are specified herein for the design of an element of the RTD LRT system, then the most recent edition(s) shall be used. Responsibility for design remains with the Design Engineer in accordance with the terms and conditions of their contract with RTD.

Where design codes conflict with each other, the Design Engineer shall notify RTD in writing and recommend a solution. The Design Engineer shall also investigate those codes and manuals that have precedence.

Specific codes and standards include, but are not limited to, the following:

- Americans with Disabilities Act (ADA)
- Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)
- Americans with Disabilities Act Accessibility Guidelines for Transportation Vehicles
- Colorado Department of Transportation (CDOT) - Standard Specifications for Road and Bridge Construction
- CDOT - Standard Plans (M&S Standards)
- CDOT - Highway Design Manual

- CDOT – Drainage Design Manual
- City and County of Denver - Rules for Street Standards
- City and County of Denver - Standard Construction Specifications
- FHWA - Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)
- Colorado Public Utilities Commission (PUC)
- RTD - Commuter Rail Design Criteria
- RTD - Design Guidelines and Criteria for Bus Transit Facilities
- RTD - Standard Plans for Bus & Light Rail Transit Facilities
- Uniform Building Code (UBC)
- Uniform Fire Code
- American Association of State Highway and Transportation Officials (AASHTO) - Standard Specifications for Highway Bridges
- AASHTO - Standard Specifications for Structural Supports for Highway Signs, Luminaries, and Traffic Signals
- Transit Cooperative Research Program (TCRP) No. 57 " Track Design Handbook for Light Rail Transit"
- American Railway Engineering and Maintenance Association (AREMA)
- American Institute of Steel Construction (AISC)
- American Welding Society (AWS)
- American Concrete Institute (ACI)
- American Society for the Testing of Materials (ASTM)
- National Bureau of Standards
- National Electric Code (NEC)
- National Electric Safety Code (NESC)
- American National Standards Institute (ANSI)
- National Fire Protection Association (NFPA) including NFPA 130 and 101
- Local jurisdictional codes, requirements and ordinances, as applicable

Individual sections of these criteria may also define additional code requirements.

1.5.0 CLIMATIC CONDITIONS FOR SYSTEMS DESIGN

The Denver metropolitan area, within which RTD operates, is situated at the foot of the eastern slope of the Rocky Mountains in central Colorado. The area has a semi-arid climate that is somewhat characteristic of the High Plains, but is modified by the Rocky Mountains to the west. Because of this, Denver lies in a belt where there is a fairly rapid change in climate from the foothills to the plains. This change is largely caused by the increase in elevation as you travel west to the foothills. Denver has an elevation of 5,280 feet.

The average annual temperature is about 50°F at this elevation, though this varies a few degrees as elevation changes. The wide average range in daily temperature of 25° to

30°F in the Denver metropolitan area and a wide average range in annual temperature are typical for the High Plains. Variations in temperature are wide from day to day; extremely hot weather in summer and extremely cold weather in the winter normally do not last long and are followed by much more moderate temperatures.

System equipment including vehicles, electrification power and distribution system, signal system and fare collection/validation equipment along with trackwork, stations and other civil features shall be capable of maintaining operation within the following conditions:

TABLE 1A – CLIMATIC CONDITIONS

Ambient Temperature	-30°F to +110°F
Relative Humidity	8 to 100%
Maximum Rainfall in 24 Hours	1.88 inches
Maximum Snowfall in 24 Hours	10.1 inches
Maximum Wind Speed	54 mph
Average Elevation	5,280 Feet

TABLE 1B – TEMPERATURE AND PRECIPITATION

MONTH	TEMPERATURE				PRECIPITATION			
	AVERAGE DAILY MAXIMUM	AVERAGE DAILY MINIMUM	2 YEARS IN 10 WILL HAVE AT LEAST 4 DAYS WITH		AVG TOTAL	2 YEARS IN 10 WILL HAVE		AVG NO. DAYS WITH SNOW COVER
			MAX TEMP EQUAL OR HIGHER THAN	MIN TEMP EQUAL OR LOWER THAN		LESS THAN	MORE THAN	
	°F	°F	°F	°F	IN	IN	IN	
JAN	43	14	61	-6	0.43	0.1	0.8	8
FEB	47	18	64	-2	0.47	0.2	0.7	9
MARCH	52	23	70	4	0.87	0.4	1.6	7
APRIL	62	33	79	19	1.86	0.7	2.8	3
MAY	71	42	86	32	2.54	0.9	3.7	1
JUNE	84	51	96	40	1.58	0.7	2.6	0
JULY	91	57	99	50	2.01	1.0	3.2	0
AUGUST	89	56	98	49	1.49	0.7	2.1	0

MONTH	TEMPERATURE				PRECIPITATION			
	AVERAGE DAILY MAXIMUM	AVERAGE DAILY MINIMUM	2 YEARS IN 10 WILL HAVE AT LEAST 4 DAYS WITH		AVG TOTAL	2 YEARS IN 10 WILL HAVE		AVG NO. DAYS WITH SNOW COVER
			MAX TEMP EQUAL OR HIGHER THAN	MIN TEMP EQUAL OR LOWER THAN		LESS THAN	MORE THAN	
	°F	°F	°F	°F	IN	IN	IN	
SEPT	80	47	94	35	1.14	0.2	1.7	***
OCT	69	36	83	25	0.72	0.1	1.5	1
NOV	54	23	71	7	0.54	0.2	0.9	5
DEC	46	18	64	2	0.40	0.1	0.6	7
YEAR	66	35	*101	**-14	14.05	9.2	18.3	41

* Average annual highest temperature
** Average annual lowest temperature
*** Less than one-half day

Data for long periods indicate that the average annual precipitation ranges from 13.5 to 14.5 inches, with the highest precipitation occurring at the western edge of the metropolitan area. Particularly in summer and spring, precipitation may vary from year to year and in different areas in the same year. Precipitation in the winter is more in the western part of the Denver metropolitan area than it is in other parts. These differences are small but consistent from October to May. The annual snowfall is about 59 inches. The eastern part of the metropolitan area, however, usually receives more rainfall in summer than the west, but local rainfall varies widely from year to year.

The relative humidity averages 39% during the day and 62% at night, but these averages are slightly higher in winter than in summer. In an average year, the percentage of sunshine is about 69%.

Hailstorms cause some local damage almost every year. The hail usually falls in strips 1 mile wide and 6 miles long. These storms are more common in the eastern part of the Denver metropolitan area than the western part and they generally occur from about May 15 to September 1 but are most common in June and July.

Requirements for climatic conditions defined in other sections of these Design Criteria take precedence.

1.6.0 ACRONYMS AND ABBREVIATIONS

The following acronyms and abbreviations appear in this document. They are defined as indicated:

AAR	Association of American Railroads
AASHTO	American Association of State Highways and Transportation Officials
ABS	Automatic Block Signals
AC	Alternating Current
ACI	American Concrete Institute
ACOE	Army Corps of Engineers
ADA	Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities
AFC	Automatic Fare Collection
AFI	Air Filter Institute
AFO	Audio Frequency Overlay
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
AMCA	Air Moving and Conditioning Association, Inc.
ANSI	American National Standard Institute
APTA	American Public Transit Association
AREMA	American Railway Engineering and Maintenance Association
ARI	Air Conditioning and Refrigeration Institute
ASA	Acoustical Society of America
ASCII	American Standard Code for Information Interchange
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ASIC	Application Specific Integrated Circuit
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATP	Automatic Train Protection
ATS	Automatic Train Stop
AWO	Maximum empty vehicle operating weight: 97,000 lb
AW1	Full seated load of 77 persons (passengers plus operator), plus AWO: 108,858 lb
AW2	Standees at 4 persons per m^2 suitable standing space per passenger, 90 persons minimum, plus AW1: 122,718 lb
AW3	Standees at 6 persons per m^2 of suitable standing space per passenger, minimum 136 persons, plus AW1: 129,802 lb
AW4	Standees at 8 person per m^2 suitable standing space per passenger, minimum 180 persons, plus AW1: 136,578 lb

AWG	American Wire Gauge
AWS	American Welding Society
BLS	Bureau of Labor Statistics
CCC	Central Control Center
CCD	City and County of Denver
CCH	Communication Control Head
CCIR	International Radio Consultation Committee
CCITT	Consultative Committee for International Telephone and Telegraphs
CCTV	Closed Circuit Television
CDA	Copper Development Association
CDOT	Colorado Department of Transportation
CDPHE	Colorado Department of Public Health and Environment
CFR	Code of Federal Regulations
CMOS	Complementary Metal Oxide Semiconductor
CPM	Critical Path Method
CRB	Columbia River Basalt
CRT	Cathode-Ray Tube
CTS	Cable Transmission System
DB	Dry Bulb
DBE	Disadvantaged Business Enterprise
DC	Direct Current
DF	Direct Fixation
DIN	Deutsche Industry Norm (German Industrial Standard)
DOGAMI	Department of Geology and Mineral Industries
DWG	Drawing
ECS	Environmental Control System
ECU	Electronic Control Unit
EIA	Electronic Industries Association
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EPABX	Electronic Private Automatic Branch Exchange
FAA	Federal Aviation Administration
FACP	Fire Alarm Control Panel
FCC	Federal Communications Commission
FOB	Fahrenheit Dry Bulb
FHWA	Federal Highway Administration
FEA	Finite Elements Analysis
FMP	Fire Management Plan
FRA	Federal Railroad Administration

FTA	Federal Transit Administration
FWB	Fahrenheit Wet Bulb
GSA	General Services Administration
HPCU	Hydraulic Pressure Control Unit
HSCB	High Speed Circuit Breaker
HVAC	Heating, Ventilating and Air Conditioning
IBC	International Building Code
ICEA	Insulated Cable Engineers Association
IEC	International Electro-technical Committee
IEEE	Institute of Electrical and Electronic Engineers
IES	Illuminating Engineering Society
ISO	International Organization for Standards
JEDEC	Joint Electronic Device Engineering Council
JIG	Joint Industrial Council
LAHT	Low Alloy High Tensile Strength (Steel)
LED	Light Emitting Diode
LOS	Level of Service
LRT	Light Rail Transit
LRV	Light Rail Vehicle
LVPS	Low Voltage Power Supply
MB	Maximum Brake
MCE	Maximum Credible Earthquake
MDBF	Mean Distance Between Failure
MIL	Military Specification
MIS	Management Information System
MOV	Metal Oxide Varistor
MOW	Maintenance-of-Way
MSB	Maximum Service Brake
MSS	Manufacturers Standardization Society of the Valve and Fitting Industry
MTTR	Mean Time to Repair
NBS	National Bureau of Standards
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NETA	National Electrical Testing Association
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
OCS	Overhead Contact System
OSI	Open System Interconnect

OSHA	Occupational Safety and Health Administration
PA	Public Announcement
PABX	Private Automatic Branch Exchange
PE	Preliminary Engineering
PIV	Peak Inverse Voltage
PUC	Public Utilities Commission
RMS	Root Mean Square
ROW	Right-of-Way
RTU	Remote Terminal Unit
SAE	Society of Automotive Engineers
SCADA	Supervisory Control and Data Acquisition
SES	Subway Environment Simulation
SIC	Standard Industrial Code, U.S. Department of Labor
SMAC	Sheet Metal and Air Conditioning Contractor's National Association
SSP	System Safety Program
TES	Traction Electrification System
TIG	Tungsten Inert Gas
TIR	Total Indicated Runout
TOR	Top of Rail
TPSS	Traction Power Substation
TVM	Ticket Vending Machine
TWC	Train to Wayside Communication
UBC	Uniform Building Code
UDFCD	Urban Drainage and Flood Control District
UFC	Uniform Fire Code
UL	Underwriters Laboratories, Inc
UPS	Uninterruptible Power Supply
USASI	United States of America Standards Institute
USDCM	Urban Storm Drainage Criteria Manual
USDOT	United States Department of Transportation
VPI	Vacuum Pressure Impregnation
VSWR	Voltage Standing Wave Ratio
WB	Wet Bulb

1.7.0 UNITS OF MEASURE

A	Ampere
Amp	Ampere
BTU	British Thermal Unit
CFS	Cubic feet per second

dB	Decibel
dBA	Decibel on the 'A' weighted scale
FC	Foot-candles
ft	Foot or feet
ft/min	Foot per minute
ft^3/mi	Cubic feet per minute (or cfm)
ft^3/sec	Cubic feet per second (or cfs)
g	Acceleration due to Gravity (32.2 $ft/s^2 = 9.81\ m/s^2$)
gpm	Gallons per minute
H	Hour
Hz	Hertz
In	Inch
J	Joule
kg	Kilogram
kHz	Kilohertz
km	Kilometer
km/h	Kilometer per hour
kWh	Kilowatt hour
l	Liter
lb	Pound
lbf	Pound force
m	Meter
MHz	Mega Hertz
mi	Mile
mph	Miles per hour
mphps	Miles per hour per second
min	Minute
mm	Millimeter
mV	Millivolt
μV	Microvolt
N	Newton
oz	Ounce
pcf	Pound per cubic foot
plf	Pound per linear foot
psf	Pound per square foot
psi	Pound force per square inch
s	Second
sec	Second
sq ft	Square Feet (or sf)

V	Volt
V_{ac}	Volt alternating current
V_{dc}	Volt direct current
°C	Degree Celsius
°F	Degree Fahrenheit

SECTION 2 – OPERATIONS PLAN

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2.1.0 GENERAL

RTD's objective is to operate all LRT and bus routes safely, reliably and efficiently and to integrate LRT operations with bus service for the greatest convenience to the public. The LRT system is a means by which the integration of transportation services will assist the region in meeting clean air standards, alleviating traffic congestion and improving the overall quality of life in the area.

The LRT system has been designed to address transportation needs of the public in the Denver metropolitan area. The most recent addition to the LRT system is the Central Platte Valley Light Rail Spur (CPV LRT Spur), a 1.8 mile long light rail segment that provides an alternative route into downtown Denver and also provides direct light rail access through the rapidly growing Central Platte Valley and to downtown Denver. This segment opened in April 2002 and is a welcome addition to the Central Corridor and Southwest Corridor that opened in 1994 and 2000, respectively. Due to the complexities of a growing system, RTD introduced a letter and color designation for easier customer recognition. Currently the C Line (Orange) operates between Mineral Station and Denver Union Station. The D Line (Green) operates between Mineral Station and 30th/Downing Station with alternate weekday peak hour trips turning in downtown Denver on 19th St. Both lines operate on common track between Mineral Station and the Junction near Colfax Avenue. The C Line swings to the West and serves the Auraria Administration Building, Invesco Field at Mile High football stadium, Pepsi Center/Six Flags Elitch Gardens with the terminus at Denver Union Terminal in Lower Downtown Denver serving many thousands of sports and entertainment spectators attending events at Invesco Field, Pepsi Center, and Coors Field. The D Line turns easterly at the Junction and northeasterly into central Downtown, and serves the Auraria Campus at the Colfax at Auraria Station, the Performing Arts Center and new Colorado Convention Center before bisecting downtown by running along California Street northbound, and Stout St. southbound conveniently serving the large employment population in Central Downtown and the Welton St. community.

The Southeast Corridor (T-REX) is a 19 mile long extension of light rail originating at I-25/ Broadway Station and extending south along I-25 to Lincoln Avenue in northern Douglas County, with a spur on I-225 connecting from the light rail on I-25 to Parker Road. T-REX also includes highway and access improvements. This corridor has been in Final Design and under construction since 2001. In December 2006, T-REX will realize its final major milestone when Southeast Corridor Light Rail opens to the public. The new line will expand RTD's existing light rail system and extend light rail service along the southeast corridor of I-25 and I-225. An extensive bus feeder system will make it easy for people to get to and from the 13 new light rail stations. Bridges and underpasses will provide pedestrian access to several of the stations.

2.2.0 MAINLINE

The LRT is a conventional light rail transit system extending from 30th Avenue and Downing Street and Denver Union Station from the north to Littleton/Mineral Station on the south. Operations through downtown Denver are contra-flow relative to normal traffic, with trains heading northeasterly on California Street and southwesterly on Stout Street. The LRT provides direct connections between the light rail stations and Arapahoe Community College, Downtown Littleton, Englewood Civic Center, Broadway Marketplace, Auraria Campus, Colorado Convention Center, the 16th Street Mall, (Market Street Station and Civic Center Station), Five Points, the Auraria Administration Building, the Invesco Field at Mile High football stadium, Pepsi Center/Six Flags Elitch Gardens with the terminus at Denver Union Terminal in Lower Downtown Denver serving many thousands of sports and entertainment spectators attending events at Invesco Field, Pepsi Center, Coors Field, and many major hotels and businesses in between. The addition of T-REX in 2006 introduces rail service to University of Denver students and faculty, thousands of employees at the Denver Tech Center, Greenwood Plaza Office Park, Inverness, and Meridian Office Parks, the Ritchie Center at DU, the Coors Events Center (formerly Fiddler's Green), Park Meadows Mall and the Colorado Center.

The Design Engineer shall coordinate with RTD specific requirements for future corridors which include pocket track, tail track, end of line geometries, maximum speed, consists, minimum headway and cross over locations.

2.3.0 LRT STATIONS

As part of the initial LRT Central Corridor project, 14 passenger stations were constructed along the 5.3 mile corridor. A new station was added at 27th and Welton in late 1995. With the construction of the Southwest Corridor, an 8.7 mile extension to the Central Corridor, 5 new stations were added to the alignment in July 2000. The 1.8 mile Central Platte Valley extension, which opened in 2002, added 4 stations. All station platforms are unattended and utilize automated fare machines for ticket sales and ticket validation. This self-service proof of payment system is monitored by Fare Inspectors. Platform security is provided by Light Rail Transportation Supervisors and local jurisdictional Police Departments, as part of their normal duties. A private contract security service also rides the trains and patrols all stations and park and rides. When T-REX opens in 2006, 19 miles of LRT will be added and 13 more stations will be added at Louisiana, University, Colorado, Yale, Southmoor, Belleview, Orchard, Arapahoe, Dry Creek, County Line, Lincoln, Dayton and Nine-Mile and all, but Louisiana Station, will have new or expanded park-n-rides providing 6,000 parking spaces along the corridor.

2.4.0 LRV FLEET

Presently, RTD has a fleet of light rail vehicles (LRV) to service the Central, Southwest, and Central Platte Valley Corridors. Additional vehicles will be delivered by March 2006 for use on the Southeast Corridor. The LRV has 6-axles, is single-articulated, double-ended, and bi-directional. They are approximately 80 feet in length, 8 feet 9 inches in width, 13 feet high and weigh approximately forty (40) tons. These vehicles operate on a standard railroad track gauge of 4 feet 8 1/2 inches. They are powered from an overhead wire by

750VDC (nominal) direct current and capable of speeds up to 55 mph. Each vehicle can seat 64 passengers and will accommodate up to an additional 61 standing passengers at normal loads. Additional standees may be accommodated at a crush load capacity.

2.4.1 Operations

LRVs on the RTD alignment are operated manually. Automatic block wayside signals, traffic signals, radio communication, operational procedures and train orders govern operators regarding all movements of the vehicles. Appropriate street traffic signals, speed limit signage and wayside signals assist the operator in selecting proper movement sequence and speeds. Powered switches are operated by operators via carborne equipment. All city street operations are by line of sight. City street crossings coordinate adjacent street intersection traffic signals. High speed crossings are protected using gate crossings with flashers and warning bells. Medians have also been installed at crossings to prevent traffic from driving around active gates. Gated crossings shall be monitored and recorded by video equipment. Multiple crossings are jointly used and maintained by the Union Pacific Railroad and RTD.

2.4.2 Transit Integration

The system is operated by (RTD) as part of a fully integrated mass transit system which includes local bus routes, express bus routes, regional routes, shuttle bus routes and demand-response service for passengers with disabilities. RTD provides transit services to one of the largest geographical districts in the United States. RTD has a service area of approximately 2,400 square miles and serves the City and County of Denver and Broomfield, and all or portions of Adams, Arapahoe, Boulder, Jefferson and Douglas counties. RTD serves 38 municipalities within those 7 counties and operates 176 total fixed bus routes and 11 call-n-Rides. The service area population is 2.5 million. In 2003 the RTD fleet logged over 3 million hours of service with total annual boardings (including the Sixteenth Street Mall Shuttle, Light Rail and Access-a-Ride) of over 78.9 million. The size of the service area, population density, the nature of the roadway system and the development of suburban activity centers, has led to the creation of a system with a wide range of service types intended to most effectively serve this large and diverse region.

2.5.0 HOURS OF SERVICE

The LRT system operates in revenue service from approximately 3:30 a.m. to 2:15 a.m. on weekdays. On weekends, a late trip leaves from Union Station at 2:15 a.m. Departure of the first train of the day from the yard is prior to the 3:30 a.m. service start because of the travel time required between the yard and the first passenger station stop. This train will loop the system at reduced speed and will act as a sweep train, ensuring that the alignment is free of obstruction or other problems. The arrival of the last train into the yard will occur later than the scheduled revenue hours per day due to travel time from the last in-service station to the Light Rail Operations Facility.

2.6.0 SERVICE AND VEHICLE LOAD STANDARDS

Service standards include vehicle loading standards and service frequency, and establish criteria to determine the maximum level of crowding and service frequencies that a passenger would experience on the LRT system. The load standards established for RTD's light rail service are described below:

- Peak periods – 125 passengers per vehicle
- Off-peak periods – 64 passengers per vehicle (seated load)
- Special Events -- 180 passengers per vehicle (crush load)

2.7.0 STATION DWELL TIMES

Train dwell times at each passenger station are estimated to be 20 seconds on average, which allows sufficient time for normal boarding and exiting of passengers. At certain mixed traffic stations in the Denver CBD, additional dwell time is required for both large passenger loading and unloading as well as the need to adhere to the City Traffic Signal System. Adequate layovers at terminals for operators to use the restroom and switch vehicle ends are an essential part of the operating schedules.

2.7.1 City and County of Denver (CCD) Traffic Signals

The desired LRT headways lend themselves to light cycles of 75 seconds and CCD has made the changes to adopt a 75-second light cycle throughout the day and re-timed the lights in general to support the automobile traffic flows and LRT contra-flows on California and Stout Streets.

2.7.2 Other Jurisdiction Signals

The Design Engineer shall coordinate with RTD and other jurisdictions as necessary.

2.8.0 FACILITIES AND EQUIPMENT

These criteria will provide an overview of the facilities and equipment required to operate and maintain RTD's LRT system.

2.9.0 COMMUNICATIONS EQUIPMENT

The key element of the communications system is the Supervisory and Control and Data Acquisition (SCADA) system and the radio. Each LRV operating cab and mobile units will have fixed mobile radios installed. In addition, all Train Operators, Light Rail Supervisors, Shop Supervisors and Maintenance of Way (MOW) employees working in the field will carry portable radios while on duty. Mobile and portable radios will provide two-way voice communications over channels designated for light rail use. The Operations channel will provide direct two-way communications between Central Control and all train operations personnel. A separate Maintenance channel may be utilized for communications between Maintenance personnel in the course of their activities and for exclusive use by operators/supervisors/maintenance personnel in moving vehicles during abnormal operations (dead car tow, foul weather, etc.) or other situations which may present a safety hazard.

In addition to the radio channel for Light Rail operations, a Bus Operations channel and Supervisors' channel may be utilized by Light Rail Operations for security or coordination with Bus Operations Dispatch whenever required.

Additional communication equipment includes:

- Emergency and public pay telephones are provided on some platforms for passenger use. Telephones will also be used in Central Control for emergency contact of Fire/Police and emergency medical services. Public pay telephones shall not be included on new platforms, but may be located near them. See Section 14 for emergency telephone requirements at new stations.
- Public Address (PA) equipment will be used for announcements on the LRVs, in the yard and the Maintenance shop.
- Automatic Vehicle Locator (AVL) will be utilized on LRVs and other mobile units as required.
- Public Address (PA) systems and variable message signs (VMS) will be utilized on selected platforms.
- Fax Machine: Central Control (located at the Mariposa facility) will utilize fax for receiving and sending information.

2.9.1 SCADA

The SCADA system provides for overall control and monitoring of traction power facilities, signals, station platform CCTV, ticket vending machines intrusion and fault alarms, passenger information systems and security systems. Information and signals for the SCADA system are transmitted through fiber optic cables with communications houses located at various points along the ROW.

2.10.0 TRAIN TO WAYSIDE COMMUNICATIONS SYSTEM

The train-to-wayside communication system will be used for providing routing wherever there are powered switches. The signals and switches on the operator's console provide the operator information regarding the status of the route and the ability to make changes in the switch positions. This is accomplished via street imbedded loops, interrogator equipment and carborne transponders. This enables the operator to make changes in the route quickly and safely thus enabling service schedule adherence in the event of abnormal operations. This same equipment may also be utilized in the build out of a rapid transit system to preempt traffic signals.

SECTION 3 – CIVIL ENGINEERING

SECTION 3 - CIVIL ENGINEERING

3.1.0 GENERAL

The Design Criteria establish the minimum standards to be used in the design of RTD's LRT system.

The criteria presented herein were developed considering safety, accepted engineering practices, passenger comfort, ride quality and protection for the LRT system.

3.2.0 CONTROL SURVEY

3.2.1 Horizontal Control

The Horizontal Control for all alignments shall be coordinated with and approved by RTD. All projects shall use a "Project Coordinate Base" for field stationing. Minimum accuracy of survey work based on the control network shall be one part in 20,000 for linear measurements and 5 seconds per transit station for angular measurements. Legal descriptions of transit right-of-way (ROW) shall be tied into the established property lines of adjacent properties and on established section monumentation. The coordinate system will be approved by RTD at the beginning of the project.

3.2.2 Vertical Control

The Vertical Control for all projects shall be based on the North American Vertical Datum of 1988 (NAVD 88).

Where proposed work is to be in a certain relationship to an existing structure or facility, elevations of the existing structure or facility shall be established by field survey and tied to existing benchmarks.

The error of closure in feet for establishment of vertical elevations shall not exceed $0.05\sqrt{M}$, where M is the distance in miles.

3.3.0 CLEARANCES

3.3.1 General

The criteria developed in this section apply to the design of the entire system. All designs shall provide not less than the minimum clearances as specified in this section.

Assurance of adequate and appropriate clearance for the passage of light rail vehicles (LRV) throughout the mainline trackage, switches and special trackwork, stations, storage yards and operations facilities is one of the most fundamental concerns inherent in the design process and must be rigorously monitored during the construction phase. Design criteria for clearances are complex and are based on numerous assumptions and interfaces.

It is in the development of clearance requirements that the build-up of concurrent, multiple tolerances must be scrutinized and balanced with the practicality of available space and other functional requirements. The clearance requirements in this Design Criteria seek to make that balance.

3.3.2 Public Utilities Commission (PUC) Approvals for LRT Crossings

The construction, operation and maintenance of the LRT, as it crosses at, above, or below any "public highway" (which term shall be interpreted to include pedestrian walkways, bicycle paths, equestrian trails, and roadways for motor vehicles, as well as overcrossings and undercrossings of the same), are subject to approval by the PUC pursuant to Section 40-4-106, Colorado Revised Statutes (C.R.S.). In order to expedite the issuance of such approval a General Concept Application shall be prepared of those anticipated LRT/public highway crossings and submitted to the PUC for approval. LRT crossing analysis for PUC approval shall include but not limited to the following:

- Gated crossings
- Track signalization implementation and supporting data
- Cross-sections
- Warning devices
- Submittal chain
- Traffic study/analysis

In addition the General Concept Application shall include but not be limited to the following:

- Plan Drawing showing the public crossing of the LRT alignment
- Property owners and their legal addresses on all four corners affected by the public/LRT crossing
- An elevation drawing showing the proposed horizontal and vertical clearances of the LRT envelope with the public crossing for both at-grade and grade-separated crossings, which includes, but is not limited to, street crossings, cross sections and clearance envelopes.
- If the crossing includes any structures, details of the type of structure shall be included in both the plan view and elevation views

3.3.3 Clearance Envelope

See Section 4 - Trackwork, General Track Alignment and Clearances.

3.4.0 STREET DESIGN

3.4.1 General, Horizontal & Vertical Geometry and Public Streets

Unless otherwise specified, all road and street design including horizontal and vertical geometry and public street roadway sections, shall be in accordance with the current specifications and design guidelines of the involved local jurisdictions (or CDOT in the case of State Highways). For those cases where the local jurisdictions have no design guidelines, the most current versions of the Colorado Department of Transportation (CDOT) Design Guide and/or the Policy on Geometric Design of Highways and Streets by the American Association of State Highway and Transportation Officials (AASHTO) shall be used.

3.4.2 Clearance to LRT Facilities

Where the LRT corridor is located adjacent and parallel to roadway facilities, then the standards presented in the System Safety and System Security Sections 14.7, 14.8 and 14.9 of this Design Criteria shall apply.

Clearance height shall be in accordance with RR, CDOT and local jurisdictional requirements.

3.4.3 Signs, Bollards and Markers

Where ROW permits, signs, bollards and markers shall conform to the clearance requirements listed in Section 4. Breakaway units shall be used where the installation is in a location exposed to traffic, except where the purpose is protection of passengers (e.g., at platform ends).

3.4.4 Pavement

All pavements in public streets shall be in conformance with the current specifications and practices of the involved local jurisdictions (or CDOT in the case of State Highways). In a case where the local jurisdictions have no codes or standards, the CDOT Pavement Design Manual or the Metropolitan Government Pavement Engineers Council (MGPEC) criteria shall be followed. Pavement on RTD owned property shall be in conformance with the standards and specifications presented in the RTD Design Guidelines and Criteria for Bus Transit Facilities.

3.4.5 Traffic Signals

3.4.5.1 Codes and Standards

All relocations, temporary or permanent, and restoration of traffic signal facilities shall be in accordance with the practices of the involved local jurisdictions (or CDOT in the case of State Highways). In the case where the local jurisdictions have no standards, the Manual on Uniform Traffic Control Devices (MUTCD), as modified by the State of Colorado, shall be followed.

3.4.5.2 New and Existing Signal Installations

New traffic signal installations shall provide for all required auto and pedestrian movements in addition to signal preemption that may be required for LRVs. All existing signals shall be modified to accommodate any revisions to auto and pedestrian movements and signal preemption for LRVs where required. All revisions shall be compatible with the involved local jurisdiction's traffic signal control program (or CDOT in the case of State Highways).

3.4.6 Signs and Striping

All signs and striping in public streets shall be in conformance with the current specifications and practices of the involved local jurisdictions. In a case where the local jurisdictions have no standards, the MUTCD, as modified by the State of Colorado, shall be followed.

3.4.7 Curb Ramps and Curb Cuts

The Design Engineer shall obtain approval from the local jurisdiction or proper authority for the geometry and locations of curb cuts.

The design of curb cuts and curb ramps shall be in strict accordance with the applicable provisions of the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG).

Curb cuts are to be included when curbs in public space are constructed or restored as part of the LRT Project.

Walkway, highblock and structural access ramps shall not exceed 4.75%.

3.4.8 Roadway/LRT At-Grade Crossings

The Design Engineer shall coordinate with the local jurisdiction and with the Colorado PUC during the design of at-grade roadway crossings.

3.5.0 DRAINAGE

3.5.1 General

This section provides standards for the design of drainage facilities associated with the LRT infrastructure and systems impacted by development of new LRT systems. Drainage facilities may include storm sewer, cross-culverts, detention ponds, water quality ponds and open channels that may serve the LRT, adjacent properties or may be a part of a regional drainage system.

The purpose of drainage facilities associated with LRT and the goal of the LRT drainage Design Engineer is to protect the LRT infrastructure, protect public safety, and to protect other public and private property from damage caused by flooding. All signal, OCS equipment, TES equipment and communication equipment shall be protected from major storm events. Such protection shall be provided in accordance with locally and regionally accepted engineering standards and practices, as modified for LRT by the standards presented in this Design Criteria Manual.

Facilities shall be designed according to the criteria of the agency in whose jurisdiction each project or section of project is located. For work located within or adjacent to CDOT ROW, CDOT standards as specified in the CDOT Drainage Design Manual shall be followed. If local jurisdictions do not have applicable criteria or standards, the designer shall use the design standards and technical criteria presented in the Urban Drainage and Flood Control District's Urban Storm Drainage Criteria Manual (UDFCD USDCM) Volumes 1, 2 and 3, and the CDOT Drainage Design Manual. Facilities shall be designed in cooperation with local jurisdictions.

3.5.2 Hydrologic Criteria

Unless otherwise noted, hydrologic criteria used in design of LRT facilities shall be in accordance with the Urban Drainage and Flood Control District's Urban Storm Drainage Criteria Manual (UDFCD USDCM).

3.5.2.1 Minor and Major Storm Drainage Facilities

The minor storm drainage system transports runoff from minor frequency storm events with minimum disruption to the urban environment. The minor storm may be conveyed in curb and gutter, ditches and storm sewer. The 5-year event shall be the minor design storm for LRT facilities.

The major storm drainage system shall be designed to convey runoff from the 100-year frequency storm event to minimize health and life hazards, damage to structures and interruption of services.

LRT and appurtenant facilities shall be designed for both recurrence intervals with the following criteria:

- LRT drainage facilities shall be designed to protect the LRT system, all parts of LRT trackway and LRT stations from flooding due to the major storm. LRT trackway and station platforms shall not be located in a 100-year floodplain, and conveyance systems adjacent to LRT trackway shall be designed so that the ballast shall not be inundated during a 100-year event. The LRT trackway (including paved and ballasted sections) shall not be used for conveyance of stormwater. Where located within roadways, LRT trackway drainage shall be coordinated with the roadway drainage system.

- For facilities appurtenant to the LRT, including roadways and parking lots, the minor storm drainage system shall be designed for the 5-year recurrence interval storm. The major storm system shall be designed for the 100-year recurrence interval storm. Park-n-Ride facilities are addressed in the RTD Design Guidelines and Criteria for Bus Transit Facilities.

3.5.2.2 Runoff

Design peak runoff rates shall be determined using methods specified by the criteria of the local jurisdiction. If a method is not specified by the local jurisdiction, the Rational Method or the Colorado Urban Hydrograph Procedure (CUHP) and Storm Water Management Model (SWMM) as presented in the USDCM shall be used, as applicable.

3.5.2.3 Federal Emergency Management Association (FEMA) Regulatory Floodplains

Facilities that cross or are adjacent to a FEMA-regulated flood zone shall use FEMA jurisdictional flows in facility design. Facilities shall be designed in accordance with the floodplain ordinance of the local drainage authority. The design shall include preparation of the documentation required for submittal of CLOMR application, and preparation of LOMR documents, if required.

3.5.3 Hydraulic Criteria

All storm sewer, hydraulic structures and appurtenances shall be designed in accordance with the design standards and technical criteria of the local jurisdiction, as modified in this section.

Drainage design shall consider areas adjacent to the tracks where elements such as streets, parking facilities, roads, landscaping, walls, etc. may have an impact on the drainage of the trackway area.

Special attention shall be directed to providing drainage in all track areas. Ditches, grated inlets, curb and gutter, storm sewers and/or underdrains shall be provided along the track alignment to prevent water from ponding or covering any part of the track structure, or contributing to subgrade instability. Trackside ditches shall be provided wherever possible. Minimum ditch grades shall be 0.3%.

3.5.3.1 Design Storms

Facilities shall be designed for the design storm frequencies discussed in Section 3.5.2.

3.5.3.2 Replacement of Existing Facilities

Necessary replacement of existing storm drainage facilities shall, at a minimum, provide services equivalent to the existing facilities. New facilities shall be designed in accordance with the current design standards of the jurisdictional authority. Services to adjoining properties shall be maintained at all times during construction.

3.5.3.3 LRT Trackway

Standard trackway drainage is shown in Figure 3-1 and 3-2. Ditches shall be located parallel to the trackway to convey trackway drainage and to intercept runoff entering the ROW.

Stormwater runoff from off-site areas shall be intercepted and conveyed out of the ROW in ditches and storm sewer, and shall not be conveyed in trackway underdrains.

The design hydraulic grade line (HGL) in ditches adjacent to the trackway for the 100-year event shall not be above the top of subgrade during the peak 100-year runoff.

3.5.3.4 Storm Sewer

All storm sewer or culverts crossing under the LRT ROW shall be constructed with Class V Reinforced Concrete Pipe (RCP). The minimum pipe diameter shall be 15 inches.

Plastic and metal pipe shall not be used without RTD approval. Variances shall be based, in part, upon the ability of the material to withstand light rail loading and to resist corrosion due to stray current.

Storm sewer constructed outside of the LRT trackway shall be constructed with Class III or better RCP.

Storm sewer shall be placed with a minimum clearance of 5 feet from top of rail to top of pipe unless otherwise approved by RTD. The 100-year energy grade line (EGL) in the storm sewer system shall be below the top of subgrade. The Design Engineer shall include EGLs/HGLs on all storm sewer and ditch profiles.

Cross-culverts under the LRT trackway shall have a maximum headwater to depth ratio of 1.5. The EGL in cross-culverts shall be below the top of subgrade for all areas adjacent to the trackway.

Any structures that vary from agency standards, including manholes, junction boxes, inlets, vaults or other structures shall be subject to acceptance by RTD for maintenance. For storm sewer construction through contaminated subsurface materials, consideration shall be given to pipe design features, such as a pipe lining system, to eliminate infiltration of contaminated groundwater into the storm pipe.

Storm drainage facilities for the LRT shall be designed for an expected functional life of 50 years as a minimum.

3.5.3.5 Inlets

Inlet boxes and grates within the LRT trackway shall be designed for LRT loading. Inlets shall not be placed in paved trackway adjacent to station platforms. Flangeway drains or trench drains shall not be used within paved trackway unless approved by RTD.

Inlet grates located within the LRT trackway shall be designed to prevent ballast rock from passing into the storm sewer system. Inlets located directly adjacent to the trackway shall be designed with a ballast retaining wall between the inlet and the track, or shall be constructed with ballast-proof grates.

Inlet grates in pedestrian areas shall be heel-proof and non-slip. Bicycle-safe grates are required where bicycle traffic will occur.

Inlets shall be located in sumps rather than on grade wherever possible. Inlets shall be located at the low points of the profile. The design 100-year ponding depth over inlets in parking areas, driveways and roadways shall not exceed 9 inches.

3.5.3.6 Underdrains

Where ROW constraints do not allow use of the standard ditch section, underdrains may be used. Underdrains shall be sized based on a hydraulic analysis of local drainage. Underdrains shall consist of perforated concrete or perforated plastic pipe. Underdrain pipes shall be a minimum of 6 inches in diameter for lengths less than 500 feet, and a minimum of 8 inches in diameter for lengths greater or equal to 500 feet. The perforated pipe shall be surrounded by a minimum 4 inches of crushed rock or gravel drainage material. The underdrain systems shall be wrapped with a filter fabric (minimum weight 4 ounces per square yard) by placing the fabric between the gravel drain material and the subgrade. Underdrain depth and cover shall be in accordance with RTD Standard Drawings. Underdrain clean outs, pipes and culverts shall be designed and located to facilitate maintenance and to reduce the possibility of becoming clogged. The distance between cleanouts shall not exceed 200 feet or as required by local code. See Figure 3-1.

The designer shall check the HGL of the system where the underdrain outfalls to confirm that the 100-year HGL of the downstream system will not allow the introduction of stormwater into the trackway subgrade through the underdrain system. Flap gates shall not be used in underdrain systems.

Underdrain systems constructed for the purpose of intercepting groundwater shall not be connected to the storm sewer system unless approved by RTD.

3.5.3.7 Station Platforms

The designer shall minimize the amount of offsite runoff entering trackway in station areas and avoid placing inlets within station platforms. Inlets that are located within platform areas shall be constructed for HS-20 loading and shall be installed with pedestrian friendly, heel-proof grates.

3.5.3.8 Park-n-Rides

See the RTD Design Guidelines and Criteria for Bus Transit Facilities for Park-n-ride drainage design criteria.

3.5.3.9 Rail Embankment Edge Treatment

Underdrains shall be provided adjacent to track in areas where more than 50 feet of trackbed width contributes runoff to a fill slope. Concentrated flow from underdrains and storm sewer shall be conveyed down the slope in pipe or rundowns to prevent erosion of the embankment.

3.5.4 Bridges/Structures

3.5.4.1 Retaining Walls

Retaining wall drainage shall be coordinated with the retaining wall structural designer. Concentrated flows shall not be allowed to discharge behind any retaining wall. Such flows shall be intercepted and conveyed down to grade before reaching the wall.

Underdrains shall be provided adjacent to track supported on MSE walls.

3.5.4.2 Bridges

Bridge deck drainage shall be in accordance with the criteria presented in the CDOT Bridge Design Manual, Subsection 16.1, and the FHWA publication HEC-21, Design of Bridge Deck Drainage.

Drainage of elevated LRT bridges from the deck down to the local system shall be conveyed to an approved point of discharge, which may include storm sewer, ditch, roadway, channels or other approved conveyance system.

Bridge deck drainage systems for LRT bridges are required to meet the following criteria:

- The flow across expansion joints in a 5-year event shall not exceed 0.2 cfs. Where track is directly fixed to the bridge deck surface, the depth of bridge deck surface flow in a 100-year event shall not exceed the elevation of the bottom of the rail at any location on the bridge deck surface. All gutter flow at both ends of bridges shall be intercepted in a 100-year event. Storm water flowing toward or leaving the bridge shall be intercepted prior to the approach slab.

All deck drain inlets shall be grated. Inlets shall be sized to intercept the design storm runoff and allow no bypass. The drainage system shall be compatible with the structural reinforcement components and aesthetics of the bridge. Outfalls shall be positioned to avoid corrosion of structural members, erosion of embankments, and splash on moving traffic (vehicular, train, and sidewalk) areas below the bridge. Downspouts shall be galvanized steel pipe 10-inch minimum diameter for bridge drains and shall meet the requirements of ASTM A53; they shall be standard weight (Sch. 40). Downspout pipe shall be hot dipped galvanized after fabrication. Galvanizing shall meet the requirements of AASHTO M111. Gray iron castings shall conform to the requirements of AASHTO M105, class 30. Ductile iron castings shall conform to the requirements of ASTM A536. Grade shall be optional unless otherwise designated. Structural steel shall conform to the requirements of AASHTO M183. Cleanouts shall be provided for downspout systems in a manner as to provide access to all parts of the deck drainage system.

The Design Engineer shall consider the use of trench drains at the ends of all direct-fixation bridges. The use of trench drains at the ends of direct-fixation bridges shall be evaluated on a case by case basis and approved by RTD.

All drainage components located in the trackbed and on grade separation structures (i.e. bridges, tunnels, cut and cover structures, etc.) shall be designed and installed following the guidelines pertaining to stray current stated in this Design Criteria.

Bridge deck drainage shall be intercepted and conveyed to ground in downspout systems. Wherever possible, bridge deck drainage systems shall discharge directly to existing drainage systems, rather that discharging directly onto the ground surface.

3.5.4.3 Bridges over Drainageways

Bridge abutments and piers located within the floodplain shall be designed to withstand scour during a 100-year storm event. The potential for scour shall be evaluated in accordance with the FHWA publications HEC-18 and 21.

Bridges and structures across FEMA regulated floodplains shall be designed so that impacts to the floodplain are within allowable limits in accordance with the criteria of FEMA and the local floodplain ordinance. Bridges and structures across floodways that are not FEMA regulated shall be designed so that the improvements shall not adversely impact upstream or downstream properties.

3.5.5 Detention Facilities

Detention facilities shall be provided in accordance with local criteria. If the local jurisdiction does not have detention facility design criteria, the UDFCD USDCM criteria shall be used. Underground detention shall not be used unless approved by RTD in writing. If the LRT facilities are located within an area served by regional detention facilities, detention shall be provided under the terms associated with those facilities.

3.5.6 Water Quality

Structural water quality facilities shall be provided for stations to meet the requirements of the local jurisdiction. Water quality facilities shall be combined with stormwater detention facilities, unless required otherwise by the appropriate jurisdiction, and shall be designed with consideration for aesthetics and ease of long-term maintenance. Underground facilities (such as water quality vaults and inlets) shall not be used unless approved by RTD.

3.5.7 Pump Stations

The use of pumping stations shall not be permitted unless approved by RTD, and shall be used only where storm water removal by other means is not feasible. Pump stations shall be designed to protect LRT facilities in accordance with the criteria presented in Section 3.5.2 of this Design Criteria. The FHWA publication Highway Stormwater Pump Station Design (Hydraulic Engineering Circular 24) shall be used for pump station design. The extent of the 100-year storm shall be determined and safeguards against flooding shall be provided.

A storage reservoir shall be incorporated with the pump station design. The maximum water level in storage shall be more than 2 feet below the lowest grate elevation in the tributary system. The configuration shall provide for screening out debris and a minimum of 3 pumps. Pump equipment and controls shall be explosion proof, corrosion resistant and appropriate for the application. Backup systems for power, control and pumping shall be provided.

The design shall include access for ordinary maintenance, including provisions for replacing pumps. The pump house shall have locked doors, fence and gate for security and an adequate ventilation system. The design shall eliminate the need for confined space entry as defined by OSHA and NIOSH where possible. The site layout shall address mitigation of aesthetics and noise. The installed equipment shall be certified and tested prior to acceptance. Operation and maintenance manuals for the facility shall be provided by the Contractor.

Pump station equipment shall be connected to RTD's SCADA system.

3.5.8 Erosion Control

A Stormwater Management Plan (SWMP) for erosion control Best Management Practices (BMP) during construction is required for all projects. If the local jurisdiction does not require prepared plans, SWMPs will be the responsibility of the LRT construction Contractor.

SWMPs will be prepared in accordance with the standards and criteria of the local jurisdiction and with the State of Colorado Department of Public Health and Environment (CDPHE) requirements. The LRT construction Contractor shall be responsible for obtaining local permits and coverage under the CDPHE Stormwater General Permit for Construction Activities.

All erosion control activities shall comply with the conditions of RTD's Light Rail Corridor Stormwater Management Program.

3.5.9 Easements

All storm sewers crossing the LRT ROW that serve upstream properties shall become the ownership of the local jurisdiction. Where such storm sewer facilities are located outside of public ROW, license agreements shall be prepared for the conduit crossing.

The Design Engineer shall identify any temporary or permanent easements required to construct and maintain storm water drainage facilities. The Design Engineer shall coordinate easements with RTD's Property Management Division.

3.5.10 Permits

404 Permit - Acquisition of an individual or nationwide permit required for construction of the LRT corridor and appurtenant facilities shall be the responsibility of the Design Engineer, unless otherwise excluded in the Contract Requirements.

Erosion Control Permits - The Design Engineer shall prepare materials as necessary for inclusion of the LRT corridor in RTD's Municipal Separate Storm Sewer permit. Acquisition of state and local stormwater discharge permits required for construction shall be the responsibility of the construction Contractor, unless otherwise specified in the Contract Requirements.

3.6.0 UTILITIES

3.6.1 General

This section establishes design standards for the relocation, adjustment, and abandonment of existing utilities, and the construction of new utilities, within the LRT ROW. In general, such work will be designed by the utility owners. Some utilities, such as water and sanitary sewer utilities required for new LRT construction will be designed by RTD's Design Engineer in coordination with the utility owner. Water service shall be provided to the station platforms. Consideration shall be given to the need to provide electrical power to the traction power substations. No new or existing utilities shall be located within the trackway or within the limits of track pavement, except for the purpose of crossing the tracks. The utility design engineer shall provide corrosion protection in the design and construction of new utilities that cross the LRT trackway. Refer to Section 10 - Stray Current/Corrosion Control for design criteria.

3.6.2 General Design Guidelines

The following general design guidelines shall be followed for all utility work.

- Depth of cover under the LRT envelope shall be a minimum of 5 feet from the top of rail to the top of all utilities (top of encasements, if encased), unless otherwise approved by RTD.
- Utilities encountered or located close enough to be affected by transit construction shall be:
  - Protected in place;
  - Temporarily relocated; or
  - Permanently relocated
- Maintain utility service continuity to abutting property or subject said property to the least interruption practicable. Utility relocations shall be designed to provide service equal to that offered by the existing facility. No betterments shall be included, unless approved by RTD.
- All pressurized pipelines crossing the LRT and pipes carrying flammable or volatile substances shall be encased. The length of the casing pipe shall extend across the width of the ROW. Casing pipes shall be designed to withstand LRT loadings, and shall be coated with a suitable material to provide cathodic protection. See Figure 3.3 for LRT loadings. See Figures 6.1 through 6.6 for typical cross-sections and Figure 6.7 for the zone of influence. The Design Engineer shall coordinate with RTD's Utility Engineer for casing pipe specifications.
- No encasements are required for pipelines greater than 10' below LRT track ties.
- All crossing utilities shall cross beneath the LRT ROW at 90° to the LRT centerline unless approved by RTD. Manholes, valves, and other utility-related appurtenances requiring periodic maintenance or operation should not be placed within the LRT ROW. Such features shall be relocated outside of a zone 10 feet either side of centerline of track during new LRT construction.
- All new or relocated utilities shall be placed so that the edge of excavation is no less than 10 feet to the centerline of track. See Figures 6.1 through 6.6 for typical cross-sections and Figure 6.7 for the zone of influence.
- All non-metallic buried utilities shall have detection aids or tone wires within LRT ROW for field-locating buried pipes.
- All abandoned pipes beneath the trackbed shall be plugged and filled with flow-fill or other suitable material approved by RTD.
- All relocation, restoration and construction of utility improvements shall be in conformance with the current standards and specifications of the responsible local and state jurisdiction or utility agency and shall comply with other applicable codes.
- All utility work shall be coordinated through RTD with the appropriate city, county or utility agency.

- Utilities located over the LRT ROW will not be allowed unless specifically requested and approved by RTD. Design of approved utilities located over LRT ROW shall be approved in writing by RTD.

During new LRT construction, all water service lines that cross the LRT ROW shall be placed in a sleeve with a minimum diameter 2 inches larger than the service line. Sleeves shall be constructed without vertical or horizontal bends or curves, shall be capable of withstanding LRT loading, and shall be constructed to allow for future replacement of the service line within the sleeve.

During new LRT construction, utility agencies may elect to encase utilities crossing the LRT ROW that may otherwise not require encasement. Pursuant to license agreements and easements, such construction shall be done at the expense of the affected agency, as required, and shall conform to these criteria. Each end of the encasement shall terminate outside the LRT ROW and shall have sufficient additional length that future excavation of either end of the encasement will not extend into LRT ROW.

3.6.3 Coordination

RTD will coordinate design of installation of new or the relocation of existing utilities between RTD and all impacted utility agencies. Utilities designed by the utility agency will be submitted to RTD for review and approval. Generally, a design review and utility coordination process will be as follows:

1. A preliminary drawing of the utility owner's preferred new or relocation alignments and requirements will be prepared by the utility owner and submitted to RTD for review.
2. RTD will review the utility design requirements and preferred alignment and issue a draft composite utility map showing proposed utility alignments and orientations from various utility agencies.
3. Each utility will respond to RTD with either acceptance of proposed alignments and orientations or submittal of a request for further alteration.
4. RTD will issue a final composite utility plan showing utility orientations. The final design of each utility will then be developed on this basis by the utility owner.

Utilities designed by RTD will be submitted to the utility agency for approval and coordination. Construction plans for utility relocations will be approved by the utility agency that owns the affected utility.

3.6.4 License Agreements and Easements

The placement of any utility within RTD owned ROW requires an Easement, Permit or License Agreement for that utility from RTD, depending upon the circumstances. Easements, Permits and License Agreements are issued through RTD's Property Management Division. Each Easement, Permit or License Agreement shall require the grantee to provide RTD as-built drawings in CADD format for the utility and grantee emergency contact information. As-built drawings shall be in conformance with RTD's CADD Standards.

The replacement or modification of an existing utility shall be considered a new utility installation, and the utility owner shall conform to the standards and criteria for new utilities as presented in this Design Criteria. The Easement, Permit or License Agreement must be renewed per above.

3.6.5 Relocation of Utilities

In the event RTD's construction requires the relocation of a utility located within RTD's ROW, the relocation will be evaluated on an individual, case by case basis considering at a minimum the following factors:

- the right by which the utility is located in RTD ROW prior to construction;
- the ability of RTD to provide an alternate location within RTD ROW;
- the responsibility of who performs actual relocation; and
- who pays for the relocation.

3.6.6 LRT Utilities

3.6.6.1 Codes and Standards

All utilities specifically designed for the LRT shall conform to the standards, codes, and requirements of the local jurisdiction within which the LRT utilities are located.

3.6.6.2 General Design Guidelines

Final design of the LRT utilities shall be done by RTD's Design Engineer. Design approvals from the local jurisdictions and public utility agencies shall be coordinated through RTD.

The design of the LRT utilities shall conform to the appropriate design guidelines indicated in Sections 3.6.1 through 3.6.6 of these criteria.

3.7.0 CONCRETE

For reinforced concrete, precast concrete, and prestressed concrete structures other than structures subjected to LRT, railroad or highway loading, the "Building Code Requirements for Reinforced Concrete (ACI 318)", hereinafter referred to as the ACI Code, shall be followed.

For mildly reinforced concrete structures, the "Building Code Requirements for Structural Concrete (ACI 318)" shall be followed.

Portland Cement Concrete Pavement shall conform to the requirements for Class P concrete as specified in Section 601 of CDOT – Standard Specifications for Road and Bridge Construction.

3.8.0 STRUCTURAL STEEL

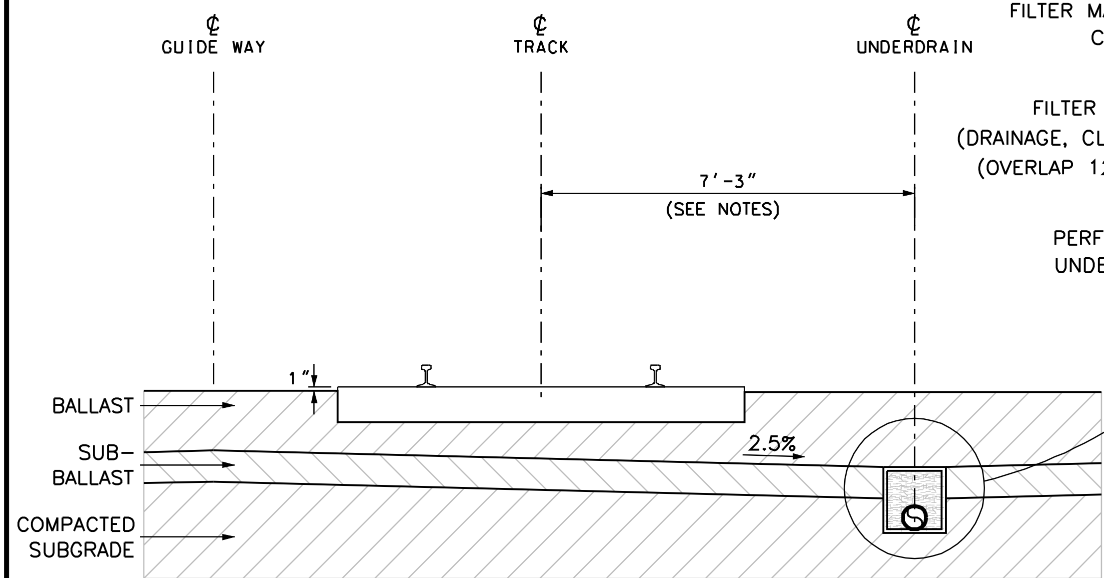
For structural steel structures other than structures subjected to LRT, railroad or highway loading, the Specifications for the Design, Fabrication and Erection of Structural Steel for Buildings of the American Institute of Steel Construction, hereinafter referred to as the AISC Code, shall be followed.

LIST OF FIGURES

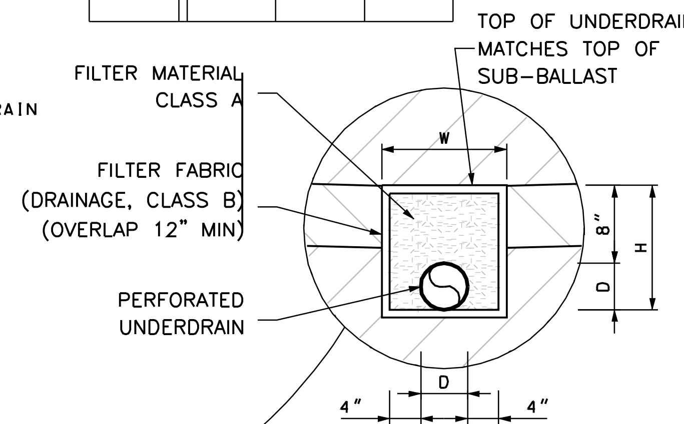
NOTES:

1. SUB-BALLAST TO SLOPE TOWARD SIDE DRAIN AT 2.5%
2. FOR UNDERDRAIN IN MSE FILL SECTIONS, SEE MSE DETAIL SHEETS.
3. DESIGNER MUST CALCULATE Y IF DISTANCE IS DIFFERENT THAN 7'-3"

UNDERDRAIN TABLE			
PIPE SIZE D	6"	8"	10"
W	1.17'	1.33'	1.5'
H	1.17'	1.33'	1.5'
Y	3.37'	3.53'	3.70'



TYPICAL UNDERDRAIN



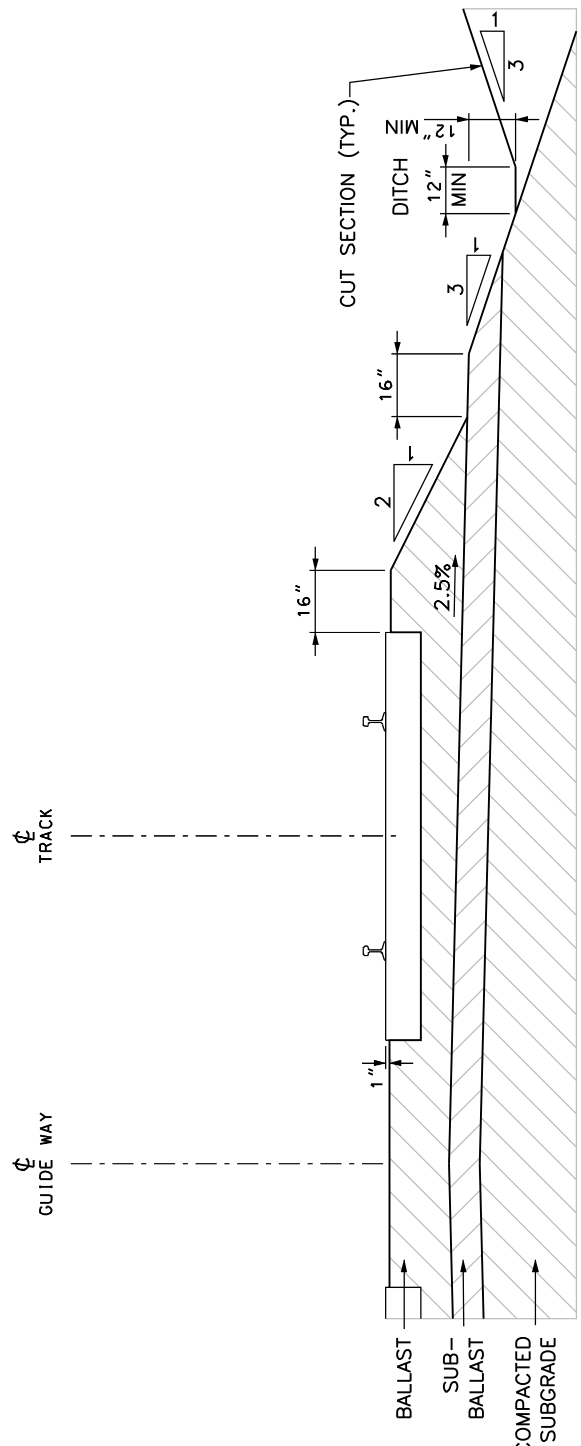
UNDERDRAIN DETAIL

RTD

DESIGN CRITERIA

TITLE: TYPICAL UNDERDRAIN

FIGURE: 3.1



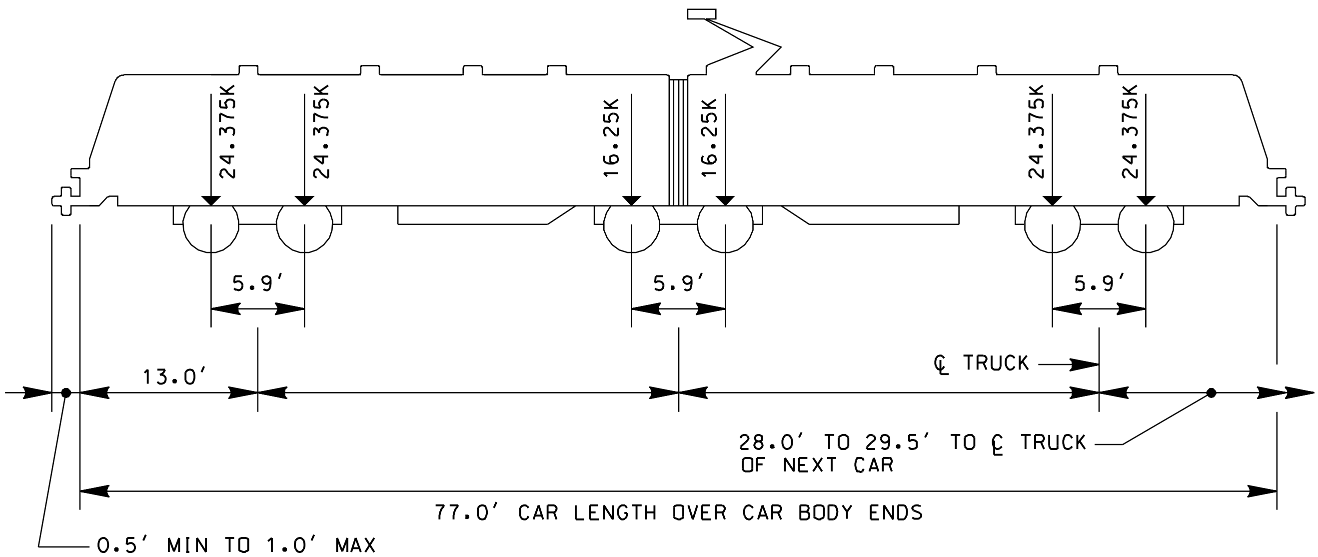
TYPICAL DITCH

RTD

DESIGN CRITERIA

TITLE: TYPICAL DITCH

FIGURE: 3.2



NOTE:

1. TOTAL CRUSH LOAD 130 KIPS/CAR
2. MAXIMUM LOADING WILL OCCUR WHEN (2) THREE-CAR TRAINS PASS EACH OTHER ON ADJACENT TRACKS

RTD

DESIGN CRITERIA

TITLE: LRV LOADING DIAGRAM

FIGURE: 3.3

GROUP	GAMMA FACTOR	BETA FACTORS																	
		D	(L+I) H	(L+I) P	(L+I) RT	(L+I) DR	(L)RT	CF	E	B	SF	W	WL	NF	LF	PS	R+S+T	EQ	ICE
1H	1.30	D	1.67	0	1	0	0	1	E	1	1	0	0	0	0	0.77	0	0	0
1PC	1.30	D	0	1	1	0	0	1	E	1	1	0	0	0	0	0.77	0	0	0
1PW	1.30	D	1	1.15	1	0	0	1	E	1	1	0	0	0	0	0.77	0	0	0
1RT	1.30	D	0	0	1	0	0	0	E	1	1	0	0	1	0	0.77	0	0	0
II	1.30	D	0	0	0	0	0	0	E	1	1	1	0	0	0	0.77	0	0	0
III	1.30	D	1	0	1	0	0	1	E	1	1	1.3	1	1	1	0.77	0	0	0
IV	1.30	D	1	0	1	0	0	1	E	1	1	0	0	0	0	0.77	1	0	0
V	1.25	D	0	0	1	0	0	0	E	1	1	1	0	0	0	0.80	1	0	0
VI	1.25	D	1	0	1	0	0	1	E	1	1	1.3	1	1	1	0.80	1	0	0
VII	1.00	1.0	0	0	0	0	0	0	E	1	1	0	0	0	0	1.00	0	1	0
VIII	1.30	D	1	0	1	0	0	1	E	1	1	0	0	0	0	0.77	0	0	1
IX	1.20	D	0	0	0	0	0	0	E	1	1	1	0	0	0	0.83	0	0	1
X	1.30	D	1.67	0	1	0	0	0	E	0	0	0	0	0	0	0.77	0	0	0
XI	1.30	D	0	0	0	1	1	1	E	1	1	0	0	0	0	0.77	0	0	0

RTD

DESIGN CRITERIA

TITLE: LOADING GROUPS

FIGURE: 3.4

SECTION 4 – TRACKWORK

SECTION 4 - TRACKWORK

4.1.0 GENERAL

This section of the Design Criteria details minimum standards and design policies to govern the engineering, materials and construction standards for trackwork and its interfaces with other elements of RTD's LRT system. The interfacing elements of the system include but are not limited to, trackway, stations, structures, traction power, communications, signal systems and drainage. Except for the requirements established in these criteria and RTD's CADD Standards, construction plans and specifications shall generally follow the AREMA Manual for Railway Engineering and Portfolio of Trackwork Plans and the Transit Cooperative Research Program (TCRP) Report 57 "Track Design Handbook for Light Rail Transit", modified as necessary to reflect the physical requirements and the operating characteristics of RTD's LRT system. Track construction and maintenance standards shall at all times exceed the current track safety standards of the Federal Railroad Administration (FRA).

In addition, where the LRT operates in a public street or shares its right-of-way (ROW) with buses, the design requirements and concepts of AASHTO, CDOT, Colorado State's Public Utility Commission (PUC) and the local municipality shall also be utilized.

This Design Criteria takes into consideration many factors including passenger comfort, vehicle-operating envelope and track safety requirements. Passenger comfort requirements normally will drive the final track geometry design. For this reason, there are desired RTD maximum and minimum values and absolute maximum and minimum. The desired values are based on passenger comfort, initial construction cost and maintenance considerations. Absolute values are determined primarily by the vehicle design, with passenger comfort a secondary consideration.

The track designer shall make every attempt not to exceed the desired values outlined in this design criteria manual. Where desired values cannot be met, absolute values may be used with prior written RTD approval.

4.1.1 Track Gauge

Track gauge shall be a standard gauge of 4 feet 8-1/2 inches. The gauge is the distance between the inner sides of the head of rails measured 5/8 inches below and perpendicular to the top of rail (TOR). LRT track construction tolerances shall comply with Figure 4.1.

The track gauge shall be widened by 1/4 inch for all curves requiring restraining rails with a radius less than 500 feet. Although the restraining rail is primarily designed to reduce rail wear, it also inhibits lateral vehicle movement. Therefore no allowance will be made in the clearance calculation for the gauge widening.

4.2.0 GENERAL TRACK ALIGNMENT

The track alignment shall be designed to maximize passenger ride quality at the highest permissible operating speeds. Where cost, geometric or other physical constraints permit, the Design Engineer shall establish alignment, superelevation and track clearance conditions which will permit 60 mph operation in the future by adjusting the actual superelevation.

The LRT track alignment for each line section shall be stationed along the centerline of track North Bound "NB". Stationing along track "NB" shall be the basic control for locating all other system facilities along the route. Separate stationing shall be used for track "SB" where tracks are neither parallel nor concentric, where widened track centers are required around curves, or where tracks are in separate structures. The stationing along track "SB" shall be equated to track "NB" at the points where parallel alignment resumes. For East/West track, the East Bound (EB) will be the basic control.

4.2.1 Horizontal Track Alignment

In general the horizontal alignment shall consist of tangent sections connected by circular curves with spiral transition curves unless otherwise approved by RTD.

4.2.2 Tangent Sections

The minimum length of tangent track between curved sections is based on passenger comfort and vehicle truck/wheel forces. Based on the AREMA Manual, Chapter 5, the minimum length is equal to the longest car that will traverse the system. Due to the forces between the trucks/wheels on the light rail vehicle (LRV) it is recommended that all trucks be on tangent track before negotiating a curve, at a minimum two sets of trucks should be on tangent track.

The minimum length of tangent between curved sections (except those with compound curves) shall be as follows:

TABLE 4A – TANGENT LENGTHS BETWEEN CURVED SECTIONS

Condition	Tangent Length
Desirable Minimum	200 feet
*Minimum	100 feet or 3 times the design speed (in mph), whichever is larger
Absolute Minimum	50 feet

(* Not to be exceeded without prior written RTD approval)

(not applicable with compound curves)

The minimum length of tangent track preceding a point of switch shall be as follows:

TABLE 4B – TANGENT LENGTHS PRECEDING A POINT OF SWITCH

Condition	Tangent Length
Desirable Minimum	50 feet
*Minimum	30 feet
Absolute Minimum	12 feet

(* Not to be exceeded without prior written RTD approval)

The horizontal and vertical alignment shall be tangent along all station platforms and continue a minimum of 50 feet from the end of platform.

All special trackwork shall be located on horizontal tangent track.

4.2.3 Curved Sections

4.2.3.1 Circular Curves

Circular curves are required to connect tangent track alignments. Circular curves for LRT designs shall be defined by the arc definition of curvature, and specified by their radius rather than the degree of curvature. If a comparison between curve radius and degree of curvature is required the following conversion approximation can be made:

$$D_c = \frac{5729.578}{R} \qquad R = \frac{5729.578}{D_c}$$

Where:

R = radius of curvature

D_c = degree of curvature

The minimum curve radius is determined by the characteristics of the LRV. The distance between the truck centers on the LRV play the critical role in determining minimum radius. For RTD's LRVs the absolute minimum curve radius is 82 feet.

It is recommended that curved sections of track be designed with a radius greater than 500 feet since track maintenance and wheel squeal is drastically increased on small radius curves. For curves with a radius less than 500 feet restraining rail will be required, see Section 4.4.8.

The minimum radius for a given curve is based on design speed, length of spiral and superelevation through the curve.

TABLE 4C – MINIMUM CURVE RADII

Condition	Curve Radius
Desirable Minimum	500 feet
Absolute Minimum	82 feet

The desired minimum length in feet of each curve element (spiral, simple curve, spiral) is 3 times the maximum speed in mph, or 100 feet whichever is longer.

4.2.3.2 Spiral Curves

Spiral curves shall be provided between circular curves with radii less than 10,000 feet and horizontal tangents. Spirals shall be Barnett or Talbot as defined by the AREMA Manual for Railway Engineering. See Figure 4.2 for spiral nomenclature.

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

1. $L_s = 1.63\ E_u V$
2. $L_s = 33\ E_a$
3. $L_s = 60$ feet

Where

L_s = Length of spiral curve (in feet)
E_a = Track superelevation for the circular curve (in inches)
E_u = Unbalanced superelevation for the circular curve (in inches)
V = Design Speed (in mph)

If the minimum spiral length obtained above is less than 1/100 of the curve radius, then spirals may be omitted with prior RTD approval.

4.2.3.3 Superelevation

Mainline tracks are designed with superelevations that permit desired design speeds to be achieved without resorting to excessively large curve radii. The design speed criteria stated below are based on a maximum lateral passenger acceleration of 0.1 g.

$$E_t = E_a + E_u = \frac{4V^2}{R} = 0.0007\ V^2 D_c$$

Where:

- E_t = Total superelevation required to balance the centrifugal force at a given speed (in inches)
- E_a = Actual track superelevation to be constructed (in inches)
- E_u = Unbalanced superelevation the difference between E_t and E_a (in inches).
- V = Design Speed (in mph)
- R = Radius of Curve (in feet)
- D_c = Degree of Curve

The amount of E_u shall vary gradually as follows:

$$E_u = 1.33 \frac{V^2}{R} + 0.67$$

$$E_a = 2E_u - 2$$

Actual track superelevation (E_a) shall not exceed 6 inches with a desired 4 inch maximum.

A minimum of 1/2 inch of superelevation should be used on all mainline curves with radii less than 10,000 feet. Exceptions with RTD approval only.

Unbalanced superelevation (E_u) shall not exceed 3 inches with a desired 1.5 inch maximum. Actual superelevation should be attained and removed linearly throughout the full length of the spiral transition curve by raising the outside rail while maintaining the inside rail at the rail profile grade. Superelevation shall not extend in tangent track without RTD approval.

Yard tracks shall not be superelevated.

4.2.3.4 Reverse Curves

Reverse curves without tangent track between them shall be avoided on mainline track. Every attempt shall be made to use standard circular curves and spirals with tangent sections as described in Sections 4.2.2 and 4.2.3. For those sections where reverse curves must be used, the following criteria may be used with prior RTD approval:

- Reverse curves shall have spiral transition curves that meet at the point of reverse curvature, with the rate of change of superelevation constant through both of the spiral curves.

- If either of the reverse curves is less than 170 feet in radius, each spiral shall be at least 62 feet in total length. The length of spirals shall conform to the criteria in Section 4.2.3.2.
- The superelevation transition through the spirals shall be accomplished by sloping both rails through the entire transition, as shown in Figure 4.3.

4.2.3.5 Compound Circular Curves

Compound circular curves may be used provided that they are connected by an adequate spiral transition curve. In order to provide a comfortable ride at lower speeds, the superelevation of the circular curve should be maintained through the spiral transition curve. The length of the spiral curve shall be determined by the criteria in Sections 4.2.3.2 and 4.2.3.3.

For high-speed conditions where the spiral transition curves are longer, a differential in the superelevation of the two circular curves may be allowed, provided the design does not compromise safety or riding comfort and has prior approval from RTD. For this condition, the minimum length of spiral shall be the greatest length of spiral determined from the criteria in Section 4.2.3.

The minimum length of spiral between compound circular curves shall be 62 feet. Spiral transition curves need not be used between compound circular curves when:

$R_L - R_s$ less than or equal to $0.34\ (R_s/V)^2$

Where:

R_L = Radius of the larger curve (in feet)

R_s = Radius of the smaller curve (in feet)

V = Design Speed (in mph)

4.2.4 Clearances

4.2.4.1 General

The criteria developed in this section apply to the design of the entire system. All designs shall provide not less than the minimum clearances as specified in this section.

Assurance of adequate and appropriate clearance for the passage of LRVs throughout the mainline trackage, switches and special trackwork, stations, storage yards and operations facilities is one of the most fundamental concerns inherent in the design process and must be rigorously monitored during the construction phase. Design criteria for clearances are complex and are based on numerous assumptions and interfaces.

It is in the development of clearance requirements that the build-up of concurrent, multiple tolerances must be scrutinized and balanced with the practicality of available space and other functional requirements.

The Design Engineer shall confirm that all structural elements provide adequate clearance for the rail maintenance of way (MOW) equipment.

4.2.4.2 Clearance Envelope

The clearance envelope (CE) represents the space in or into which, other than the LRV, no physical part of the system may be placed or constructed or may protrude. The clearance envelope is normally referenced from, or represented by its relationship to, the theoretical centerline of track at TOR.

Clearance on Tangent Sections:

Horizontal clearance from the centerline of the track shall be no less than 6 foot 2 inches in tangent sections.

CE = 6’2” (tangent)

Clearance on Curved Sections:

Clearance on curved sections shall be calculated and or computer modeled to insure that the nose, tail and mid section of the LRV does not “chord” the curve less than the tangent CE. There are several methods of calculating the appropriate distance. The method needs to be approved by RTD prior to design acceptance.

For horizontal curves with spirals, the tangent clearance envelope shall end 50 feet before the point of Tangent-to-Spiral (TS) and 50 feet after the point of Spiral-to-Tangent (ST). The full curvature clearance envelope shall begin 25 feet prior to the point of Spiral-to-Curve (SC) and end 25 feet beyond the point of curve-to-spiral (CS). The horizontal component of the vehicle dynamic envelope between these two offset points (i.e., 50 feet before TS and 25 feet before SC) shall be considered to vary linearly with distance between the two points. Horizontal offsets at intermediate locations shall be calculated with straight line interpolation. For horizontal curves that do not include spiral transition curves, the full curvature clearance envelope shall begin

50 feet prior to the Point of Curvature (PC) and extend to 50 feet beyond the Point of Tangency (PT). More detailed computer simulations with more precise geometry may be used, subject to RTD approval, to define the clearance envelope in place of these 25 foot and 50 foot locations and straight line interpolations. The clearance envelope through turnouts shall be calculated based on the turnout centerline radius.

Superelevation correction (e) = 2.15 inches per inch of actual superelevation (E_a) at car mirror, but not to exceed 10 inches for outside end overhang, 1.15 inches per inch of E_a at 5.5 feet above TOR.

4.2.4.3 Special Clearance Situations

In addition to the more routine clearance envelope determinations above, there are several special clearance situations warranting further attention and definition. These special situations include undercar clearances, vehicle interface at station platforms, and general walkway areas along the ROW where applicable.

a) Undercar Clearances

Vertical undercar clearance is defined from TOR with the maximum suspension deflection and car body roll, minimum vertical curve radius and fully worn wheels. The minimum vertical undercar clearance envelope shall be in accordance with Section 13.2.4.2.

b) Station Platform Interface

The relationship of the vehicle at rest and the station platform is one of the most fundamental interfaces in any rail transit system. Horizontal and vertical static clearances or gaps (between platform edge and vehicle step) determine the ease of boarding/alighting for passengers, and platform edges often must be placed within the strict confines of clearance envelopes so as to permit safe and practical passenger movement.

Highblocks: The station platform interface shall include a platform edge located 65 inches horizontally from centerline of track and 38 inches vertically from TOR with a tolerance of +0.5 inches vertically and 0.0 inches horizontally from track centerline on tangent track.

Curb Loading: The station platform interface shall include a platform edge located 55 inches horizontally from centerline of track and 6 inches vertically from TOR with a tolerance of +0.5

inches vertically and 0.0 inches horizontally from track centerline on tangent track.

c) Walkways along Structures and Tunnels

An emergency/maintenance walkway shall be provided along structures and tunnels in accordance with Section 14.8. There shall be at least one walkway per track. Single track structures only need one walkway. This walkway shall be above Top of Tie and below TOR at the track edge and shall be located at a horizontal distance from track centerline as determined by regulations. The walkway shall have a minimum width of 30 inches.

d) Walkway Area along Trackway

In addition to the clearance envelope requirements per Section 4.2.4.2, it is desirable that space be provided for maintenance walkways adjacent to the trackway. The walkway envelope shall extend at least 2 feet-6 inches from the edge of the clearance envelope and shall extend to 6 feet-6 inches above the walkway. Unless otherwise approved by RTD, walkways shall be provided on both sides of the ROW, and shall permit unobstructed passage from which passengers can be evacuated. For walkway clearance calculations only, traction power poles shall not be considered a permanent obstruction. If there are two parallel grade separated single track structures, the requirement is to have a minimum 30 inch walkway on each structure.

This requirement is not applicable to paved track sections in street ROW.

e) Track Centers with Center Poles

For open track with center traction power poles, the track centers shall be calculated based on the appropriate clearance envelopes, a design width for the traction power poles of 14 inches, and lateral deflection due to loading of 0.75 inches below 15 feet from TOR and 1.0 inch above 12 feet from TOR.

Figure 4-6 provides a simplified outline of the dynamic envelope of the LRV.

4.3.0 VERTICAL TRACK ALIGNMENT

4.3.1 General

Vertical alignment shall be defined by the "top-of-rail profile" along tangent sections and the low rail in superelevated sections. Parabolic vertical curves having a constant rate of change in grade shall be employed for changes in gradient.

4.3.2 Grades

Grades shall not exceed the maximums specified below:

TABLE 4D – MAXIMUM VERTICAL GRADES

Condition	*Desirable Maximum	Absolute Maximum
Mainline Track	3.5%	6.0% (not more than 2500 ft)
Stations	1.0%	2.5%
Yard	0.0%	0.5%
Storage Track	0.0%	0.25%
Special Trackwork	0.0%	4.5%

(* Not to be exceeded without prior written RTD approval)

All tracks entering the yard shall be pitched downward away from the main line, or dished to prevent any vehicles from rolling onto the mainline tracks.

Grade shall be equalized to the most practical extent possible.

The minimum length of constant profile grade between vertical curves shall be determined as follows:

$$L_g = 3V$$

Where:

L_g = Minimum length of constant profile grade (feet)
V = Design velocity through tangent (miles per hour)

Absolute minimum L_g shall be 90 feet, unless otherwise approved by RTD.

4.3.3 Vertical Curves

4.3.3.1 Length of Vertical Curves

The minimum length of vertical curve shall be determined as follows:

$L = 70(G_1-G_2)$ for V greater than or equal to 35
$L = 40(G_1-G_2)$ for 15 less than or equal to $V < 35$

$L = 20(G_1 - G_2)$ for $V < 15$

Where:

L = Length of vertical curve (in feet)
$(G_1 - G_2)$ = Algebraic difference in grades (%)
V = Design Velocity (in mph)

Standard Vertical Curves are shown in Figure 4.7.

The minimum length of any vertical curve shall be as follows:

TABLE 4E – VERTICAL CURVES – MINIMUM LENGTH

Condition	Length of Vertical Curve
*Desirable Minimum	200 feet
Absolute Minimum	150 feet

(* Not to be exceeded without prior written RTD approval)

Vertical curves shall not exceed the limits identified in Section 4.3.3.4.

4.3.3.2 Reverse Vertical Curves

Reverse vertical curves may be used provided the minimum length of each curve is not less than that defined by Section 4.3.3.1, and prior RTD approval has been obtained.

4.3.3.3 Compound Vertical Curves

Compound or non-symmetrical vertical curves may be used provided the requirements of Section 4.3.3.1 are met, and prior RTD written approval has been obtained.

4.3.3.4 Combined Vertical and Horizontal Curves

A four-car train shall be capable of negotiating a combined (horizontal and vertical) curved section involving:

- 82 foot radius horizontal curve and 1640 foot vertical curve either crest or sag.
- 89 foot radius horizontal curve and an 1150 foot vertical sag curve.
- 95 foot radius horizontal curve and an 820 foot vertical crest curve.

Combined horizontal and vertical curves shall not be more restrictive than these absolute minimum requirements.

4.4.0 MAINLINE TRACK

For typical track sections, refer to Figures 4.8, 4.9 and 4.10.

4.4.1 Subgrade

The subgrade 11 feet both sides of track centerline shall be compacted to a minimum density of 95% of the maximum density determined in accordance with AASHTO T 180. The subgrade shall be in a moist condition (within ±2% of the optimum moisture content as determined by AASHTO T 180.

If laboratory results indicate that existing material is unsuitable, the material must be removed and replaced with clean, sound and properly compacted material, per ASTM standards.

The compacted subgrade shall be sloped at 40:1 downward and away from the center point located midway between the two tracks in double track territory. In single track areas, the compacted subgrade shall slope toward the underdrain at 40:1. Refer to Figures 4.8, 4.9 and 4.10 for typical subgrade configurations.

Configurations other than those mentioned above may be adopted if drainage requirements or specific locations dictate a special treatment with prior RTD approval.

4.4.2 Subballast

Subballast is the transition zone between the subgrade and the ballast. The subballast acts as a barrier filter separating the ballast section from the subgrade material. This material plays an integral role in the track structure. The quality of the subballast has a direct relationship to the overall performance of the track structure. This layer acts as a drainage median for the track bed.

An 8 inch layer of subballast shall be installed on top of the subgrade. The subballast shall conform to AREMA specifications. Subballast should extend the full width of the subgrade and at a minimum 24 inches past the toe of the ballast.

4.4.3 Geotextile Fabrics

Geotextile fabrics shall be placed under all special trackwork (on the mainline and in the yard) and tracks with potential subgrade stability issues. Fabric will extend the entire interface zone between the ballast and subballast. Fabric will extend 20 feet before point of switch and 10 feet after the last long tie. Geotextile fabric specifications shall be as recommended by a Geotechnical Engineer.

4.4.4 Ballast

No. 4 (1-1/2 inches to 3/4 inches) and or No. 3 (2 inches to 1 inch) ballast conforming to AREMA specifications shall be used on all main tracks except for those in streets and yards, where No. 5 (1 inch to 3/8 inch) ballast will be used. All ballast is to be thoroughly washed and or re-screened (0.5% maximum passing #200 sieve) as necessary to remove fine particles prior to placement.

A minimum depth of 8 inches of ballast shall be used between the bottom of ties and top of the subballast. The ballast shoulder shall extend 16 inches beyond the ends of the ties parallel to the plane formed by the top of the rails. Ballast shoulder shall then slope downward to the subballast at a 2:1 slope. The final top of ballast elevation shall be one inch below the top of tie, when compacted. Refer to Figures 4.8, 4.9 and 4.10.

Ballast shall be placed in-between track, around platforms and other areas where the tracks are splayed out.

4.4.5 Concrete Cross Ties

Mainline tracks shall use concrete cross ties, approximately 8 feet 3 inches in length and 7 inches by 9 inches in cross section spaced 30 inches, center to center. Tie spacing through curves with less than 1000 feet radii shall be 27 inches. All concrete cross ties shall conform to AREMA specifications.

4.4.6 Timber Switch Ties

Timber switch ties shall be of various lengths conforming to the specific requirements of the turnouts used. Anti-splitting devices shall be used on all wood ties. Ties shall be free of twist, bow and detrimental splitting.

4.4.7 Rail

Rail for all mainline track shall be 115 RE section, new Premium or Standard rail manufactured in accordance with current AREMA specifications (See Figure 4.11). Used No. 1 or new IQ rails may be used in yard and other non-main tracks.

High Carbon (0.90% Carbon minimum) rails shall be used in all special trackwork and on all curves of radii equal to or less than 600 feet and extending into the spiral until the point of radius on spiral exceeds 600 feet. High Carbon rails shall not be installed on seldom used emergency or storage tracks, even though they may satisfy the above criteria. High Carbon rails may be used in other locations where excessive rail wear is anticipated.

All rails shall be ground to remove mill scale from the top and gauge side profile of the rail head prior to the start of integrated/acceptance testing.

Rail in curves of radii equal to or less than 300 feet shall be precurved using standard shop practices.

4.4.8 Restraining Rails

Restraining rails are used to provide continuous support to LRVs negotiating sharp radius curves. This use of restraining rails reduces the wear to the flanges and to the rail also reducing the possibilities of a derailment.

All mainline track excluding special trackwork with a centerline radius of 500 feet or less shall have inner restraining rail mounted adjacent to the low rail in accordance with RTD plans and specifications. The flangeway shall be set at 1 7/8 inches wide to engage the back of the inside wheel. Restraining rail shall extend beyond the curve on both ends a minimum distance of 10 feet. Restraining rail shall be continuously welded (CWR) or jointed to prevent rail end offset. Restraining rail detail is shown on Figure 4.12.

Restraining rail joints shall be bolted using D-bar installation.

4.4.9 Emergency Guardrails

Emergency guardrails are used as a safety device. In the event of a derailment, the guardrail is designed to catch the inside of the wheel and guide the LRT along the track until it stops and/or to prevent derailed LRV from striking an abutment wall or any support structure. Emergency guardrails shall be installed adjacent to the inside running rail of all tracks on bridges and fills with a vertical drop of more than 3 feet. Guardrails shall also be applied where the guideway is located adjacent to major structures, unless that structure is constructed with an approved safety barrier. Emergency guardrails will not be installed within the limits of special trackwork or restraining rail. Guardrail is required under overhead bridges unless the overhead structure has sufficient crash wall protection.

Emergency guardrail shall be designed so as to retain the wheels of a derailed vehicle moving at maximum speed. The striking face of the emergency rail shall be uniformly located approximately 1 foot from the gauge line of the running rail. Guardrail shall be fastened to every second tie in ballasted track.

4.4.10 Rail Seats and Fastenings

Due to the negative return requirements, the rail seats and fasteners not only hold the rail to the ties; they also need to insulate the rail from the ground (see Figure 4.13). Concrete and wooden cross ties will use spring clips isolated from the tie using plastic insulators and placed on an insulating pad. Rail anchors will not be needed or used.

Other rail fastening methods shall be evaluated for street track, ballasted track and Special Trackwork. Direct fixation rail fasteners shall provide the required lateral and longitudinal restraint for continuous welded rail (CWR) and the electrical insulation required for the negative return current and the proper operation of 60 Hz track signal circuits. Direct fixation fasteners or concrete ties shall provide a 40:1 cant of the rail.

Direct fixation fasteners shall incorporate, or be placed on, a suitable elastomeric pad for reducing transmission of high frequency (i.e., greater than 30 Hz) loads to the support structure.

Rail fasteners for use in direct fixation special trackwork shall be of a design compatible with the standard fastener used in conventional direct fixation track.

Rail clips or other devices used in direct fixation fasteners shall produce the required longitudinal rail restraint after repeated load testing in accordance with AREMA Chapter 10, except load application angle in that test shall be 27°. The clearance envelope for direct fixation fasteners is shown in Figure 4.15.

4.4.11 Rail Welds

Rail shall be welded into CWR strings of site-specific length by the electric flash-butt or aluminothermic weld processes in accordance with AREMA specifications. The ends of the welded rail strings will then be field-welded together by the thermite welding or flash-butt process according to AREMA specifications. All welds will be ultrasonically proof tested with documentation delivered to RTD prior to service operation.

4.4.12 Rail Joints

Insulated and standard rail joints shall be placed only at locations where required to accommodate signal track circuits and connections to special trackwork. The insulated rail joints for signal operations shall be prefabricated miter cut plugs, welded into the CWR rail using the welding techniques specified in 4.4.11. Insulated plugs should be trimmed down to 14 feet. Only frogs may be bolted. Insulated joints shall use huckbolts. Any other bolted connection must be approved by RTD. In no case will joints be located within street or pedestrian crossings.

4.4.13 Rail/Switch Heaters

Electric switch heaters shall be installed on all power and spring operated turnouts in both mainline and yard tracks in accordance with requirements of the signal system. A list of approved manufacturers and types can be obtained from RTD. Others may be submitted for approval.

4.4.14 Special Trackwork

Special trackwork shall be manufactured and installed in accordance with RTD's specifications generally following AREMA plans and specifications. All frogs and flangeways shall be designed to accommodate the LRV wheel profile.

All special trackwork shall be fabricated using galvanized lag screws and Pandrol e-clips. (no spikes)

The preferred location of special trackwork is in ballasted at-grade areas. Single crossovers shall be used in lieu of double crossovers unless space restrictions dictate their use, and then only with prior approval by RTD. Special trackwork in paved track shall be kept to an absolute minimum; however, when it must be so located, it shall be designed to reduce the exposure of pedestrians to the operating mechanisms. Switch points shall not be located in areas designated as pedestrian crossings.

All special trackwork shall be located on vertical and horizontal tangents. The desirable minimum horizontal and vertical tangent distance preceding a point of switch shall be 50 feet (absolute minimum shall be 20 feet with prior RTD written approval). Special trackwork shall not be superelevated.

As special trackwork is a source of noise and vibration, its location shall be selected to minimize their effect.

Operating speed through turnouts shall be as indicated in Figure 4.16. Turnouts and crossovers for various applications shall be selected in accordance with the following criteria:

- No. 10 turnouts (19 feet-6 inch curved switch points) shall be used on mainline ballasted track. At specific locations where high-speed operation is essential No. 20 turnouts (39 feet-0 inches switch points) should be used.
- No. 8 turnouts (19 feet-6 inch curved switch points) shall be the standard mainline turnout in paved track areas.
- No. 6 turnouts (13 feet-0 inch curved switch points) shall be used on the mainline in areas where space limitations prevent the use of No. 8's with prior RTD approval.

Rail clips shall be installed in lieu of cut spikes on ties for special trackwork.

All turnouts shall use AREMA Point Detail 5100 with graduated risers. All mainline track frogs shall be of the rail-bound manganese type with high Carbon steel guardrails. Self guarded frogs are to be used in yard tracks. Paved track switch points shall be bolted to closure rails with a solid heel block.

Special drainage provisions shall be made in paved track turnouts to preclude standing water in flangeways, switch points and in switch-throwing mechanisms.

Special trackwork in paved areas shall have removable replaceable precast concrete panels throughout the special trackwork limits.

4.4.15 Paved Track

All road and street design shall be in accordance with the current specifications and design guidelines of the involved local jurisdictions. For those cases where the local jurisdictions have no design guidelines, the Colorado Department of Transportation (CDOT) Design Standards shall be used.

Corrosion preventive measures must be utilized on all embedded track components.

Trackwork located in streets shall use 115RE rail on concrete ties, except for special trackwork, which will use timber switch ties on AREMA No. 5 ballast. Figure 4.17 shows paved track with a concrete surface. Figure 4.18 shows typical section of rail connection detail in embedded track. Flangeway filler material shall have a volume resistivity of 10^{12} ohm-cm or greater. Flangeway filler shall be a "Polypro EPFLEX RAILSEAL field side spec 12-621 and gauge side 12-622" or approved equal. The flangeway filler shall be formed to tightly surround the e-clips and or other specified railroad tie fasteners. Fasteners under the flangeway filler shall be coated with a corrosion resistant material "Petrolatum" or approved equal.

Particular attention shall be directed toward proper drainage of street trackage. The adjacent surface pavement shall be designed so surface water will drain away from the track. Track drains shall be used to prevent water from standing. In areas of special trackwork, particular attention will be directed to provide drainage for the special trackwork units and switch-throwing mechanisms. When possible, track drains shall be located in tangent track.

The pavement material shall be 1/4 inches below the TOR on the field side to prevent the wheel tread from damaging the pavement material. An elastic or filler material shall be placed between the rails and pavement materials in order to prevent damage to the pavement materials and increase electrical isolation. Any application of flangeway filler shall allow for the future removal of the rail. Rail clips in paved track shall be protected from corrosion.

4.4.16 Direct Fixation Track (DF)

Direct fixation (DF) track is a ballastless track structure in which the rail is mounted on direct fixation fasteners that are attached to a concrete deck or slab. Trackwork located on DF shall use 115RE rail attached to the direct fixation fasteners using spring clips and isolated from the structure using elastomeric pad and plastic insulators.

Any grade separated structure longer than 400 feet in length, including bridges, tunnels and cut and cover structures will require DF unless otherwise approved by RTD. It shall consist of a second pour concrete plinth block and a fastening system to hold the running rails onto the concrete surface canted 1:40 toward the track centerline. An approach slab shall be provided at each transition between DF and ballasted track.

DF sections shall be designed for storm water runoff of a 100-year storm event.

4.4.17 Grade Crossings

Mainline grade crossings shall be prefabricated and made of durable, long-lasting materials. Grade crossing panels shall be constructed with due regard to removability for track maintenance, electrical isolation, to non-interference with electrical track circuits or rail fastenings, tire adhesion and slip resistance for vehicles and pedestrians.

Grade crossings shall be located on tangent track and away from special trackwork areas unless otherwise approved by RTD. Rail joints and thermite welds shall not be located in grade crossings.

Cross tie size and spacing at grade crossings shall be in accordance with the grade crossing manufacturer's recommendations.

Crosswalks shall be provided at areas where pedestrians will be crossing mainline tracks. They shall be located on tangent track, if possible, and away from special trackwork areas.

4.4.18 Maintenance Access Point

Access points for maintenance personnel and equipment shall be provided everywhere possible. Areas shall be provided at or near wayside equipment for the parking of maintenance vehicles to prevent infringing on highway travel lanes or pedestrian areas. Tail track shall be constructed with adjacent paved walkway(s), 30 inches wide and 4 inches thick.

High-rail access points shall be provided at least every 2 miles. They shall be located on tangent track and be constructed of grade crossing materials durable enough to withstand maintenance vehicles. High-rail access points shall be adequately secured to prevent unauthorized entry.

4.4.19 Track Bumping Posts

Track bumping posts shall be designed to clear the coupler and engage the car's anti-climber. They shall be installed at the ends of all stub-end yard and mainline tracks. Track bumping post shall be primed and painted yellow.

4.4.20 Rail Expansion Joints

During final design, locations where rail expansion/contraction is anticipated to present a problem (on bridges and certain sharp curves on ballasted track), shall be analyzed for methods of control. If mechanical rail expansion joints are used, the expansion capacity of the joints shall be greater than the anticipated rail movement within the full range of rail temperatures. Expansion joints must be bonded for negative return electrical conductivity.

4.4.21 Noise and Vibration

Noise and vibration shall be measured and mitigated, if necessary, according to environmental studies and the current FTA guidelines.

4.5.0 YARD TRACK

Yard tracks will be constructed to the same standards as mainline track, with the following exceptions:

4.5.1 Subballast

Subballast will not be required unless it is needed for subgrade stabilization. Use of subballast shall be as recommended by a Geotechnical Engineer.

4.5.2 Ballast

No. 5 ballast conforming to AREMA specifications shall be used on at least the top 2 inches on all yard tracks. No. 4 ballast may be used for the remainder of the section.

A minimum depth of 9 inches of ballast shall be used between the bottom of tie and top of subgrade. The top of ballast elevation shall be at least 1 inch below the base of rail yet fills the tie crib to 1 inch from top of tie. The ballasted shoulder shall extend level 18 inches level on the field side with a maximum slope of 2 foot horizontal to 1 foot vertical beyond the 18 inches. Crushed slag ballast will not be permitted.

4.5.3 Cross Ties

Yard tracks shall use timber cross ties 9 feet in length spaced 26 inches center to center, except at braced and guarded track, where spacing shall be 24 inches. All cross ties shall be size 7 inches by 9 inches and conform to AREMA specifications. Switch ties shall be of various lengths as required for a No. 6 AREMA turnout with 13 feet-0 inch switch points.

4.5.4 Rail

Yard tracks shall be constructed with 115 pound CWR new Standard or IQ (Industrial Quality). Used No. 1 rail may be used with prior RTD approval.

4.5.5 Restraining Rails

All yard track curves, with a centerline radius of 300 feet or less, shall have restraining rails mounted adjacent to the inside rail in accordance with AREMA plans and specifications.

4.5.6 Guardrails

Emergency guardrails shall be installed on tracks adjacent to all major structures that may cause extensive damage to a car in the event of a derailment or intrusion into the mainline envelope.

4.5.7 Rail Joints

Rail joints shall not be used.

4.5.8 Special Trackwork

Special trackwork shall conform to the requirements of Section 4.4.14.

All yard turnouts shall be AREMA No. 6's with 13 feet-0 inch curve switch points conforming to AREMA Point detail 5100 with graduated risers. Self guarded frogs shall be used.

The switch stand area shall have a level and sufficient area for switch tending.

The operating speed through the turnouts shall be as indicated in Figure 4.16.

4.5.9 Grade Crossings

Grade crossings shall conform to the requirements of Section 4.4.17, except yard grade crossings may consist of asphalt with flangeway liners.

4.5.10 Crosswalks

Crosswalks shall conform to the requirements of Section 4.4.17. In the yard, they may be located on curves and may consist of asphalt.

4.5.11 Yard Lighting

The yard is to be illuminated to provide a safe working environment for ultimate 24-hour operation of the facility. Yard lighting will also provide an element of security. Yard lighting shall be in conformance with local requirements.

4.5.12 Service Roads

Service roads shall be provided around the operations facility and between alternate pairs of tracks in the LRV storage areas. Service roads shall also be provided to access switches within the yard. Service roads shall be designed as applicable to the need.

4.5.13 Crew Change Platforms

Paved crew change platforms with gates shall be provided.

LIST OF FIGURES

TYPE OF TRACK	GAUGE VARIATION (1)	CROSS LEVEL AND SUPERELEVATION VARIATION (1)	VERTICAL TRACK ALIGNMENT		HORIZONTAL TRACK ALIGNMENT	
			TOTAL DEVIATION (2)	MIDDLE ORDINATE IN 62' CHORD	TOTAL DEVIATION (2)	MIDDLE ORDINATE IN 62' CHORD
MAIN LINE	± 1/8"	± 1/8"	± 1/2"	± 1/8"	± 1/2"	± 1/8"
YARD	+ 1/4" − 1/8"	± 1/4"	± 1"	± 1/4"	± 1/2"	± 1/8"

NOTES:

(1) VARIATIONS OF GAUGE, CROSS LEVEL AND SUPERELEVATION SHALL NOT EXCEED 1/8 INCH PER 31 FEET OF TRACK.

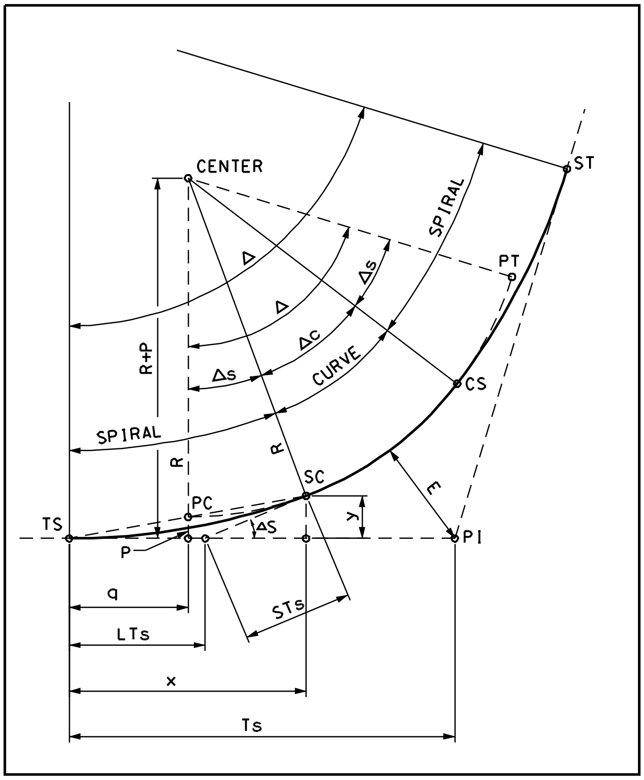
(2) TOTAL DEVIATION IS MEASURED BETWEEN THE THEORETICAL AND ACTUAL ALIGNMENTS AT ANY POINT IN THE TRACK, TOTAL DEVIATION IN STATION AREA 1/4 INCH.

RTD

DESIGN CRITERIA

TITLE: TRACK CONSTRUCTION TOLERANCES

FIGURE: 4.1



$$\Delta = \frac{DLs}{200}$$

$$i = \frac{\Delta s}{3}$$

$$s = \frac{Dl^2}{200Ls}$$

$$X = l \cos i$$

$$y = \frac{D(rad)\ Ls^2}{600}$$

$$q = X - R \sin \Delta s$$

$$P = y - R \text{ vers } \Delta s$$

$$(\text{vers})\ \Delta s = 1 - \cos \Delta s)$$

$$Ts = (R + P) \tan \frac{\Delta}{2} + q$$

$$E = (R + P) \text{ ex sec } \frac{\Delta}{2} + P$$

$$LTs = X - (y / \tan \Delta s)$$

$$STs = y / \sin \Delta s$$

$$Tc = R \tan \frac{\Delta c}{2}$$

$$D = \frac{5730}{R}$$

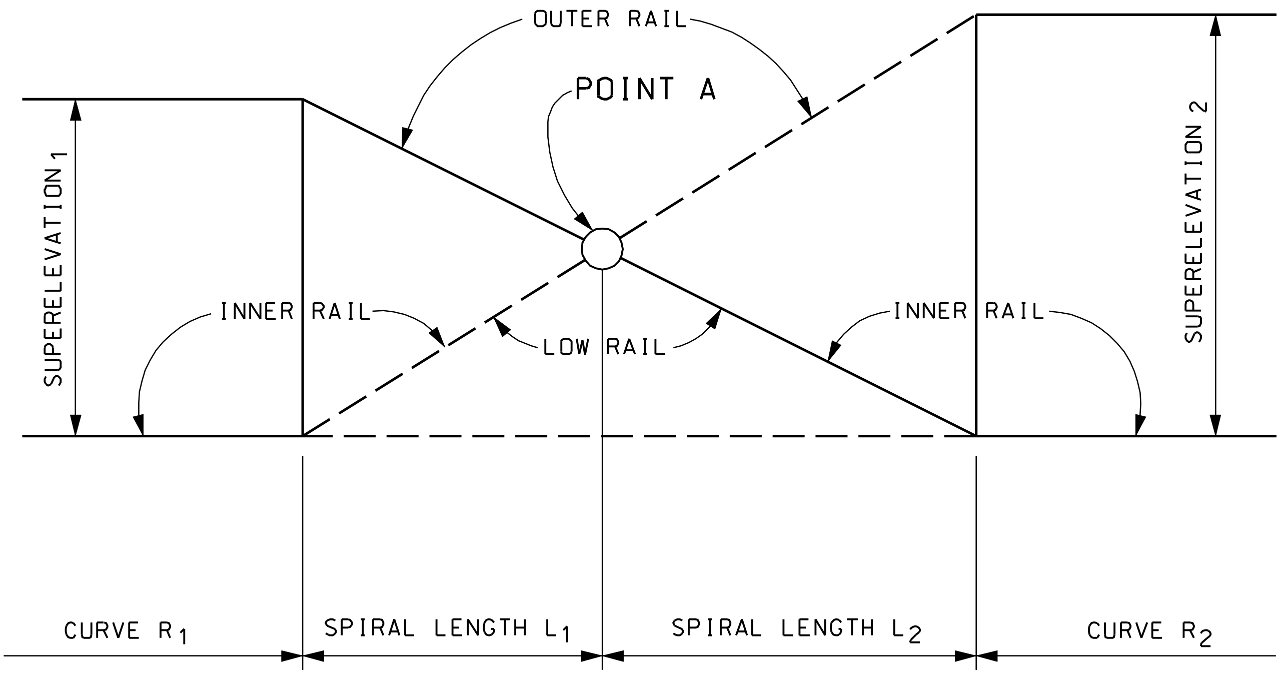
$$Lc = \frac{100\ \Delta c}{D}$$

R = radius
D = degree of curvature
P = offset of the PC/PT of simple curve, measured from main tangent of spiral
q = distance from TS/ST to the PC/PT of simple curve, measured along main tangent of spiral
X = distance from TS/ST to the SC/CS, measured along main tangent of spiral
y = offset of SC/SC, measured from main tangent of spiral
E = external distance
Ls = length of spiral arc (limiting value of l)
Lc = length of curve
l = length of spiral arc from Δ_s to any point on spiral
LTs = long tangent of spiral
STs = short tangent of spiral
Ts = total tangent distance TS/ST to PI
Δ = total central angle
Δs = total spiral central angle
Δc = simple curve central angle
i = deflection at Δ_s from tangent to any spiral point

DESIGN CRITERIA

TITLE: CURVE & SPIRAL NOMENCLATURE

FIGURE: 4.2



NOTE: ON SUPERELEVATION CURVE, TOP OF RAIL ELEVATIONS SHOWN ON PROFILE ARE FOR THE LOWER RAIL.

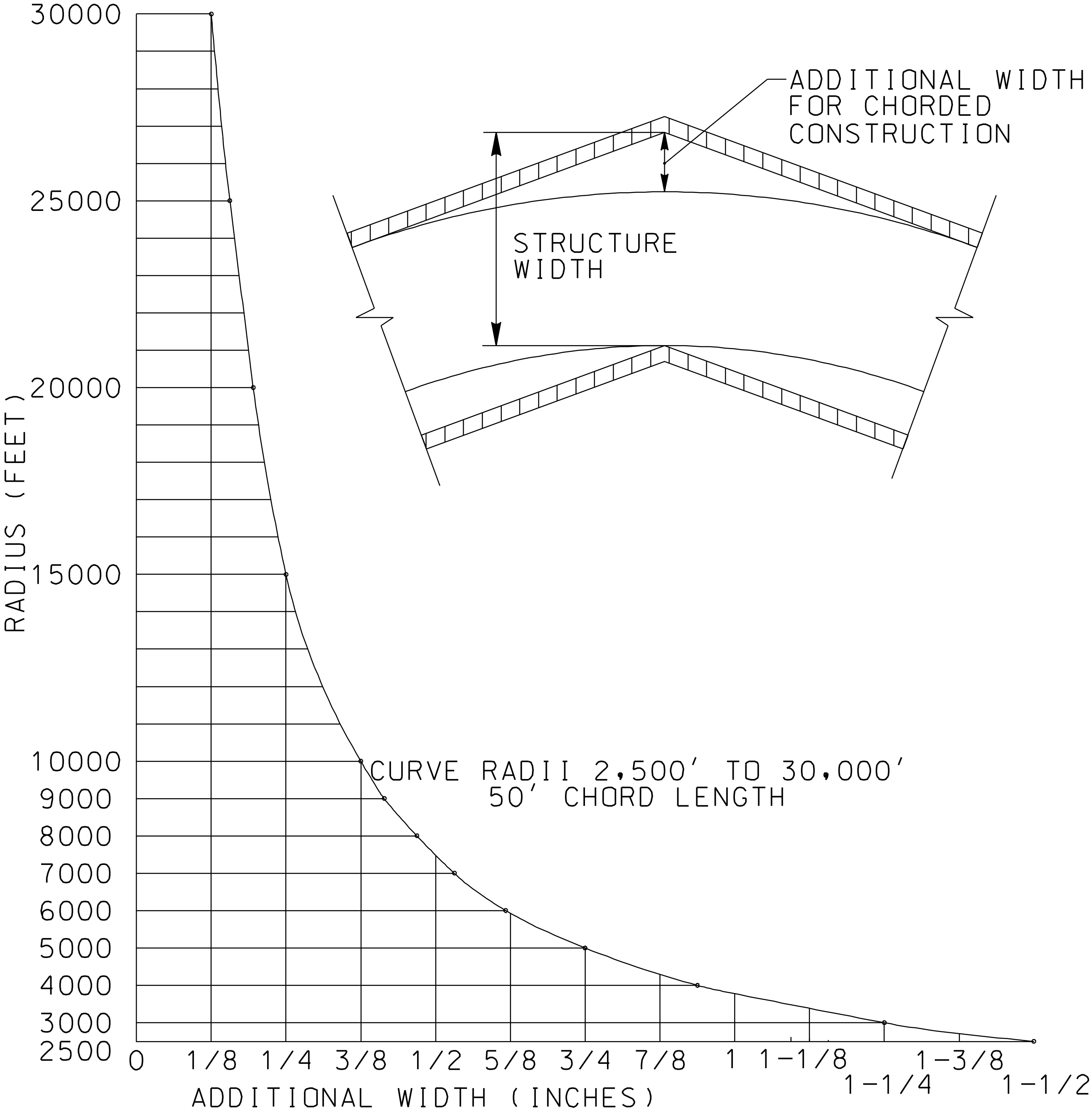
1. POINT "A" = POINT OF REVERSE CURVES
2. RATE OF SUPERELEVATION CHANGE TO BE SAME FOR BOTH SPIRALS.
3. SPIRALS MUST BE 62' MINIMUM.

RTD

DESIGN CRITERIA

TITLE: SUPERELEVATION TRANSITIONS FOR REVERSE CURVES

FIGURE: 4.3

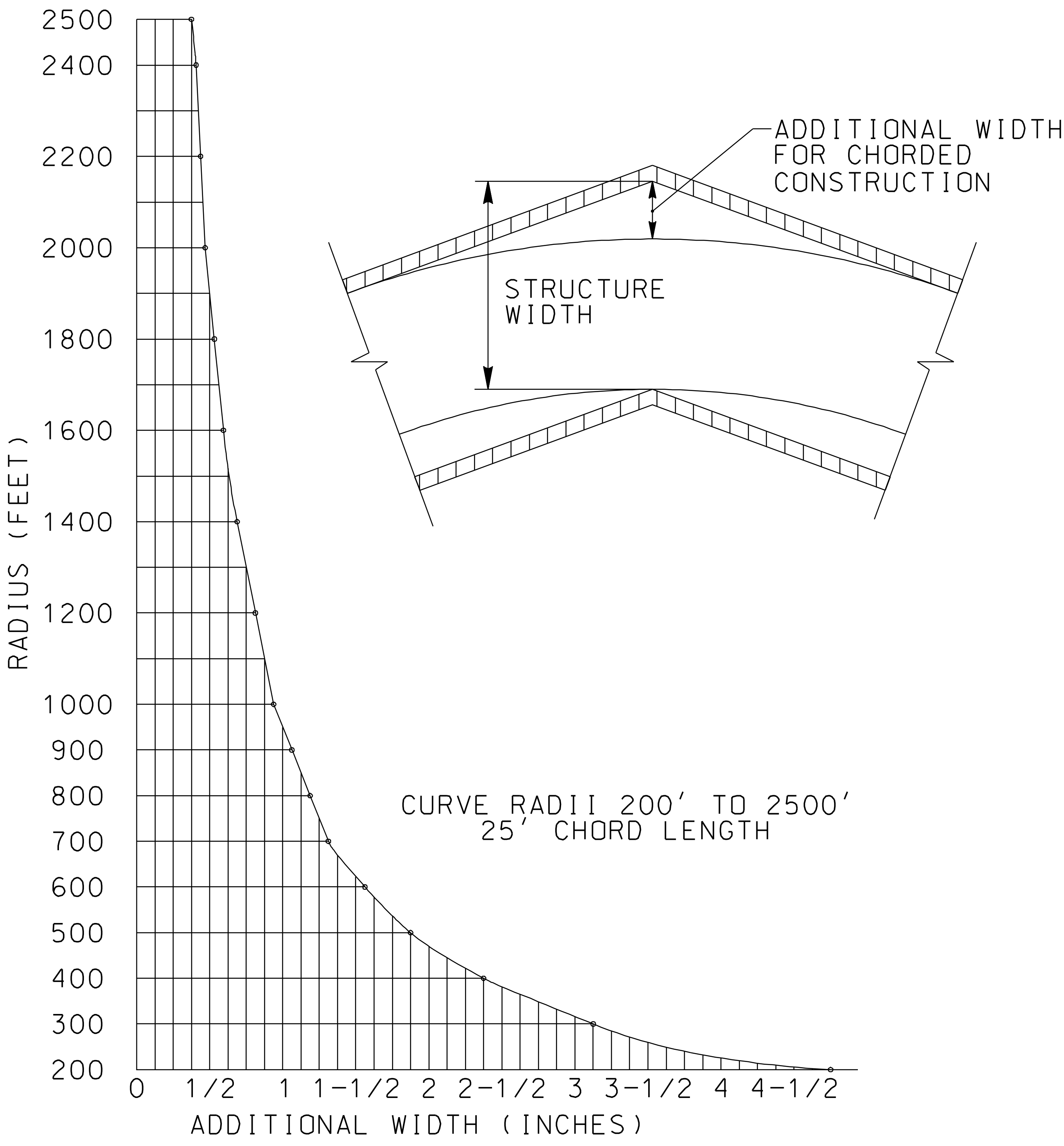


RTD

DESIGN CRITERIA

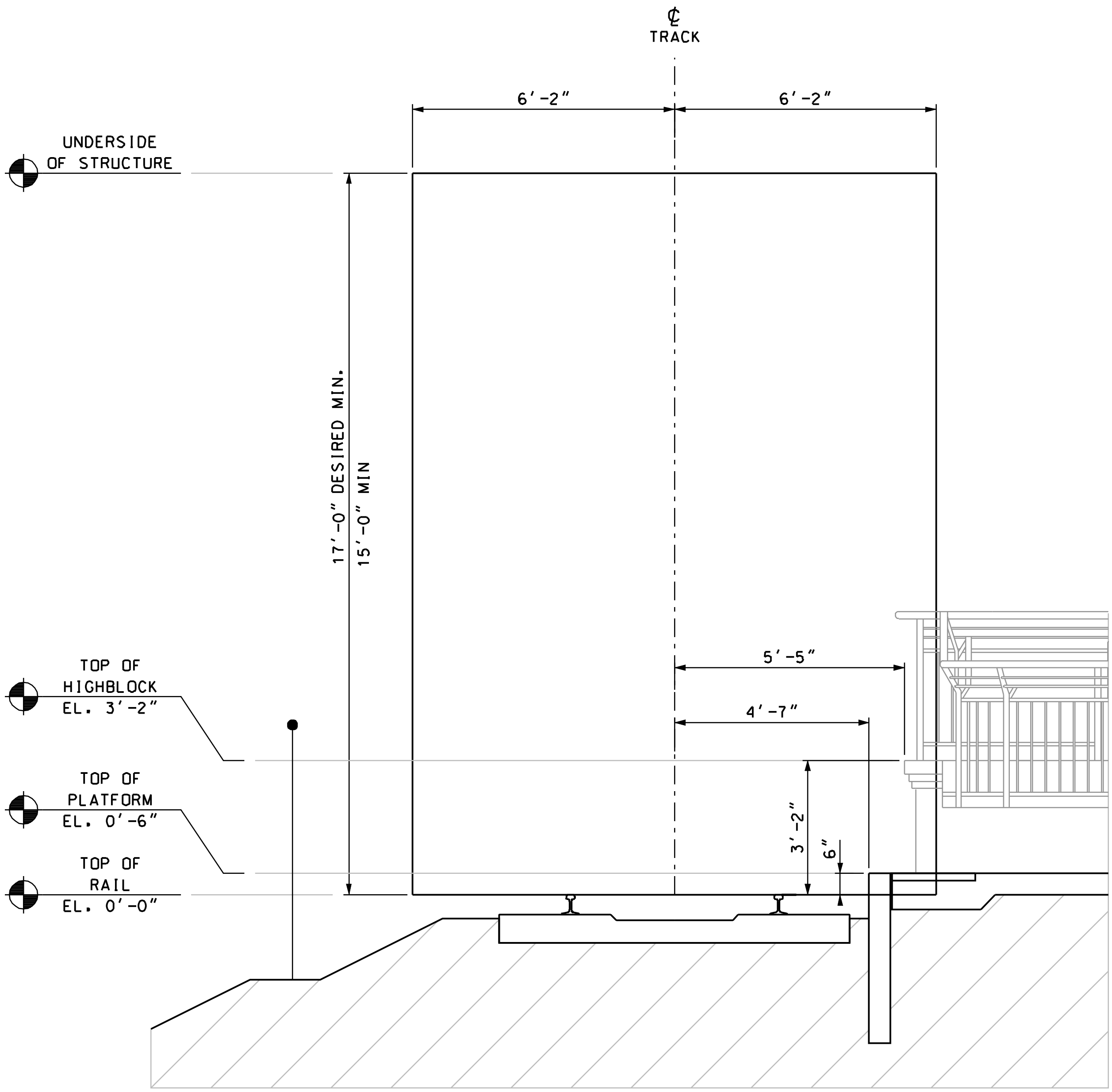
TITLE: ADDITIONAL WIDTH FOR CHORDED CONSTRUCTION

FIGURE: 4.4



RTD

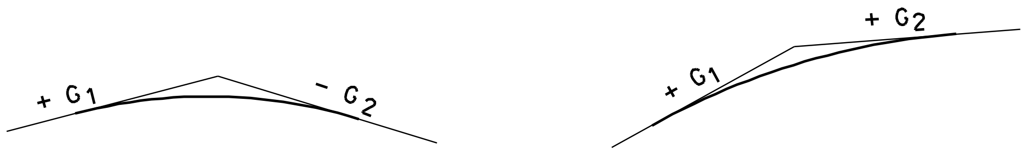
DESIGN CRITERIA	**TITLE:** ADDITIONAL WIDTH FOR CHORDED CONSTRUCTION
	FIGURE: 4.5



DESIGN CRITERIA

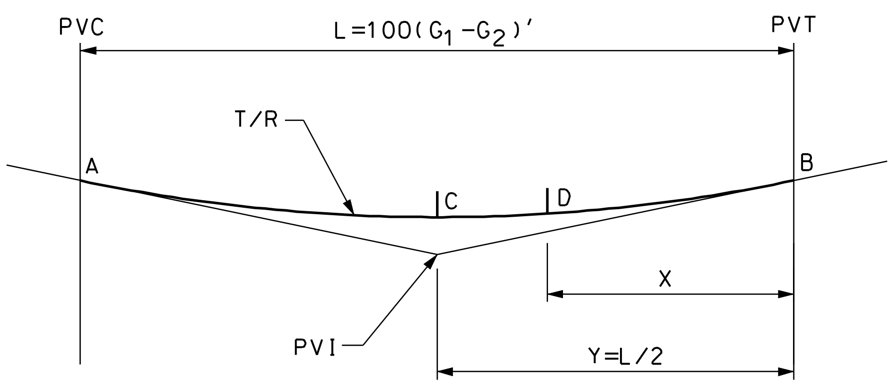
TITLE: LRV DYNAMIC ENVELOPE

FIGURE: 4.6



CREST TYPE VERTICAL CURVES

SAG TYPE VERTICAL CURVES



$$\text{ELEV C} = \frac{\text{2 ELEV PVI + ELEV A + ELEV B}}{4}$$

OFFSET AT D = DIFFERENCE BETWEEN ELEV C & ELEV PVI

OFFSET AT D = OFFSET AT $C(X/Y)^2$

T/R AT D = OFFSET AT D $\pm$ GRADIENT ELEV AT D

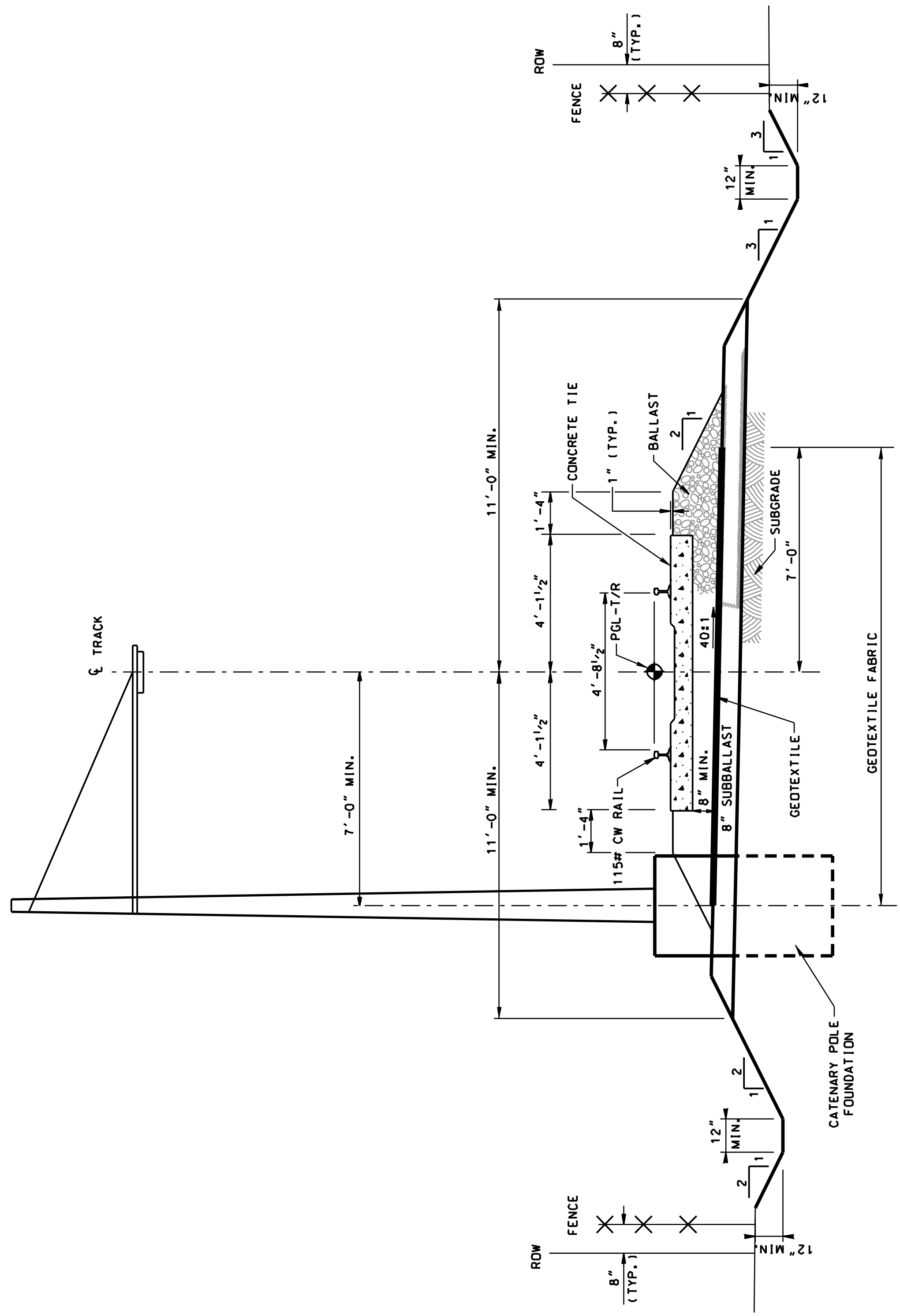
STANDARD VERTICAL CURVE

RTD

DESIGN CRITERIA

TITLE: STANDARD VERTICAL CURVES

FIGURE: 4.7

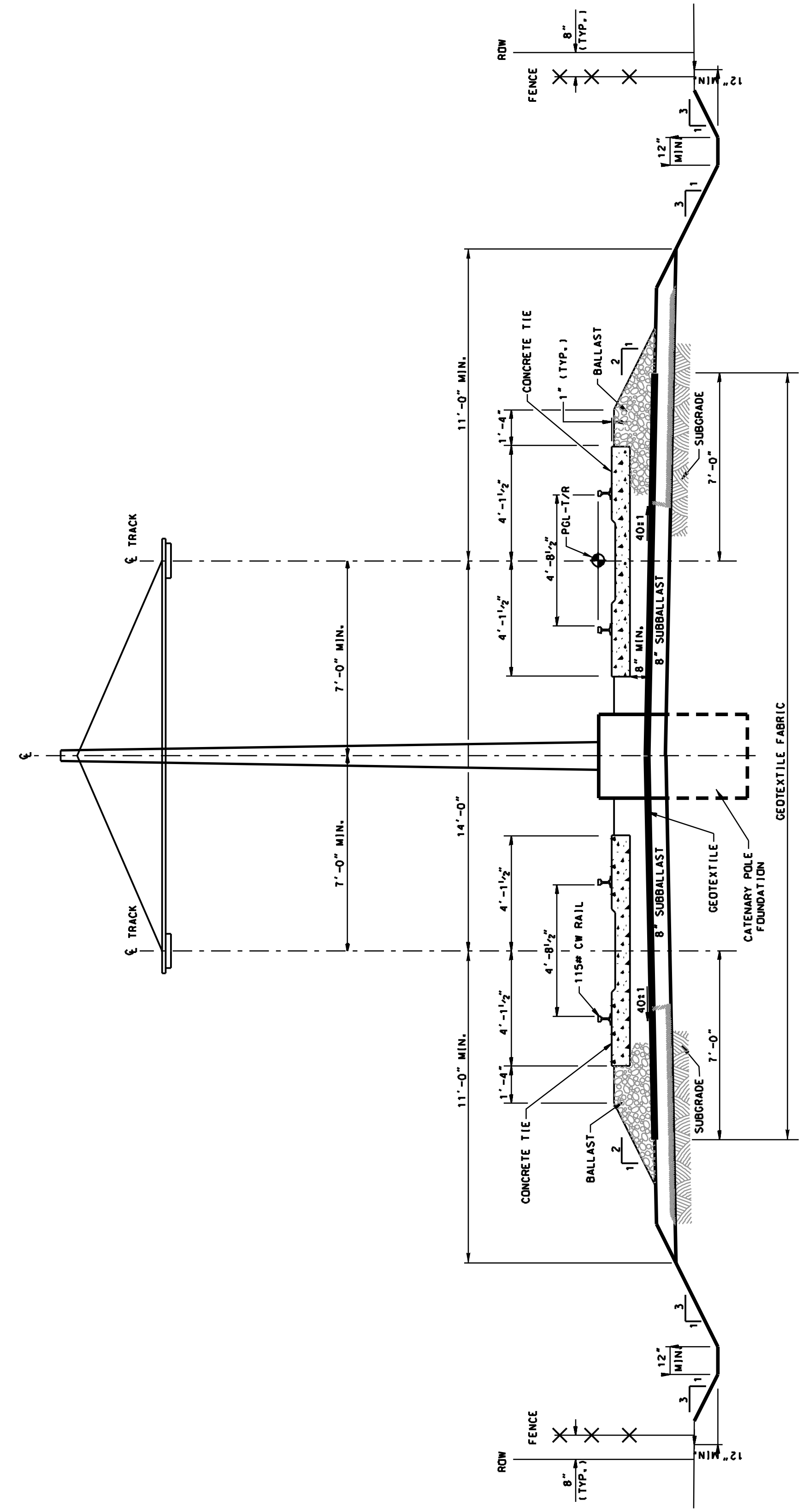


RTD

DESIGN CRITERIA

TITLE: SINGLE TRACK BALLASTED TRACK SECTION

FIGURE: 4.8

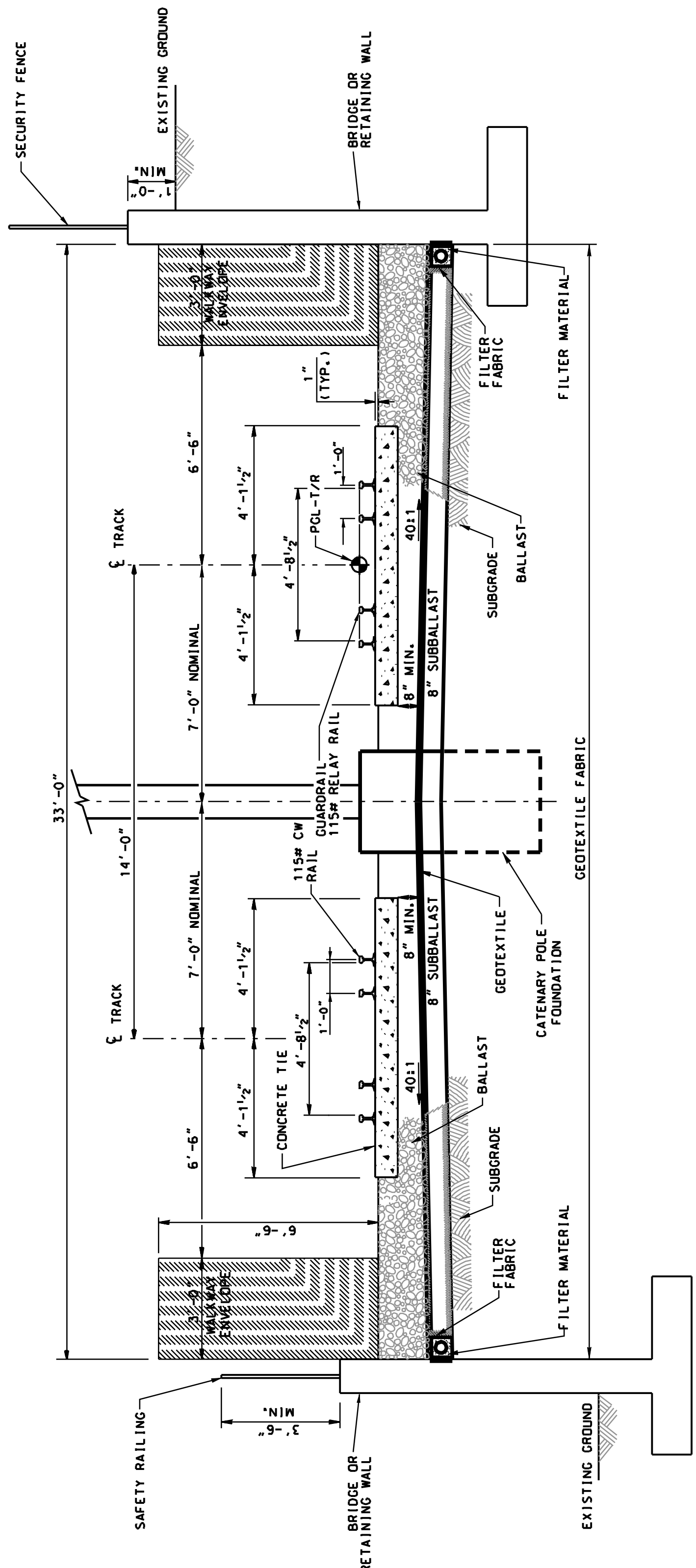


RTD

DESIGN CRITERIA

TITLE: DOUBLE TRACK BALLASTED TRACK SECTION

FIGURE: 4.9

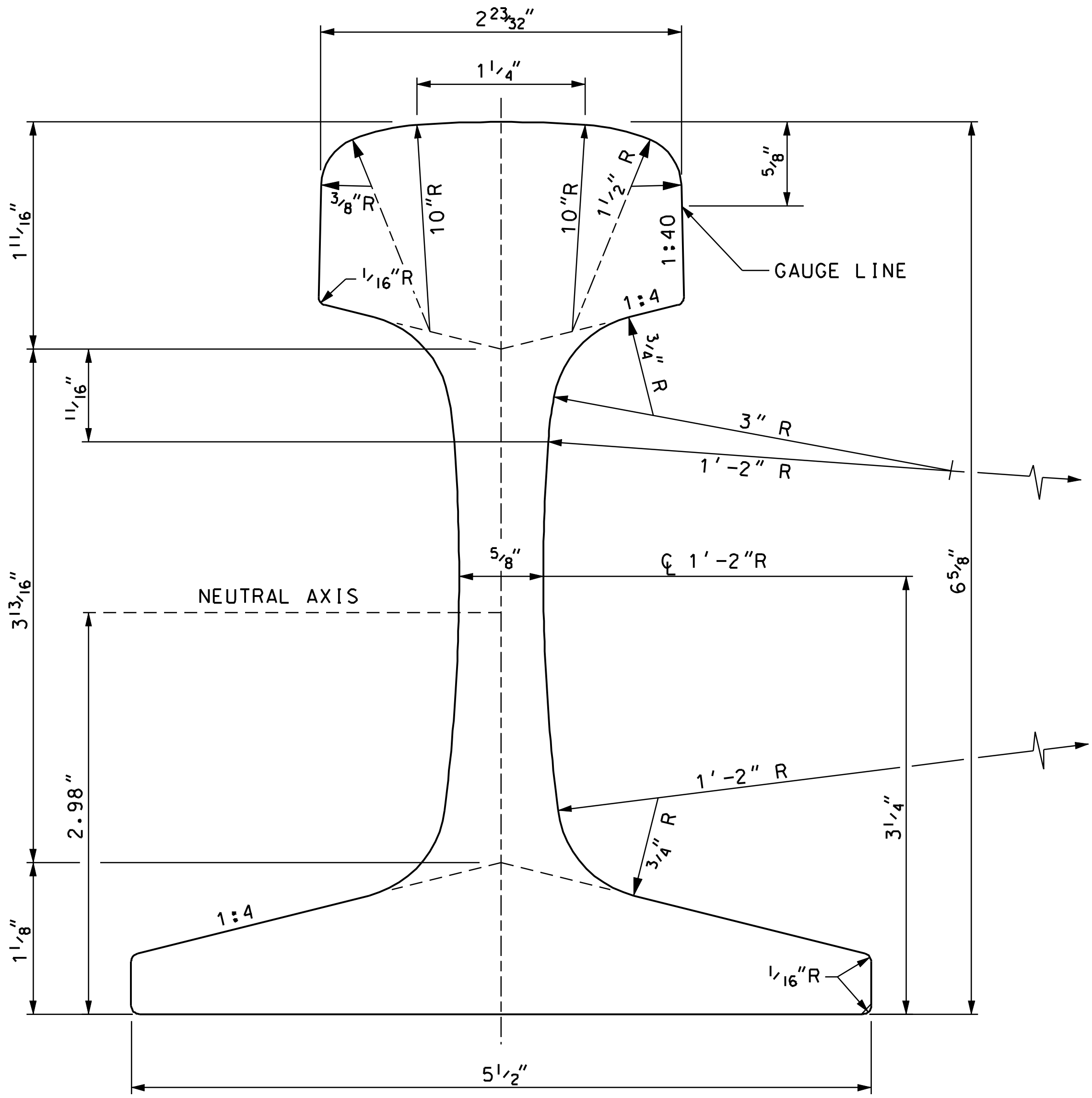


RTD

DESIGN CRITERIA

TITLE: TYPICAL RETAINED TRACK – TANGENT

FIGURE: 4.10



	AREA SQ. IN.	PERCENT
HEAD	3.91	34.8
WEB	3.05	27.1
BASE	4.29	38.1
TOTAL	11.25	100.0

MOMENT OF INERTIA	65.6
SECTION MODULUS, HEAD	18.0
SECTION MODULUS, BASE	22.0
CALCULATED WEIGHT, LB PER YD	114.7

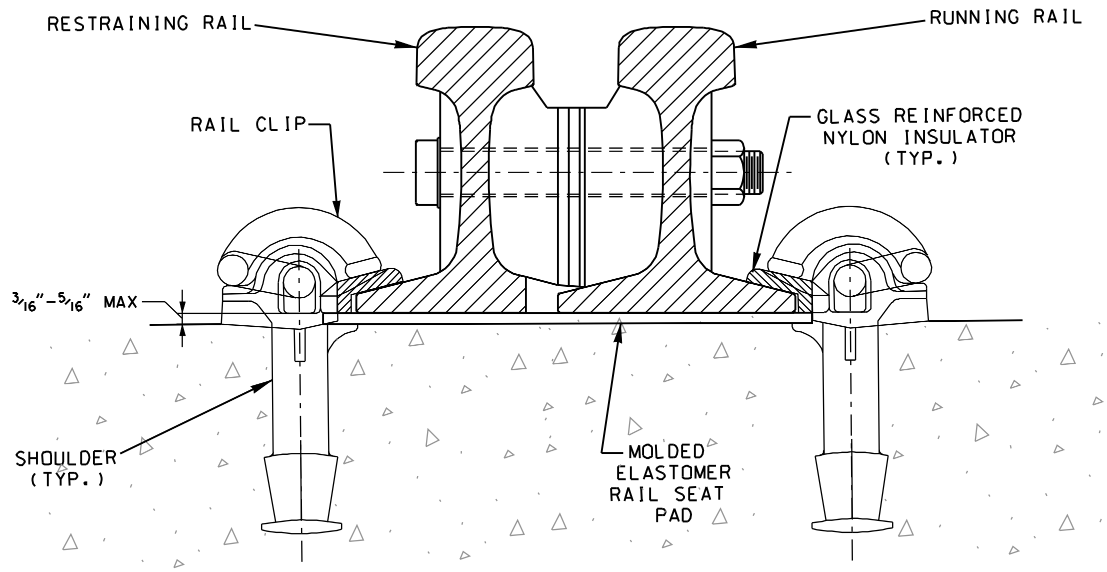
115 RE RAIL SECTION

RTD

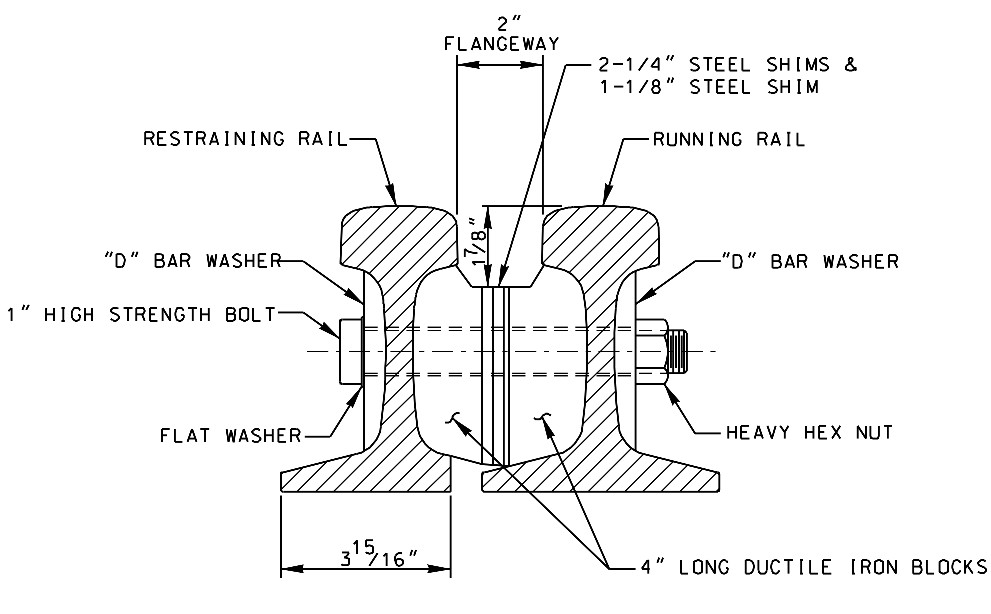
DESIGN CRITERIA

TITLE: 115 RE RAIL SECTION

FIGURE: 4.11



TYPICAL FASTENER DETAIL



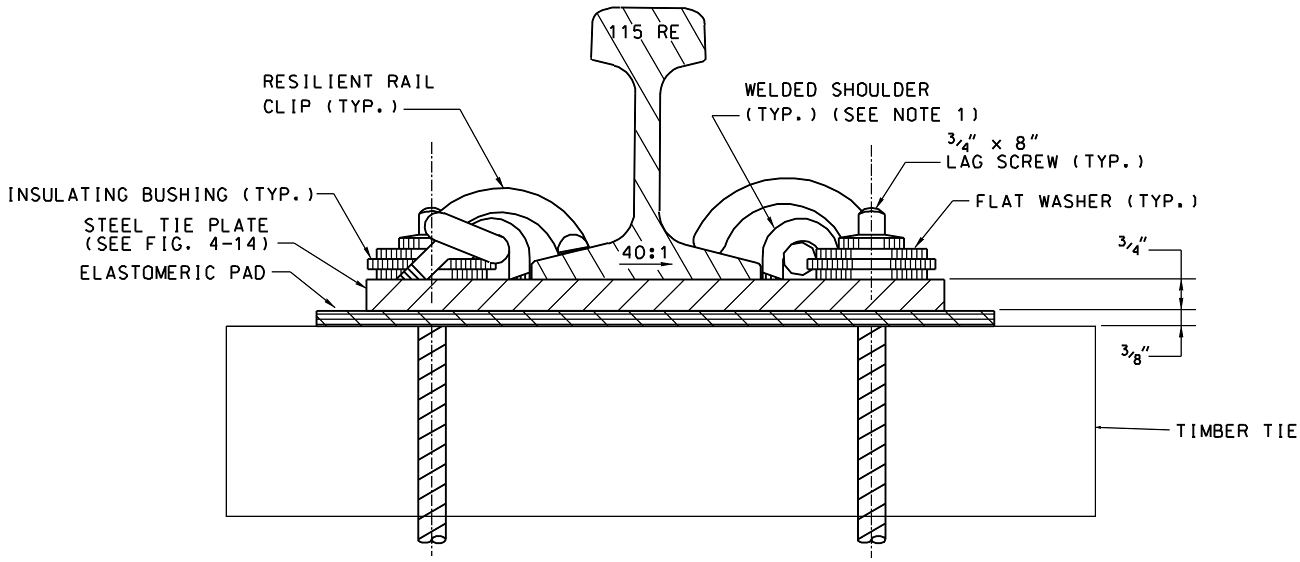
SECTION AT SEPARATOR BLOCK

RTD

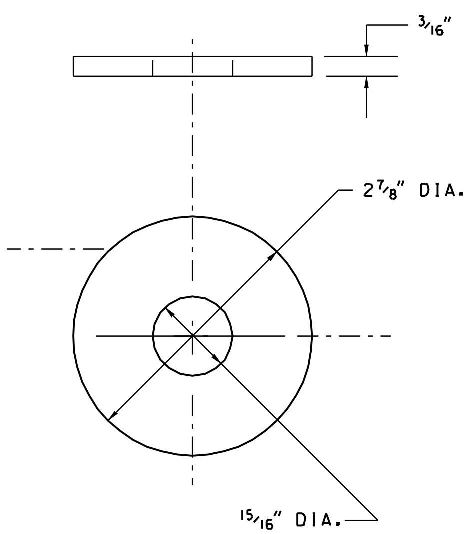
DESIGN CRITERIA

TITLE: RESTRAINING RAIL DETAIL

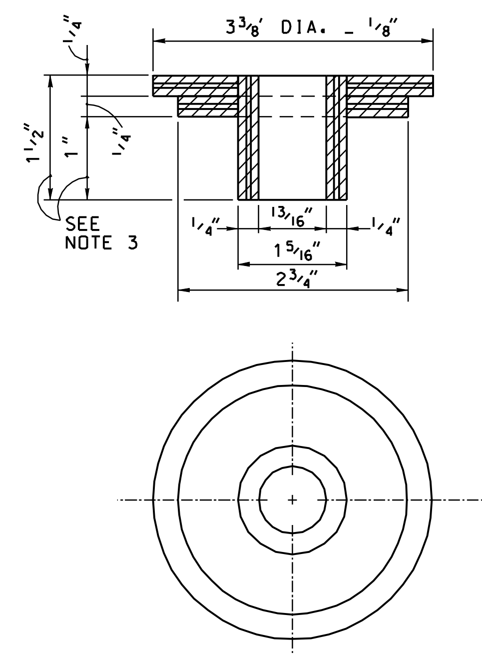
FIGURE: 4.12



ELEVATION



STEEL FLAT WASHER



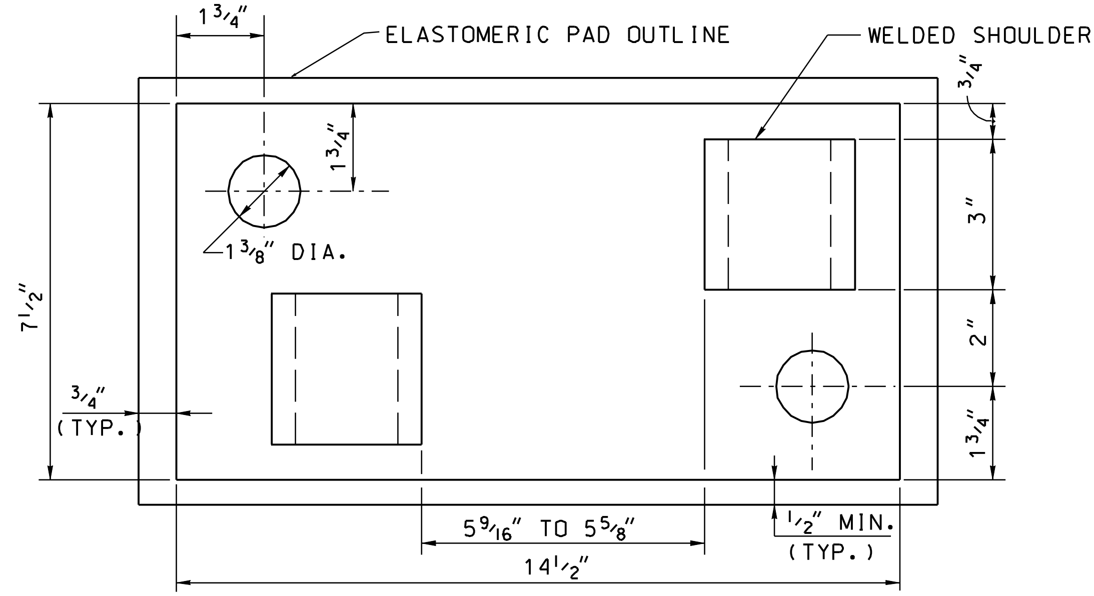
INSULATING BUSHING

RTD

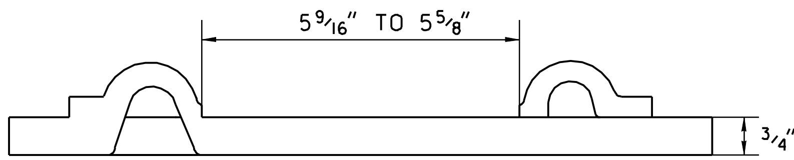
DESIGN CRITERIA

TITLE: STANDARD STEEL TIE PLATE ASSEMBLY

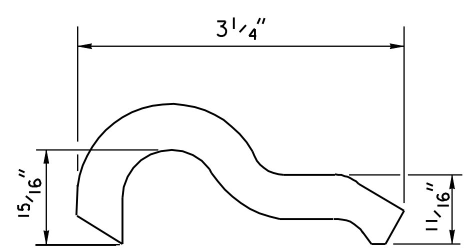
FIGURE: 4.13



PLAN



ELEVATION



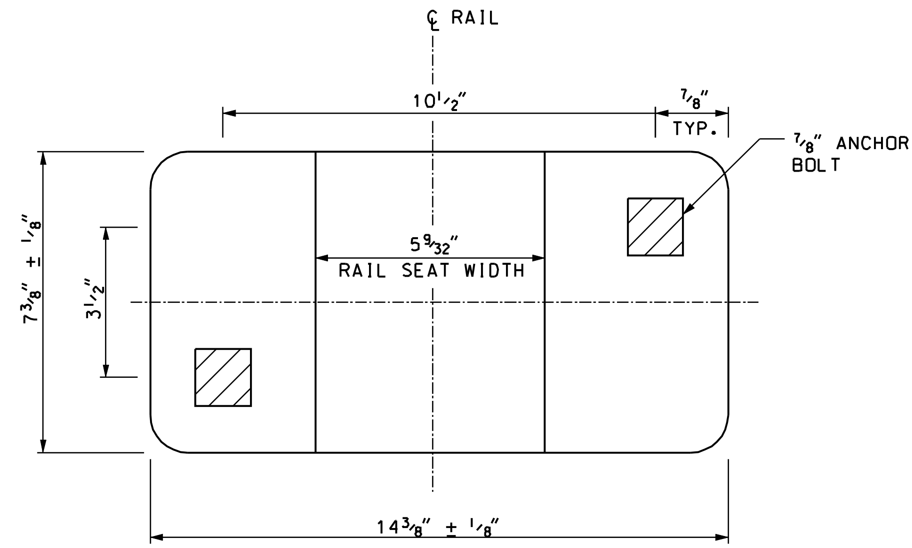
SHOULDER DETAIL

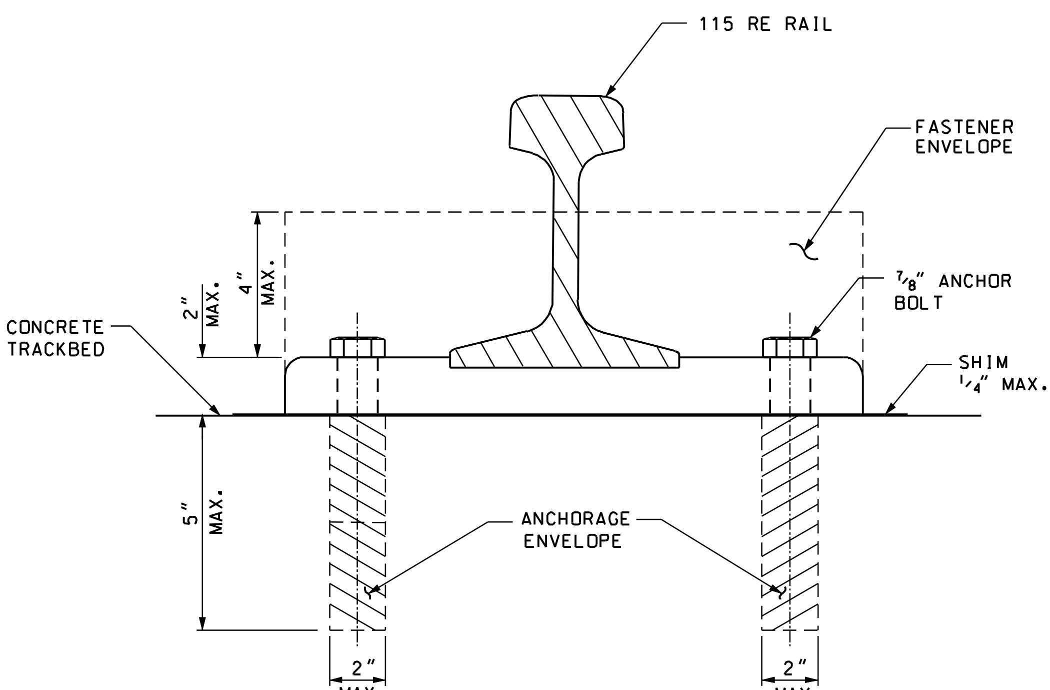
RTD

DESIGN CRITERIA

TITLE: STANDARD STEEL TIE PLATE FOR LAG SCREW INSTALLATION

FIGURE: 4.14





RTD

DESIGN CRITERIA

TITLE: CLEARANCE ENVELOPE FOR DIRECT FIXATION TRACK

FIGURE: 4.15

TURNOUT NUMBER	SWITCH POINT LENGTH	SWITCH POINT TYPE	OPERATING SPEED - MPH* (Diverging side of Turnout)
No. 6	13'-0"	CURVED	10
No. 8	19'-6"	CURVED	15
No. 10	19'-6"	CURVED	20
No. 20	39'-0"	CURVED	45

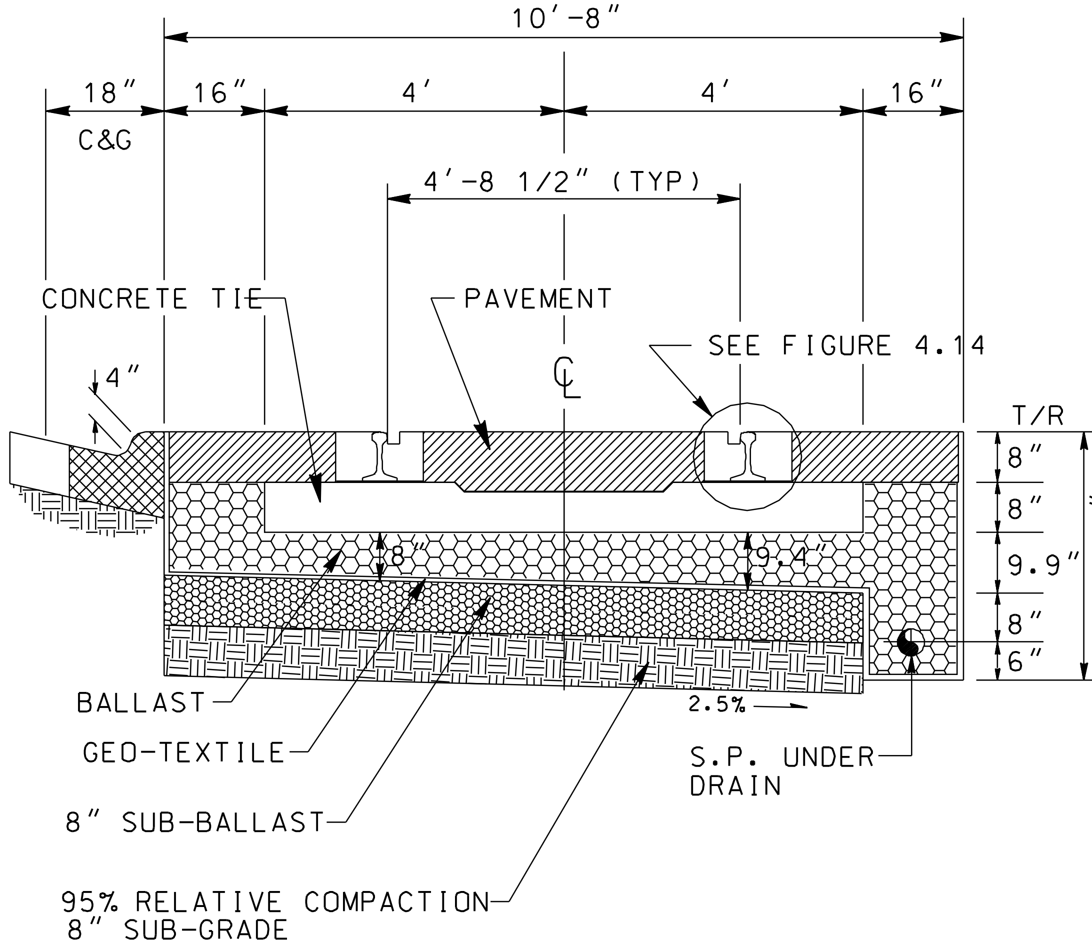
* THE SPEED THROUGH THE STRAIGHT SIDE OF THE TURNOUT IS NOT LIMITED EXCEPT THAT IT SHOULD CONFORM TO THE SPEED DESIGNATED FOR THAT SPECIFIC SECTION OF TRACK IN WHICH IT IS LOCATED.

RTD

DESIGN CRITERIA

TITLE: TURNOUT OPERATING SPEEDS

FIGURE: 4.16



TYPICAL CROSS-SECTION
PAVED TRACK

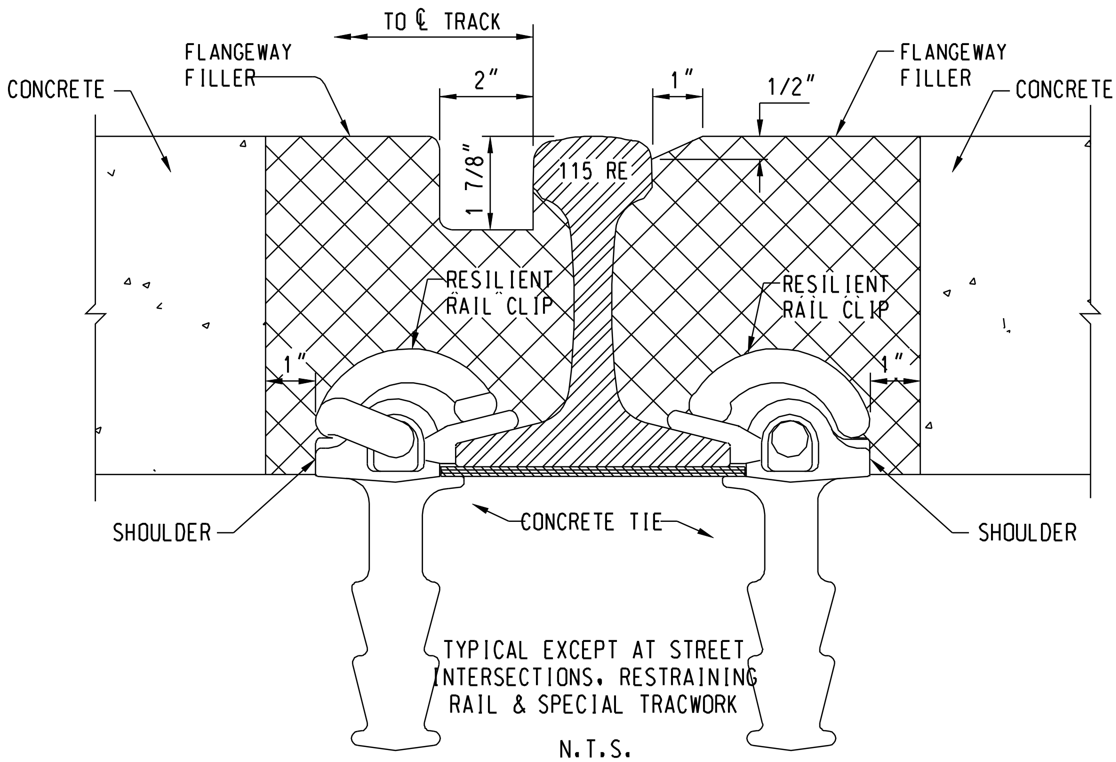
NOT TO SCALE

RTD

DESIGN CRITERIA

TITLE: PAVED TRACK

FIGURE: 4.17



RTD

DESIGN CRITERIA

TITLE: EMBEDDED RAIL DETAIL

FIGURE: 4.18

SECTION 5 - STATION DESIGN CRITERIA

SECTION 5 - STATION DESIGN CRITERIA

5.1.0 GENERAL

These criteria are intended to direct the Design Engineer in the design and preparation of light rail transit (LRT) station contract documents.

These criteria have also been established to enhance the safety and quality of the LRT system, which has a fundamental impact on the ability to attract and sustain patrons.

A LRT station comprises site access, parking (multi-modal access), transition plaza, platform (concourse), tracks and all appurtenances necessary to provide for the public safety, protection from the elements and public information. The station also serves as a gateway in and out of a community as the origin/destination source of passenger traffic.

See figures 5.1 through 5.5 for various platform configurations.

5.1.1 Basic Goals

The goals for this Design Criteria were derived from a rigorous evaluation and review of the station design for other transit agencies as well as lessons learned through RTD past projects. These goals provide the basis for decisions and will be used to evaluate designs for new and renovated facilities.

The goals are presented in several categories: Inter-Modal Function, Alignment, Architecture, Station and Community Relationship and Basic Design Objectives are applicable to all sections of this section.

5.1.1.1 Inter-Modal Function

Inter-Modal Functions are defined as bus automobile, bike and pedestrian means of travel to the station.

- Provide a safe, efficient and convenient configuration for inter-modal transfer at the station.
- Provide clear and easily understood transit information that can be referenced quickly and that minimizes disorientation.
- Develop operational efficiencies that simplify modal interchange and passenger processing.
- Minimize congestion and LRT crossings of inter-modal functions.
- Provide the best service possible at a reasonable cost.

5.1.1.2 Alignment

- Follow FTA TCRP Report 57, Track Design Handbook for Light Rail Transit, applicable AREMA standards, FRA guidelines for track geometry and Section 4 of this Design Criteria.
- Adhere to AREMA and FRA guidelines for at grade and grade separated LRT crossings.
- Locate stations on horizontal and vertical tangent sections.
- Coordinate track alignment and at grade/grade separated crossings with CDOT and local agencies, i.e. planning departments, traffic and emergency access.

5.1.1.3 Architecture

In general, on corridors with existing light rail, the extension design should match the existing architectural elements. On new alignments:

- Create a civic architecture that is permanent, functional and pleasant, has a LRT character and contributes to its context -- one that is not entirely a derivative of the transit system, but of the neighborhoods and community of which it is a part, yet maintains an overall line recognition and system identity.
- Develop a family of station parts and furniture that are interchangeable and allow for the individual character of each neighborhood or community as appropriate.
- Protect transit passenger from adverse weather conditions (snow, rain, wind and summer sun) and vehicular traffic. Provide seating at shelters and other protected locations on the platform.
- All designs must conform to Uniform Building Codes, ANSI 117.1, Americans with Disability Act Accessibility Guidelines for Buildings and Facilities (ADAAG), current editions and other applicable codes.
- Make transit a safe, secure, friendly and enjoyable experience and accessible to all, including the disabled.
- Develop systems that use maintainable materials and minimize life cycle costs.
- Provide an architectural and urban design framework that defines and encourages joint development opportunities.

5.1.1.4 Station

Stations consist of three elements; **platform** (concourse) area where passengers walk to and from the trains and where passengers queue in anticipation of boarding trains. The **transition plaza**, a space necessary to facilitate the movement of patrons from the parking areas or other means of access (modal access) to the platform and from the platform to their modal access. The **multi-modal access** is defined as the choice of transit used by a patron to access the station, i.e. car, bus, bike or walk. The basic design criteria for stations are as follows:

- Meet setback from centerline of track and dynamic envelope requirements for clearances at the platforms.
- Meet requirements of ADA, ADAAG and ANSI 117.1, NFPA 130, and Part IV DOT, 49 CFR Parts 27, 37 and 38.
- Adhere to FRA AREMA and TCRP Report 57 governing railroads and RTD guidelines for platform safety requirements.
- Minimum platform and transition plaza areas are defined by the crush load of the train consist x2 x5 sf. Length of the platform is determined by the length of the train consist plus 50 feet of tangent section at each end.
- Coordinate platform and transition plaza with bus, kiss-n-ride, park-n-ride, pedestrian and bike access.
- The transition plaza is a space described as an area necessary to facilitate the movement of patrons from the parking areas or other means of access to the platform. The transition plaza is where patrons can obtain, tickets, view public information systems and wait for pick-up. In many instances the transition plaza also acts as a side loading platform, and should be held to the same clearance and lighting requirements as a platform.
- Coordinate platform and transition plaza design with neighboring community. Community involvement is necessary to establish a sense of place of the station in the community and to develop a design for shelters, windscreens and other elements. As a part of the community development, RTD, its design team and community planners could facilitate a plan to develop transit-oriented development (TOD) adjacent to the mass transit site. This is only viable if, the governing body has zoning ordinances in place that allow a mixed use TOD to occur. TOD however needs to occur with a balance toward providing a convenient and pleasant experience for the

transit user as well as providing opportunities for mixed use development.

5.1.1.5 Community Relationship

- Protect, maintain and enhance existing qualities which are valued.
- Promote desirable TOD.
- Recognize emerging development that can compliment station development and increase ridership.
- Initiate and coordinate programs with the community that limit local traffic impacts and minimize disruption during and after the implementation phase.
- Utilize local jurisdictional processes and agencies throughout project design and implementation.
- Implement an Art-at-the-Station program to instill a sense of ownership by the community and a sense of "place" for the station in the community and as a recognizable feature along the corridor.

5.2.0 SITE PLANNING

The purpose of this section is to describe the system-wide design philosophy for station layout and related site development. The facilities to be designed shall address the following:

- Rail track way – use existing commercial railroad ROW or public ROW where possible. Keep consistent with system goals and objectives.
- Rail platforms – develop on tangent sections of track, linear progression from train to platform to transition plaza to multi-modal means of station access.
- Bus and auto roadways – primary multi-modal means of accessing station. Coordinate with local traffic patterns and segregate from secondary multi-modal means of access. It is also necessary to separate bus and automobile traffic, particularly as they enter and exit the park and ride and move through the park and ride.
- Pedestrian walkways – coordinate with local jurisdictions for connections to existing or planned pedestrian access ways; segregate from motorized vehicles.
- Bicycle paths – coordinate with local jurisdictions for connection to existing and proposed bicycle access ways, segregate from motorized vehicles. Bicycle paths shall not cross platforms at grade and shall be separated from platforms with a barrier when parallel.
- Auto and taxi drop off and waiting zones - Coordinate through RTD Design Guidelines and Criteria for Bus Transit Facilities.
- Parking lots/structures – elements that are determined by ridership and available land use and ownership. RTD Design Guidelines and Criteria for Bus Transit

Facilities shall be used as a reference for the overall design. Coordinate through local jurisdiction for parking lot requirements.

- Shelters – passenger shelters shall be designed to reflect the context of the overall urban design of the corridor and the neighborhoods that are adjacent to the station. Bus shelters shall be a standard design shelter provided by RTD.
- Landscaping – is used to enhance the overall aesthetic value of the station. Landscaping can be used to define the boundary from multi-modal access to the transition plaza and from the transition plaza to the platform. Landscaping shall not impede visibility of the platform areas or create hiding spaces or security barriers. At the transition plaza landscaping can be used to define edges, direct pedestrian traffic, provide shade and separate the transition plaza from the platform. Generally landscaping shall not be included on the platform (concourse).
- Elevators, escalators, ramps and stairs – Site selection should serve to eliminate the need for vertical circulation. In cases where this is not possible, follow local jurisdictional agencies regulations, RTD standards and practices, building codes; IBC, UBC, ADA, ADAAG, ANSI 117.1, NFPA 130, 101 and other applicable codes and standards. At a minimum elevator shafts and cars shall have three sides that are transparent the full length of travel and full height of the car.
- Site Furnishings - Bicycle lockers/racks, benches, blast resistant trash receptacles, fare collection equipment, newspaper racks, etc. shall be standardized for each corridor to provide a uniform appearance and for ease of maintenance and replacement. Bicycle lockers, news racks, trash receptacles and other publicly accessible receptacles shall meet the security requirements in section 14.15 Publicly Accessible Receptacles.
- Driver Relief Station (restrooms) – drivers restroom facilities shall be located in an area that is both convenient for the train operators and the bus operators. These facilities are not open to the general public. Buildings shall be constructed of durable materials with a low possibility of replacement needs. Building design shall follow standard layout for restroom facilities in RTD Standard Plans. End of the line facility shall be large Driver Relief Stations as shown in the Standard Plans. All facilities shall utilize approved card reader system for access.
- Signage – review RTD's Rail System Signage Standards.

These elements are to be located at each station site in a manner that is functional, safe, easily maintained and attractive to passengers and neighboring residents.

5.2.1 Jurisdictional Codes

The nature of LRT causes its alignment to travel through numerous districts, cities, and counties. Each of these legally defined areas has different land use and development regulations and legislative procedures directly affecting station site planning and design. Each individual jurisdiction may have special amendments or supplements to codes and standards that apply on a statewide and national basis. Therefore:

- Identify the governing jurisdiction for each site at every governmental level.
- Locate jurisdictional boundaries.
- Review applicable adopted master plans and municipal codes.
- Use the latest edition of the following:
  - International Building Code
  - Uniform Building Code
  - Fire protection codes
  - State of Colorado "Building Regulations for Protection from Fire and Panic."
  - Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG)
  - Americans with Disabilities Act Accessibility Guidelines for Transportation Vehicles
  - "Standards for Accessible Transportation Facilities",
    - ANSI 117.1
    - ADAAG
    - NFPA 130 101
    - AREMA
    - FTA
  - Rail Agency requirements when applicable.

In general, station facilities should be designed to meet all requirements of all applicable federal, state, and local codes and regulations. Codes shall be analyzed with regard to this Criteria Manual, the governing jurisdictions interpretation and the code that provides the most stringent application for the public good.

5.2.2 Site Analysis

Site analysis is the process in which the characteristics of a potential station site are gathered together. Typical physical characteristics to be evaluated are:

- General circulation and access
- Context
  - Views to and from the site
  - Weather conditions
  - Topography
  - Existing infrastructure and building improvements
  - Land use
  - Existing vegetation
  - Drainage
  - Solar orientation
  - Traffic counts
- Soils information
- Existing utilities

5.3.0 CIRCULATION AND SITE REQUIREMENTS

Each mode of transportation has specific circulation and operational requirements. While each mode has its own unique characteristics, it is recognized that all modes must respect and enhance the operation and access of other modes that interface in and around rail transit facilities.

Underlying site requirements that support transit such as parking, furnishings, operating equipment, shelters, and landscaping provide convenience, comfort, accessibility and an enhanced quality of life for transit passengers and employees.

Performance standards based on design objectives shall be the basis for all design decisions. They provide the fundamental framework for resolving the inter-relationship between each of the station activities and the means for minimizing conflicts and maximizing efficiency.

Above is a broad description of circulation and site requirements, it and the following descriptions need to be developed with the use of the RTD Design Guidelines and Criteria for Bus Transit Facilities

5.3.1 Modal Interchange

Modes are the means that passengers and employees access LRT stations. Typical access modes considered in these criteria are:

- Light Rail Transit (LRT)
- Bus
- Walk
- Bike
- Automobile
- Commuter Rail

There are distinct differences between each mode in terms of maneuverability, safety, speed, visibility, space requirements, compatibility, and reliability. The following describes the basic characteristics for each mode.

5.3.2 Access Modes

LRT is a more predictable and confined form of transit in that it operates within a semi-exclusive ROW.

Passengers tend to arrive at or near the scheduled LRT departure time and do not spend a lot of time waiting. Therefore, modal interchange becomes a key consideration in station design.

5.3.2.1 Bus Access

The bus system will be integrated with LRT and provide feeder routes to station facilities. Where applicable, there will be a hierarchy of vehicular modes of access, giving priority to feeder buses. The following are general criteria that will help guide the site planning process:

- Buses should be able to get as close to LRT transition plazas as possible with a maximum walking distance of 400 feet to the platform.
- Eliminate situations where buses are required to cross LRT tracks.
- Make provisions to provide emergency bus service in the event of an LRT system failure.
- Bus and automobile access should be separated wherever possible.
- Minimize conflicts between buses, trains, automobiles, bicycles and pedestrians.

5.3.2.2 Walk Access

Good pedestrian circulation to, from, and across train platforms is essential for the smooth and safe operation of stations. 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 follow:

- Avoid unnecessary turns and dead ends.
- Pedestrian access from bus, kiss-and-ride and park-and ride areas must be as clear and as simple as possible.
- Circulation elements shall use color, texture and sight distances to increase visual pleasure, guidance, patron safety and security.
- Provide adequate space to avoid bottlenecks.
- Avoid cross-circulation at fare collection and decision points. Generally provide right-hand circulation.
- Provide well lit pedestrian walkways.
- Provide a minimum of 7’ wide of clear space where possible between the edge of the platform and obstructions such as stairs, escalators, railings or columns.
- Provide adequate 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, shelters and stairways to encourage balanced train loading and unloading. Passengers tend to board at such connection points on the platform.
- Provide ramps and elevators as required for disabled patrons. Walkway, highblock and structural access ramps shall not exceed 4.75%.
- Grade changes are to be minimized, and where necessary they shall conform to slope criteria for disabled access.
- Cross flows, dead ends, and turns greater than 90 degrees are undesirable for both patron security and circulation.
- Circulation shall be designed to provide ample space adjacent to, but out of the mainstream of, pedestrian flow. This will accommodate for disabled, infrequent or waiting patrons.
- Surge and queuing spaces shall be provided ahead of every barrier and change in circulation, direction, or mode.
- Obstructions such as telephone booths, pylons, advertising displays, coin changers, concessions, seating or maps are not allowed within the pedestrian through zone.
- Shelter elements shall have sufficient transparency to provide adequate visual surveillance of the station area to discourage vandalism and enhance patron safety.
- Provide adequate sight distance and visibility along pedestrian routes.
- Provide track crossing clear of four car train for pedestrians to clear center platform.
- Provide a minimum of two points of access/egress from the platform that meet the requirements of NFPA 130.

5.3.1.3 Bike Access

Those passengers arriving by bicycle shall be accommodated in the safest and most inviting manner possible. Except at the downtown Denver stations, space shall be provided for racks for at least 10 bicycles if possible at every station. These facilities shall be located to minimize conflicts with pedestrian and vehicular traffic, make the most effective use of roadways and curb cuts, and reduce the need for special graphics. To promote security, bicycle storage areas should be visible from the street or station entrance. Where possible, bike racks and lockers should be located on the transition plaza and segregated from large group gathering areas. No bike racks or lockers are to be located on the platform (concourse).

5.3.1.4 Auto Access

Auto access shall be provided in a manner that meets all state and local codes and does not interfere with access modes of higher priority.

5.3.3 Parking

Reference the RTD Design Guidelines and Criteria for Bus Transit Facilities

5.3.4 Emergency Exiting

Design Objectives

- Any fully loaded station platform shall be able to be evacuated in accordance with NFPA 130.
- Provide not less than two exits from any station area or platform.

5.3.5 Historic Preservation

At the beginning of the station siting process, potential applicability of requirements of the Historic Preservation Act and Section 4(f) of the Transportation Act of 1966 should be addressed.

Where LRT stations may affect historical areas or structures, potential impact zones should be identified. These would include areas where station placement would block views or interfere with pedestrian circulation and access.

If joint use were to be planned, the Design Team should develop a design program which identifies those agencies or citizen groups which are likely to be involved and the procedure to be followed for approach of design. The program should also identify significant architectural features which should be taken into account in station and site design.

If a portion of a historic structure is to be retrofitted to accommodate an LRT station, security and safety features necessary to preserve the significant historic characteristics of the structure should be incorporated into the station design. Approval from SHPO is required.

5.4.0 PLATFORM ARRANGEMENTS

Three alternative platform arrangements for on-line stations exist as follows:

- Side Platforms - Side platforms are located directly opposite one another, each servicing one mainline track.
- Center Platform - Single platform to service tracks located on each side of the platform.
- Side Center Platform – Side platform located on one side only and a center platform to service the other tracks.

The center platform arrangement offers the most efficient use of platform space and furnishings.

5.4.1 Platforms (concourse)

The following presents fundamental criteria that are intended to produce efficient and passenger-sensitive platforms.

- All platforms shall be designed to conform with the ADAAG, including detectable warning strips on platform edges.
- Platform length for both center and side platforms shall accommodate a four-car train and have a minimum length clear of approach ramps of 360 ft., unless approved otherwise by RTD.
- The nominal horizontal gap between the platform edge and the edge of vehicle floor shall be 6 inches. On tangent tracks, the platform edge is located 55 inches from track center line with a tolerance of +0.50 inches vertically and 0.0 inches horizontally.
- The platform height at the edge of platform face shall be 6 inches above the top-of- rail profile. When stations are located on or within streets or existing sidewalks, consider the crown of the street when calculating the platform height.
- Minimum platform width for side platforms shall be 12 feet with 21 feet preferred.
- Minimum width for center platforms shall be 16 feet with 21 feet preferred.
- Platforms must be located on tangent tracks.
- Cross slopes shall not exceed 2% with a minimum of 1% and the maximum longitudinal slope shall be no more than 1% unless approved by RTD in writing.
- Mechanical and electrical equipment shall be placed in vertical surfaces, rooms or underground to reduce obstructions. Consider maintenance implications for each piece of equipment prior to underground placement.
- Provide clear emergency exiting from platforms.

- Concentrate fixed objects such as furniture, signage, shelters, etc. within a furniture zone while maintaining adequate distance between elements for circulation. Keep as much of the platform clear of fixed elements as possible.
- The track area between platforms shall be covered or paved at designated pedestrian crossings only.
- Platforms and station exits shall be sized and located to accommodate the estimated or expected volume of passengers as defined by NFPA 130 Occupant Load.
- Exits shall provide safe exiting from trains and platforms under normal operational and emergency conditions. Platforms and exits shall be sized to allow passengers to completely clear the platform prior to the arrival of the next train.
- Secondary access or exit points should be provided, make them visible, inviting and safe.
- Barriers should not trap anyone between the LRV or vehicular traffic.
- Where possible, provide clear and unobstructed diagonal pedestrian access across platforms wherever modal interchange occurs.
- Platforms shall be provided with a source of water for cleaning and maintenance purposes.
- Any electronic passenger information systems such as variable message signs shall be located to maximize visibility to passengers while minimizing obstructions.

5.5.0 TRANSITION PLAZA

The transition plaza is a space described as an area necessary to facilitate the movement of patrons from their multi-modal access to the platform. The transition plaza is where patrons can obtain tickets, view public information systems and wait to be picked up.

The following are basic design criteria;

- Design to conform to ADAAG standards and code requirements (see subsection 5.2.1)
- Provide easy access to Ticket Vending Machines (TVM), stand alone validating machines (SAV), information technology and public communication systems without impeding the flow of patrons to the platform.
- TVM, SAV and information systems and other furnishings must be located adjacent to the line of travel without impeding the pedestrian flow. All vending machines must be oriented away from direct sunlight.
- Preferably vertical circulation needed to reach the platform shall be constructed on the edge of the transition plaza and the platform. When ROW and site design constraints cause vertical circulation elements to be placed on the platform, the design should follow ADAAG requirements for minimum circulation space.

- Existing requirements from the plaza are the same as the platform; follow NFPA 130 2-5.2 and 2-5.3.

5.6.0 SHELTERS AND FURNITURE

These criteria have been developed as a technical guide to safe and efficient station design while promoting community pride. Stations are the public focus of the rail system in that they are central to modal interchange and serve thousands of passengers on a daily basis. It is key to the operation of the entire transit system that station platforms are easily understood, friendly and efficient for passengers. Station design should not only consider the functional and operational efficiencies, but also integrate humanistic and community spirit into the design.

5.6.1 Passenger Shelters

The following is a list of objectives that LRT, bus, and kiss-and-ride shelters should achieve:

- Provide passengers with comfort and protection from expected adverse weather conditions -- snow, rain, wind and summer sun.
- Provide identity for the station as well as the surrounding area.
- Provide a feeling of security and means of surveillance.
- Help provide adequate lighting.
- Utilize materials and construction practices that minimize maintenance requirements.
- Utilize materials and construction practices that minimize life cycle costs.
- Standardize materials and construction practices.
- Utilize materials and construction practices that are compatible with existing RTD facilities.
- Arrange and articulate shelters to create an enjoyable experience.
- Height of Shelter protective edge should be no greater than 10 feet 4 inches or eave height to match height of window head of passenger car.
- Minimum length of shelter to be 60 feet. Length of dual shelters to be determined by large ridership, local jurisdiction requirements and the potential for a shelter to tie into TOD.
- Width of shelters shall not infringe on the dynamic envelope for the rail cars. A minimum width is 12 feet.
- High block platforms shall be protected by canopy.

5.6.2 Windscreens

The following is a list of criteria for windscreens:

- Maximum height 6 feet 8 inches.
- 75% of the surface area must be translucent or transparent.
- Overall width depends on flow of pedestrians and location of the screen.
- Place where most effective in blocking prevailing winds.
- Provide a minimum of one bench on the lee side of the windscreen.
- Comply with ADAAG for access and circulation around the windscreen.

5.6.3 Furniture

The following is a list of furniture to be used at the stations:

- Newspaper racks by RAK systems or approved equal. Newspaper racks shall be placed according to security requirements outlined in section 14.15 Publicly Accessible Receptacles.
- Bicycle lockers/racks are not to be placed on the platform, only on the transition plaza or the park-n-ride. Bicycle lockers shall be placed according to security requirements outlined in section 14.15 Publicly Accessible Receptacles.
- Provide a minimum of 4 benches per station.
- Trash receptacles are not to be placed on the platform, only on the transition area away from locations where large groups may gather. Trash receptacles shall be placed according to security requirements outlined in section 14.15 Publicly Accessible Receptacles.
- Reference RTD Facilities Maintenance Design Manual for preferred manufacturer and style.

5.6.4 Service Buildings

Service buildings are defined as all structures not open to passengers, but which need to be accessible to RTD employees or contractors. Design of service buildings at stations shall comply with NFPA 130.

- Equipment Rooms - Signal, electrical and communication rooms shall be sized according to the requirement identified by RTD Systems Engineering. Location to be coordinated with Systems Engineering, Operations and the Station Design Team. Equipment rooms shall not be located on station platforms.
- Driver Relief Station - Driver relief stations (DRS) are to be provided at stations where they can be used by both bus and LRT operations. No access will be provided for public use. Generally, driver restrooms

will be located in association with larger park-n-rides or at the end of line stations.

5.6.5 Materials and Finishes

The quality and character of station materials utilizing simple, durable materials has a direct effect on maintenance requirements and the image of each facility. Simple, durable materials in minimal sizes with long-standing availability, installed to facilitate replacement can diminish damage and maintenance while balancing the character and visual quality of each station. Because vandalism tends to breed upon itself, materials should be used such that repair time is reduced and stations never appear underused or abandoned.

In specifying manufactured items or materials, preference shall be given to standard off-the-shelf items available from more than one supplier over custom-made or single-source items. In specifying finish, size, color, pattern or composition, slight variations in appearance should be allowed so less costly products or materials of equal quality can be utilized.

5.6.6 Performance Standards

5.6.6.1 Durability

Durable and cost-effective materials shall be used that have consistent wear, strength and weathering qualities. Materials shall be capable of good appearance throughout their useful life and shall be colorfast.

5.6.6.2 Low Maintenance

Life cycle maintenance costs should be considered in the evaluation of all materials and finishes.

5.6.6.3 Quality of Appearance

Materials should be appealing and harmonious in appearance and texture. They should reinforce system continuity while relating to the local context.

5.6.6.4 Cleaning

Materials that do not soil nor stain easily shall be used and shall have surfaces that are easily cleaned in a single operation. Minor soiling should not be apparent. Commonly used equipment and cleaning agents should be able to be utilized. All porous finishes subject to public contact shall be treated or finished in a manner that allows easy removal of "casual vandalism."

5.6.6.5 Repair or Replacement

To reduce inventory and maintenance costs, materials shall be standardized as much as possible for easy repair or replacement without undue cost or disruption of LRT operation. For example, hose bibs, electrical outlets, lighting fixtures and lamps, glass or plastic lights, information panels, signs, shelter materials, etc., shall be standardized on commonly available sizes and finishes for easy inventory stocking and installation.

5.6.6.6 Nonslip

Entrances, stairways, platforms, platform edge strips, and areas around equipment shall be high nonslip properties. Floor finishes shall be nonslip even when wet. This is particularly important at stairs, elevators and other areas near station entrances, as well as platform areas.

5.6.6.7 Corrosion Resistance

Because of moisture and the electrical currents involved in transit operation, special consideration must be given to prevention of corrosion. Non-corrosive metals shall be utilized when possible or required.

5.6.6.8 Compatibility

Selected materials shall be compatible with the Denver metropolitan area climate and consistent with existing materials within the station vicinity. Materials for structures should harmonize with existing facilities on a site-specific basis.

5.6.6.9 Availability

Selection of materials shall permit competitive bidding and emphasize regional products and processes over those not locally available.

5.6.6.10 Fire resistance

"Flame spread" ratings shall conform to the applicable building code definition for the material being used.

5.6.6.11 Finish Materials

Dense, hard, nonporous materials shall be used in all applications. Finish materials shall be corrosion, acid, and alkali resistant and shall be compatible with chemical compounds required for maintenance.

5.6.6.12 Detailing

Detailing of finishes shall avoid unnecessary surfaces which may collect dirt and complicate cleaning. Wall surfaces shall be vertical and flush allowing for texture. All edge and finish materials shall be detailed, incorporation joints and textures which reduce the requirements for true, visually perfect installation over long distances.

5.6.6.13 Waterproofing

All finish materials in underground spaces shall be selected and detailed with proper attention to waterproofing, cavity walls, drainage and venting. All drainage cavities shall be provisions for cleanout.

5.6.6.14 Texture

Materials within reach of passengers shall be easily cleaned, with a finish to prevent or conceal scratching, soiling, and to maintain desired illumination levels. Materials with homogeneous colors shall be selected. The use of paint, stains and coatings shall be minimized.

Graffiti resistant products shall be used to protect surfaces susceptible to graffiti. Graffiti resistant products shall allow for removal of graffiti without damage to the surface.

5.7.0 STATION EQUIPMENT

This section includes all electromechanical equipment located at the stations other than communications equipment. The major items covered here include fare collection equipment.

5.7.1 Fare Collection

All platforms shall have provisions for either free standing or integrated fare vending machines.

RTD shall determine the number of initial machines and future provisions.

Weather protection shall be provided for each machine unless otherwise approved by RTD. At no time shall the front face of the vending machines be oriented to the south, west, or southwest, unless protection from the sun is provided.

See "Fare Collection Equipment" in Section 12 for more detailed information.

5.7.2 Equipment Location

All equipment located at the station shall be coordinated through the station Design Team. This shall include but is not limited to all above and below grade equipment and structures such as water and electric in ground boxes and power stations.

5.8.0 COMMUNICATIONS

This section includes all communications media and devices used to communicate with transit passengers.

5.8.1 Directional Signs

Obvious, simple and clear signage between modes of transportation and throughout stations reduces confusion and frustration while increasing patron comfort. The less time spent searching for connections, the more time will be available for enjoying the convenience of transit. Signage shall conform to Section 4.30 of "Standards for Accessible Transportation Facilities," U.S. Department of Transportation, Denver Light Rail Systems Signage Standards dated 1-12-02, NFPA 130 3-1.3 Warning Signs and the MUTCD.

5.8.2 Platform Kiosk

Free standing or integrated information kiosk shall be provided in all stations.

Kiosks shall be sized to accommodate standard RTD information materials, including LRT and bus system maps and schedules and to accommodate internal maintenance that may be required.

5.8.3 Platform Identification Blade Signs

Free standing or integrated blade signs shall provide system, station and destination identification.

Two blade signs shall be provided on each platform to cover the areas that are not covered by the pylons.

5.8.4 Shelter Signage

Provisions shall be made for station identification signs in passenger shelters and shall conform to current ADAAG standards.

5.8.5 Telephones

Provisions for emergency telephones shall be provided as required in each station and shall conform to the requirements of Section 4.31 of "Standards for Accessible Transportation Facilities", U.S. Department of Transportation.

Public phones are not to be located on the platforms but shall be located at or near the edge between the platform and the transition plaza.

Public phones shall be easily visible from the station platforms, but located outside of circulation areas where the noise level is acceptable

5.8.6 CCTV and VMS (Variable Message Signs) Displays

Provisions shall be made for initial or future CCTV VMS displays; either free standing or integrated, as required by RTD.

5.8.7 Security Equipment

Refer to Section 14 System Safety and Security.

5.9.0 ELECTRICAL SYSTEMS

This section establishes the design criteria for all electrical equipment for Light Rail stations.

These criteria include functional and design requirements for the supply, control, and protection of AC power electrical systems. All exposed conduit on platform structures shall be painted to match the structure. The electrical and mechanical equipment requiring power shall include the following:

- Lighting
- Fare Collection Equipment
- Communications and CCTV
- Emergency Lighting and Power Systems (if required)
- Transit Signal Equipment

5.9.1 Standards and Codes

AC power and electrical system design shall conform to the latest edition of the following standards and codes where applicable:

- National Electric Code (NEC), National Fire Protection Association (NFPA) No. 70
- National Electrical Safety Code (ANSI C.2)
- Electrical Codes of the local jurisdiction
- American National Standards Institute (ANSI)
- National Electrical and Electronic Engineers (IEEE)
- Life Safety Code (NFPA) - 101
- Insulated Power Cable (IPCEA)

5.9.2 Station Power and Electrical System

These criteria establish the basic design requirements for AC Station Power Systems.

5.9.3 System Voltages

Service Voltage: All stations shall have 240/120-V or 120/208 power supply. (Please reference Electrical Systems Design Criteria in this Manual)

Utilization Voltages:

Lighting Fluorescent
Lighting(Sodium/metal halide) .... Use applicable voltage
Lighting Incandescent .... Use applicable voltage
Fare Collection Equipment .... Use applicable voltage
Communication and Cable TV .... Use applicable voltage
Other loads .... Use applicable voltage

Where single-phase power is taken from a 3-phase source, the loads shall be balanced among the three distribution phases.

5.9.4 System Capacity

Station power systems shall be structured from a single power distribution panel. The power distribution panel shall be of sufficient capacity to power all station loads plus a minimal spare capacity of 50%.

Demand Factors: In calculating system capacity, the following demand factors shall apply:

TABLE 5A – DEMAND FACTORS

Element Demand	Factor
Lighting (normal)	1.0
Heating (optional)	0.5
Fare Collection Equipment	0.5
Communications and Cable TV	1.0
Others	varies*

(* per duty cycle and code requirements)

Convenience receptacles shall be 0.89 of branch rating or a demand load of 9.8 KVA per outlet.

5.9.5 Performance Standards

Illumination Engineering Society Lighting Handbook

Underwriters Laboratories, Inc.

5.9.6 Standard Elements

All luminaries and lamp types shall be standardized system wide to provide design and perceptual unity and simplify maintenance requirements.

5.9.7 Illumination Levels

Illumination levels shall define and differentiate between task areas, decision and transition points, and areas of potential hazard. In addition to quantity of light, it is essential that illumination be designed to minimize glare and provide uniform distribution. Luminaries shall be selected, located, and/or aimed to accomplish their primary purpose while producing a minimum of objectionable glare and/or interference with task accuracy, vehicular traffic and neighboring areas.

Minimum illumination levels are shown below:

TABLE 5B – MINIMUM ILLUMINATION LEVELS

Locations	Minimum Foot-candles
Station Platform and Plaza Areas	5 minimum
Fare Vending Area	8 minimum
Parking Lots & Accessways	(0.5 min at property line) 2 average
Tunnels & Pedestrian Accessways	5 minimum

5.9.9 Station Site Lighting

Station lighting includes internal site circulation and access to the station. The placement of luminaries shall not obstruct the movement of vehicles. Luminary placement shall be coordinated with the landscape and site plan to protect light standards which are located adjacent to roadways, and to ensure that plantings will not obscure the lighting distribution pattern.

5.9.10 Vehicular Access Lighting

Vehicular access lighting shall provide a natural lead-in to the bus area and Kiss and Rides. The illumination on all access and egress roads shall be graduated up or down to the illumination level of the adjacent street or highway.

5.9.11 Pedestrian Accessways Lighting

Pedestrian accessways lighting shall define pedestrian walkways, crosswalks, ramps, stairs, tunnels and bridges.

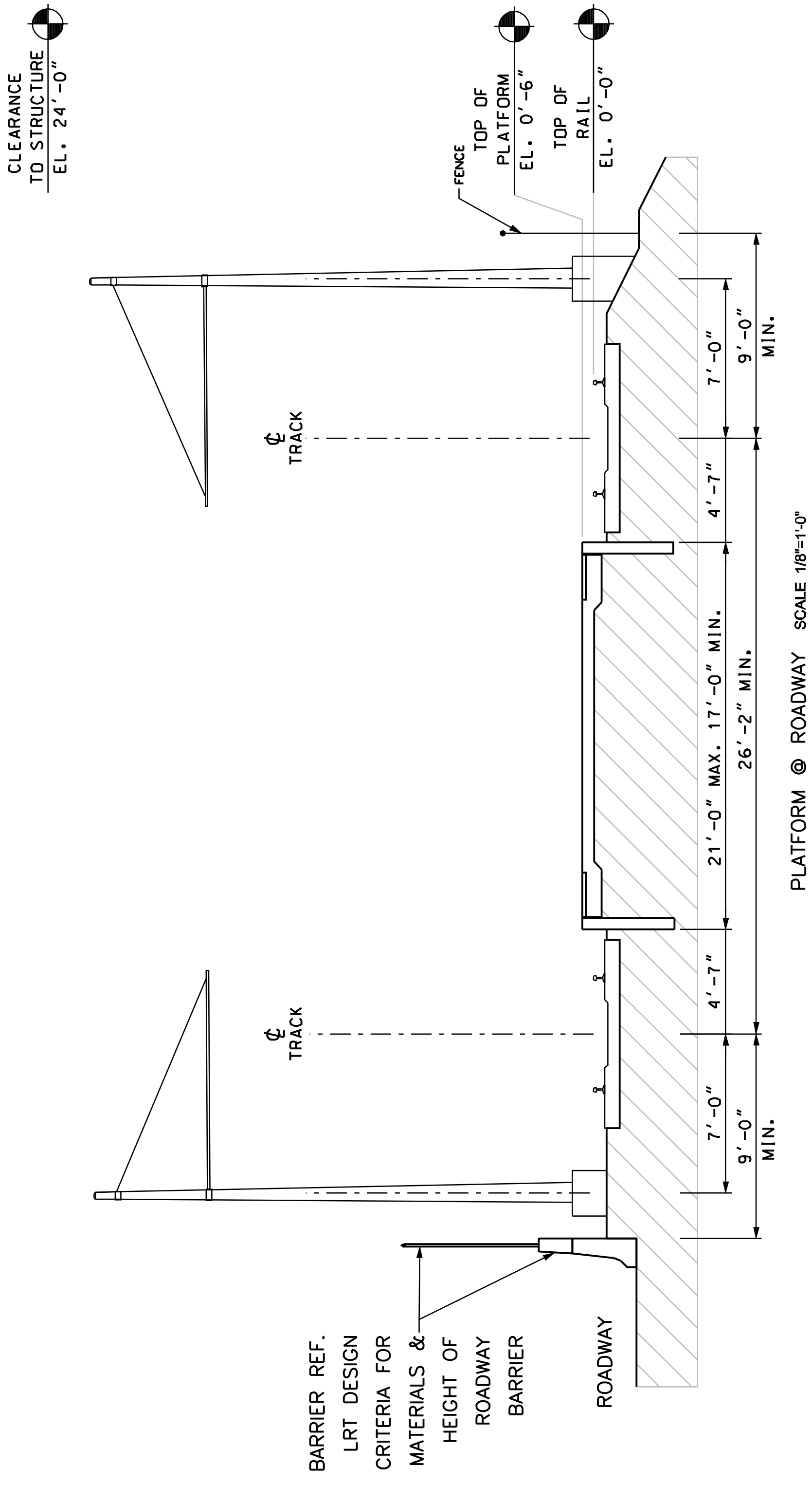
5.9.12 Platform Lighting

Platform area lighting shall be in any area that is used to load and unload a train. The lighting elements shall extend the entire length of the platform and shall demarcate the platform and emphasize the platform edge and vertical vehicle surfaces. Care shall be taken to avoid "blinding" LRT operators or other vehicle drivers with excessive or misdirected lighting.

5.9.13 Control of Lighting Systems

Lighting control shall be designed to use energy efficiently. Automatic and manual control arrangements shall ensure efficient utilization of energy and maintenance procedures. All exterior site areas shall be illuminated by a photocell with time clock or manual override.

LIST OF FIGURES

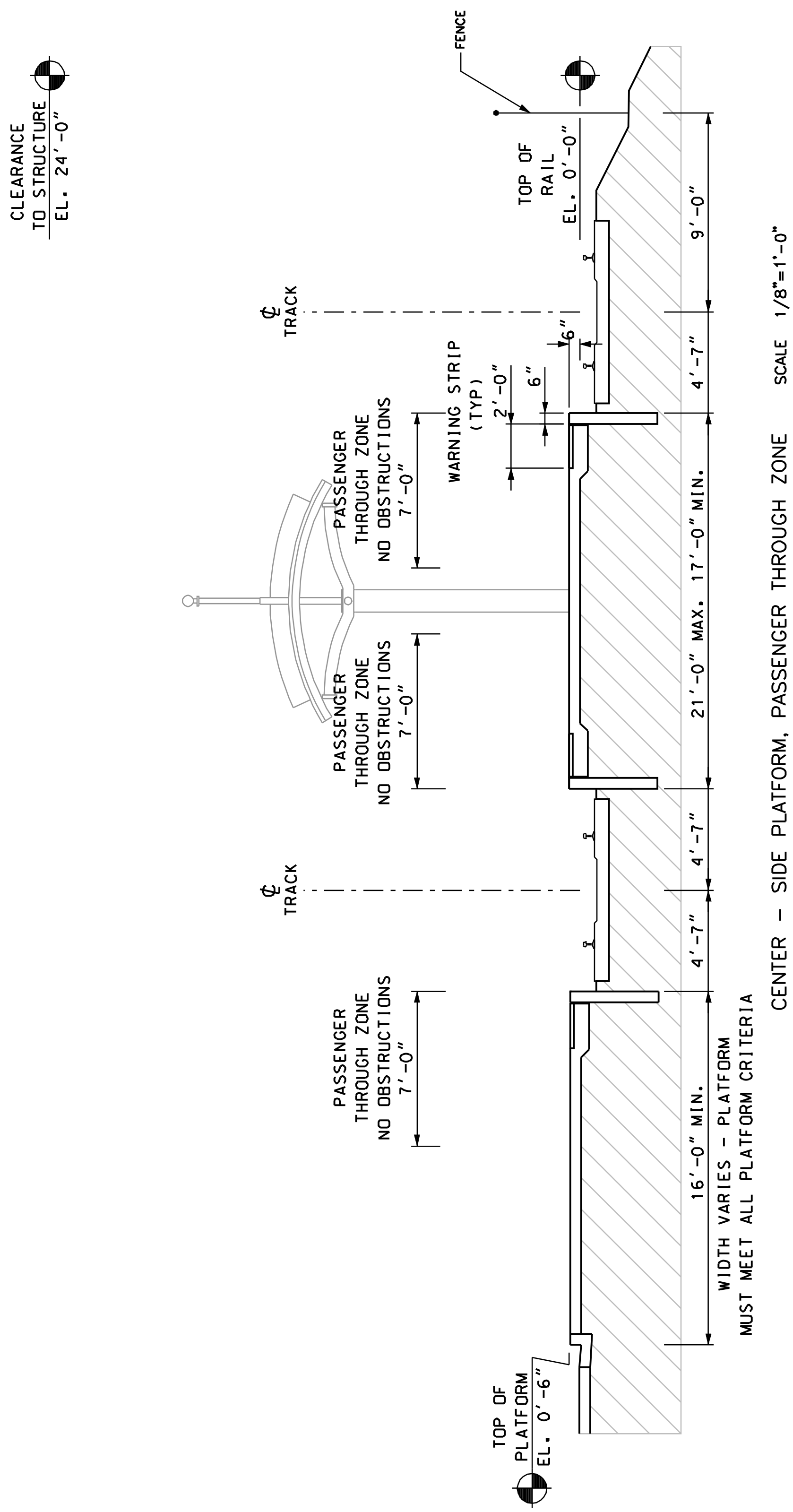


RTD

DESIGN CRITERIA

TITLE: PLATFORM @ ROADWAY

FIGURE: 5.1

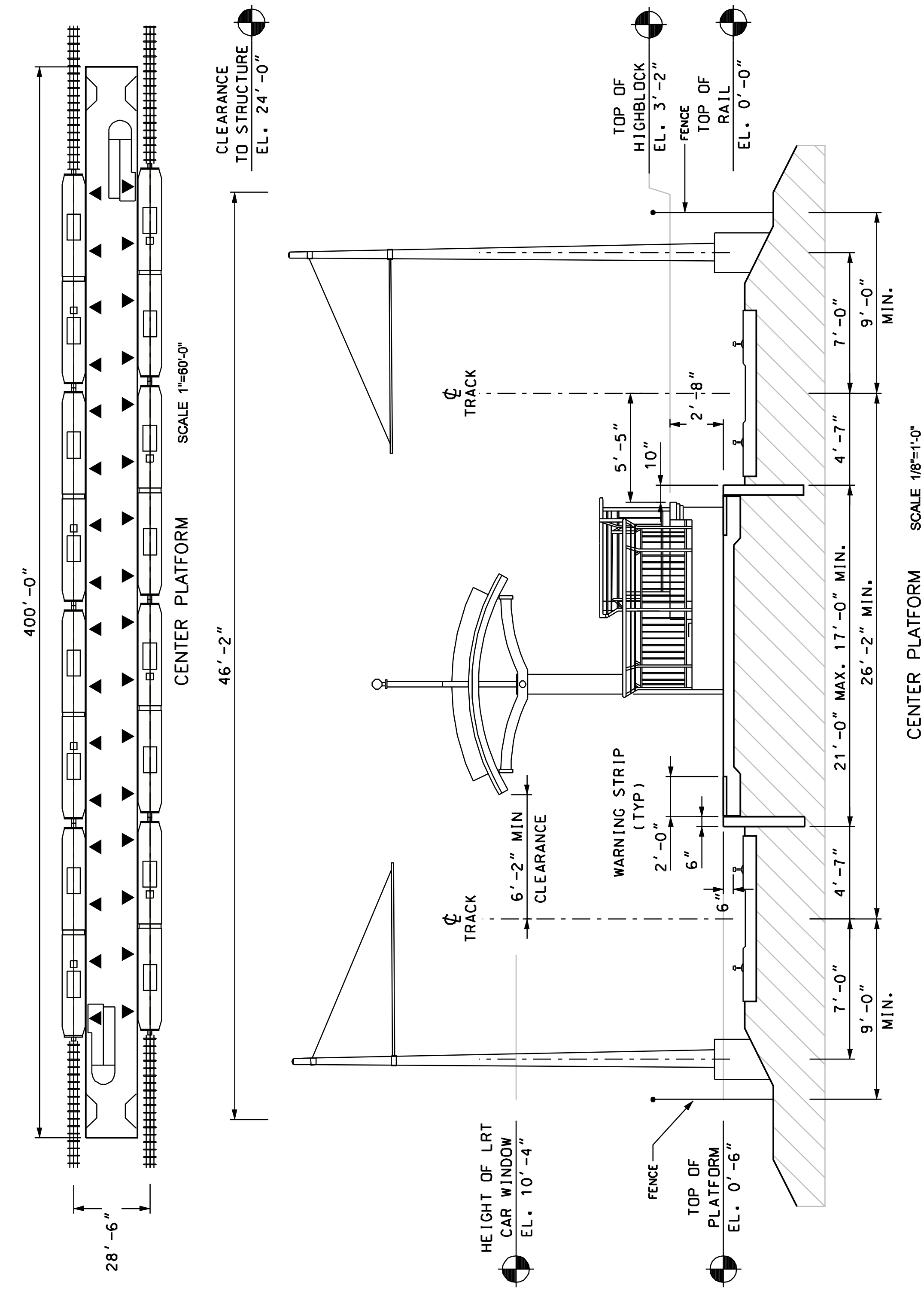


RTD

DESIGN CRITERIA

TITLE: PASSENGER THROUGH ZONE

FIGURE: 5.2

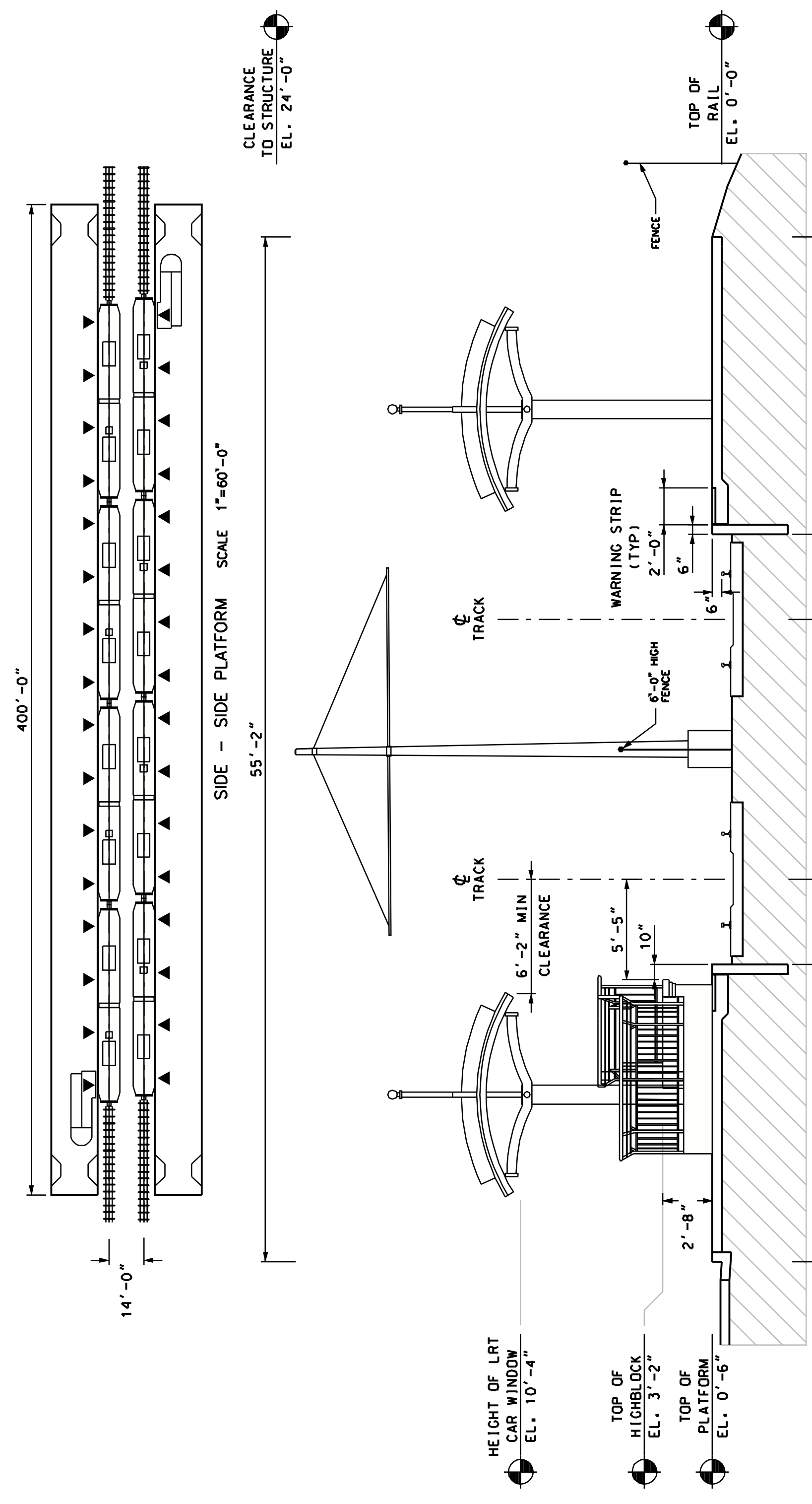


RTD

DESIGN CRITERIA

TITLE: CENTER PLATFORM

FIGURE: 5.3

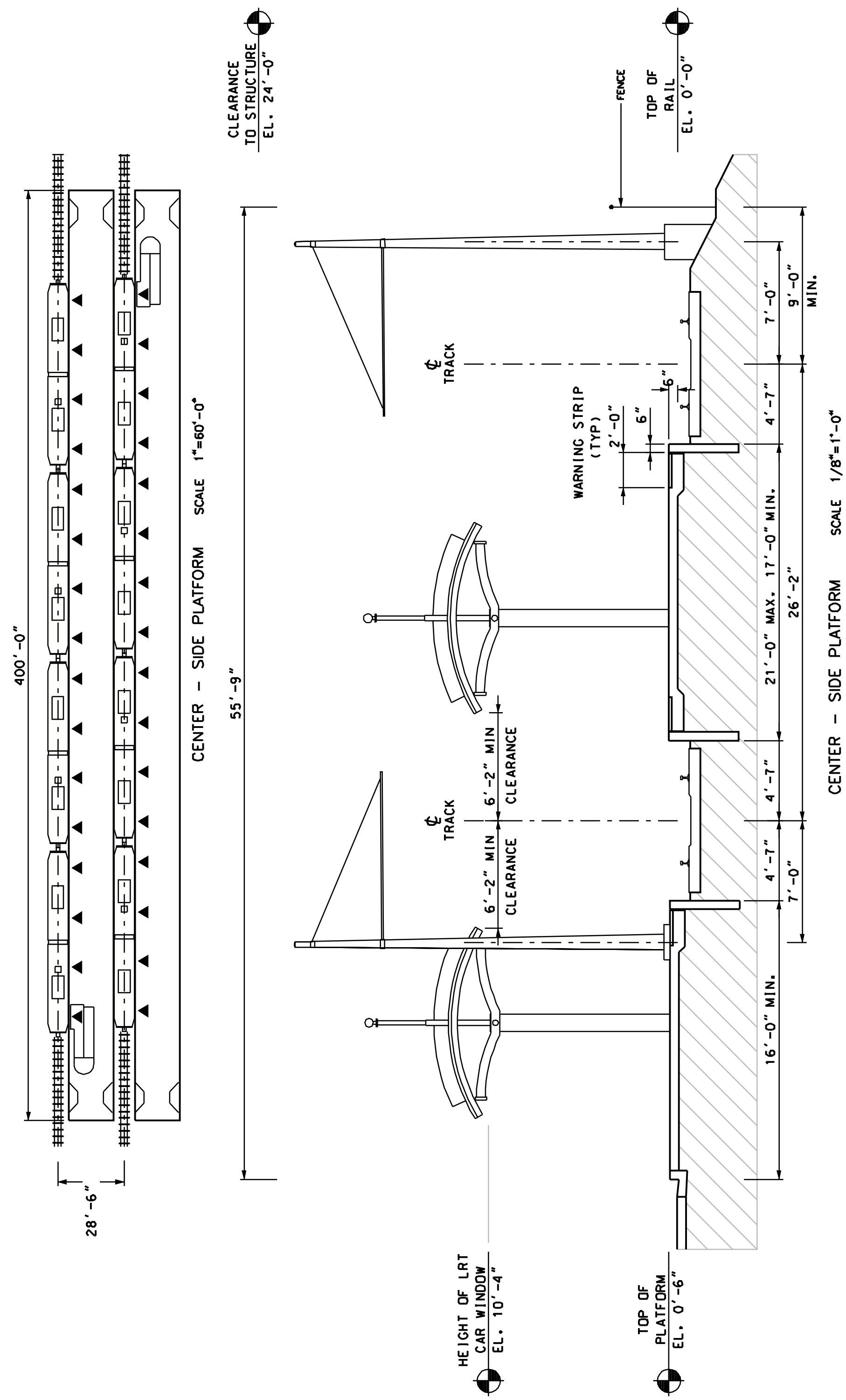


RTD

DESIGN CRITERIA

TITLE: SIDE - SIDE PLATFORM

FIGURE: 5.4



RTD

DESIGN CRITERIA

TITLE: CENTER - SIDE PLATFORM

FIGURE: 5.5

SECTION 6 – STRUCTURAL DESIGN

SECTION 6 – STRUCTURAL DESIGN CRITERIA

6.1.0 STRUCTURAL DESIGN CODES, MANUALS & SPECIFICATIONS

Load Factor Design, Allowable Stress Design and Load Resistance Factor Design (LRFD) are acceptable design concepts upon written approval from RTD. The designer shall coordinate the specific design methodology with RTD's structural engineer prior to commencing with preliminary design calculations and layout. All structural designs shall be signed and sealed by a Registered Professional Engineer in the State of Colorado. All revisions shall be reviewed, and signed and sealed by a Registered Colorado Professional Engineer. Unless otherwise specified herein, the following codes, manuals or specifications as appropriate or codes, manuals or specifications of other local jurisdictions shall guide the structural design.

6.2.0 BUILDING CODES

The most recent edition of: Uniform Building Code, International Building Code, City and County of Denver and State of Colorado, Structural Specialty Code and Fire and Life Safety Code, and local jurisdictional codes, as required.

6.3.0 EARTH RETAINING STRUCTURES

For earth retaining structures located either on caissons or other foundations, the AASHTO Specifications for Retaining Walls and CDOT design specifications shall be followed.

6.3.1 Geometry

Retaining wall layout shall address slope maintenance above and below the wall. Provide returns into the retained fill or cut at retaining wall ends where possible. Any residual wall batter should be into the fill. Design and construction shall consider surface and subsurface drainage. A drainage system shall be provided to intercept or prevent surface water from entering behind walls. A fence or pedestrian railing with a minimum height of 42 inches above a standing surface shall be provided at the top of walls 30 inches or higher.

6.3.2 Type

Metal walls, including bin walls and sheet pile walls, and recycled material walls will not be permitted for permanent retaining walls. Timber walls will not be permitted for permanent retaining walls supporting LRT structures unless prior approval by RTD. Wall types, proposed for use, shall have successfully been used in similar geotechnical locations and environmental conditions.

6.3.3 Design Requirements

Retaining walls shall be designed in accordance with the applicable standards and references outlined in this Design Criteria. The design of MSE and modular walls near or in bodies of water shall account for soft saturated soils and scour. All project walls near irrigation lines for landscaping shall account for the additional hydrostatic load due to a waterline break. The use of free draining backfill material and/or leak detection devices to reduce hydrostatic loads on retaining walls shall be included. All wall systems shall be designed to have a minimum service life of 50 years.

6.3.4 Characteristics

Mechanically Stabilized Earth (MSE) Walls - Wall panels shall be constructed of reinforced concrete. Provide corrosion protection for prestressing or posttensioning steel. Cover to reinforcing steel shall be a minimum of 2 inches. All reinforcing, mild or prestressed shall be galvanized or epoxy coated in splash zones of adjacent roadways.

Panel joints - shall accommodate differential settlement. Use section 206 of the CDOT – Standard Specification for Road and Bridge Construction for backfill requirements.

Modular Walls - Modular wall height shall not exceed 15 feet. A mechanical connection to the wall facing for soil reinforcement shall be provided; friction connections relying on gravity alone will not be acceptable. Modular walls cannot be used for primary mainline retaining walls. Modular walls may be used for secondary retaining wall locations, such as RTD park-n-ride and light rail stations.

Cast-in-Place Walls - Cast in place walls shall be designed and constructed in accordance with the current AASHTO Standard Specifications for Highway Bridges, CDOT design specifications and all interims through the present. Construction joint spacing shall accommodate differential settlement.

Anchored Walls - Anchored wall design and construction shall use FHWA RD-82-046, FHWA RD-82-047 and FHWA-IF-99-015 as guidelines. Anchors shall be encapsulated with plastic sheathing. Proof load tests for anchors shall be provided in accordance with the above FHWA guidelines. Shotcrete shall meet the aesthetic requirements set by RTD.

Soil Nail Walls - Soil nail walls may be used when top-down construction is warranted. Soil nail walls shall not be used if ground water seepage will be a problem. Design and construction shall use FHWA-RD-89-93, FHWA-SA-93-086 and FHWA-SA-96-069 as guidelines. Load testing for nails shall be provided in accordance with the above FHWA guidelines. Shotcrete shall meet the aesthetic requirements, including final finish, as established by RTD.

Soil Reinforcement - Soil reinforcement for MSE and modular walls shall be galvanized, epoxy coated steel or geogrids meeting creep requirements of AASHTO Standard Specifications for Highway Bridges. Design shall account for any item projecting through the soil reinforcement. Avoid placing culverts and utilities perpendicular to soil reinforcement within the reinforced soil mass. Soil reinforcement shall be protected from corrosion of metal due to stray electrical currents. Requirements for stray current control shall follow the project standards as defined by RTD.

Structural Diaphragm Walls - Structural diaphragm walls may be used when top-down construction is warranted.

6.4.0 CONCRETE

Structures designed to carry LRV, railroad or highway loadings shall be designed to current AASHTO, AREMA or CDOT specification including the most current interims.

The use of lightweight concrete is not allowed for use in structural members.

Minimum allowable concrete strengths shall meet the requirements of Section 601 of CDOT - Standard Specifications for Road and Bridge Construction.

6.5.0 STRUCTURAL STEEL

Structures designed to carry or support LRV, railroad or highway loadings shall be designed to current AASHTO, AREMA and CDOT Specifications including the most current interims.

6.6.0 PRESTRESSING STEEL

The maximum diameter for prestressing strands shall be 0.6 inches for a 2 inch minimum spacing and 0.5 inches for a 1-3/4 inch minimum spacing.

6.7.0 POST-TENSIONING STEEL SYSTEMS

Provide corrosion protection for the strands consisting of grout filled galvanized or nonmetallic ducts. Grout shall meet the requirements of Section 618 of CDOT Standard Specifications for Road and Bridge Construction. Prestressing systems shall be from PTI Certified plants.

6.8.0 REINFORCING STEEL

The use of epoxy coated reinforcing steel for all bridges, walls, tunnels and box culverts shall adhere to the requirements of Table 1, Subsection No. 8.1 of the CDOT Bridge Design Manual. The design category for anticipated level of de-icing salt application shall be “Low.” The protection of reinforcing steel LRT bridges shall follow the requirements for stray current/corrosion control, outline in chapter 10. Specific reinforcing steel for LRT bridges, not covered in Chapter 10, shall conform to the requirements of CDOT Standard Specifications for Road and Bridge Construction.

Abutments, pier columns, and superstructures exposed to splash from adjacent roadway shall use epoxy coated reinforcing steel conforming to the requirements of CDOT.

6.9.0 TIMBER

For timber structures other than structures subjected to LRT or highway loading, the National Design Specification for Wood Construction, by the National Forest Products Association shall be followed. Timber structures with over 20 feet of span length shall not be allowed for permanent structures.

6.10.0 TEMPORARY STRUCTURES

All materials for temporary structures both above and below ground shall be removed unless given specific permission from RTD to leave in place.

6.11.0 SLABS

Structural slabs shall be designed to handle all loading that may be potentially placed upon them. For slabs in areas handling pedestrian loading and snow loads, design shall include HS15 truck loading at a minimum. Reinforcing in areas exposed to weather and de-icing chemicals shall have galvanized or epoxy coated reinforcement.

6.12.0 TUNNELS

Tunnel structures required for LRT, highway under LRT, and pedestrians shall be considered buried structures or culverts, and shall be designed in accordance with AASHTO Standard Specifications for Highway Bridges. All buried structures longer than 400 feet shall and designed to carry LRV shall have direct fixation track. Grade separation shall have a drainage system designed to prevent any freestanding water on the structure bottom slab and also prevent any ground water infiltration under and into the structure.

Standpipes shall be provided in all tunnels in accordance with NFPA 130 requirements. Requirements address standpipes both during and after construction. Tunnel ventilation shall be provided in accordance with NFPA 130. Emergency telephones shall be consistent with NFPA 130 and the authority having jurisdiction.

6.13.0 BRIDGES

6.13.1 Geometry

All fill and cut slopes along the longitudinal axis of bridges with spill through abutments shall not be steeper than 2:1. There shall be a 2-foot berm at the top of slopes in front of abutments. Minimum vertical clearance over highways and city streets (traveled way) shall be 16 feet-6 inches for vehicular bridges and 17 feet-5 inches for pedestrian bridges, allowing for future pavement overlays on the roadway below unless otherwise approved by RTD. Provide 17 feet-0 inches preferred vertical clearance over all light rail tracks (top of rail to bottom of bridge). The vertical clearance may be reduced below the 17 feet-0 inches preferred dimension (for light rail) to 15 feet-0 inches minimum vertical clearance at special locations, with the approval of RTD. Along the LRT alignment, where the tracks are depressed or elevated on a structure, a 2 foot-6 inch emergency/maintenance walkway shall be provided. Bridge supports shall be located radially for curved structures where practical. The maximum bridge skew shall be less than 30° away from radial supports, if practical.

Bridges greater than or equal to 400 feet in length shall be designed using direct fixation track. Bridges less than 400 feet in length shall be designed using ballasted track, unless as approved otherwise by RTD. Bridge deck and approach slab surface smoothness on Direct Fixation bridges shall not deviate more than 3/8 inch in 25 feet using a profilograph as described in Subsection 412.17(a) of the CDOT Standard Specifications for Road and Bridge Construction. The profile index shall start and terminate on the bridge approach slab. One profile shall be taken for each track lane.

6.13.2 Structure Type

Bridge type will be restricted to those historically used by RTD. Other types and components may be used, but will be allowed only if they have been accepted for general use by other transportation authorities and the Design Engineer can demonstrate that the design of the bridge type and components will perform well under the project's environmental conditions, including frequent freeze-thaw cycles and seismic criteria. Experimental bridge types, timber bridges, masonry bridges and structural plate arches are not permitted. Bridges shall incorporate as few joints and bearings as possible, be continuous over supports, not use intermediate hinges and use integral abutments whenever possible. The RTD representative reserves the right to reject the use of non-historic bridge types proposed by the Design Engineer, if they cannot meet the project design and performance criteria in this section.

6.13.3 Inspection Access

All bridge superstructures, joints and bearings (type II or type III) shall be made accessible for long-term inspection and shall be designed and detailed for ease of replacement. Superstructures consisting of I-girders with exposed cross frames shall be made accessible with walkways, ladders or by use of a snooper truck. Box girders with and inside depth of 5 feet or more shall be made accessible for interior inspection. Bottom slab access doors shall be placed at locations which do not impact traffic under the bridge and shall swing into the box girder. Box girders shall be protected from access by vermin.

6.13.4 Components

6.13.4.1 Bridge and Pedestrian Fencing

All LRT structures shall have a pedestrian fence adjacent to the emergency/maintenance walkway with the top being no less than 42 inches above the walkway surface curbing. The fence shall be vinyl-coated for bridges with 3/8 inch mesh in areas around stations and platforms that are adjacent to highways or where snow and ice may be thrown from snow removal equipment onto patrons. All walls greater than 30 inches above the adjacent surface outside of the LRT envelope shall have pedestrian fence or barrier 42 inches above the trackway or walkway surface.

6.13.4.2 Approach Slabs

Provide an approach slab at the end of each LRT bridge. The approach slab shall be a minimum of 25 feet in length measured along the centerline of the bridge. The end of the approach slab shall be perpendicular to the track centerline if at all possible. The approach slab for LRT bridges shall be 2 feet wider than the track tie length at a minimum, the approach slab may be the same width as the bridge deck (minus the width of the pedestrian rail or curb) and provide for the smooth transition from ballasted section to direct fixation where required. Track tie spacing shall be reduced from 30 inches to 21 inches on approach slabs.

An underdrain system shall be designed beneath all approach slabs to reduce water in embankment fills at bridge abutments. Bridge deck drains shall be located, so as to minimize the amount of water flowing across all joints.

Differential settlement across approach slabs shall be less than 1 inch. Ground improvement techniques to the approach embankment subgrade shall be implemented if necessary to meet this requirement.

6.13.4.3 Bridge Decks

Provide a minimum deck thickness of 8 inches. Open or filled grating decks and orthotropic decks will not be permitted. Concrete decks designed to the simplified “Ontario” or any empirical methods will not be permitted. Precast deck slabs shall require cast-in-place topping slabs and joint closures, and post tensioning across joints. Pretensioned, precast concrete deck forms shall be a minimum of 3 inches thick and have a full grout or concrete bearing. Stay-in-place (SIP) metal deck forms are permitted. Parallel bridges shall have a minimum 1 inch (4 inch preferred) longitudinal gap between decks or parapets, or shall be tied together to make on structure. Ballasted track bridges shall be protected with an appropriate waterproofing.

6.13.4.4 Deck Joints

Avoid or minimize joints. Bridges up to 300 feet (steel) or 400 feet (Precast or cast-in-place concrete) long shall be jointless. All expansion joints shall be an approved strip seal or modular joint. Design and location of joints shall provide for maintenance accessibility and future replacement. Aluminum joints will not be permitted. Modular joints shall be designed and tested for fatigue loading.

6.13.4.5 Superstructures

Ensure that all superstructures meet the requirements for redundancy, fatigue, crack control, and deflection in AASHTO Standard Specifications for Highway Bridges. Utilities shall not be placed on structures without prior approval of RTD and, if accepted, shall be designed by a Colorado licensed Professional Engineer. The placement location shall hide utilities from view if they are required to be placed on the structure. For structural steel, redundant member structures are preferred. For concrete box girder structures, the designer shall consider the effects of a temperature gradient.

Steel superstructures within 4 feet of the electrified Overhead Catenary System (OCS) envelope shall not be used. However, if this requirement is not feasible or attainable, steel superstructures within the 4-foot envelope shall be electrically insulated and protected from the power supply system, and provided with a ground electrode system. If a glastic, phenolic, or other insulating non-conductive material is used it shall be placed the entire length where the height is less than 4'0" and must at a minimum extend a width of 4'0" from the center of the OCS wire for the entire length of the non-conductive barrier. The Design shall provide for ease of future maintenance when designing superstructures over the OCS envelope.

6.13.4.6 Bearings

Provide design and location of bearings to allow maintenance accessibility and future replacement. Elastomeric bearings are preferred. Sole plates, when used, shall have a ¾ inch minimum thickness. At expansion bearings, the edge of the sole plate shall not slide past the edge of the elastomeric pad, by the use of a positive stop. Provide at least 3 inches of cover between anchor bolts and the edge of the concrete pedestals. Provide reinforcement for pedestals greater than 3 inches high.

6.13.4.7 Piers and Pier Caps

Design a type of pier cap that is consistent with the rest of the corridor and the bridge system used. Drop caps or integral caps are acceptable. Integral caps are preferred with cast-in-place concrete box section systems. The Design Engineer shall minimize the use of integral steel pier caps. If integral steel pier caps are used, they shall be post-tensioned. If practical, inspection access for integral steel pier caps shall be provided.

6.13.4.8 Abutments

Abutments shall be integral, end diaphragm-type abutments for bridge structures where practical. Retaining walls may be used in lieu of wingwalls at the abutments.

6.13.4.9 Slope Protection

Concrete slope protection shall be provided for all slopes under bridges. Slope protection shall conform to details contained in the CDOT Standard Structural Worksheets Slope Paving Details.

6.13.4.10 Foundations

Foundation design shall be recommended by a Geotechnical Engineer.

6.13.4.11 Drainage

Supply splash blocks at all deck drain daylight locations. The bridge deck drainage systems shall be in accordance the bridge drainage section 3.5.4.

Where direct fixation is used on LRT bridges, a trench drainage system, perpendicular to the tracks, shall be used at the end of the bridge deck, prior to joint between the approach slab and the bridge superstructure.

6.13.4.12 Stray Current Control

Ensure that all structures and structural components shall be protected from corrosion of metal due to stray electrical currents. Reinforcing steel in bridge structures may either be protected by use of a continuously welded steel mat that has been properly grounded, epoxy coated steel or in the case of ballasted decks by use of an insulating membrane placed beneath the ballast. All structures placed below grade or buried structures shall be properly protected and insulated from stray currents.

Structures and structural components shall be treated with Polyurea or approved equal for waterproofing and corrosion control.

6.13.4.13 LRT Loading

LRT structures subjected to light rail vehicle loadings shall be designed in accordance with the requirements of AASHTO Standard Specifications for Highway Bridges and CDOT Standard Specifications for Road and Bridge Construction, except as modified by loading depicted in Figure 3-3, which depicts the LRV loading diagram. A train shall consist of up to four cars whichever number causes the most severe condition.

6.14.0 PEDESTRIAN BRIDGES

Pedestrian bridges shall be designed in accordance with the requirements of AASHTO Standard Specifications for Highways and Bridges, AASHTO Guide Specification for Pedestrian Bridge, and CDOT Standard Specifications for Roads and Bridge Construction.

The Design Engineer shall coordinate with RTD for the design of covers on pedestrian walkways over LRT tracks or roadways.

6.15.0 PARKING STRUCTURES

See RTD Design Guidelines and Criteria for Bus Transit Facilities.

6.16.0 GEOTECHNICAL ANALYSIS

The soils in the Denver metropolitan area vary. Soil and geologic data and reports for the preliminary design of structures shall be site specific. Preliminary recommendations shall be provided in the project structural reports prepared during the Preliminary Engineering phase. On Final Design, site-specific soil and geological data shall be obtained to develop the design parameters.

Commonly used foundations for bridges, retaining structures and buildings include: spread footings, driven precast concrete piles and drilled shafts. Foundations recommendations shall be made in a site-specific project geotechnical report. Foundations shall be designed according to AASHTO, CDOT Standards, or local requirements. River scour shall be included in geotechnical reports where appropriate.

6.17.0 LOADS AND FORCES

6.17.1 Dead Load

Dead load design weights shall be as prescribed below:

TABLE 6A – DEAD LOAD DESIGN WEIGHTS

Aluminum alloys	175 pcf
Asphalt mastic, bituminous macadam	150 pcf
Crushed stone	120 pcf
Ceilings, plasterboard, unplastered	3 psf
Gypsum ceiling tile, 2" unplastered	9 psf
Prestressed steel	2 psf
Ceramic glazed structural facing, 4"	33 psf
Concrete crosstie	620 lbs
Electrical overhead pickup equipment @20' cc in subsurface	60 lbs
Floors, gypsum floor slab, per inch	5 psf
Asphalt mastic	5 psf
Ceramic tile, on 1" mortar bed	23 psf
Linoleum, 1/4"	2 psf
Maple, 7/8" on sheathing, 2" cylinder fill, No ceiling	18 psf
Oak, 7/8" on sheathing, wood joists @ 16" centers, no ceiling	11 psf
Glass	160 pcf
Gravel, sand	120 pcf
Iron, Cast	450 pcf
Partitions Plaster, 2" channel stud metal lath	20 psf
Plaster; 4" channel stud, metal lath	32 psf
Hollow plaster; 4" metal lath	22 psf
Gypsum block, solid; 3", both side plastered	19 psf
Gypsum block, hollow; 5', both side plastered	22 psf
Steel partitions	4 psf

Ceramic glazed structure tile, 4"	33 psf
Rail and fastenings, per track (2 rails)	200 plf
Roofs, roofing felt, 3 ply, and gravel	5 ½ psf
5 ply	6 ½ psf
Sheathing, 3/4" thick	3 ½ psf
Steel	490 pcf
Timber, untreated	48 pcf
Treated	60 pcf
Walls, brick solid, per in	10 psf
Glass, structural, per in	15 psf
Windows, frame, glass, sash	8 psf
Stone, 4"	55 psf
Steel sheet, 14 gauge	3 psf
Concrete, reinforced or prestressed	150 pcf
Concrete median barrier	500 plf
Future surfacing allowance (ballast) (6" additional)	60 pcf
Sign structures	as required
Utilities, including scuppers	100 plf of track
Drain pipes & light poles	as required
Double Track Dead Load: 115RE rail and accessories, wood ties, 8"	4000 plf of 28-ft. wide bridge
Ballast	120 pcf

6.17.2 Live Load

Live load design weights shall be as prescribed in Figure 3-3, which depicts the LRV loading diagram. A train shall consist of up to four cars whichever number causes the most severe condition.

Highway live loads shall be as specified in AASHTO Standard Specifications for Highway Bridges and supplemented by the CDOT Design Specifications for Design and Construction of Highway Bridges.

Detailed discussion of both vibration and deflection control for aerial structures. Deflection is limited to L/1000 under LRT loads and L/375 for cantilevers. This corresponds to AASHTO specifications for highway, bridge and pedestrian traffic. In addition, limits are placed on dynamic interaction between the superstructure and the LRT vehicle, by limiting the first mode natural frequency of each simple span to not less than 2.5 hertz, and not less than 3.0 hertz for one span in a series of three consecutive spans. For longer span structures that exceed these limits, a special dynamic analysis shall be conducted. That special dynamic analysis will also be used to determine whether impact in excess of their 30% limit is warranted.

6.17.3 Derailment Load

Vertical

Vertical Derailment Load shall be produced by two to three vehicles placed with their longitudinal axis parallel to the track.

Lateral vehicle excursion shall vary from 4 inches minimum to 36 inches maximum for tangent track and curved track with radius greater than 5000 ft. For track with smaller radii, the maximum excursion shall be adjusted so that the derailed wheel flange is located 8 inches from the rail traffic face of the nearest barrier, if any, or the edge of deck. In any case, for tracks protected by guardrails, the maximum excursion shall be limited to that allowed by the placement of the guardrails.

A vertical impact factor of 100% of vehicle weight shall be applied in computing the equivalent static derailment load. The derailment impact shall be applied to any two adjacent axles (within a single truck assembly with axles spaced 5.9 feet apart) at a time, and the normal AASHTO vertical impact factor shall be used for all other axles, which produces the critical loading condition for the structure.

When checking any component of superstructure or substructure, which supports two or more tracks, only one train on one track shall be considered to have derailed, with one other track being loaded with a stationary train.

All elements of the structure shall be checked assuming simultaneous application of all derailed wheel loads. However, the reduction of positive moment in continuous slabs due to derailed wheel loads in adjacent spans shall not be allowed.

Horizontal

For cross-sections having clearance between vehicle and barrier wall of 6 inches to 36 inches, with maximum vehicle speeds of 60 mph, the force due to horizontal derailment loads shall be taken as 40% of a single vehicle weight acting two feet above top of rail and normal to the barrier wall for a distance of 10 feet along the wall. Barriers farther than 36 inches clear from vehicles are not contemplated. For tracks supported by guardrails, the guardrails will resist this force.

6.17.4 Impact

In addition to the vertical impact provided in AASHTO specifications, a Horizontal Impact (or Nosing) Force, equal to 10% of rail transit design vehicle load shall be applied. This force shall be equally distributed to the individual axles of the vehicle, and shall be applied horizontally in the vertical plane containing each axle. The force shall be assumed to act in either direction transverse to the track through a point 42 inches above the top of the lower rail.

6.17.5 Longitudinal Forces

A force equal to 15% of the LRV, without impact, per track, shall be applied 5 feet above the top of rail on all tracks. Consideration shall be given to combinations of acceleration and deceleration forces where more than one track occurs. 50% of this force maybe assumed to be transferred outside of the structure when ballasted tracks with continuously welded or bolted rails spanning the entire structure are used.

6.17.6 Centrifugal Force

Determination of centrifugal force due to rail transit vehicles on curved track shall be as provided in AASHTO specifications except the resulting force shall be applied four feet above the top of the lower rail of the track.

6.17.7 Wind Loads

For trains operating on aerial structures with the underside of the main girders not more than 40 feet (H) above the mean retarding surface, wind on live load, WL, shall consist of a transverse wind load of 115 pounds per lineal foot of train and a longitudinal wind load of 28 pounds per lineal foot of train. These loads shall be applied simultaneously. The transverse force shall be applied to the rails and superstructure as loads concentrated at the axle locations, and in a plane 6 feet 4 inches above the top of the lower rail. The longitudinal force shall be applied to the rails and superstructure as a load uniformly distributed over the length of the train in a horizontal plane 6 feet 4 inches above the top of the lower rail.

For higher aerial structures, the value of WL in the transverse and longitudinal directions shall be as follows:

H = 41 to 60 feet:	Transverse wind pressure = 126 plf
	Longitudinal wind pressure = 31 plf
H= 61 to 100 feet:	Transverse wind pressure = 130 plf
	Longitudinal wind pressure = 34 plf

These loads apply to the design of the substructure elements supporting a single track. For the design of substructure elements supporting two tracks, these loads shall be increased by 30%, when both tracks are loaded; this factor accounts fully for shielding effect of vehicle on vehicle as the two trains run alongside each other.

Wind loading on catenary shall be considered in the design of both superstructure and substructure elements. Loads (magnitude and location) shall be determined by catenary Design Engineer.

6.17.8 Application of Loadings

For structures carrying rail transit loads, one train per track, for both strength and serviceability considerations in all materials. When intended to occupy the same deck space as highway loads, either concurrently or at separate periods of structure life, the rail transit loads shall be treated as alternatives, interchangeable with the highway loads. When all or a portion of deck width is dedicated exclusively to rail transit, the rail transit loads shall apply only to that width.

6.17.9 Reduction in Load Intensity

For structures carrying rail transit loads, a track shall be as a traffic lane in applying the provisions for structures of AASHTO Bridge Specifications.

6.17.10 Force Due to Rail Restraint

To avoid excessive longitudinal forces, continuous welded rail shall not be terminated on structures

6.17.11 Loading Combinations

Rail transit loads shall be incorporated into the loading combination provisions of AASHTO Bridge Specifications by means of the following modifications:

a. Add B_{NF}, NF to the expression for Group (N).

b. Add to the list of terms:

RT = Rail Transit

NF = Nosing Force

DR = Derailment

c. Add Group I RT and Group XI as shown in Figure 3.4.

d. Add loads (L + I)RT, (L + I)DR, (L)RT, and NF to the loading groups with the values of B as shown in Figure 3.4.

6.17.12 Distribution of Loads and Design of Concrete Slabs

Modify AASHTO specifications by the following additions:

Ballasted Track

Axle Loads may be assumed as uniformly distributed longitudinally over as length of 3 feet, plus the depth of the ballast under the tie, plus twice the effective depth of slab, except as limited by axle spacing.

Wheel loads may be assumed to have lateral distribution over a width equal to the length of tie plus the depth of ballast under the tie, except as limited by the proximity of adjacent tracks or the extent of the structure.

Direct Fixation Track

Where wheel loads are transmitted to the deck slab through rail mountings placed directly on the slab, the wheel load shall be assumed as uniformly distributed over the length of three feet along the rail. This load may be distributed transversely (normal to the rail and centered on the rail) by the width of the rail fastener pad plus twice the depth of the deck and track concrete.

6.17.13 Rail Transit Collision with Structures

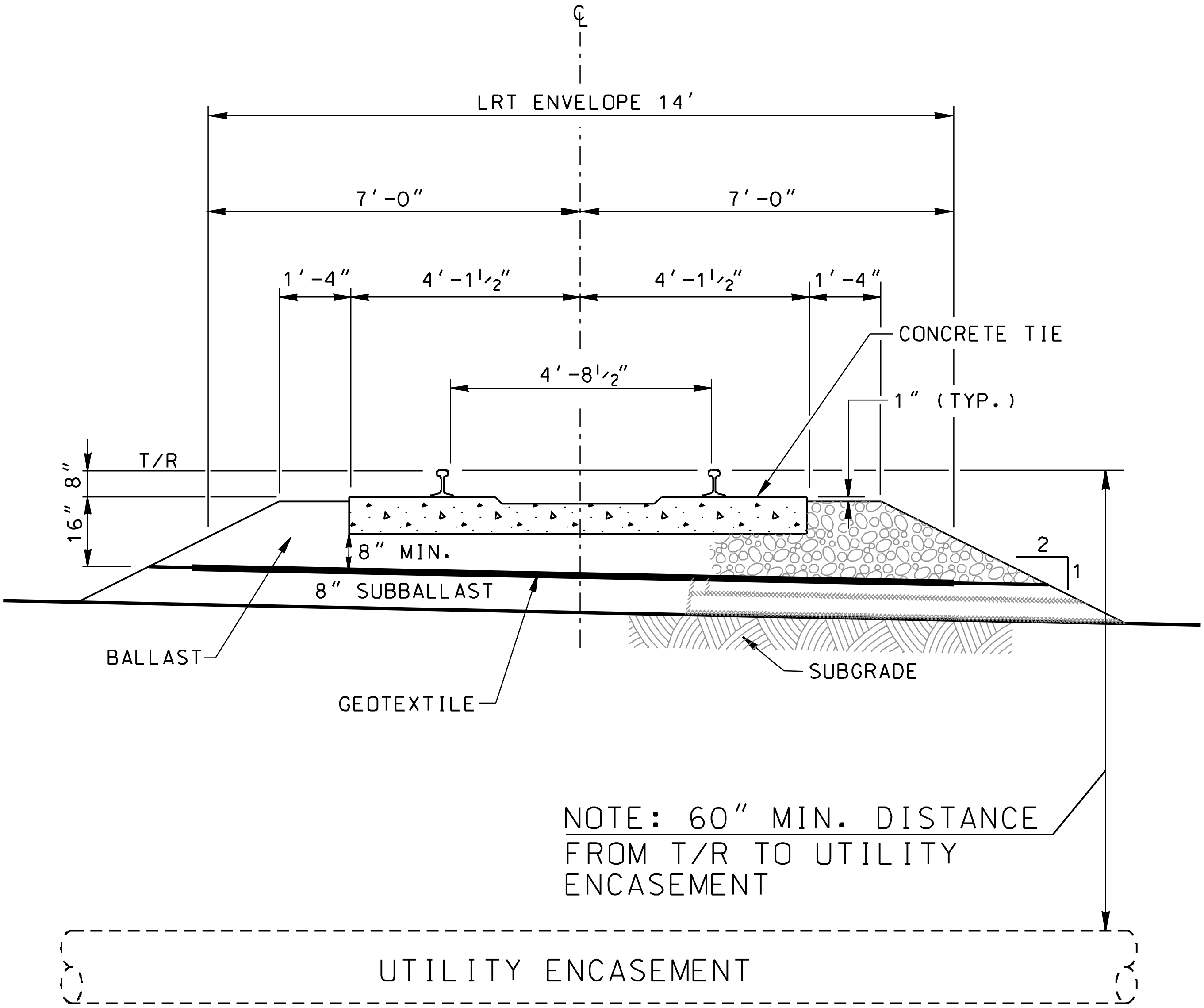
Unless otherwise protected by an embankment or barrier, abutments and piers located within a distance of 25 feet to the centerline of a rail transit track, shall be protected by a reinforced concrete crash wall.

The provisions of this section need not be considered for structures if they are protected by:

- an embankment,
- a structurally independent, crashworthy ground mounted 6 feet high barrier or wall, located within 10 feet from the component being protected,
- a 42 inch high barrier located at more than 10 feet from the component being protected.

In addition, where the rail transit vehicles are restrained with guardrails or direct fixation containment walls, any adjacent abutments and piers need not be designed for the collision force.

LIST OF FIGURES

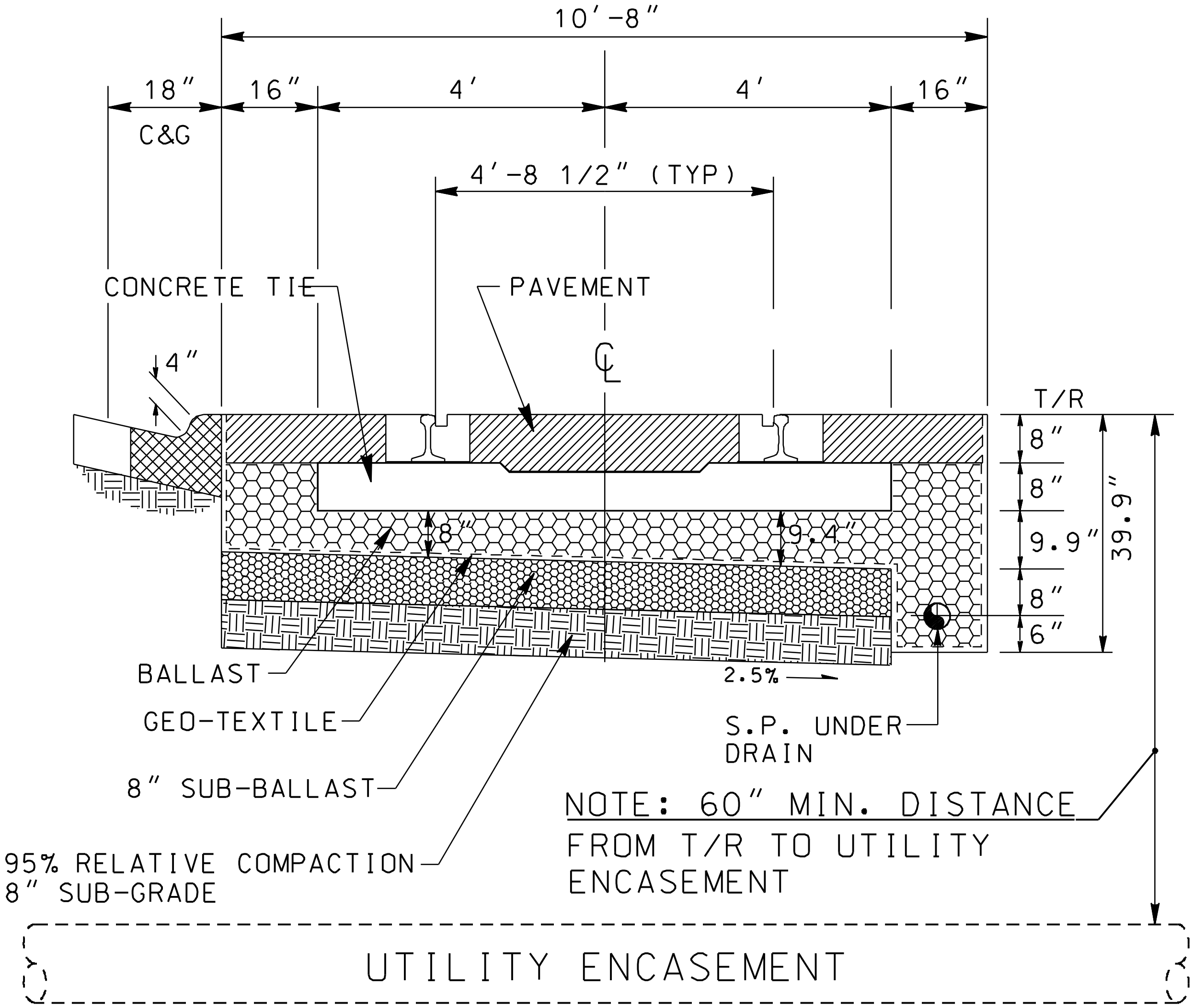


RTD

DESIGN CRITERIA

TITLE: BALLASTED SINGLE TRACK

FIGURE: 6.1

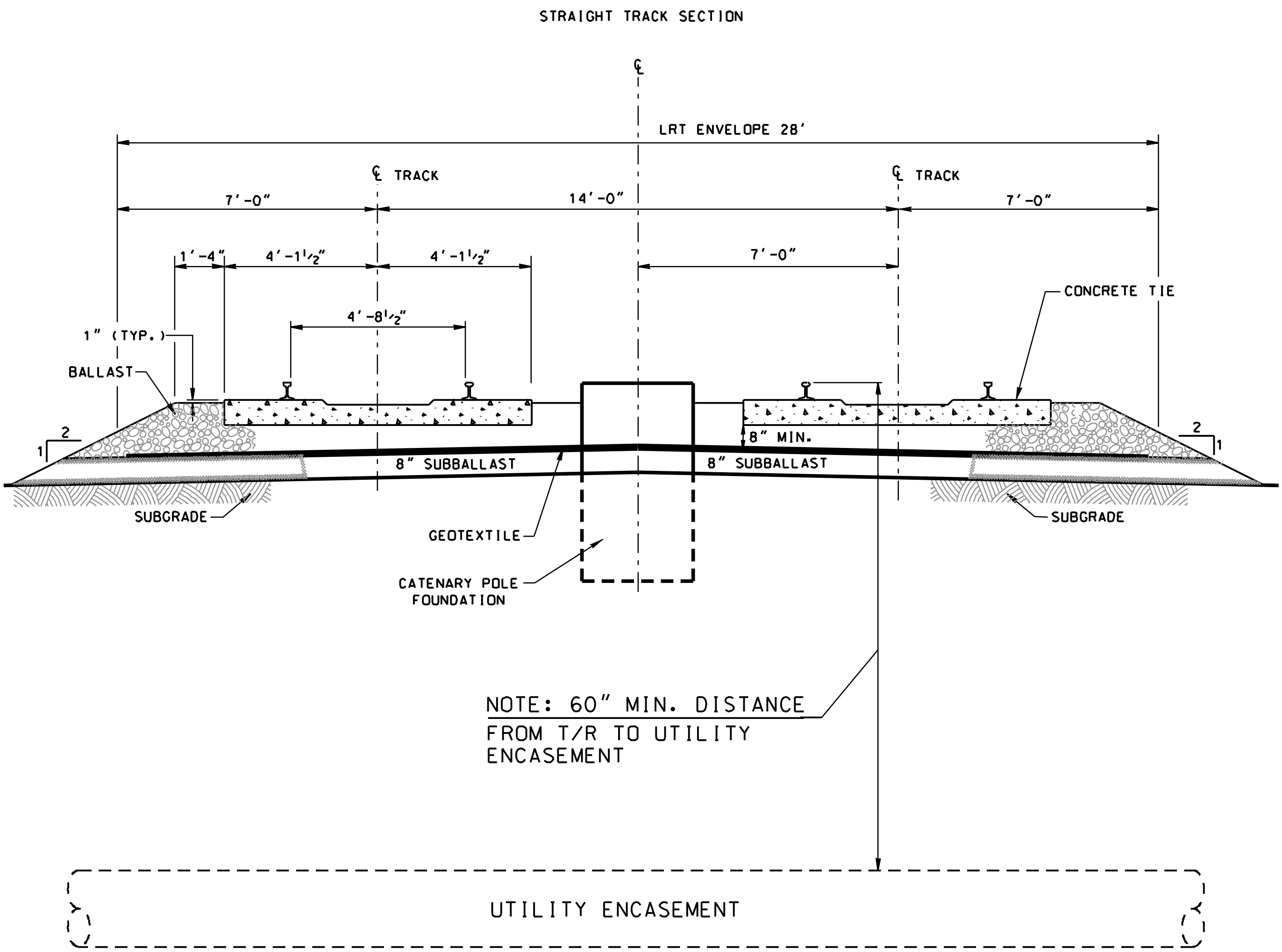


TYPICAL CROSS-SECTION
PAVED TRACK

NOT TO SCALE

RTD

DESIGN CRITERIA	**TITLE:** SINGLE TRACK - PAVED
	FIGURE: 6.2



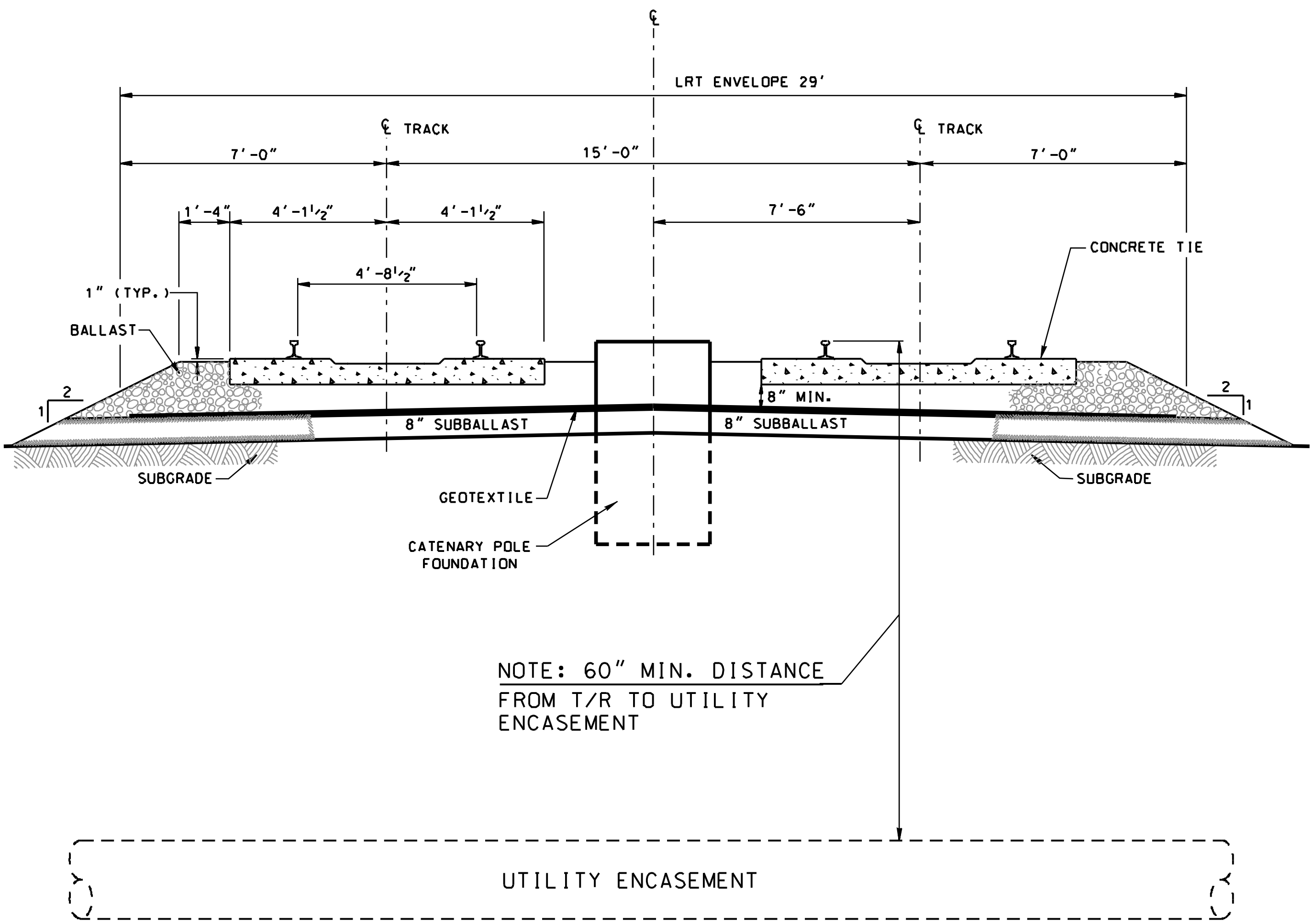
RTD

DESIGN CRITERIA

TITLE: DOUBLE TRACK BALLASTED - STRAIGHT

FIGURE: 6.3

CURVED TRACK SECTION



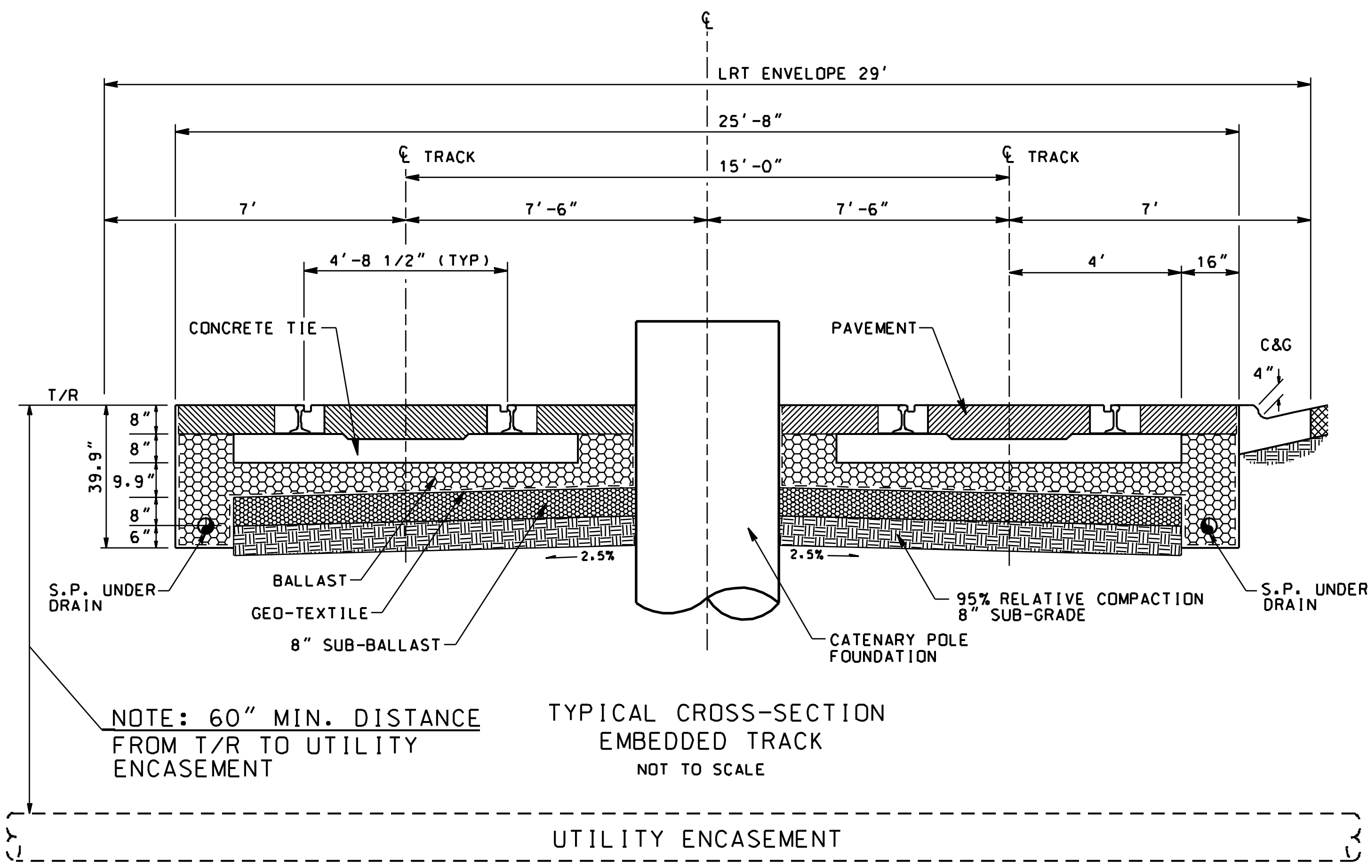
RTD

DESIGN CRITERIA

TITLE: DOUBLE TRACK BALLASTED - CURVED

FIGURE: 6.4

CURVED TRACK SECTION



TYPICAL CROSS-SECTION
EMBEDDED TRACK
NOT TO SCALE

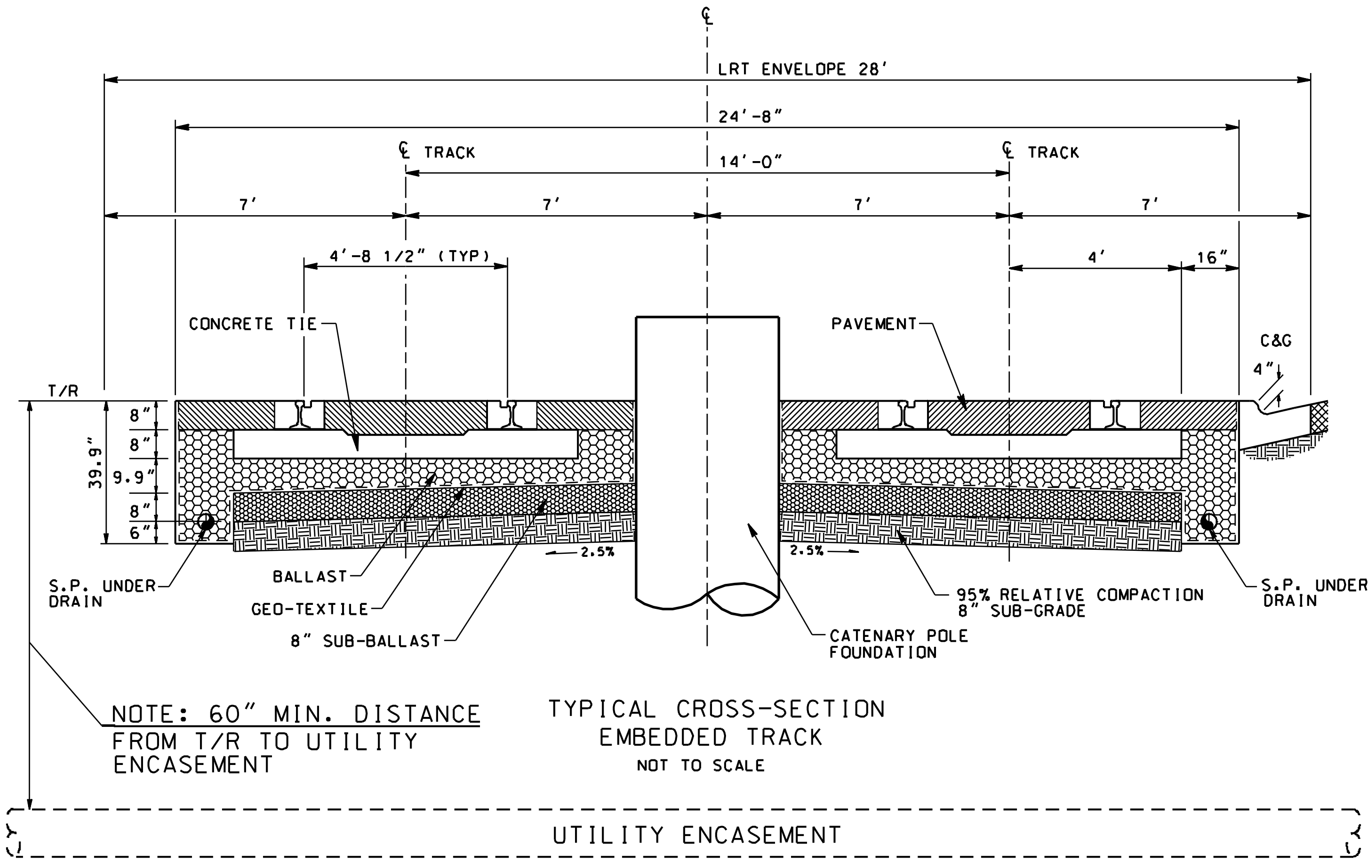
RTD

DESIGN CRITERIA

TITLE: DOUBLE TRACK EMBEDDED - CURVED

FIGURE: 6.5

STRAIGHT TRACK SECTION



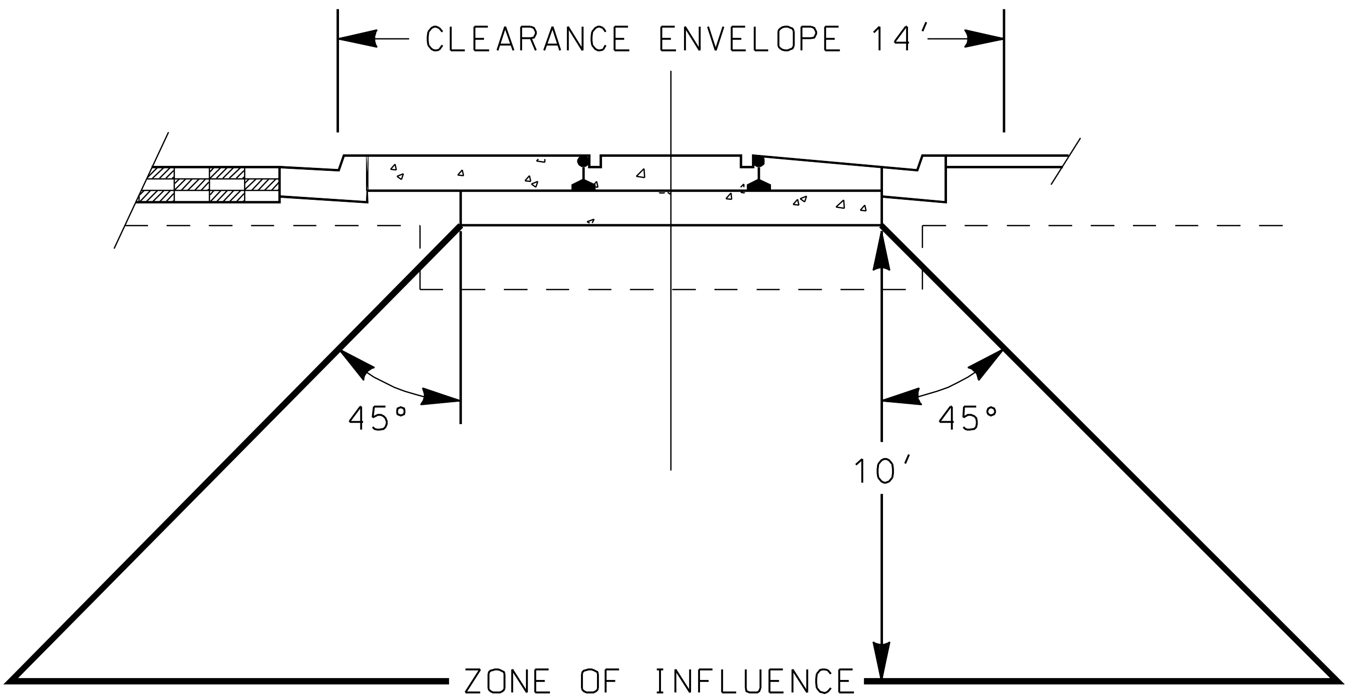
TYPICAL CROSS-SECTION
EMBEDDED TRACK
NOT TO SCALE

RTD

DESIGN CRITERIA

TITLE: DOUBLE TRACK EMBEDDED - STRAIGHT

FIGURE: 6.6



The Zone of Influence is defined as that area underground, contained within lines projected downward at 45° angles from the edge of the ties, to a minimum depth of 10 feet from tie.

NOT TO SCALE

RTD

DESIGN CRITERIA

TITLE: ZONE OF INFLUENCE

FIGURE: 6.7

SECTION 7 - COMMUNICATIONS AND CENTRAL CONTROL

SECTION 7 - COMMUNICATIONS AND CENTRAL CONTROL

7.1.0 GENERAL

The Communications and Central Control System (CCS) includes communications equipment, the remote I/O equipment, and the human interface equipment to help allow controllers to monitor wayside systems and facilities and supervise mainline rail operation. The CCS and Supervisory Control and Data Acquisition (SCADA) System shall be provided on the entire LRT system. The scope includes:

- A CCS with supervisory control to allow RTD Operations personnel to remotely monitor the signal system, traction electrification system, ticket vending machines, and station and wayside facilities, issue route requests to the signal system and issue commands to open and close breakers to the traction electrification system.
- Remote I/O equipment interconnecting RTD's OCC with signal cases and houses, communications equipment houses and cabinets, and traction power substations.
- Radio control equipment to be used at the control room.
- Microwave equipment to connect RTD facilities.
- Telephone PBXs and telephones for voice communication from the control room to other RTD personnel and to outside personnel.
- Emergency telephones installed in elevators, LRT tunnels, on platforms and other passenger waiting areas.
- A closed circuit television (CCTV) system to allow RTD personnel at the control room and in the Security Command Center to monitor activity at parking facilities, elevators and station platforms. Refer to Section 14 - System Safety and System Security.
- A public address/variable message sign system (PA/VMS) and interface equipment, accessible from the control room and at designated passenger stations to enable audible and visual text display of passenger information.
- A communications transmission system (CTS) consisting of hardware, and copper and fiber optic cable to carry RTD voice, data, and video communication information. The Design Engineer shall coordinate fiber optic specifications with RTD’s SCADA Communications Engineer.
- Communication houses, cabinets, batteries, chargers, raceway, etc. to enable reliable operation of wayside communications equipment.

7.2.0 STANDARDS AND CODES

The communications and central control system shall be designed and implemented to the latest revision at the time of award of contract of the applicable codes and standards of the following organizations:

- American National Standards Institute (ANSI)
- Electronic Industries Association (EIA)

- Federal Communication Commission (FCC)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Organization for Standardization (ISO)
- National Electrical Manufacturers Association (NEMA)
- National Fire Protection Association (NFPA)
- Building Industry Consulting Standards Institute (BICSI)
- Internet Engineering Task Force (IETF)

7.3.0 OPERATIONS CONTROL CENTER (OCC)

The OCC shall be designed to be a comfortable, quiet, and uncluttered working area that meets the requirements of the Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG).

7.3.1 Control Room Layout

The layout of the control room shall be such that the control room staff can work and interact with each other effectively and efficiently. To be most effective, the staff positions within the control room shall be within line-of-sight of one another to allow the use of visual signals to supplement their voices.

Access to the control room shall be located to minimize the disturbance to staff communications or their view of the overview display.

7.3.2 Consoles

Control room staff shall utilize consoles to supervise LRT system activities. Each console within the control room shall contain the communications, reporting, controls, and monitoring equipment necessary to carry out the assigned functions by the controllers. All controller consoles shall be identical.

All consoles shall have the following design requirements:

- Like equipment and procedures shall be used for like functions and like functions shall be in the same general physical location in each console.
- Frequently used equipment shall be located most conveniently. Most frequently used procedures shall require the fewest, least extended motions possible.
- The amount of equipment and variety of procedures at a console shall be minimized, consistent with requirements for modular and expandable design.
- Voice communication interfaces shall be integrated such that OCC staff need not switch between more than two devices to interact

with the several parties with whom they may need to maintain contact. Audio outputs shall have volume and tone controls.

- Console physical dimensions shall be consistent with ergonomic limits. Consoles shall be designed to accommodate the reach of a 5^{th} percentile female and the size of a 95^{th} percentile male.
- Console components shall be modular to allow replacement of a failed unit within 30 minutes, and replacement shall not require shutdown of the functioning portion of the console.
- Writing and documentation storage space shall be provided. The controller consoles shall have the following design requirements.

A keyboard and point-and-click device shall be able to be used for display item selection and function initiation. Single purpose function buttons and switches may be used for, but limited to, functions which are frequently used or require rapid activation.

Console display monitors shall be high resolution, low flicker. Color capabilities shall be consistent with information requirements. Console monitors shall be selected and placed to minimize emission exposure. Monitors shall have easily accessible intensity and color controls.

Console furniture and chairs shall be consistent with ANSI/HFS 100, "American National Standard for Human Factors Engineering of Visual Display Terminal Workstations".

Controller consoles shall be assignable to a geographic portion of the LRT system.

7.3.3 Environmental Considerations

The following site requirements shall apply at the OCC:

- The OCC shall meet all applicable fire safety requirements, including NFPA 130. A fire alarm and suppression system shall be provided for the control room and equipment room.
- Raised flooring with removable tiles may be provided for the control room and equipment room. The metallic floor framing shall be grounded.
- Wide door access shall be provided at the control room and equipment room to accommodate the movement and placement of equipment.
- The control room and equipment room shall each be fully enclosed to create a secure environment and to minimize noise. The equipment room shall also be a secure area.

- The lighting within the control room shall be generally uniform, and at a level of at least 50 foot-candles. Consoles shall have additional, locally controlled, adjustable spot lighting to 100 foot-candles.
- Reflected glare on display screens, overview display and console work surfaces shall be minimized.
- Noise within the control room shall be minimized. There shall be acoustic treatment of the control room, including floors and walls, to absorb noise. Background noise, including background noise from Communications System equipment, shall not exceed 55 dba.
- The control room and Equipment Room shall be provided with air conditioning. There shall be independent temperature controls for the control room and Equipment Room. The temperature in each area shall be adjustable to be within the comfort zone for humans for interior spaces. The air distribution shall minimize temperature gradient and drafts. The temperature shall be maintained in the range of 24°C to 28°C.
- Approximately two air exchanges per hour shall be provided for. The air distribution shall minimize temperature gradient and drafts.
- Electrostatic control shall be provided for in the Control Room and Equipment Room. Antistatic flooring and carpeting shall be used.

7.4.0 SCADA

7.4.1 Safety Constraints on SCADA

The relationship between the Communications System and the Signal System shall be such that no action or failure of the CCS/SCADA (nor any other Communications System element) can cause or allow an unsafe train operating condition. Should the CCS/SCADA become completely inoperative, for any reason, the LRT System shall be able to continue to operate safely.

7.4.2 System Operation

CCS/SCADA shall normally function without operator intervention except for routine service.

CCS/SCADA shall have the capability for performing orderly system start-up and shut-down as commanded by a system operator.

Remote CCS/SCADA equipment shall operate in an unattended mode. The central CSS/SCADA equipment shall continue operation in the event of a failure of remote SCADA equipment, and upon return to service of failed equipment, automatically resume normal monitoring and management of that equipment.

7.4.3 System Requirements

7.4.3.1 Response Times

The elapsed time from the first possible detection by remote I/O equipment of an alarm or device change of state until display at the control room shall not exceed 2.5 seconds.

When a user enters a command for any individual device control, the remote I/O equipment shall generate the associated output signal, in the field, in no more than 2.5 seconds.

When a user requests a display, the completed display shall appear on the screen in not more than two (2) seconds.

7.4.3.2 Accuracy of Information

Display of train position shall be accurate to within a track circuit for signaled territory.

7.4.3.3 Availability

CCS/SCADA is intended to operate 24 hours a day, seven days a week. The CCS/SCADA central system availability shall be at least 99.8% for all operating functions.

Any console shall be capable of fully backing-up a failed console of the same type. Back-up shall take the form of assuming the full geographic and functional responsibilities of the failed console.

The CCS/SCADA shall be constructed such that it can be put in place and continue to operate while:

- Already-operating lines are retrofitted for the new Communications System
- New lines are equipped, tested and brought into service.

7.4.4 Displays

Displays at the control room shall be graphic and text displays. Graphic displays shall be provided at both the overview display and at the console displays. The overview display and console graphics displays shall provide a semi-geographic representation of the LRT System and its major subsystems. Information displayed shall be kept up-to-date.

At the control room, user interface equipment characteristics, equipment location, and display contents shall be consistent with MIL-STD-1472 "Human Engineering Design Criteria for Military Systems, Equipment, and Facilities" or an equivalent human factors standard or guide such as the FAA's Human Factors Design Guide.

For all graphic displays the following guidelines shall be followed:

- Distinct colors and display attributes (e.g., flashing) shall be used to draw attention to alarm or abnormal conditions.
- There shall be consistent use of colors, geographic orientation, labels, display attributes, and object symbols.
- Label and message contents shall be in language consistent with RTD train operations terminology.

7.4.5 Software

Software design and implementation of CCS shall:

- Follow guidelines for software design and documentation as defined in IEEE Std. 729
- Conduct a software quality assurance program for software development consistent with practices as defined in IEEE Std. 730
- The LRT software system shall be easily definable and modifiable so that:
- The overview display and console display contents can change as track, stations, and devices are added;
- Console display devices can be changed.

Application software shall be written in an industry-standard high level language. It shall be built on a commercially prevalent or industry-standard operating system and be portable to higher capacity computer system configurations running that standard operating system. Networking system software shall satisfy the Open System Interconnect (OSI) requirements and/or utilize industry-standard physical level and link level communication protocols.

All CCS software shall be completely tested before it is used for train operations.

7.4.6 Central Equipment

The CCS central equipment shall be compatible with the existing system and shall:

- Utilize commercially available computer equipment and peripheral devices. Custom equipment shall be limited to special functions and interfaces.
- Normally operate unattended.

- Have sufficient redundant equipment to permit automatic switch-over so that no single failure will interrupt operation for more than 30 seconds.
- Automatically detect equipment failures and provide corresponding failure indications.
- Where feasible, provide for on-line replacement of failed components, console devices, computers, peripheral devices and data communications interface equipment while it continues to operate
- Be sized to handle the defined LRT system size under peak period operating conditions and have provisions for future expansion
- Be capable of communicating and providing control and indication of all of the existing RTD remote I/O, VMS, PA, signal and traction electrification equipment.
- Be physically located and configured in such a way so as to provide for easy maintenance access.
- Be provided with an UPS, with a minimum capacity of 4 hours, and a redundant source of AC power.

7.4.7 Remote I/O Equipment

The Remote I/O Equipment (e.g. PLCs or RTUs), which is the field portion of SCADA, shall:

- Be solid-state, microprocessor based with logic elements and auxiliary components configured on easily replaceable plug-in modules.
- Be of common design for all remote sites to provide interchangeability of modules.
- Be capable of continued operations with the loss of communication to the OCC as a result of either communication equipment failures or central equipment failures.
- Operate normally unattended. Remote I/O equipment logic and configuration data shall reside in non-volatile memory.
- Perform self-tests upon power up and on command from local test equipment and from OCC. Self-tests shall also be performed by input/output subsystems and input/output cards.
- Provide for maintenance of input/output circuits (including disabling power to output circuits) and safe replacement of input/output cards without the removal of any wiring.
- Operate within a power supply range of 90 to 130 volts ac and a frequency between 57 to 63 Hz.
- Be capable of continued operation in the electromagnetic environment where they will be located, such as TES substations, signal cases, and communications houses.

- Support local initialization and troubleshooting with either a local control panel or portable test equipment. Also support remote initialization and troubleshooting via the data communications network.
- Be modular in design to provide expansion of performance and capacity by adding subsystem modules. This shall include the ability to add a minimum of 20% more input/output subsystem modules, be supplied with hardware and software tools and documentation for reconfiguration and expansion.
- Temperature specification of -40ºC to +65ºC
- See the below sections for SCADA requirement interfaces to other LRT elements:
  - Traction Electrification System – Section 9
  - Signals – Section 8
  - Elevators - Section 5
  - Train-to-Wayside Communication – Sections 8 and 13
  - Fare Collection Equipment – Section 12

7.4.8 Simulator

A CCS simulator shall be provided. The simulator shall allow training of CCS users.

The simulator shall model the physical plant so as to present accurate representations of train movement, interlocking response, and traction power system response for the above purposes. The simulator shall model all discrete state indications, which are normally presented to the CCS. The simulator shall be deterministic. The simulator shall be capable of simulating normal and abnormal equipment operation. The simulator shall also provide the capability to playback (e.g. re-display) real wayside events as originally depicted on the controllers' displays and the overview display.

The simulator shall provide both an Instructor user interface and a trainee user interface. The Instructor shall be able to alter the simulated behavior of trains as well as all wayside devises. The trainee's user interface to the simulator shall be the same displays as those used in normal operations at the controller consoles. The simulator shall use the standard commands and displays, which normally support active operations, supplemented by simulator-specific commands.

The simulator shall model the entire physical plant including the traction power system. The simulator shall be capable of modeling train control and traction power simultaneously together.

7.5.0 COMMUNICATIONS

7.5.1 Radio System

Modifications to RTD's existing UHF radio system shall be made to enable communication between:

- LRT trains and Controllers
- LRT trains and Rail Supervisors
- LRT Rail Supervisors and Controllers
- LRT non-revenue vehicles and Controllers
- LRT MOW personnel and Controllers
- LRT trains and maintenance personnel
- LRT Controllers and other LRT personnel along the ROW

All LRT LRV's and transportation and MOW non-revenue vehicles are equipped with mobile radio transceivers, with a minimum of 25 watts of radio frequency output power. A sufficient number of hand-held portable radios are furnished to allow LRT train operators and RTD employees along the LRT right-of-way to carry a portable transceiver.

Radio coverage along the LRT alignment including covered sections shall enable a two-watt portable radio to be heard with 20-dB quieting at the OCC along 98% of the alignment, 99% of the time. No "dead sections," with less than 20-dB quieting, longer than 100 feet shall be allowed.

7.5.2 Microwave System

Where required for communications to RTD facilities not on the ROW, RTD LRT maintenance and operations facilities and the OCC shall be interconnected via LRT's existing microwave system. The number of microwave channels supplied shall be consistent with RTD's operating requirements for that location. The microwave system may carry RTD's radio audio. All new microwave equipment shall be of the same manufacturer and model number as RTD's existing equipment and shall be installed to support the 'ring' configuration whenever possible.

7.5.3 PBX/Telephone System

Each RTD maintenance and operations facility shall be equipped with its own Private Automatic Branch Exchange (PBX) and networked into RTD’s existing telephone system. PBX, telephones, and interface equipment will provide communications between Operations personnel and RTD personnel and personnel outside of RTD property. The PBX/Telephone system shall be compatible with RTD's existing telephone system at other RTD facilities.

The emergency telephone system on station platforms shall be designed to permit passengers at stations to communicate with 911 dispatch. In addition, the emergency telephones shall allow monitoring of the audio between the station emergency telephone and 911 by rail operations. The phones will be activated by push button and contain Braille lettering to be ADA compliant.

Tunnel 'bluelight' phones and elevator phones in station elevators will be received by Rail Controllers only.

All phone conversations at the controller workstations shall be recorded.

See Section 14 – System Safety and System Security for additional telephone requirements in elevators, tunnels, parking facilities, pedestrian bridges and pedestrian tunnels.

7.5.4 CCTV System

The CCTV system shall comply with the requirements of Section 14 of the Design Criteria – System Safety.

In addition the CCTV system shall be coordinated with Section 5 – Station Design Criteria and 11 – Operations Facility to ensure that the CCTV system design is optimized based on the requirements of these elements. Refer to Section 14 System Safety and Security.

7.5.5 PA/VMS System

Where requested, RTD station platforms and public areas will be equipped with PA/VMS equipment. PA/VMS equipment will consist of amplifier-driven loudspeakers and variable message signs installed and operated in compliance with ADAAG requirements. Local input to both audible and visual portions of the PA/VMS system will be provided at designated stations

Text message entry will be by way of easily and understandable graphical user interface with Windows-type entry screens and prompts. Audible and text messages will be coordinated so that playback to the public occurs at the same time. It shall also be possible to transmit audio and text messages independent of each other.

Controllers at the control room shall be provided with the ability to distribute both pre-recorded and ad-hoc messages to passenger stations. This ability will include provisions to send messages to an individual station, a group of stations, or all stations.

7.5.6 Communication Transmission System

A high bandwidth, fault tolerant, wide area communications transmission system (CTS) shall be installed along the LRT ROW to inter-connect the various field CCTV, data and voice signals to/from the field from/to the

OCC. The CTS includes fiber optic cable plant, optical and electronic transmission equipment, grooming and provisioning equipment, and other equipment necessary to provide communications channels at native signal level between sites. The portion of the CTS that interconnect communications system nodes, central control, and major RTD operating and administration facilities shall be configured so that it will continue to operate normally on loss of a single fiber or any single equipment module. The reliability of this system shall be 99.99% with failover and resumption of normal communication traffic to a redundant path on loss of the operating path in less than 1 second.

The CTS shall be compatible with the existing system.

See section 12 for the communication transmission system interface to the fare collection network.

7.5.7 Network Management System

Network management for the CTS shall be on the same platform as the CCS management. SNMP compatible MIBs shall be provided on all electronic devices on the CTS and configured on the network management system for alarm and monitoring. The NMS shall be compatible to the existing tiered level approach utilized.

7.5.8 Communication Houses and Enclosures

Material and equipment shall be designed to ensure satisfactory operation and operational life in the environmental conditions which will prevail where the material or equipment is installed. Communications and CCS equipment that is not housed in an environmentally controlled enclosure shall be rated to operate in the environmental conditions described in Section 1 – General Information. In addition the equipment shall be designed to operate and not have degraded operational life in the below conditions:

- ½ inch ice loading
- 85 mph wind withstand load
- Seismic zone 1 rating

Field communications equipment will be located in dedicated communications equipment houses or cabinets. All houses and cabinets shall be equipped with appropriately sized air-conditioning and heating equipment to maintain temperatures within the operating range of all equipment.

Outdoor security lighting shall be provided above communications houses. The security lighting will be controlled by a photo-electric cell and shall not overflow into surrounding residential communities.

Communication house and cabinet foundations shall be designed to withstand all live and dead loads of the house and cabinet and equipment. Foundations will be designed in accordance with all applicable standards as well as local Building Codes. An appropriate factor of safety according to the standards shall be applied at each site. Each foundation slab will be provided with openings to connect the equipment to the local power supply system and to outside circuits.

Communication houses will be of double roof and wall construction to accommodate insulation material to reduce heat transfer.

7.5.9 Communication Power System

All critical devices in the CCS, remote I/O equipment, CTS, radio equipment, and microwave equipment shall be powered from an uninterruptible power supply. A device is considered critical if removing power to it will degrade the performance of the system it is a part of. The UPS shall be sized to carry the full load of the above equipment at a communication house, case or RTD facility for at least 4 hours. The UPS charger shall be sized to carry the above load while recharging a completely discharged battery set. The UPS charger shall be able to recharge the batteries under these conditions in less than 12 hours.

7.5.10 Location of Communication Enclosures and Equipment

All communications devices, including platform mounted equipment, houses, cabinets, antennas and raceway shall clear the LRV dynamic clearance envelope by a minimum of 6 inches. This requirement includes clearance for enclosure doors in any open, intermediate, or closed position. Communication houses and cabinets shall be located so as not to obstruct the LRV operators', motorists' or pedestrians' view of trains.

Communication house placement and access shall accommodate the addition of heavy equipment via a roll cart or dolly.

7.6.0 INTERFACE REQUIREMENTS

7.6.1 Central Control Facility

The communications system and human interface equipment within the OCC, including consoles, radios, telephones and computers, shall be connected to essential power. Other equipment to be connected to essential power includes all OCC emergency systems and at least 40% of OCC and Equipment Room lighting.

A grounding system shall be installed in the OCC. This grounding system shall include a ground bus connected to the building entrance power distribution grounding and shall interface to connection points in the Equipment Room and the Control Room.

7.6.2 SCADA Remote I/O Equipment

Remote I/O equipment shall support digital inputs and outputs via relay contact closures (or optically isolated solid state equivalents such a silicon controlled rectifiers). All digital inputs to SCADA shall be of the same type. All digital outputs by SCADA shall be of the same type. The following SCADA input and output requirements shall be met:

- Digital inputs to SCADA shall be from normally open and normally-closed contacts. The operating voltage DC power supply shall nominally be in the SCADA domain. Contact ratings shall be as required for the circuit.
- Input and output signals shall be electrically isolated from SCADA equipment.
- SCADA shall generate outputs via relays. Transient suppression circuits shall be provided by the SCADA contractor. Contact ratings shall be as required for the circuit. SCADA interface relays and relay contacts shall have an MTBF at rated loads of 5,000,000 cycles or more.
- SCADA outputs shall be momentary contact closures with a time duration that is stable and adjustable.
- The remote SCADA equipment shall prevent unintended action such as energizing output circuits upon power-up and power restore.

SCADA shall be designed and implemented so that wiring and cabling between remote I/O equipment and field devices are uniform in type, routing, and connection locations. The following interface requirements shall be met:

- I/O signals to/from SCADA at each signal facility shall terminate at one centralized location.
- I/O signals to/from SCADA at each TES site shall terminate at one centralized location.
- SCADA terminations shall include test points and rapid disconnect
- All wires and cable shall be labeled using a logically consistent labeling convention

Remote I/O equipment shall be equipped for protection from electromagnetic interference levels consistent with their locations. Bus bars shall be provided for grounding in all input/output termination cabinets.

Data communications between SCADA remote I/O equipment and the OCC shall utilize industry non-proprietary protocols, which support error detection and message retransmission.

Conduits

Adequate conduit shall be provided to a communication house or case to accommodate the initial cabling requirements and still have the equivalent of one 4 inch conduit spare.

For communication conduit requirements in the mainline ductbank, stations, parking facility, or to a TVM see section 9.7.0 – Conduit and Ductbanks.

SECTION 8 –SIGNAL SYSTEM

SECTION 8 –SIGNAL SYSTEM

8.1.0 GENERAL

Railway signaling techniques shall be applied at various LRT locations to enhance safety in the movement of trains and to improve the overall efficiency of train operations. These functions include the protection and control of track switches; the protection and control of bi-directional train operation where applicable; the protection for following trains operating with the normal current of traffic; and highway grade crossing warning. The need for signaling, and the type of signalization provided, shall be determined by the specific requirements of each line segment.

8.2.0 AUTOMATIC BLOCK SYSTEM

Automatic Block System (ABS) shall be installed at certain locations along the LRT right-of-way to permit higher operating speeds than would be possible by relying on line-of-sight operation without signals. The ABS system shall provide information to train operators concerning the condition and occupancy of the track ahead, and provide sufficient stopping distance, when required. Automatic Train Stop (ATS) shall be provided if a train passes a stop signal. A violation of a stop signal shall be reported to the Operations Control Center by means of the SCADA system.

Unless limited by operational constraints, all signals shall comply with a “double red” philosophy. Cab signals functioning in a “go-no-go” environment shall provide enforcement for all signaled moves, including those against the normal direction of traffic. There shall be no overlap where the next signal in advance is an "END ABS" sign.

All signals shall be controlled, in regard to any track switch in the block, to display a red aspect when:

- The switch points are not in position for safe train movement.
- A hand operated switch is not in the normal position.
- A switch-and-lock movement is not fully locked.
- An electric switch-locking movement is not fully normal.
- The selector lever of a dual-control switch-and-lock movement is not in the "MOTOR" position.
- A manual switch electric lock access door is not fully closed.

No signal shall display an aspect less restrictive than approach, when the next signal, in advance, displays an aspect requiring a stop. Three-aspect, non-interlocked signals shall display a proceed aspect when the next signal, in advance, displays an approach aspect.

8.3.0 INTERLOCKINGS

Interlockings shall be provided for all power switches used on the mainline in open track. Interlocking signals shall be provided to govern train movements into and through interlocking limits.

Detector, time, route, and approach locking shall be provided at all interlockings. Detector locking shall not be released until five seconds after the slow pick-up track repeater relays have closed their front contacts.

All non-interfering train movements, through interlockings, shall be permitted simultaneously.

Interlocking design shall comply with principles and accepted practices of the Association of American Railroads (AAR).

8.4.0 HIGHWAY GRADE CROSSING WARNING

Warning devices for highway grade crossings shall be installed at certain locations. Each such crossing shall include automatic gates, LED flashing lights, bells, signs, approach and island track circuits, emergency batteries and associated circuitry, cabling and cases as required. Crossing gates shall be Western-Cullen-Hayes model number 3593-131 with “Gate Keeper” protective devices or approved equal.

The design of each crossing shall be specific to that site and shall provide a minimum of 20 seconds warning time, from the time that the lights first begin to flash until the time that a train traveling at track speed enters the crossing. The design of the crossing circuitry shall avoid unnecessary delays to motorists. Where necessary, the grade crossing warning system shall preempt adjacent traffic lights to avoid automobiles forming a queue across the tracks.

Center lane divider island shall be installed at all grade crossings to aid in the prevention of traffic gate runarounds. Crossings with permitted train speeds in excess of 30 mph shall have warning signs “High Speed Trains” with flashing yellow lights facing highway traffic. Provisions for the installation of video monitoring equipment shall be installed at each grade crossing. Highway grade crossing warning devices will be installed consistent with AAR Signal Manual and the Manual on Uniform Traffic Control Devices Standards (MUTCD).

8.5.0 TRAIN-TO-WAYSIDE COMMUNICATIONS (TWC) SYSTEM

RTD's LRVs are equipped with a Train-to-Wayside Communication (TWC) system. The carborne portion of the TWC system consists of two transponders (one for each end of the LRV), and two car control units (one for each cab). The wayside portion shall consist of an inductive loop antenna and a wayside transceiver. The wayside transceiver, through the wayside loop antenna, shall constantly transmit a message asking that any carborne TWC transponder, in the immediate area, identify itself. A carborne TWC transponder receiving this message shall respond by transmitting a serial 19-bit message, identifying the LRV's car number, the train number, route number (destination), and other information. Thumb-wheel switches and push buttons in each cab are provided to train operators to enter the route number and train number of their consist and other requests such as switch call and preempt call.

A TWC system, compatible with the LRV equipped TWC system, shall be installed at all interlockings, at all passenger stations adjacent to highway crossings and provisions made for all passenger stations in street running, and at all power switches in street running, to allow train operators to enter switch call and route requests. Use of the TWC system shall be the primary method of entering route, switch requests, and SCADA train identification at those locations.

A TWC loop and handhole shall be installed at all highblocks for improved SCADA control of LRV movements. It shall include a TWC antenna and conduits to a nearby signal case for future utilization.

The TWC wayside interrogator operating frequency shall be 100 Khz. It must be capable of recording and storing data history to include all inputs and outputs for download and review for a backlog of at least 48 hours from the time of download. Data acquisition and unit programming must be easily accomplished by a signal technician with moderate laptop computer skills. Installation shall include one interrogator per loop. The wayside loop shall be a single wire loop mounted between the rails with the end to end dimension of the loop being 15 feet. The loop shall be mounted no higher than top of rail and no lower than 6 inches below top of rail. In open track areas the loop shall be housed in a pre-fabricated protective non-metallic enclosure.

Assignment of destination codes shall take into consideration future expansion plans of the LRT system. Assignments shall be developed to provide a logical progression of destination codes throughout RTD's LRT expansion plans.

8.6.0 STANDARDS AND CODES

The signal system shall be designed, constructed and tested in accordance with ~~to~~ the latest revision at the time of award of contract of the following codes and standards:

- U.S. Code of Federal Regulations (CFR), Title 49, Part 236
- American Railway Engineering and Maintenance Association (AREMA)
  - Signal Manual of Recommended Practice
  - American Railway Signaling Principles and Practice
  - Communication Manual of Recommended Practice
  - Typical Circuits Representing Current Practice for Railway Signaling
- Rules and Regulations of the Colorado Public Utilities Commission (PUC)
- National Electrical Code (NEC)
- National Electrical Safety Code (NESC)
- Insulated Cable Engineers Association (ICEA)
- American Society for Testing and Materials (ASTM)
- American National Standards Institute, Inc. (ANSI)
- Underwriters Laboratories, Inc. (UL)
- U.S. Department of Transportation, Federal Highway Administration, Manual on Uniform Traffic Control Devices (MUTCD)

- Institute of Electrical and Electronic Engineers (IEEE)

8.7.0 SAFETY DESIGN

Train safety shall be the prime consideration in the design of the signal system and in the selection of its components, including relays and other devices with moving parts, insulated wire, wire terminals, binding posts, housings, conduits, resistors, capacitors, transformers, inductors and other similar items. The entire signal system shall meet the requirements of this section. Circuit design shall conform to the "American Railway Signaling Principles and Practices" of the AAR Communication and Signal Section.

The following requirements shall govern the design of the portions of the system or a subsystem which affect train safety:

- Only components which have high reliability and predictable failure modes and rates and which have been proven in conditions similar to the projected service shall be utilized.
- Components shall be combined in a manner that ensures that a restrictive rather than a permissive condition will result from component failure.
- All circuits which are not confined to one housing and which affect safety shall be double-wire, double-break, except signal and switch indicator light circuits.
- The design shall be based on closed circuit principles.
- Component or system failures shall cause a more restrictive signal indication than that permitted with no failure. The built-in fault detection and alarm generation capability are preferred.
- System safety design shall be such that any single independent component or subsystem failure will result in a safe condition. Failures that are not independent (those failures which in turn always cause others) shall be considered in combination as a single failure and will not cause an unsafe condition.
- Any latent failure of the equipment, that is a failure, which by itself does not result in an unsafe condition, but which in combination with a second or subsequent failures could result in an unsafe condition, must be detected and negated within a stipulated time period.
- Electronic circuit design shall insure that the following types of component failures have a restrictive rather than a permissive effect:
    - o Two terminal devices: open, short, partial open or short
    - o Multi-terminal devices: combination of opens, shorts, partial opens and/or partial shorts
- Wherever possible, built-in checks shall be included that impose a restriction and/or actuate an alarm whenever a device fails to assume its most restrictive position when conditions require that it should.
- Redundant design by itself shall not be considered an acceptable method of achieving design safety.

8.8.0 HEADWAYS & BLOCK LAYOUT

The design of the LRT signal system shall provide for minimum train headways of 130 seconds, or less. Headway is defined as the length of time taken for a given automatic block signal to upgrade to a permissive (restricting or approach) aspect after a leading train has passed that signal at normal track speed. Maximum train length will be 4 cars under normal conditions. Three-aspect signals are required to provide information about the aspect displayed by the next signal ahead so as to avoid the necessity for always approaching it while prepared to stop.

Wherever it is displayed, a stop indication shall be an absolute signal, requiring that train operators bring their trains to a full stop and call the LRT controller for authorization to pass the signal at restricted speed (i.e., prepared to stop, within one-half the range of vision, short of anything that may so require).

Signal system design headways are calculated without regard for variations in vehicles, weather conditions or individual operators. Signal system design headways will provide for sustained five minute scheduled headways.

8.9.0 SAFE BRAKING DISTANCE

Safe braking distances shall be calculated using a 2 second vehicle reaction time, a minimum adhesion which would allow a deceleration rate on level tangent track of 1.95 MPHPS and a 35% (distance) safety margin. The assumed deceleration rate shall be reduced on downhill grades to compensate for the effects of gravity. In addition, all safe braking distance calculations in open-track territory shall assume a LRV entry into the governed area at a maximum authorized speed plus 10 mph to a maximum of 60 mph.

8.10.0 ENVIRONMENTAL CONSIDERATIONS

All equipment shall be designed to operate from a minimum temperature of -40°C (ambient) to a maximum temperature resulting from a combination of an ambient temperature, maximum sun loading and maximum normal internal heat generation, of 70°C.

8.11.0 SERVICE PROVEN EQUIPMENT AND DESIGN

All signal equipment shall be proven in similar North American railroad or transit service. The signal system shall have an expected service life of 40 years at the specified level of service. Achievement of this useful life shall be through the use of off-the-shelf proven hardware. Each major component shall incorporate provisions to allow for functional and physical interchangeability of replacement spare parts.

8.12.0 TRAIN DETECTION

Train detection in the ABS sections and at interlockings shall be accomplished by using one of the following types of track circuits.

- Two-rail, shunt type 60 Hz, phase selective track circuits with impedance bonds and two-element vital vane relays.
- Solid state electronic, coded track circuits suitable for use in overhead propulsion territory.

Single-rail (not to exceed 60 feet in length) or double rail, shunt-type 60 or 100 Hz AC track circuits shall be used to detect train presence in embedded track.

Audio-frequency, overlay, shunt-type track circuits shall be used for train detection in the control of highway grade crossing warning equipment.

The design of the LRV propulsion and traction systems and selection of track circuit frequencies and modulation schemes shall be coordinated to preclude interference between the LRV and the signal system.

A shunt with a resistance of 0.2 ohm or less at any point between the two rails of any track circuit shall cause the track circuit to indicate train occupancy. Shunt fouling shall not be allowed, and multiple track relays or series fouling shall be used for all turnouts, with the exception of the two (or four) turnouts used in crossovers between mainline tracks. Voltage regulating transformers in the feed to the track may be used or additional track circuits may be installed, if necessary, to provide this shunting capability. Impedance bonds shall be used to enhance track circuit stability.

8.13.0 SIGNALS & SWITCH INDICATORS

8.13.1 Color Light Signals

With the exception of those signals noted below and two-aspect interlocking signals, standard railway color light, high signals, including backgrounds and split base junction boxes shall be provided for ABS sections and interlockings in open-track sections. Signals at station platforms which do not have to be viewed from a distance may be dwarf-type railway color light signals on pedestal bases. Low, dwarf-type railway color light signals may be used for non-normal moves.

8.13.2 Signal Aspects

Each signal aspect shall have an indication (meaning), which is the same wherever it is displayed throughout the LRT system. The system shall have two-aspect and three-aspect signals.

Fundamental aspects of color light signals shall consist of the following:

TABLE 8A - FUNDAMENTAL ASPECTS OF COLOR LIGHT SIGNALS

Name	Aspect	Indication
Stop	Red Light	Stop
Approach	Yellow Light	Proceed on primary route prepared to stop at next signal
Proceed	Green Light	Proceed on primary route at permitted speed
Diverging	Flashing Yellow Light	Proceed on secondary route prepared to stop at next signal
Diverging	Flashing Green Light	Proceed on secondary route at permitted speed
Exit	Red over Yellow	Proceed out of signalized territory into yard or storage track

TABLE 8B - STREET RUNNING AREA SIGNALS

Name	Aspect	Indication
Stop	Red	Stop
Proceed	Yellow	Divergent track clear; proceed in street running rules
Proceed	Green	Proceed on primary route at permitted speed

TABLE 8C - POINT INDICATORS

Name	Aspect	Indication
Stop	Dark	Stop
Reverse	Yellow Light	Switch Lined Reverse
Normal	Green Light	Switch Lined Normal

8.13.3 Light-Out Protection

"Light-out" protection shall be provided on all three-light interlocking signals to prevent a signal from displaying a more permissive aspect from that intended because of a burnt-out lamp or broken wire. Light out protection shall cascade to the rear as required to provide an orderly arrangement of signal aspects.

8.13.4 Signal Locations

Signals shall be located to the right of the track governed. There may be locations where there is no room for signals to the right; however, if site conditions permit, every effort shall be made to adjust clearances so that the signals can be located on the right.

8.13.5 Signal Height

All signals governing normal movements shall be close to the train operator's eye level depending upon civil interference constraints.

8.13.6 Signal Lighting

Approach lighting shall be used and signal lights shall be extinguished when there are no trains in position to view the signal. Exceptions to this will include the first signal approached when leaving non-signaled and entering signaled territory. These signals shall be lighted continuously. Lamp voltage shall be from 85% to 90% of rated voltage in order to extend lamp life and to retain proper light color. LED signal light assemblies are an acceptable substitute to the incandescent bulb type.

8.13.7 Signal Numbering

All LRT signals shall have number plates attached to facilitate identification and simplify record keeping. Signals shall be assigned numbers coinciding with the signals physical track distance from the northern terminus of the Downing Street station and a suffix letter indication of the associated corridor. Signal numbers shall reflect this distance rounded to the nearest 100th of a mile. Example: Signal 379 in the Central Corridor is approximately 3.79 track miles from the Downing Street terminal and would be labeled S379CC. Signal plates will have black background with white reflective lettering.

8.13.8 Red Signal Violation

All signals shall be equipped with a positive means of detecting a red signal violation. Red signal violations shall be recorded on the local event recorder, as well as being sent to the central office via the SCADA system.

8.13.9 Cab Signals

All signals shall have an associated enforcement function provided by a “go/no-go” cab signal system. All moves in both the normal and reverse directions of traffic shall be protected by this system.

8.14.0 MAINLINE TRACK SWITCHES

8.14.1 Track Switches in Open-Track

a) Manual Track Switches

Manually operated switches in signaled territory shall be equipped with switch and lock movements with operating rods, lock rods and point detectors, and electric switch locks as required by Federal Railroad Administration (FRA) requirements. Removing a padlock from the electric switch lock and opening the front access door shall put neighboring signals to stop and shall start a timer to ensure clearance of trains that may have just passed the controlling signals. Expiration of the 30 second timer shall permit the switches to be unlocked and hand lined.

b) Powered Track Switches

Ballasted

Switches shall be powered by dual control (motor driven/manual) switch machines on open trackwork. Power for the dual control switch machines shall be from the signal power line or from commercial 120 VAC power source, rectified to 110 VDC. Switch machines shall be equipped with operating rods, lock rods and point detectors. Electric switch and lock movements shall be US & S Type M23-A, GRS model 5F, or approved equal.

c) Switch Heaters/Snow Melters

Switch heaters are to be provided and installed by the Signal Contractor at designated locations where the presence of ice and snow could affect rail service. Switch heaters shall be operated automatically or manually and an indicator shall be provided at the control equipment enclosure to indicate that the unit is on. Snow melters shall be powered from a 208 or 240 VAC source with heater pads wired in parallel sufficiently rated to keep the switch points and stock rails free of snow and ice.

8.14.2 Track Switches in Paved Track

a) Manual Track Switches

Manual track switches shall be equipped with toggle type switch movements. Facing-point switches shall be equipped with switch circuit controllers and switch indicator as determined by RTD

b) Powered Track Switches

Embedded

For in street running switches designed for embedded in street applications shall be utilized. Switches shall be powered off a rectified AC source originating from the control enclosure. Power shall be a nominal 120 VAC. Switch machines shall be equipped with operating rods and point detectors. Switches shall be Western Cullen Hayes, electro-hydraulic, or approved equal.

A successful operating record shall require a minimum of 3 years of successful operation on a comparable North American transit system or railroad, as determined and approved by RTD.

8.15.0 CONTROL CIRCUITRY

All safety circuits or logic shall be designed using vital relays and/or Vital Processors (solid state interlocking) of proven design and successful operating record.

Non-vital logic circuits may be controlled either by non vital relays or non vital solid-state logic controller or emulator.

All relays shall plug into separate relay bases. All non-vital relays shall be identical. All relays shall be furnished with at least one spare independent front-back contact.

The use of diodes, capacitors, or resistors to change a vital relays timing characteristics shall not be allowed for vital relays. All such timing characteristics shall be accomplished magnetically.

8.16.0 VITAL MICROPROCESSOR INTERLOCKING SYSTEMS

If interlockings are not controlled by vital relays, then Vital Microprocessor Interlocking Systems (VMIS) shall be employed to execute all vital safety signal system functions. The VMIS system shall be compatible with the existing microprocessor equipment currently in service on the RTD light rail system.

The VMIS shall be capable of operating in a light rail transit environment including exposure to temperatures, humidify and vibration. The VMIS shall be capable of operation at temperature of -40°C to +70°C at 90% humidity non-condensing.

The VMIS software systems shall be segregated into two independent software levels as follows:

- Executive Software shall consist of the coding that performs the input, internal and output operations that is defined within the individual interlocking application logic. The executive software shall be configured on a closed loop principle to ensure that the individual vital microprocessors operate in a fail-safe manner. The executive software shall reside in a read only memory.

- Application Software shall be segregated from the executive software and consists of the vital signal logic defining a specific interlocking configuration. The application software shall derive its safety from signal circuit design practices similar to that used for relay logic. The application software shall be capable of being modified to reflect changes in a specific interlocking configuration by RTD signal engineering staff with basic computer skills. To perform these software modifications, the VMIS system shall incorporate an application software development system and software simulator in order that the modifications can be tested and verified prior to final implementation.

For large interlockings (more than four power switches and/or movable point frogs), the VMIS system shall be segregated into zones and configured in a manner that failure in one zone will not affect the operation of an adjacent zone. Redundant microprocessors (normal and hot standby) shall be provided at selected microprocessor interlocking locations and configured such that shut down of the primary microprocessor would automatically permit seamless transfer to the standby unit.

Individual VMIS units shall include both vital serial ports to interface with adjacent VMIS unit, and non-vital serial ports for interface with the non-vital control system. Interface connections to wayside signal equipment shall be designed to function with existing RTD signal equipment operating at a standard voltages for the type of equipment in service. Where necessary, the VMIS system shall include vital relays to provide interface to wayside signal appliances.

The VMIS shall be equipped with a data recorder and diagnostic system capable of being accessed on-site at the VMIS location, or remotely over telephone or dedicated data lines using a diagnostic terminal or standard laptop personal computer. Data shall be capable of being accessed remotely from the data recorder and in real time on-site directly from the VMIS equipment. The diagnostic system shall be capable of identifying a failure, the nature of the failure and failure location. In addition to the diagnostic system, individual cards including; input/output boards, central processor cards and internal power supply boards shall be equipped with indicator lights that illuminate when respective input/output devices or ports are active.

The VMIS system shall be configured to operate from local available signal system power supply sources. Individual VMIS units shall be equipped with protection against unwarranted power surges at the power supply input terminals. The VMIS units shall also be protected against high levels of electric noise transmitted from external sources including radio, vehicle propulsion systems and hi-tension commercial power lines. Lightening protection including appropriate lightening arresters and equalizers shall be provided at all input terminals interfacing with wayside signal appliances.

VMIS units shall be modular and consist of stand alone card files capable of being mounted in standard instrument racks. Included in the instrument rack shall be all signal equipment required to provide a complete stand alone system.

8.17.0 PROGRAMMABLE LOGIC CONTROL SYSTEM

A Programmable Logic Control (PLC) system shall be employed for control and indication of the signal system. The PLC system shall interface with the VMIS at individual field locations. The PLC system shall perform all entrance-exit functions, receive inputs from various sub-system components (including; individual local control panels and central control) and transmit the appropriate command to the VMIS system. Status indications received from the VMIS shall be processed and transmitted to the local control panel and central control. The PLC system shall be compatible with equipment currently in-service on RTD's LRT system.

The PLC system shall consist of a fault tolerant microprocessor based control system, utilizing either a single unit or fully redundant normal and standby microprocessors. The RTD shall determine which locations require redundant systems based upon the affects a failure of the microprocessor would have on overall system operations. The normal and standby units shall exchange information on operations and health of each respective unit over a serial link. Automatic switch over to the standby unit shall occur if a failure is detected in the hardware or through diagnostic routines of the on-line unit.

The system software shall be field proven, commercially available and prevalent in the industry. The software system shall be designed in a manner that will permit future expansion. The application programs shall be stored on Erasable Programmable Read Only Memory (EPROM), with temporary data (controls and indications) stored in Random Access Memory (RAM). The software shall be capable of being modified to reflect changes in system configuration by RTD signal engineering staff with basic computer skills. To perform these software modifications, the non-vital PLC system shall incorporate a software development system and software simulator in order that the modifications can be tested and verified prior to final implementation.

The PLC units shall be capable of operation in a light rail transit environment including exposure to temperatures, humidify and vibration. The PLC shall be capable of operation at temperatures of -40°C to +70°C at 90% humidity non-condensing. The PLC unit shall be protected against high levels of electrical noise transmitted from external sources including radio, vehicle propulsion systems and hi-tension commercial power lines. In addition, appropriate lightening protection shall be provided where the PLC unit interfaces with external cable systems.

The PLC units shall consist of modular card files capable of being mounted in standard instrument racks. Individual cards including; input/output boards, central processor boards and internal power supply boards shall be equipped with indicator lights that illuminate when functions on the boards are active.

8.18.0 SIGNAL POWER

8.18.1 Power Line

Primary power will be provided to the various signal locations by individual power drops provided by the local utility. Because the track relays shall be of the phase-selective, two-element type, it shall be necessary for a fixed-phase relationship to be maintained between adjacent track circuits and between the two ends of each individual track circuit. Reference voltage between locations may be required to be provided via line wire.

8.18.2 Frequency Converters

If 100 Hz (rather than 60 Hz) track circuits are determined to be necessary as the result of electromagnetic interference studies, 60 Hz to 100 Hz converters of solid state design shall be provided.

8.18.3 Batteries

All grade crossing warning equipment shall be provided with emergency batteries. Nickel-cadmium or sealed lead-acid batteries, with a minimum capacity of 240 Ampere-hours shall be provided. Separate battery banks for logic and gates flashers shall be provided. Battery backup shall provide sufficient power to allow the crossing to operate for a minimum of 8 hours under normal operating conditions.

8.18.4 Redundant Signal Power

Redundant signal power shall be provided at junctions.

8.19.0 SCADA INTERFACE

Each signal equipment room/case shall be equipped with a SCADA interface to provide the following controls and indications to the SCADA system:

- TWC Indications for all Passing Trains
- Track Circuit Occupancy Indications
- Switch or Crossover Position Indications
- Electric Switch Lock Indications
- Switch Heater Indications and Controls
- Signal Aspects Indications
- Route Request Indications and Controls
- Interlocking Mode of Operation Indications and Controls
- Commercial Power Status Indications
- Signal Power Status Indications
- Signal Power Line Indications and Controls

8.20.0 LIGHTNING AND TRANSIENT PROTECTION

Track circuits shall be protected from lightning per AAR Signal Manual Part 11.1.10. Grounding electrodes rods shall be provided and installed in the signal rooms/case. Connections between arresters, other signal equipment, and grounding electrodes shall be per AAR Signal Manual Part 11.1.1, except that all connections to grounding electrodes shall be by exothermic welding.

All electronic and solid state devices shall have effective internal and separate external surge protection. High-voltage lightning arresters shall be applied to commercial power connections.

8.21.0 WIRE AND CABLE

Station-to-station and signal-room-to-field equipment signal wires in the signaled areas shall not be combined in the same cable or conduit with signal power or communication circuits. In general, conduit located in an underground duct bank shall be provided.

Station-to-station and signal-room-to-field equipment signal conductors shall be #14 AWG or larger conductors with 5/64" of 90°C ethylene-propylene rubber compound insulation. Multiple conductor cables shall have an outer jacket of extruded, black, low density, high-molecular weight polyethylene.

Case wiring shall be #16 AWG or larger and shall have either 90°C ethylene-propylene rubber compound or Teflon insulation. Wire, cable and its installation shall comply with the applicable requirements of the AAR Signal Manual. A minimum of 10%, but not less than 2 spare conductors, shall be required in each cable.

8.22.0 LOCATION OF SIGNAL EQUIPMENT

Signal system equipment shall be located in wayside houses. Wayside cases shall be used only in the event it is physically impossible to locate a house at the required location.

All signal equipment, including signals, switch machines, switch indicators, cases and houses shall clear the LRV dynamic outline by a minimum of 6 inches.

Doors of signal equipment cases and houses shall be restrained from opening to a position less than 6 inches from the LRV dynamic outline.

Equipment cases shall be located in such a way as to not obstruct the train operators or motorists (insofar as grade crossing warning equipment is concerned) view of the governing signal.

To the maximum extent possible, all signal relays shall be located in signal equipment rooms/cases at each passenger station.

So far as possible ABS signals shall be located approximately 50 feet from the exiting end of station platforms.

SECTION 9 - TRACTION ELECTRIFICATION SYSTEM

SECTION 9 - TRACTION ELECTRIFICATION SYSTEM

9.1.0 GENERAL

The Traction Electrification System (TES) provides electrical power to a Light Rail Vehicle (LRV) by the means of Traction Power System (TPS) and the Overhead Contact System (OCS). The TPS consists of the Traction Power Substations (TPSS) and the Traction Power Feeder System (TPFS). The TPFS includes both the positive and negative feeder cables and their respective conduits. The LRV will collect current from the contact wire by means of pantographs and will return the current to the substations via the running rails.

The TPSS consists of traction power substations located along the Light Rail Transit (LRT) lines, which receives primary power from the local power utility company. The substations include all the equipment necessary to transform and rectify the primary AC three-phase power to DC traction power. Traction power will be supplied to the OCS via positive underground feeder cables. The negative return underground feeder cables shall be connected to the running rails via impedance bonds.

The OCS can be of two styles;

- Constant tensioned simple catenary style comprising a single messenger wire and single contact wire, including low profile simple catenary; or
- a variable tension single contact wire.

Unless directed otherwise by RTD simple catenary shall be used on mainline applications and single contact wire shall be used for all yards and shops. Single contact wire style shall be used in aesthetically sensitive areas such as city center streets and malls in which cases the single contact wire will be electrically reinforced by underground parallel feeder cables, with cable risers to the OCS every 300 to 400 feet. The use of a underground feeder to support a single contact wire is much more expensive then using a simple catenary style and therefore shall only be used where directed by RTD.

The traction power substations shall provide power to the OCS at sectionalizing points. The OCS shall normally operate as a dual multi-feed system for the full length of the main lines with each track being electrically separated from the other. The OCS for the maintenance facility and storage tracks shall operate independently from the main line OCS and shall have its own traction power substations. The mainline tracks will be isolated from ground and connected to the negative bus at the TPSS. The yard and shop tracks will be grounded and separated from the mainline tracks by insulated rail joints.

9.2.0 FUNCTIONAL REQUIREMENTS

The traction electrification system shall maintain the OCS voltage above the minimum allowable value. The spacing of the substations shall be established to prevent the temperature of the OCS conductors from exceeding the limit recommended by the conductor manufacturer. The OCS shall be designed to ensure that the LRVs operate with all pantographs in continuous contact with the contact wire up to the maximum allowable track speed. The design shall avoid sudden changes in contact wire height that would cause arcing during current collection.

All traction power and distribution system equipment shall be designed taking into account the effects of the harmonic content of the traction load, the highly fluctuating pattern of traction current, and system faults. The TES shall be designed for a minimum functional life expectancy of thirty (30) years. All traction power substations shall meet the harmonic requirements of IEEE 519.

9.3.0 DESIGN REQUIREMENTS

9.3.1 Traction Power System (TPS)

The TPS includes the traction power substations and the pad mounted disconnects located adjacent to the substations from which the underground positive feeder cables run directly to the OCS feeder poles and the underground negative return cables run directly to the track rails in non-signalized territory and to the rails through impedance bonds in signalized territory.

9.3.1.1 Substation Spacing and Location

Traction power substation spacing shall be based on the system load flow simulation. The substations shall be located so that the distribution system voltage does not drop below the minimum level requirements, the temperature of the distribution system conductors does not exceed the maximum allowable value, and the rail voltages do not exceed the maximum permissible values.

9.3.1.2 System Load Flow Simulation

The design of the TES shall be based on a computer-aided load flow simulation. The simulator shall simulate operation of the trains along the alignment and calculate all necessary parameters for the electrification system design. Four car trains shall be simulated to operate on the system at the minimum projected headways, as specified by RTD, under normal and individual substation outage conditions, with the cars loaded to AW3. Under these operating conditions the TES design shall be shown to operate successfully within the required design parameters and the voltage at the trains shall not fall below 525 Vdc.

The input data shall include track gradients, track speed limits, passenger station locations and station dwell times, as well as the electrical and mechanical characteristics of the trains. Further, the input data shall represent the utility electrical system, the traction power substations, the distribution system and the power return system.

The output data shall include train operational data such as speed, distance traveled, power demand and energy consumption for each station-to-station run. For each substation, the results shall include average power output, energy consumption, rectifier current and current for each feeder breaker. For each substation to substation section of the, line the results shall include voltage profile and current flow in each OCS section. Calculations for maximum substation bus current, feeder cable size, equipment temperature rating and OCS conductor temperature shall be performed.

9.3.1.3 Substation Incoming Service

Incoming primary AC power to the TPSS may be supplied by the local power utility company at a nominal 13.2 kV, three phase, three wire, 60 hertz. The substations shall be connected by overhead lines or underground cables to the utility three-phase distribution network. The AC service and AC protection scheme shall be coordinated with the electrical utility.

One primary feeder shall supply each transformer rectifier. Each primary feeder shall originate from a different utility bus, and shall be as independent as possible. Feeders connected to the same utility bus shall not supply adjacent substations.

9.3.1.4 Substation Types

Each mainline substation shall have one transformer/rectifier unit and four DC feeder breakers unless otherwise specified by RTD. Substations located in the vicinity of mainline junctions shall have six DC feeder breakers.

9.3.1.5 Substation Equipment Rating

The continuous rating of the mainline substation equipment such as the traction transformer, rectifier, circuit breakers and cables shall be based on the system load flow simulation.

Each mainline and yard substation shall be capable of supplying the following load cycle in accordance with NEMA standards:

- Constant temperature of all equipment shall be reached following operation at 100% rated power for a minimum of 2 hours.
- Equipment shall then be able to sustain a 150% overload for 2 hours with five evenly spaced periods of one minute each at 300% of rated load and one 5 second period at 450% of rated load, followed by a maximum short circuit current with duration equal to substation protective device clearing time.
- Equipment shall be capable of sustaining such an overload twice a day, once in AM peak and once in the PM peak periods.

The shop substation shall be capable of supplying 100% rated load continuously, 150% rated load for two hours following temperature stabilization at 100% load or 300% load for one minute following temperature stabilization at the 100% load.

9.3.1.6 TPSS Site Access, Grading and Drainage

A minimum 12 foot wide access drive shall be provided to each substation from adjacent roadways. The access drive shall be surfaced with gravel or asphalt and shall not exceed a 6% grade. The surfacing material shall be as recommended by a Geotechnical Engineer or as required by local jurisdictions.

A minimum clearance of 10 feet shall be provided around the perimeter of each substation to permit access for RTD and maintenance vehicles and equipment. Clearance width may be reduced at one side of the substation with approval from RTD. A 72 inch high barbed wire chain link fence shall be provided around the perimeter of the substation and a 12 foot wide gate shall be provided at the access drive.

The fenced area shall be generally flat with finished grade sloping a minimum of 2% away from the building. Decorative stone (3/4 inch) shall be placed over geotextile weed barrier within the fenced area.

The Design Engineer shall analyze drainage at the substation and provide stormwater infrastructure as appropriate.

9.3.2 Traction Power Feeder System (TPFS)

The TPFS shall be an underground feeder cable distribution system comprising positive feeder cables, negative return cables, transfer trip cables and high voltage AC power cables.

9.3.2.1 Positive Feeder Cables

The positive feeder cables shall be insulated with low smoke, flame retardant, ozone resistant, non-shielded, single multi-strand flexible conductors. Class B stranded copper conductor with ethylene propylene (EP) rubber compound insulated rated 5 kV, and heavy-duty chlorosulforated polyethylene (CP) jacket. The cables shall be suitable for installation in an underground conduit or duct, for use in wet and dry locations. The maximum operating conductor temperature shall be 90°C for normal operation and 110°C for hot spot. The cable construction shall comply with ASTM D2802 and ICEA S-58-516. The feeder design shall be coordinated with the OCS pole foundations.

9.3.2.2 Negative Return Cables

The negative return cables are the same as in Section 9.3.2.a, and shall be installed from the substation negative bus to the running rails. The negative return conduit location shall be outside the track, not between two rails, and shall be coordinated with the design of the substation foundation.

9.3.2.3 Transfer Trip Cables

The transfer trip cables shall be fiber optic cables. Material and workmanship of all fiber optic cables shall be of the highest quality assuring durability for a 40 year design life. All cables shall be suitable for both wet and dry installations. The cable shall be suitable for direct field termination with most standard optical connectors. The outer jacket material shall be suitable for long-term exposure to sunlight and weather with a life expectancy in excess of 40 years. Suitability shall be determined in accordance with MIL-STD-810, method 505.

9.3.2.4 High Voltage AC Power Cables

The high-voltage AC power cables shall comply with all of the local utility requirements.

9.3.2.5 Ductbank, Manholes and Hand Holes

Positive and negative cables shall be run in separate ducts, manholes and handholes.

9.3.3 Overhead Contact System (OCS)

9.3.3.1 Basic Design

The design of the OCS for the mainline, the yard and the shop facilities shall be based on engineering studies.

9.3.3.1.1 Maximum Tension Lengths

The maximum tension length shall be determined based on:

- Along track movement of in running cantilevers
- Stagger Change
- Balance Weight Movement
- Loss of Tension (4%)

9.3.3.1.2 Pantograph Security

The pantograph security study shall include calculations which take into account all factors that contribute to displacement of the contact wire with respect to the pantograph. This study is required for different contact wire heights as needed and shall include:

- Climatic condition: wind and temperature

- Conductor dimensions and tensions
- Conductor stagger
- Stagger changes due to along track conductor movement
- Stagger effect
- Mast deflection due to live loads such as wind and conductor tension change due to temperature change
- OCS erection tolerances
- Vehicle roll and lateral displacement, or 50% maximum roll into 'operating' wind
- Pantograph width
- Pantograph sway
- Track maintenance tolerances
- 'Wind' and 'no-wind' operating conditions

The results of this study shall include:

a) Maximum structure spacing as a function of track curvature

b) Conductor blow-off

c) Permissible midspan static offset for spans in 5 foot increments of length for tangent and curved tracks.

d) Conductor along track movement and stagger variation.

e) Maximum tension section length to the last in-running steady arm.

f) Pantograph security

9.3.3.1.3 Conductor Tension Calculations

Conductor tension calculations shall be made for various equivalent spans based upon the following:

a) Conductor normal tension at 60°F

b) Conductor temperatures

i) Minimum -25°F

ii) Maximum 125°F

c) Conductor ice loads

i) Operational loading conditions

½ inch ice on the messenger

¼ inch ice on the contact

ii) Non-operational loading conditions

½ inch ice on the messenger

½ inch ice on the contact

d) Maximum tension length to the last in-running steady arm. The results of the tension calculations shall include the following for various equivalent spans:

Maximum and minimum messenger and contact wire tensions and factors of safety for:

- Conductors with no ice loading
- Conductors with 'operational' ice loading
- Conductors with 'non-operational' ice loading

9.3.3.1.4 Catenary Hanger Tables

Catenary hanger tables shall be prepared with a maximum hanger spacing of 30 feet for:

a) Standard span with 5-foot increments of length

b) Overlap spans

c) Anchor spans

9.3.3.1.5 Catenary (messenger) Sag

Catenary messenger sag shall be calculated for various spans at 60°F, in 2-foot increments of span length.

Rise and fall of the contact wire shall be calculated for various spans in 5-foot increments of span length. The rise or fall of the wire is the increase or decease of wire height as compared to the height of the wire at 60° F due to the following:

- Rise
  - Conductors with no ice loading at minimum wire temperatures

- Fall
  - Conductors with 'non-operational' ice loading with a wire temperature of 32°F
  - Conductors at maximum wire temperature

9.3.3.1.6 Catenary Vertical Loads

Catenary vertical loads for 5-foot increments of span length shall be calculated for:

a) With no ice loading

b) With 'non operational' ice loading

9.3.3.1.7 Messenger Wire and Contact Wire Radial Loads

Tangent Track:
Messenger wire and contact wire radial loads due to maximum tension for 5-foot increments of span length shall be calculated for tangent track with maximum staggers.

Curved Track:
Messenger wire and contact wire radial loads shall be calculated for every degree of angle deviation, in one degree increments, between 1 degree and 15 degrees. Radial loads greater then 15 degrees are not acceptable.

9.3.3.1.8 Maximum Stagger Calculations

Maximum stagger calculations shall be prepared using 50% of all allowances made for pantograph security calculations. Maximum stagger shall be determined by subtracting the 50% allowance total from the half width of the pantograph carbons.

9.3.3.1.9 Pantograph Clearance Envelope

A pantograph clearance envelope shall be developed for application on all tracks including superelevation, for worst case track conditions and full vehicle roll plus a 6 inch mechanical clearance. No equipment, except OCS steady arms attached to the contact wire, shall intrude into the pantograph clearance envelope.

9.3.3.2 Pole Clearances

Minimum pole lateral clearances to track are specified in Section 4 - Trackwork.

9.3.3.3 OCS Styles

Two OCS styles are standard on the RTD System:

- simple catenary style including low profile simple catenary; and
- single contact wire style.

A simple catenary system shall consist of a messenger wire supporting a contact wire by the means of hangers. The contact wire shall be without sag at the normal temperature of 60°F. The catenary conductors shall be auto-tensioned by means of counterweights, which shall be mounted on anchor poles located at the ends of each tension length. The anchor pole, counterweight and associated hardware constitute a balance weight assembly (BWA). As the conductors contract and expand with temperature variation, the counterweights will rise and fall and thus maintain a constant conductor tension throughout the specified temperature range. Suitable anchor arrangements shall be used in the center of each tension length to prevent along track movement of the catenary system at that point. The catenary system shall be supported and registered by means of hinged cantilevers attached to steel poles located between the tracks wherever possible. At special locations such as track crossovers and turnouts, the catenary system may be supported by cantilevers mounted on poles located on the outer sides of the track or attached to head-span arrangements. The contact and messenger wires shall be offset (staggered) at registration points. This style is referred to as Auto Tensioned Simple Catenary (ATSC).

A low profile simple catenary system is similar to a simple catenary system in all respects except that the distance between the messenger and the contact wire is reduced to 1.5 feet at supports and support of the contact wire shall be from a single cross span wire. This style is referred to as Low Profile Simple Catenary (LPSC).

A single contact wire style system shall be used in streets where the environmental impact of simple catenary construction is not acceptable. This style shall also be used in the storage yard and shop areas. The system shall use fixed conductor terminations. In the fixed-terminated system, the conductor tension will vary with temperature variation. This style is referred to as Fixed Terminated Single Contact Wire (FTSCW).

The system in the streets and in the yards shall be supported and registered by means of cantilevers and where cantilevers are not appropriate by means of cross-spans. In the shop, the system shall be attached to the building structure. The contact wire shall be staggered except in the shop where no stagger is needed.

When used in the streets the FTSCW shall be supplemented by along-track paralleling feeders connected to the contact wire at approximately equal intervals. The feeder shall be an insulated cable placed in an underground conduit.

9.3.3.4 Structure Spacing

Structure spacing for the OCS shall be as great as possible consistent with specified system height and maximum midspan offset criteria.

9.3.3.5 Tension Length Design

For ATSC the OCS shall consist of a number of overlapping tension sections. Each tension section shall be designed as long as practical considering the mechanical constraints of the overhead system design, such as along track movement of the last in running cantilever, tension loss along the system, counterweight travel and manufacturing limits of conductor length. Where practical, overlaps shall take into account the sectioning requirements.

Tension lengths shall be terminated at each end by auto-tensioning devices or fixed terminations, as necessary. A full tension length has an auto-tensioning device on each end of the tension length and a midpoint anchor midway between the two tensioning devices. A half tension length has a fixed termination on one end and an auto-tensing device on the other.

If over a half tension section the track is 20 or more feet lower at one end than the other the BWA shall be placed on the lower end.

9.3.3.6 Wiring at Overlaps and Turnouts

Overlaps shall be used between adjacent tension lengths to provide mechanical continuity of the OCS and to permit passage of the LRV pantographs from one tension section to another. Turnout arrangements shall be used at track special work locations where trains change tracks and where they leave or enter the mainline.

The contact wire heights at overlaps and turnouts shall be designed considering the mechanical properties of the OCS. The design shall enable a smooth transition between adjacent contact wires without hard spots, by equalizing the contact wire heights over approximately 10 to 15 feet of track.

Sufficient electrical and mechanical clearances shall be maintained between adjacent cantilevers and between the cantilever frames and adjacent conductors of the auto-tensioned catenaries at all temperatures.

The overlap and turnout wiring shall be designed using single poles with twin cantilevers. Alternatively, two poles with one cantilever each may be used on exclusive ROW when economically justified. In areas where center poles are used, the overlaps shall be staggered along the track to accommodate the balance weight assemblies.

9.3.3.7 Contact Wire Heights

Different conditions may exist along the route, for which applicable wire height (measured from top of rail at 60° F and no wind) is shown below. Under no circumstances shall the contact wire height exceed 23.0 feet.

TABLE 9A – CONTACT WIRE HEIGHT

Condition	*Minimum Permissible Contact Wire Height at Midspan	*Normal Contact Wire Height at Support	
		Single Contact Wire	Simple Catenary
Exclusive ROW	16′ - 0″	17′ - 0″	16′ – 0″
Semi-exclusive ROW (shared with road vehicles)	18′ - 0″	19′ - 0″	18′ - 0″
Crossing railroad tracks	18′ - 0″	19′ - 0″	18′ – 0″
Shared with railroad tracks	22′ - 0″	22′ - 10″	22′ - 0″
Maintenance Building**	18′ - 0″ **	19′ - 0″ **	18′ - 0″
Storage tracks	18′ - 0″	19′ - 0″	18′ - 0″

* No allowance is made in the above table for future track rising.
** Less may be permitted on an as needs basis.

9.3.3.8 Contact Wire Gradient

The pantograph shall track smoothly under the contact wire at all times. Where the contact wire height needs to be changed, the change shall not cause bouncing and arcing of the pantograph.

The following table provides AREMA's recommendations for the maximum wire gradient versus LRV speed ranges. To allow for an installation tolerance, the design wire gradient shall be not exceed 90% of those listed here:

TABLE 9B - MAXIMUM WIRE GRADIENT VERSUS LRV SPEED

LRV Speed Range (mph)	Maximum Gradient (%)
1-15	2.3
15-30	1.3
30-45	0.8
45-55	0.6

9.3.3.9 Change of Contact Wire Gradient

The maximum change of contact wire gradient shall be equal to one-half the maximum gradient, from one span to the next.

9.3.3.10 Contact Wire Registrations

The largest acceptable stagger at registrations shall be determined from basic engineering calculations. The angle of deviation on a single steady arm shall not exceed 7 degrees or 500 pounds during operating conditions.

1) In Running Conditions

Light load	< 200 lb pull off or 80 lb direct push off steady arm
Medium load	< 500 lb pull off or push-pull off steady arm
Heavy load	< 1000 lb double medium load steady arms with contact wire swivel clamps 1 foot apart

2) **Out of Running Conditions**

Medium load	< 500 lb pull off or direct push-off registration pipe
Heavy load	< 1000 lb double medium load steady arms

9.3.3.11 Sectioning

The system sectioning shall be designed to enable the electrical protective relays to disconnect faulted sections of the distribution system, to permit planned maintenance, and to permit flexible operation during system emergencies.

Sectioning at substations shall be performed by means of insulated overlaps. Section insulators shall not be used in mainline tracks or crossovers used for normal train operations. Sectioning in crossovers and turnouts shall be performed by the use of insulated overlaps. Sectioning for emergency crossovers or turnouts, defined as crossovers or turnouts not used during normal revenue service, shall be performed using high-speed section insulators or insulated overlaps.

The primary connection and isolation of the system sections shall be performed by the substation DC feeder circuit breakers and by disconnect switches which shall be located adjacent to substations.

Circuit protection and transfer trip features between substations shall be arranged so that a fault on either track shall remove power from the associated track. Activation of a substation emergency pushbutton shall also deactivate the tracks associated with that pushbutton and leave all other tracks unaffected.

9.3.3.12 Grounding for Stray Current Corrosion Control and Safety

See Section 10.3.0.

Pole grounding resistance shall be less than 25 ohms.

9.3.3.13 Grounding for Lighting Arresters

All lighting arresters shall be grounded by an independent ground cable directly attached to a grounding device such as ground rod(s) or ground mat with a ground resistance of less the 5 ohms. Pole grounds may be connected to lighting arrester grounding devices.

9.4.0 STANDARDS AND CODES

All design work and material selection shall conform to or exceed the requirements of the latest editions of standards and codes issued by the following organizations:

- Association of American Railroads (ARR)
- American Railway Engineering and Maintenance Association (AREMA)
- American National Standards Institute (ANSI)
- American Society for Testing & Materials (ASTM)
- Institute of Electrical & Electronics Engineers (IEEE)
- National Electrical Manufacturers Association (NEMA)
- Insulated Cable Engineers Association (ICEA)
- American Society of Mechanical Engineers (ASME)
- Underwriters Laboratories (UL)
- National Fire Protection Association (NFPA)
- National Electrical Testing Association (NETA)
- National Electrical Code (NEC), where applicable
- National Electrical Safety Code (NESC)
- Applicable State, Local, and County Codes

9.5.0 PRODUCT REQUIREMENTS

9.5.1 Traction Power Supply System

9.5.1.1 Equipment Description

The traction power supply system shall consist of all equipment between the interface points with the power utility, the distribution system and negative return impedance bonds. The equipment includes AC cables, AC switchgear assemblies, transformer/rectifier units, DC switchgear assemblies, busbars, positive and negative cables, cable ductbanks, conduits and raceways, negative return and drainage assemblies, substation housings, foundations, grounding systems, protective systems, auxiliary power supply systems, HVAC systems, batteries and chargers, fire and intrusion systems, lightning arresters, annunciation and control systems, metering equipment, supervisory control equipment, portable fire extinguishers, circuit breaker test cabinet, special tools for maintenance, operating and maintenance manuals and training of RTD personnel.

The electrical equipment shall be housed in traction power substations which shall be of the package type, except where conditions do not permit. Each package substation shall be factory pre-wired, assembled and tested and housed in a self supporting, transportable enclosure suitable for outdoor installation. Each package substation shall be a completely self-contained and integrated unit installed on the previously prepared foundation designed to accommodate a 30 - inch crawl space and connected via suitable feeder cables to the utility interface point and to the traction power distribution and return systems. Where substations cannot be provided as packaged units, equipment shall be individually installed and tested in separately constructed buildings or rooms.

Entry doors shall be provided. The entry doors shall be of sufficient size for installation or removal of any piece of equipment if no other access is provided. All equipment shall be designed and arranged such that all repair, maintenance and cable connections can be accomplished from within the substation enclosure or through access panels at the rear of equipment lineups.

9.5.1.2 Incoming AC Feeders

The incoming substation service shall be by underground cables. Cable ductbanks, conduits, raceways and manholes inside the substation property line shall be designed from the point of utility interface to the traction power substation. The design shall be fully coordinated with the utility requirements and interfaced with the utility overhead or underground facilities. The feeder rating shall permit the substations to supply the specified load cycle and short circuits without exceeding the allowable equipment temperatures.

9.5.1.3 AC Switchgear

The AC switchgear assembly shall provide the means to deliver, control and measure the substation power requirements. The assembly shall be housed in dead-front enclosures containing AC disconnect switch, AC circuit breaker, metering equipment and auxiliary power supply.

The equipment shall conform to ANSI C37.20.2 "IEEE Standard for Metal Clad and Station Type Cubicle Switchgear", and shall be UL listed and labeled, or certified by an independent testing laboratory to meet ANSI and UL standards. Working space shall be provided to gain access to components from the front and the rear of the switchgear.

9.5.1.4 Rectifier Transformer

The rectifier transformer shall be 12 pulse, self-cooled, with primary voltage to be consistent with utility supply, and equipped with appropriate taps.

The transformer/rectifier shall be designed so that the maximum overall regulation rate is not greater than 6% ± 0.5% between 1% rated load and 450% rated load.

The transformer/rectifier design and component selection shall minimize harmonic distortion and shall comply with IEEE 519.

9.5.1.5 Rectifier

The rectifier shall be silicon diode type, natural convection-cooled. Thyristor rectifiers will be considered where necessary to provide improved voltage regulation or reduce overall traction electrification costs. The rectifier shall be a complete operative assembly consisting of the diodes, heat sinks, internal buses, connections, diode fuses and all other necessary components and accessories. It shall consist of full-wave bridges providing 12-pulse rectification.

The rectifier shall be capable of withstanding the duty cycles specified in Section 9.3.1.5 without exceeding the manufacturer's allowable diode junction temperature and without damage to any component:

The rectifier shall also be capable of withstanding the maximum theoretical short circuit current on the rectifier until cleared by the fault clearing devices.

9.5.1.6 DC Switchgear Assembly

The DC switchgear assembly shall consist of the positive and negative switches, rectifier, bus work, and DC circuit breakers. It shall form a lineup of dead-front metal clad switchgear built to ANSI C37.20.2 "IEEE Standard for Metal Clads and Station Type Cubicle Switchgear", except that the positive and negative switch and rectifier cubicles may alternately be constructed to ANSI C37.20.3 "IEEE Standard for Metal Enclosed Switchgear". The DC circuit breakers shall be high-speed, stored energy, draw-out, single-pole units and shall have bottom feeder cable entry.

9.5.1.7 Negative Return and Drainage Assembly

The negative return assembly shall include negative disconnect switches, negative busbar, terminations for negative return cables and other associated equipment. All equipment shall be rated at the system maximum rated voltage.

9.5.1.8 Programmable Logic Controller (PLC)

This section sets forth the minimum acceptable requirements for a Programmable Logic Controller (PLC) and associated modules as described below for the specified control, processing, and monitoring system and to interface with the Traction Power Substation equipment and the SCADA System. The Contractor shall be required to provide a full featured, integrated, modular operational PLC system. The modules shall be capable of being inserted at the site, with no factory re-wiring required.

Contractor shall provide a Programmable Logic Controller (PLC) relay interface system. All functional requirements specified shall be met or be exceeded by the PLC system. PLCs, associated network and interfaces shall be rated to utility standards for substation environment.

At a minimum, the PLC system shall consist of the following components:

- Electronic terminators shall replace the normal auxiliary and interposing relays. These shall be placed at the A/C switchgear cubicle, rectifier unit, rectifier DC disconnect switch unit, at each DC feeder circuit breaker unit and at each remote DC disconnect switch group.

- A stand alone modular programmable controller, or protective relay, shall be designed to provide the breaker reclosure relay, long time overload relay, frame fault protection relaying and lockout relays. Running rail voltage monitoring shall be furnished at each DC feeder breaker.

- "Transfer Tripping" of DC breakers adjacent to the section where a fault is detected will be provided by an optical fiber link and associated interface equipment.

- A local area network providing communication from the feeder breakers modular programmable controllers to the substation master programmable controller shall be furnished.

- A master PLC designed and programmed to integrate and control all interpanel connections and to provide substation monitoring and data logging shall be furnished at each traction power substation. The master PLC in combination with the above-described local area network shall result in the elimination of majority of the inter-panel wiring where applicable.

- A man/machine interface (operator panel) capable of providing substation status annunciation and local/remote control of substation operations (e.g. opening and closing of circuit breakers) shall be furnished at each traction power substation.

The PLC system and equipment shall be designed to operate in the environment and conditions specified by the requirements of the LRT system. All electrical interfaces, including relaying, voice and data, shall meet ANSI/IEEE surge withstand requirements. The system shall be immune to Radio Frequency Interference and shall be designed to meet the requirements of ANSI/IEEE C37.90.2 and ANSI/IEEE 281. The presence of transients on the communication interfaces shall not cause misoperation or blocking of any of critical communications. The system shall be failsafe.

The systems shall also be capable of integrating with the SCADA system using Ethernet for communication. A SCADA points list will be developed with RTD staff that includes alarms, status and supervisory control functions. Alarms will consist of all locally annunciated alarm points discussed in 9.5.1.9. Status points will consist of circuit breaker position, and other necessary points selected to give information about the condition of the remote station to Operations Control Center. The selection of a “local” control mode at the substation shall inhibit remote SCADA control of specific functions, but shall not prevent the monitoring of all substation parameters via the SCADA system.

9.5.1.9 Local Annunciation

The substations shall be equipped with an internal annunciation system. The annunciator shall be of modular design, programmable and may be integrated with the PLC described in 9.5.1.8, if provided. The annunciator shall consist of LED indicating lamps, audible alarm, test, silence, acknowledge and reset switches, as well as other associated equipment.

A flashing blue light shall be installed on the exterior of the substation, visible from the LRT trackway. The blue light shall be illuminated whenever a DC breaker is open or the DC output is not available.

An electrical alarm "points list" shall be developed listing electrical alarms to be annunciated. These alarms will be annunciated locally and by the blue light which shall be visible from the trackway.

9.5.1.10 Auxiliary Power

Each substation shall be furnished with AC and DC distribution panel boards. The AC panel board shall supply the substation lighting, HVAC, convenience receptacles and battery charger. The DC panel board shall supply circuit breaker and other control power and annunciation.

9.5.1.11 Busbars and Bus Connectors

Busbars and bus connections shall be designed to withstand, without damage to the bus or enclosure, the thermal and mechanical stresses occurring during the specified load cycle and the rated short circuit currents.

Busbars shall be made of rigid high electrical conductivity copper and shall be adequately insulated and braced with high strength insulators. Bus connections shall be bolted and furnished with silver-plated surfaces. Each joint shall have conductivity at least equal to that of the busbar.

9.5.1.12 Equipment Arrangement

Substations shall have adequate area to accommodate all the electrical equipment and ancillary components. Relative spacing and positioning of each item of equipment shall permit maintenance, removal and replacement of any unit without the necessity of moving other units. The arrangements of the equipment shall permit doors to be opened, panels to be removed, and switchgear to be withdrawn without interference to other units. Ceiling heights and structural openings shall permit entry and removal of the largest components installed in the housing.

Wall space for future growth will be provided. Minimum working clearances will be provided per the NEC. A minimum of 6 feet of space in front of high voltage switchgear shall be provided. Two exit doors with panic hardware, one from each end of the switchgear, shall be provided.

9.5.1.13 Grounding

Each traction power substation shall be furnished with a ground mat and provisions for equipment grounding. The ground mat shall be contained within the substation property lines and shall be designed so that the step and touch potentials at the rated short circuit current do not exceed the recommended safety limits of IEEE Standard 80. All grounding connections shall be capable of carrying the rated short circuit current.

Substation high voltage DC equipment enclosures shall be low resistance grounded.

9.5.1.14 Negative Return System

The substation negative bus shall be connected to the running rails. The rails shall be welded in continuous lengths. Any bolted rail joints shall be electrically bonded. At locations requiring insulated rail joints, the continuity of the negative circuit shall be maintained by the use of impedance bonds.

In areas of double track equipped with double-rail AC track circuits, cross bonding between tracks for negative return equalization shall be accomplished by impedance bond center tap connections at each substation return connection location. In areas of double track equipped with single rail AC track circuits, cross bonding between tracks shall be accomplished by direct connections between the negative traction return rails only. Single rail negative return segments shall not exceed 60 feet in length. In areas of trackage not equipped with track circuits, cross bonding between tracks shall be provided throughout the system, with a spacing of cross bonds of 1000 feet or at every second tracks circuit boundary.

9.5.1.15 Operations Facility Electrification

See Section 11.

9.5.2 Overhead Contact System (OCS)

9.5.2.1 Equipment Description

The OCS consists of all equipment between the interface with the DC traction power supply equipment and the vehicle pantograph. The equipment shall include foundations, poles, cantilevers, bridge arms, shop building supports, system conductors, feeders, hangers, jumpers, terminations, tensioning devices, sectioning equipment and all other necessary equipment.

The overhead system shall be designed to be environmentally acceptable. Within the mechanical and structural design constraints, the system structures and associated equipment shall be as lightweight as possible and shall use visually unobtrusive fittings. The system shall be double-insulated with each level of insulation compatible with the system insulation class. A minimum of 4 foot separation between energized components and grounded structure shall be provided. In areas where the grade separation or other means may allow bystanders close proximity to the OCS, at least 10 feet separation and a physical barrier e.g. chain link fence shall be provided to prevent access to any energized component. In cases where any energize component is less than 10 feet separation from the edge of the ROW, a solid barrier or panel must be placed between the energized component to prevent access to the energized component.

9.5.2.2 Foundations

The design of foundations for supporting structures and guy anchors shall be based on the structure loading calculations and soil data. The supporting structure foundations shall be designed to accept bolted base poles and shall have provision for feeder conduits and structure grounding. The size and placement of the OCS foundation anchor bolts shall be in accordance with RTD's standard OCS foundation designs. Deviation from the standard plans requires prior approval from RTD.

9.5.2.3 Poles and Supporting Hardware

All poles shall be designed as free standing except for termination poles for auto tensioned catenary. All poles shall have a base plate drilled to fit the foundation bolt pattern and shall have provision for grounding or bonding conductors.

For open track, the poles shall be galvanized wide flange beams mounted between the tracks except where special conditions require side poles. For operations in paved track where aesthetics are important, tapered tubular steel poles, side-mounted, ranging from 9 to 17 inches in diameter depending on the application will be used. Structures shall be designed so that the normal operating across-track live load deflection of any structure shall not exceed 2 inches, i.e. one inch in either direction laterally.

9.5.2.4 Cantilevers

The cantilevers shall be designed for a range of loads, pole-to-center track distances, and for a range of system heights considering the system installation tolerances. The cantilever members shall be designed for easy installation and adjustment.

9.5.2.5 Bridge and Shop Building Supports

Bridge and shop building supports shall be used where sufficient clearance to accommodate a cantilever-type assembly is not available. The supports shall be designed to restrict the uplift of the contact wire when subjected to pantograph pressure and shall be capable of providing vertical and across-track adjustment. The bridge supports shall permit the longitudinal movement of contact wire.

9.5.2.6 Insulators

Insulators shall provide electrical insulation in accordance with the system insulation class and shall have the mechanical safety factors specified.

The insulators shall have resistance against deterioration from exposure to sunlight and airborne chemical pollution. The insulators shall be a light gray, sky tone color and their life expectancy shall be compatible with that of the rest of the equipment.

9.5.2.7 Conductors and Associated Items

Contact wire shall be 350 kcmil solid, grooved, bronze-80 alloy conductor. The messenger wire shall be stranded, hard-drawn copper conductor. All feeder and connecting cables shall be insulated, stranded copper conductors with sufficient flexibility to prevent fatigue failure of the cable due to vibration of the overhead conductors.

All conductor connections, attachments, hangers and clamps shall be copper or bronze fittings and shall be designed for ease of replacement and maintenance.

Continuity and equalizing jumpers shall be flexible copper conductors. The spacing of the jumpers shall be determined based on the required current conductivity. However, a minimum of one jumper per span shall be used. In addition to the jumpers, current carrying hangers of stranded copper wire can be used. All conductive copper or bronze hardware to terminal and hardware to wire connections shall be coated with grease on the mating surface.

9.5.2.8 Terminations and Midpoint Anchors

Strain-type termination assemblies shall be light weight and of aesthetically pleasing appearance. Wire wrap, straight line, cone or wedge type designs are acceptable. Turnbuckles shall be included as appropriate and shall have adequate adjustability.

A mid-point anchor arrangement shall be used at or near the mid-point of each tension length of auto-tensioned equipment to restrict movement of the conductors at that point.

9.5.2.9 Tensioning Devices

The auto-tensioned system conductors shall be tensioned using cast iron or steel counterweights. At wide flange beam poles, the counterweights shall be positioned in the pole web to be as unobtrusive as possible. The poles with counterweights shall be fitted with guides that will prevent the counterweight from binding or jamming over the entire range of movement. The top and bottom of the weight shall be engaged by the guides at all times. The guide shall prevent the weights from falling away from the anchor pole during a broken wire condition. In areas frequented by passengers or pedestrians, the counterweights shall be provided with a protective shield. The tensioning devices shall accommodate conductor expansion and contraction and shall be provided with broken wire arrangements. All operating cables shall be of flexible stainless steel wire.

Pneumatic, spring or hydraulic tensioning devices may be used in public streets or for short tension lengths such as at crossovers.

9.5.2.10 Sectioning Equipment

Section Insulators shall not be installed in mainlines or crossovers in regular revenue service. High-speed section insulators may be used in emergency crossovers and in yards. Section insulators without skids shall be installed in the yards, except for test tracks.

No load disconnect switches shall be used to electrically connect and disconnect line sections. The disconnect switches shall be rated to withstand the system worst-case overload and short circuit conditions without overheating. The switches shall be capable of breaking the maximum load current under emergency conditions.

9.5.2.11 Lightning Arresters

Over-voltage protection for the OCS shall be provided by lightning arresters. The arresters shall be rated to withstand the maximum system voltage and anticipated voltages induced from any paralleling high-voltage transmission lines onto the system conductors. The arresters shall be capable of discharging the energy resulting from lightning strikes to the system.

All feeder riser cables shall be protected by lightning arresters. Arrester design and installation shall prevent grounding of the energized circuit during catastrophic failure.

At a minimum, arresters shall be located adjacent to each substation and in all areas of reduced clearances, such as at overhead bridges, midway between substations and high points in the alignment such as flyovers.

9.5.2.12 Protective Screening

When the LRT is constructed below a bridge, building, or structure, screening and fencing shall be erected to physically separate the catenary wires from human reach. Furthermore, the overpass screening and/or fencing shall be constructed to protect LRVs from vandals dropping objects from above. The design of the overpass screening and/or fencing shall be compatible with the local architecture and landscaping. All fencing passing over the LRT shall be grounded. Fence grounding resistance shall be less than 25 ohms.

9.6.0 DESIGN PARAMETERS

TABLE 9C – DESIGN PARAMETERS

Climatic Conditions	
Maximum Ambient Temperature:	100˚F
Minimum Ambient Temperature:	-25˚F
Radial Ice Loading:	1/2 in
Maximum Wind Speed:	
Structural design	80 mph
Pantograph Security	55 mph
CS Conductor Sizes and Material	
Messenger Wire: Copper. Alternative sizes require RTD approval	500 KCMIL HD
Contact Wire:	350 KCMIL Bronze 80
Factors of Safety -- Conductors and Wires	
Operating:	2.0
Non-operating:	1.6
Contact Wire Wear for Mechanical Design	30%
Factors of Safety -- Hardware	
Operating:	2.5
Non-operating:	2.0
Minimum Electrical Clearances	
Static Clearance:	4 in
Passing Clearance:	3 in (in addition to the static clearance)
Minimum Contact Wire Heights Above Top-of-Rail	See Section 9.3.3.7. RTD approval is required for any deviation in the minimum contact wire height (e.g. tunnels and overpasses)

Maximum Contact Wire Gradients	
Constant Gradient:	See Section 9.3.3.8
Gradient Change:	See Section 9.3.3.9
Pantograph Security	
Minimum Pantograph Security:	6 in
Loss or gain of tension within a tension section shall not exceed:	4%
Track maintenance Tolerances	
Ballast Track	
Alignment:	1 in
Cross level:	1 in
Embedded Track	
Alignment:	0.5 in
Cross level:	0.5 in
Track Gauge	
Widening:	0.625 in
Vehicle Data	
Maximum Roll (broken springs)	4%
Pantograph Data	
Width:	74.75 in
Separation of Carbons:	12-13 in
Length of Carbons:	52 in
Maximum Carbon Wear:	
40 mm x 25 mm Carbons	1 in
75 mm x 15 mm Carbons	0.625 in
Maximum Reach	23.51 ft

Maximum Operating Height	23 ft
Minimum Operating Height	13.78 ft
Lockdown Height	12.42 ft
Contact Wire Height	
Maximum Wire Height	23.00 ft

9.7.0 CONDUIT AND DUCTBANKS

The following parts apply to all conduit and ductbanks for traction power, signals, communications and high voltage (15 KV) AC.

9.7.1 Raceway and Ductbank System

This section describes the design criteria necessary to provide raceway and ductbank systems to protect all power wiring and system cables on RTD's LRT facilities. The systemwide electrical raceway and ductbank system includes conduits, ductbanks, cable trays and cable trough installations and related manhole, handhole and pullbox equipment. Generally there are two ductbank systems used within the trackway, parallel to the mainline track, namely the signal/communication (SC) mainline ductbank, and the traction electrification (TE) ductbank in addition there are various lateral ductbanks.

9.7.1.1 Scope

Systemwide Electrical Raceway and Ductbank System applies to all traction power electrification systems, communication systems, signal systems, fare collection equipment and electrical facilities including system buildings and rooms, maintenance facilities, passenger station platforms, park and ride lots, parking structures, lighting systems, pedestrian and LRT bridges, and AC low voltage and high voltage electrical systems.

9.7.1.2 System interfaces

Systemwide Electrical Raceway and Ductbank System engineering shall be coordinated with the other disciplines, including architectural, mechanical, utility, electrical, civil, structural, trackwork, electrification, signal and communication designs.

9.7.1.3 Codes and standards

Raceway and ductbanks design shall conform to the latest edition of the following codes where applicable:

- National Electrical Code (NEC)
- National Electrical Safety Code (ANSI/IEEE C.2)
- Electrical Codes or amendments of the local authority having jurisdiction
- American National Standards Institute (ANSI)
- National Electrical Manufactures Association (NEMA)
- Institute of Electrical and Electronics Engineers (IEEE)
- National Fire Protection Association (NFPA 70, 101 & 130)
- The Occupational Safety and Health Act (OSHA)

9.7.1.4 Products

Raceway products used shall in all cases be listed and labeled by a nationally recognized electrical safety testing organization.

9.7.1.5 Functional Requirements

All power wire and systems cables shall be protected by conduit, cable tray, or cable trough per this section, except for low voltage signal or communication wiring where protected from physical damage within traction power substations, signal or communication buildings and rooms, bungalows, or cases. Installations shall comply with the NEC and local county and city codes.

Spare raceway capacity of 40% minimum shall be provided in the mainline SC ductbank, TE, HV, and lateral ductbanks or conduit runs including station platforms, except where determined by RTD. Spare cable tray or cable trough capacity shall be provided in all installations for future equipment. RTD may determine that the spare capacity is not necessary at various locations; due to the expense that would be incurred and this requirement could be reduced in capacity or eliminated.

Manholes shall be provided in the mainline SC ductbank, in TE ductbanks, in HV ductbanks, in lateral ductbanks, and in conduit runs at junction points and for cable pulling requirements in the cable system. Handholes shall be provided in various lateral ductbanks or conduit runs at junction points and for cable pulling requirements in the cable system. On LRT bridges, tunnels, or shafts where raceways are provided pullboxes shall be provided.

9.7.1.6 Raceway products

Raceways may be galvanized rigid steel conduit (GRS), PVC Schedule 40 conduit, PVC Schedule 80 conduit; PVC coated galvanized rigid steel conduit (PVC/GRS), rigid non-metallic fiberglass reinforced epoxy conduit, electrical metallic tubing (EMT), liquid-tight flexible metal conduit or flexible metal conduit.

Cable trays shall be aluminum, fiberglass-reinforced plastic, welded or swaged steel hot-dipped galvanized after fabrication, ladder type with formed rungs and channel type side rails with inward or outward turned flanges. Special design circumstances may require physical protection of the cables, and solid or ventilated cable trays and covers may be used.

Cable trough and cover shall be a dielectric material, High Density Polymer Concrete, pre-fabricated, nonmetallic, rated for exterior below grade use, resistant to sunlight exposure and suitable for use in wet locations. Individual cable trough sections must interlock together to make a continuous cable trough without gaps. Covers shall sit inside the trough, be flush with the finished grade, be designed to withstand excessive loading and not shatter and be secured with stainless steel vandal proof hardware. The weight of each cover shall not exceed the allowable handling weight as per OSHA requirements.

9.7.1.7 Systemwide Ductbanks

Ductbanks are concrete-encased conduits using Schedule 40 PVC conduit, with GRS or PVC/GRS conduit ells, or Schedule 40 PVC conduit large radius elbows greater than 6 feet. Ductbanks with reinforced steel rebar are used for special utility and roadway crossings. The exact ductbank dimensions vary with the number and size of conduits. Plastic spacers shall be provided between conduits to allow for concrete–encasement around the conduits. The minimum spacing between conduits is 1.5 inches for signal/communication conduits and 3 inches for traction electrification and power conduits unless otherwise required by the NEC. The overall concrete-encasement around the outside conduits shall be 3 inches on all sides. Trench walls that are stable may provide the forms for the concrete encasement.

Ductbanks shall be located longitudinally along the length of the trackway and between the mainline tracks. Generally the ductbank is located below the end of the track ties at a depth of 36 inches so that conflict with OCS and signal foundations is avoided and the ductbank runs in a straight line between conduit transitions into manholes. If required, due to special circumstances, ductbanks located other than between the mainline tracks will be determined solely at the discretion of RTD. Ductbanks are to be set on a prepared and compacted bed.

When it is necessary, lateral ductbank crossings below the track are permitted as long as the ductbank meets the minimum depth requirements.

Where obstacles such as underground utilities or foundations are encountered the ductbank shall be gradually offset around them and must meet the concrete-encasement and conduit bending requirements. Ductbanks shall be located outside the envelope shown in Figure 9.1.

Ductbanks shall be located precisely on all plans and profile design drawings. Ductbanks shall be sloped to drain to manholes or handholes, be located to avoid interference with new or existing utilities, and be located at a minimum depth of 36 inches below finished grade. Conduits shall be limited to a maximum of 270° of bend between manholes, handholds, junction boxes, or termination points.

9.7.1.8 Systemwide Raceways

Conduit

Within the trackway, raceways may be direct buried and shall be PVC/GRS conduits if designs are encountered where concrete encasement cannot be achieved due to space restrictions.

The final signal raceway connections (normally the last 10 feet of the conduit run from last signal handhole or into bungalows and cases) to signal equipment maybe direct buried and shall be schedule 40 PVC conduit.

On LRT bridges, exposed raceways for signal, communication, traction electrification, and lighting shall be galvanized rigid steel conduit or rigid non-metallic fiberglass reinforced epoxy conduit and its use will be determined solely at the discretion of RTD. If raceways are concealed as an integral part of an emergency pedestrian walkway schedule 40 PVC conduit may be used, except for transitions at the end of the bridge, which shall be PVC/GRS conduit direct buried or ductbank with GRS conduit. Transitions at end of bridges require expansion couplings.

Cable Tray

The use of cable trays is restricted to use within system buildings, across pedestrian bridges and rooms. Cable trays and supports shall be designed to provide adequate strength to support the weight of the tray, cables, and future cables and meet the local seismic requirements. The use of fiberglass cable trays is generally used inside TP Substations for DC feeders and cables.

Cable Trough

The use of cable trough is restricted to existing trackways and its use will be determined solely at the discretion and approval of RTD. If required, due to special circumstances, cast-in-place type cable troughs may be located on LRT bridges as an integral part of an emergency pedestrian walkway as determined solely at the discretion and approval of RTD. Covers for cast-in-place cable troughs shall be pre-fabricated High Density Polymer Concrete and be secured with stainless steel vandal proof hardware. The capacity of the approved cable trough shall be 200% of the feeding conduit system.

Cable trough may be used for signal, signal power and communication cables only. The cable trough shall have integral dividers to maintain separation between signal, signal power and communication cables. Cables shall only enter or exit the cable trough through cable trough handholes or pullboxes that are an integral part of the cable trough system.

The cable trough shall be located longitudinally along the length of the trackway and shall not be located between mainline tracks. Cable troughs shall not be located directly above longitudinal runs of track drains or other utilities. Where obstacles, such as OCS and signal foundations, or utility manholes are encountered, the cable trough shall be gradually offset around the structure. Cable trough shall be placed in a level trench, with the lids flush with finished grade.

Cable troughs shall not be used in station platform areas, road and pedestrian crossings, high rail accesses and any areas accessible to pedestrians.

9.7.1.9 Manholes, Handholes and Pullboxes

Manholes and handholes shall be of the pre-cast concrete type, complete with cable supports, pulling irons, and a ground rod, and all metallic parts shall be internally grounded. Manholes or handholes installed in streets shall be equipped with a cast iron cover and grade ring suitable for H-20 street loading and which can be adjusted for final grade. In other locations, covers shall be hot-dipped galvanized steel diamond plate suitable for H-20 street loading.

Pullboxes shall be welded hot-dipped galvanized steel boxes or cast-in-place boxes with hot-dipped galvanized steel diamond plate covers, for use on LRT bridges, in tunnels and in shafts. All manholes, handholes and pull boxes shall be identified with welded raised lettering, except platform handholes, which shall be cast integral with the cover.

9.7.1.10 High Voltage Raceways and Ductbanks

High voltage raceways and HV ductbanks that are maintained by RTD, and are used for AC feeders (greater than 600V) shall be GRS, PVC/GRS, or PVC conduits encased with red concrete, and the conductors separated from other systems per the NEC.

If required because of electromagnetic interference (EMI) high voltage AC conductors shall be installed in galvanized rigid steel conduit or other means shall be taken to mitigate the effects of the EMI.

High voltage AC conduits shall have a bending radius no less than 36 inches.

9.7.1.11 Utility Raceways and Ductbanks

Utility raceway and ductbank installations shall meet the construction and material requirements of the local utility if installed under an RTD contract.

9.7.1.12 Station Platforms

For station platform, raceways shall be schedule 40 PVC conduits embedded in fill and located at a minimum depth of 18 inches below the finished grade of the platform slab. All conduit stub-ups through the platform slab or foundations shall be PVC/GRS conduit. Platform pullboxes shall be located along the platform, generally towards each end and in the middle of the platform to provide junction points for the communication cables and power wiring. Pullboxes and covers shall be pre-cast high density polymer concrete type with split covers if used for communication cables and power wiring and the box sections shall be divided. For all mainline platform conduit penetrations into the pullboxes, that run the length of the platform, they shall enter the side of the pullbox and be provided with bell ends. All lateral conduit penetrations into pullboxes shall enter the bottom of the pullbox and be provided with bell ends.

Communication conduits shall be provided to all planned and future communication equipment on the station platforms. Spare conduits shall be provided to all mainline conduit runs along the length of the platform, and to all shelters including future shelters. All exposed conduits shall be painted to match the structure which to it is attached.

9.7.1.13 Park-n-Ride Lots and Street Lighting

For park and ride lot lighting and street lighting systems that are maintained by RTD, raceways shall be schedule 40 PVC conduit, and direct buried 30 inches minimum below grade. Raceways buried less than 30 inches below grade shall be concrete encased.

Communication conduits and pullboxes shall be provided to all planned and future communication equipment at the park and ride lots. Pullbox requirements are the same as listed for station platforms.

For all street lighting systems not maintained by RTD, but installed under an RTD contract, the raceways shall meet the construction and material requirements of the local authority having jurisdiction.

9.7.1.14 Pedestrian Bridges

For pedestrian bridges, raceways for signal, communication, traction electrification, and lighting conduits shall be GRS conduits, PVC/GRS conduits, or rigid non-metallic fiberglass reinforced epoxy conduit if exposed or concealed.

9.7.1.15 Maintenance Facilities

For maintenance facilities, interior installations of raceways shall be EMT, GRS, or flexible metal conduits at dry locations not subject to damage; GRS conduits at dry locations subject to damage; and PVC/GRS or liquid tight flexible metal conduits at wet or damp locations. All exterior installations of raceways shall be GRS, PVC/GRS, or liquid tight flexible metal conduits. All raceways installations under-slabs or in-slabs of structures shall be GRS, PVC/GRS or PVC conduit, and all conduit stub-ups through the building slab or foundations shall be PVC/GRS conduit.

For the yard and site areas of maintenance facilities, ductbanks with manholes and handholes shall be provided, see the systemwide ductbanks section for requirements. All street or yard lighting system raceways within the track areas of the maintenance facility shall be schedule 80 PVC conduit, and direct buried 36 inches minimum below grade. For parking lot lighting and street lighting systems, outside the track areas, the raceways shall be schedule 40 PVC conduit, and direct buried 30 inches minimum below grade.

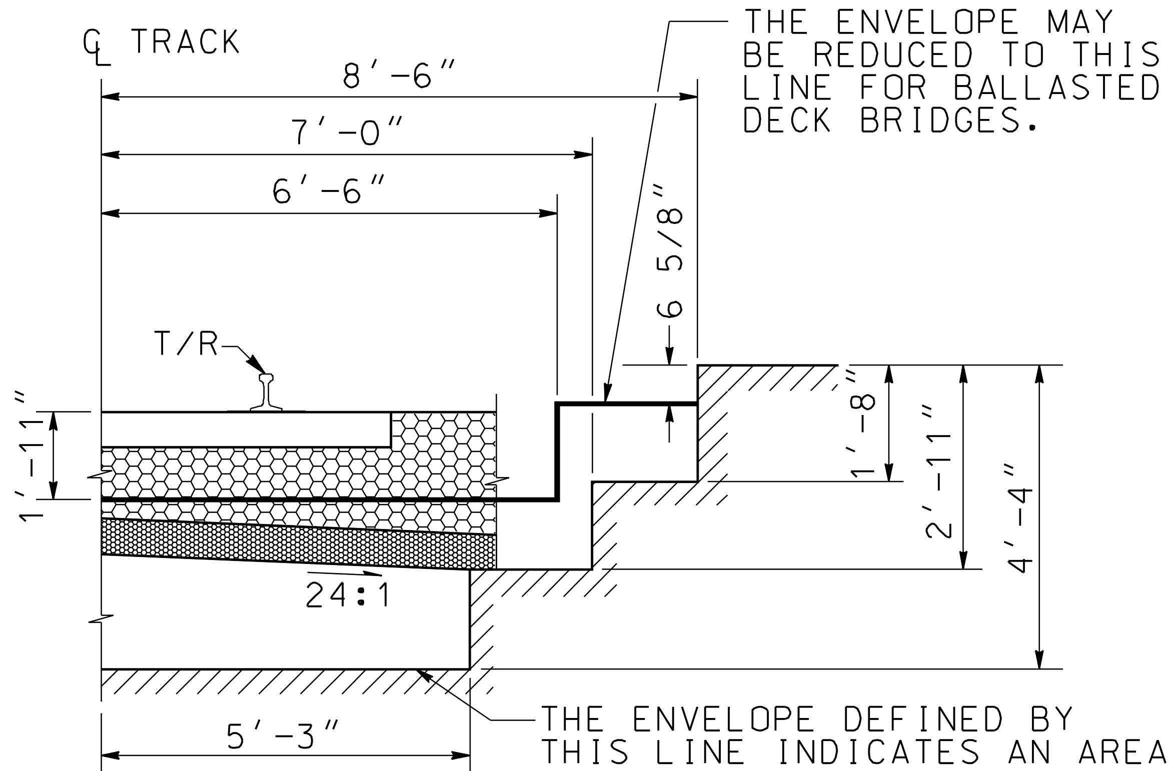
System raceways shall be provided to all planned and future system equipment at the maintenance facility. Provide spare capacity in all system raceways for future equipment.

For communication, signal, or TP substation rooms within the maintenance building, cable trays may be used. Spare cable tray capacity shall be provided for future equipment.

9.7.1.16 Parking Structures

The raceways requirements for parking structures shall be the same as for maintenance facilities.

LIST OF FIGURES



RTD

DESIGN CRITERIA

TITLE: LRT ENVELOPE

FIGURE: 9.1

SECTION 10 – STRAY CURRENT/CORROSION CONTROL

SECTION 10 - STRAY CURRENT/CORROSION CONTROL

10.1.0 GENERAL

This section describes the design criteria necessary to provide corrosion control measures. Corrosion control measures are required to prevent premature corrosion failures on transit system fixed facilities and other underground structures. Such measures will also minimize stray current levels and their effects on underground and above grade structures. Corrosion control systems should be economical to install operate, and maintain.

10.1.1 Scope

Corrosion control design criteria encompass all engineering disciplines applied to the project. The criteria are separated into three areas: soil corrosion, stray current corrosion and atmospheric corrosion. The design criteria for each of these categories, and their implementation, shall meet the following objectives:

- Realize the design life of system facilities by avoiding premature failure caused by corrosion;
- Minimize annual operating and maintenance costs associated with material deterioration;
- Provide continuity of operations by reducing or eliminating corrosion related failures of systems and subsystems; and
- Minimize detrimental effects to facilities belonging to others as may be caused by stray earth currents from transit operations.

10.1.2 System Interfaces

Corrosion control engineering shall be coordinated with the other disciplines, including mechanical, utility, electrical, civil, structural, trackwork, electrification, signaling and communications designs.

10.1.3 Codes and Standards

All design relating to implementation of the corrosion control requirements shall conform to or exceed the requirements of the latest versions of codes and standards identified in these criteria.

10.1.4 Requirements

Soil Corrosion Control

Criteria in this category apply to systems or measures installed to mitigate corrosion caused by soil/rock and groundwater.

Soil/rock samples should be obtained in conjunction with geotechnical testing in areas of extensive below grade construction. The samples should be analyzed for resistivity (or conductivity), moisture content, pH, chloride and sulfate ion concentrations, and for the presence of sulfides.

Structures shall be protected against environmental conditions by the use of coatings, insulation, cathodic protection, electrical continuity or a combination of the preceding, as appropriate.

Stray Current Corrosion Control

Criteria in this category apply to measures installed with the traction power system and trackwork to assure that stray earth currents which may be produced by the traction electrification system do not exceed maximum acceptable levels, 10^{14} ohms-cm. These levels are based on system characteristics and the characteristics of underground structures.

These criteria also apply to measures installed with fixed facilities, and to facilities belonging to others. They are based on anticipated stray earth current levels and the characteristics of fixed facilities and other buried structures.

Atmospheric Corrosion Control

Criteria in this category apply to systems or measures installed to mitigate corrosion caused by local climatological conditions and air pollutants.

10.2.0 SOIL CORROSION CONTROL

This section provides criteria for the design of systems and measures to prevent corrosion of transit system fixed facilities due to contact with area soil/rock and groundwater. Designs shall be based on achieving a minimum 50 year design life for buried structures, with exception of a 100 year design life for the stations, through consideration of the factors given below.

10.2.1 Materials of Construction

All pressure and non-pressure piping and conduit shall be non-metallic, unless metallic materials are required for specific engineering purposes.

Aluminum and aluminum alloys shall not be used in direct burial applications. If non-native fill is to be used for backfilling concrete or ferrous structures, then it shall meet the following criteria:

- pH 6 to 8 (ASTM G-51)
- Maximum chloride ion concentration of 250 ppm (ASTM D-512)
- Maximum sulfate ion concentration of 200 ppm (ASTM D-516)

Test reports shall be submitted for approval of all imported backfill.

Use of fill material, which does not meet one or any of the preceding criterion, may be acceptable after review and approval by RTD.

10.2.2 Safety and Continuity of Operations

Corrosion control protection shall be required for those facilities where failure of such facilities caused by corrosion may affect the safety, or interrupt the continuity of operations.

10.2.3 Accessibility of Installations

Permanent test facilities installed with certain corrosion control provisions shall be accessible after installation, allowing for periodic maintenance and monitoring.

10.2.4 Special Considerations

Installation of corrosion control measures for facilities owned by others, but designed as part of the transit project, shall be coordinated through RTD or its representative. This coordination shall resolve design and construction conflicts to minimize the impact on other system elements.

10.2.5 Materials and Methods

The following paragraphs establish the materials and methods to be used for soil corrosion control.

10.2.5.1 Coatings

Coatings specified for corrosion control of buried metallic or concrete facilities shall satisfy the following criteria:

- Minimum volume resistivity of 10^{10} ohm-centimeters (10 Billion ohm-centimeters) (ASTM D-257).
- Minimum thickness as recommended for the specific system, but not less than 15 mils.
- A chemical or mechanical bond to the metal or concrete surface. Pressure-sensitive systems are not acceptable; non-bonding systems may be used in special instances, after review and approval by the RTD
- Minimum 5 year performance record for the intended service.
- Mill application wherever possible, with field application of a compatible paint or tape system.

- Mechanical characteristics capable of withstanding reasonable abuse during handling and earth pressure after installation for the design life of the system.

Generic coating systems include but are not limited to the following:

- Extruded polyethylene/butyl based system
- Coal-tar epoxies (two component systems)
- Polyethylene-backed butyl mastic tapes (cold applied)
- Bituminous mastics (airless spray)

10.2.5.2 Electrical Insulation of Piping

Devices used for electrical insulators for corrosion control shall include nonmetallic inserts, insulating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

- A minimum resistance of 10 megohms prior to installation.
- Sufficient electrical resistance after insertion into the operating piping system such that no more than 2 percent of a test current applied across the device flows through the insulator, including flow through conductive fluids if present.
- Mechanical and temperature ratings equivalent to the structure in which they are installed.
- Internal coating (except complete non-metallic units) with a polyamide epoxy for a distance on each side of the insulator equal to two times the diameter of the pipe in which they are used. Where conductive fluids with a resistivity of less than 2,000 ohm-centimeters are present, internal coating requirements shall be based on separate evaluation.
- Devices (except non-metallic units) buried in soils shall be encased in a protective coating.
- Devices (except non-metallic units) installed in chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components.
- Inaccessible insulating devices, such as buried or elevated insulators, shall be equipped with accessible permanent test facilities.
- A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When

conditions do not allow a 12 inch clearance, the design shall include special provisions to prevent electrical contact with existing structure(s).

10.2.5.3 Electrical Continuity of Piping

Electrical continuity shall be provided for all non-welded metallic pipe joints and shall meet the following criteria:

- Use direct burial, insulated, stranded, copper wire with the minimum length necessary to span the joint being bonded.
- Wire size shall be based on the electrical characteristics of the structure and resulting electrical network to minimize attenuation and allow for cathodic protection.
- Use a minimum of two wires per joint for redundancy.
- Surface preparation of the structure to be coated shall be required in accordance with the coating manufacturer's recommendations.

10.2.5.4 Cathodic Protection

The design of cathodic protection shall be by a NACE International certified Corrosion Specialist or Cathodic Protection Specialist. Cathodic protection shall be accomplished by sacrificial galvanic anodes to minimize corrosion interaction with other underground utilities. Impressed current systems shall be used only when the use of sacrificial systems is not technically and/or economically feasible. Cathodic protection schemes that require connection to the transit system negative return system, in lieu of using a separate isolated anode ground bed, shall not be permitted.

Cathodic protection system design shall be based on industrial standards (NACE International), recommended practices, and criteria on theoretical calculations. Theoretical calculations shall include the following parameters:

- Estimated percentage of bare surface area (minimum 1 percent)
- Cathodic protection current density (minimum of 1.0 ma/ft^2 of bare surface area)
- Estimated current output per anode
- Estimated total number of anodes, size and spacing
- Minimum anode life of 25 years (minimum 50 percent efficiency)
- Estimated anode ground bed resistance

Impressed current rectifier systems shall be designed using potentially controlled rectifiers with permanent reference electrode facilities. Rectifiers shall be rated at a minimum of 50% above calculated operating levels to overcome a higher-than-anticipated anode ground bed resistance, lower-than-anticipated coating resistance, or presence of interference mitigation bonds. Other conditions which may result in increased voltage and current requirements shall be considered.

Test facilities consisting of a minimum of two structure connections, one reference electrode connection, conduits and termination boxes shall be designed to permit initial and periodic testing of cathodic protection levels, interference currents and system components (anodes, insulating devices and continuity bonds). The Design Engineer shall specify the locations and types of test facilities for each cathodic protection system.

10.2.6 Structures and Facilities

The following paragraphs establish the protective measures to be considered for utilities and buried structures.

10.2.6.1 Ferrous Pressure Piping

All new buried cast iron, ductile iron and steel pressure piping shall be cathodically protected. System design shall satisfy the following minimum criteria:

- Conformance with existing standards and specifications of the Owner.
- Conformance with federal, state and local codes for regulated piping.
- Application of a protective coating to the external surface of the pipe (see Section 10.2.5.1).
- Electrical insulation of pipe from interconnecting pipe, casings, other structures and segregation into discrete electrically isolated sections depending upon the total length of piping (see Section 10.2.5.2).
- Electrical continuity through the installation of copper wires across all mechanical pipe joints other than intended insulators (see Section 10.2.5.3).
- Permanent test/access facilities to allow for verification of electrical continuity, electrical effectiveness of insulators and coating, and evaluation of cathodic protection levels, installed at all insulated connections. Additional test/access facilities shall be installed at intermediate locations, either at intervals not greater than 200 feet, or at greater

intervals determined on an individual structure basis (see Section 10.2.5.4).

- Number and location of anodes and size of rectifier (if required) shall be determined on an individual structure basis.

10.2.6.2 Copper Piping

Buried copper pipe shall be electrically isolated from non-buried piping, such as that contained in a station structure, through use of an accessible insulating union installed where the piping enters through a wall or floor. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements. The insulator should be located inside the structure and not buried.

10.2.6.3 Gravity Flow Piping (Non-Pressured)

Corrugated steel piping shall be internally and externally coated with a sacrificial metallic coating and a protective organic coating.

Cast or ductile iron piping shall be designed and fabricated to include the following provisions:

- An internal mortar lining with a bituminous coating on ductile iron pipe only (not required for cast iron soil pipe)
- A bonded protective coating or unbonded dielectric encasement on the external surfaces in contact with soils (AWWA Standard C105)
- A bituminous mastic coating on the external surfaces of pipe 6 inches on each side of a concrete/soil interface

Reinforced concrete non-pressure piping shall include the following provisions:

- Water/cement ratios meeting the minimum provisions of AWWA
- Maximum 250 ppm chloride concentration in the total concrete mix (mixing water, cement, admixture and aggregates)
- Use Type 1 cement, except as noted in Table 10-A.

TABLE 10-A- ACCEPTABLE CEMENT TYPE BASED ON SULFATE CONCENTRATIONS OF SOIL AND GROUNDWATER

Acceptable Cement Type	Percent Water Soluble Sulfate (As SO_4) In Soil Samples	Sulfate (as SO_4) in Groundwater (ppm)
Type I	0 to 0.10	0 to 150
Type II	0.10 to 0.20	150 to 1,000
Type V	Over 0.20	Over 1,000

10.2.6.4 Electrical Conduits

Buried metallic conduits shall include the following provisions:

- Galvanized steel with PVC or other coating acceptable for direct burial, including couplings and fittings. The PVC coating is not required when conduits are installed in concrete.
- Electrical continuity through use of standard threaded joints or bond wires installed across non-threaded joints.

10.2.6.5 Buried Concrete/Reinforced Concrete Structures

The design of cast-in-place concrete structures shall be based on the following provisions.

- Use Type I cement, except as noted in Table 10-A. Use of a concrete mix with a cement type not specifically listed in Table 10-A must be reviewed and approved by RTD. ASTM C 452-75 and American Concrete Institute (ACI) Publication SP-77 "Sulfate Resistance of Concrete" should be used as guidelines for evaluating the sulfate resistance of concrete mixes with non-standard cement types.
- Water/cement ratio and air entrainment admixture in accordance with specifications presented in the structural criteria to establish a dense, low permeability concrete. Refer to applicable sections of ACI 201.2R "Guide to Durable Concrete".
- Maximum chloride concentration of 250 ppm in the total mix (mixing water, aggregate, cement, and admixtures). The concrete mix should be such that the water soluble and acid soluble chloride concentrations, at the concrete/reinforcing steel interface, do not exceed 0.15

and 0.2% by weight of cement, respectively, over the life of the structure. Refer to applicable sections of ACI 222R "Corrosion of Metals in Concrete".

- Concrete cover over reinforcing steel shall comply with ACI codes and provide a minimum of 2 inches of cover on the soil/rock side of reinforcement when pouring within a form and a minimum of 3 inches of cover when pouring directly against soil/rock.
- The need for additional measures, as a result of localized special conditions, shall be determined on an individual basis. Additional measures may include application of protective coating to concrete, reinforcing steel, or both.

Precast standardized facilities, such as vaults and manholes, must be reviewed on an individual basis to determine alternative criteria when they cannot be practically modified to meet some or all of the provisions specified herein.

Precast segmented concrete ring construction shall meet the requirements of this Section or be reviewed on an individual basis to determine alternative criteria when they cannot be practically modified to meet some or all of the provisions specified.

Below Grade Shotcrete

- Below grade shotcrete used for permanent support shall be in accordance with ACI 506.2 and applicable provisions specified in this Section. In the case of conflicting specifications, the more rigid or conservative specification shall be applicable.
- No special corrosion control measures are required for shotcrete applications, which are not considered as providing permanent support.

10.2.6.6 Support Pilings

The following is applicable only to support piling systems, which are to provide permanent support. Pilings used for temporary support do not require corrosion control provisions.

Designs based on the use of metallic supports exposed to the environment, such as H or soldier piles, shall include the use of a barrier coating. The need for special measures, such as cathodic protection, shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics, and the degree of anticipated structural deterioration caused by corrosion.

Reinforced concrete piling, including fabrications with prestressed members, shall be designed to meet the following minimum criteria:

- Water/cement ratio and cement types in accordance with Section 10.2.6.5.
- Chloride restrictions for concrete with non-prestressed members shall be in accordance with Section 10.2.6.5.
- Chloride restrictions for concrete with prestressed members shall be in accordance with Section 10.2.6.5, with exception that the concrete mix should be such that the water soluble and acid soluble chloride concentrations, at the concrete/prestressed steel interface, do not exceed 0.06 and 0.08 percent by weight of cement, respectively, over the life of the structure. Refer to ACI 222R "Corrosion of Metals in Concrete".
- A minimum of 3 inches of concrete cover over the outermost reinforcing steel, including prestressing wires, if present.

Concrete-filled steel cylinder columns, where the steel is an integral part of the load bearing characteristics of the support structure, shall be designed considering the need for special measures, such as increased cylinder wall thickness, external coating system, and/or cathodic protection. The design shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics and the degree of anticipated structural deterioration caused by corrosion. Chloride restrictions shall be in accordance with Section 10.2.6.5.

10.2.6.7 Reinforced Concrete Retaining Walls

Cast-in-place concrete retaining walls shall be in accordance with the requirements in Section 10.2.6.5.

Modular-type retaining walls with restraining devices or reinforcing strips placed beneath the LRT tracks shall meet the requirements in Section 10.2.6.5, FHWA Publication No. FHWA-SA-96-072, and require special consideration for stray current mitigation due to the location of critical structural components. Designers must provide for stray current and soil corrosion control for modular retaining walls with structural support components beneath the LRT tracks.

Modular-type retaining walls that do not place critical structural components beneath the tracks shall meet the requirements in Section 10.2.6 5, FHWA Publication No. FHWA-SA-96-072, and the following or be reviewed on an individual basis to determine alternative criteria when they can not practically modified to meet some or all of the provisions specified below.

- Embedded and buried steel reinforcing members of the modules should be constructed without special provisions for establishing electrical continuity.
- Steel reinforcing strips of adjacent modules should not be electrically interconnected. The reinforcing strips should be coated with a fluidized bed epoxy resin system or coal tar epoxy system.
- Tie-strips should be coated with a fluidized bed epoxy resin system or coal tar epoxy system prior to module construction.
- The tie-strips should not make electrical contact to the reinforcement steel in each module. A minimum 1 inch separation should be maintained.
- Longitudinal reinforcing steel within precast concrete parapets and cast-in-place junction slabs should not be made electrically continuous.

Pre-stressed/post-tensioned concrete cylinder pressure pipe shall not be designed for use in the vicinity of the LRT tracks or substations without review on an individual basis to determine alternate materials of construction. If these types of piping are used, the following items shall be addressed in the design.

- Possibility of hydrogen embrittlement of highly stressed steel components
- Provisions for electrical continuity within the manufactured pipe
- Provisions for electrical continuity of mechanical fittings and pipe joints
- Provisions for monitoring stray currents and hydrogen over voltages
- Provisions for reducing stray currents through the use of dielectric coatings or encasements
- Possible consequences of a failure of the pipe

10.3.0 STRAY CURRENT CORROSION CONTROL

This section provides criteria for designs to minimize the corrosive effect of stray earth traction currents from transit operations on transit structures and adjacent structures owned by others.

Stray current control shall reduce or limit the level of stray currents at the source, under normal operating conditions, rather than trying to mitigate the corresponding effects (possibly detrimental), which may otherwise occur on transit facilities and other underground structures. The basic requirements for stray current control are as follows:

- Operate the mainline system with no direct or indirect electrical connections between the positive and negative traction power distribution circuits and ground.
- Design the traction power system and trackwork to minimize stray earth currents during normal revenue operations.

10.3.1 Traction Power System

Traction power supply system shall be designed as a dedicated system, providing power solely to the light rail line. Joint use of traction power facilities, except for common civil structures, is not permitted. Individual traction power supply system for the light rail line shall be designed with two electrically isolated, independent subsystems for mainline and shop.

10.3.1.1 Traction Power Substations (Mainline)

Traction power substations shall be spaced at intervals such that maximum track-to-earth potentials do not exceed 50 volts during normal operations.

Substations shall be provided with stray current facilities to allow the connection of the negative bus to the station ground mat through a relay (normally open) and a current monitoring shunt. The test facility should be implemented to allow for periodic monitoring of the stray current return to identify changing conditions associated with the track-to-earth resistance.

Substations shall be provided remote monitoring systems to record the negative bus-to-earth potential, negative return shunt and the stray current return circuit. The remote monitoring system shall consist of either a stand-alone data acquisition module and communications package or SCADA interface.

Provisions shall be included to monitor track-to-earth potentials on a continuous basis at intervals not greater than 3.0 miles. Monitoring facilities shall be located at traction power substations and at intermediate locations, such as passenger stations, to maintain the recommended spacing. Permanently installed recorders or provisions for connection to the SCADA system shall be considered.

Space should be provided in each substation for future installation of stray current mitigation drainage devices. Additional requirements for this area are as follows:

- The designated area should have direct access to the DC negative bus or have access through a 3 inch PVC conduit or cable run. Installation of a separate drainage bus would be a preferred alternative. A suitable drainage bus would be a copper plate 6 inches high, 24 inches wide, and 1/2 inch thick, with two 250 MCM cables connected between the copper plate and DC negative bus.
- The drainage bus must be electrically isolated from other grounded facilities in the substation.
- Four 3 inch PVC conduit stubouts from the area to a manhole or weathertight enclosure conveniently located outside the substation.
- The dedicated area inside the substation should have easy access for test personnel.

10.3.1.2 Positive Distribution System

Positive distribution system shall be normally operated as an electrically continuous bus, with no breaks, except during emergency or fault conditions. Intentional electrical segregation of mainline, yard and shop positive distribution systems is the only type of segregation permitted.

Overhead contact systems (OCS), consisting primarily of support poles, the contact wire and, where applicable, the messenger wire, shall be designed to meet the following minimum requirements and include the following minimum provisions:

- A maximum leakage current to ground of 2.5 milliamperes per mile of single track OCS with 2,500 volts DC applied between the OCS and ground.
- Discrete grounding of individual at-grade support poles, in lieu of interconnecting poles to each other or to a common ground electrode system. Establish electrical continuity of reinforcing steel in OCS support poles as described in Section 10.3.1.3 and electrically connect support poles to the foundation reinforcing steel.
- Common grounding of support poles on aerial structures through electrical connection to either bonded (welded) reinforcing steel in the deck or to each other and a common ground electrode system, when present. Establish electrical connections as described in Section 10.3.2.2 for OCS poles on aerial structures.

10.3.1.3 Mainline Negative Return System

Running Rails

The mainline running rails, including special trackwork, grade crossings and all ancillary system connections, shall be designed to have a minimum, uniformly distributed, in-service track-to-earth resistance as determined by the following requirements:

- The use of a computerized simulation of the traction power system to determine the level of stray current generated at a minimum of two levels of track-to-earth resistance. The simulation shall be performed with train operations at each passenger station along the ROW and any special conditions as noted by the traction power designer.
- The use of soil layer resistivity (ASTM G-57) along the entire ROW at a maximum spacing of 500-feet between measurement locations and to a minimum depth of 15-feet. This information shall be incorporated into the stray current simulation to determine the earth potential gradients anticipated along the ROW.
- Under no circumstances shall the allowable track-to-earth resistance level be less than the following:
  - o Special trackwork and concrete tie & ballast track: 250 ohm- 1000-feet (4 rails)
  - o Direct fixation track: 250 ohm-1000-feet (4 rails)

The criteria shall be met through the use of appropriately designed insulating track fastening devices, such as insulated tie plates, insulated rail clips, direct fixation fasteners, rail fastener coating or other approved methods.

Ballasted track construction shall meet the following minimum provisions:

- Use of a hard rock, non-porous, well drained ballast material free of dirt or debris.

A minimum 1 inch clearance between the ballast material and all metallic surfaces of the rail and metallic track components in electrical contact with the rail.

Mainline track shall be electrically insulated from the shop tracks by use of insulated rail joints in both rails of each track. Location of the insulating joints shall be chosen to reduce the possibility of a vehicle bridging the insulator for a time period longer than that required to move a vehicle into or out of the shop.

Mainline track shall be electrically insulated from foreign railroad connections (sidings) by use of insulating rail joints. Location of the insulating joints shall be chosen to reduce the possibility of a vehicle bridging the insulator(s) for a time period larger than required to move onto or off of mainline.

Special trackwork shall include the following: embedded trackwork at stations, embedded crosswalks, turnouts, crossovers, grade crossings. The special trackwork shall meet the following minimum provisions:

- Electrical isolation shall be provided between the rail and all embedment materials including, grade crossings, exhibiting a minimum volume resistivity of 1×10^{14} Ohm-Centimeters as measured in accordance with ASTM D-257.
- The surface profile of the finished grade adjacent to the rails shall be sloped away from the rail to allow for drainage and reduced accumulation of debris.
- The surface profile of the finished grade within 6-inches of the rail shall be a smooth finish to support maintenance and cleaning.

Ancillary Systems

Switch machines, signaling devices, train communication systems, and other devices or systems which may contact the rails shall be electrically isolated from earth. The criteria shall be met through the use of dielectric materials electrically separating the devices/systems from earth, such that the criterion given in Section 10.3.1.3 is met.

Electrical Continuity

The running rails shall be constructed as an electrically continuous power distribution circuit through use of either rail joint bonds, impedance bonds, continuously welded rail or a combination of the three, except for the use of insulated rail joints at the locations noted in Sections 10.3.1.3 and 10.3.1.4.

10.3.1.4 Maintenance Shop

Shop traction power shall be provided by a separate dedicated DC power supply electrically segregated in both the positive and negative DC power circuits from the yard traction power system and the mainline system.

Shop track shall be electrically connected to the shop building and shop grounding system.

Other electrically grounded track, such as blowdown pit tracks, car wash tracks and interconnecting switching tracks between these facilities shall be electrically insulated from the yard tracks and powered from the shop traction power supply.

10.3.1.5 Water Drainage

Below grade sections shall be designed to prevent water from dropping or running onto the running rails and rail appurtenances and shall be designed to prevent the accumulation of freestanding water.

Water drainage systems for sections exposed to the environment shall be designed to prevent water accumulation from contacting the rails and rail appurtenances.

10.3.2 Transit Fixed Facilities

10.3.2.1 Aerial Trackway Structures

<u>Column and Bearing Assemblies, Direct Fixation</u>

This section applies to aerial structures and bridges that use a column and bearing assembly that can be electrically insulated from deck or girder reinforcing steel and will have insulated trackwork construction.

- Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.
- Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges and at abutments. Connect collector bars installed on each side of a break with a minimum of two cables.
- Provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test

wires from the collector bars and ground electrode system, if present.

- Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Column and Bearing Assemblies, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 10^{10} (10 billion) ohm-centimeters.
- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location, and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and

washers for anchor bolts and dielectric coatings on selected components.

- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

Bents and Girders, Direct Fixation

This section applies to aerial structures that use bent type supports with reinforcing steel extending into the deck/girders.

Girders can be pre or post tensioned. This type of construction precludes the electrical isolation of deck/girder steel from bent/column steel. Ground electrode systems are not required for these types of structures.

Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.

Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at bents and on each side of breaks in longitudinal reinforcing steel, such as at expansion joints, hinges and at abutments (deck side only). Connect collector bars installed on each side of a break with a minimum of two bond cables.

- Provide electrical continuity of all column/bent steel by welding appropriate reinforcing to at least two vertical column bars. Make these connections to each of the two vertical bars at the top and bottom of the column/bent.
- Electrically interconnect column/bent steel to deck/girder steel by welding at least two vertical column bars to collector bars installed at bents.
- Electrically interconnect column/bent steel to footing steel when column/bent steel penetrates the footing. Weld at least two vertical column/bent bars to footing reinforcing steel.
- Electrically interconnect pre or post tensioned cables to continuous longitudinal reinforcing steel by welding a cable between each anchor plate and the longitudinal reinforcing steel.
- Provide test facilities at each hinge and expansion joint and at every Provide other column/bent, starting with the first

column/bent from an abutment. Test facilities at hinges and expansion joints will house bonding cables from adjacent collector bars on each side of the hinge/joint. Facilities at columns/bents will house two wires from vertical column/bent steel and from the collector bar at the top of the bent.

- All copper to steel weld locations (bond cables) shall require coating with cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Bents and Girders, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction.

- Provide the same features as described in the bullet points above for direct fixation and the following additional item.
- Provide a waterproofing, electrically insulating membrane over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 10^{10} (10 billion) ohm-centimeters.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

Concrete Deck/Exposed Steel, Direct Fixation

This section applies to bridge structures that use a reinforced concrete deck with exposed steel superstructure and will have insulated trackwork construction. This type of construction precludes the electrical insulation of deck reinforcing steel from superstructure steel.

- Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.
- Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges, and abutments. Connect collector

bars installed on each side of a break with a minimum of two cables.

- Provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.
- If the total structure length exceeds 250 feet, provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector bars and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of electrical continuity is the use of epoxy coated reinforcing steel. RTD approval is required prior to the use of the alternate system.

Concrete Deck/Exposed Steel, Tie and Ballast

This section covers the same type of aerial structures covered above, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 10^{10} (10 billion) ohm-centimeters.

- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves and washers for anchor bolts, and dielectric coatings on selected components.
- If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

Existing Concrete Deck Structures, Tie and Ballast

This section applies to existing aerial structures used for LRT installation. Stay current corrosion control for existing aerial type structures shall be addressed by limiting earth current levels at the source (running rails). Meeting the criteria established in Section 10.3.1 and those items indicated below will provide the primary stray current control for these facilities.

- Provide a waterproofing, electrically insulating membrane (with protection board) over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 10^{10} (10 billion) ohm-centimeters.
- Provide an electrically continuous collector grid, such as steel welded wire fabric, directly on top of the protection board over the waterproofing membrane and beneath the ballast. The collector grid shall extend the full width of the trackway.
- Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location and earth resistance of the ground electrode system must be determined on an individual structure basis.
- Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector grid and ground electrode system, if present.
- An alternate method to the use of insulating membrane (with protection board) is the use of spray applied polyurea. RTD approval is required prior to the use of the alternate system.

10.3.2.2 Overhead Contact System (OCS) Pole Foundation Grounding

All metallic components, inclusive of the pole baseplate, that will be partially embedded or come in contact with concrete surfaces shall be coated with a sacrificial or barrier coating. The sacrificial coating shall be applied to the entire component. The barrier coating shall extend a minimum of 6 inches into the concrete and a minimum of ½ inch above the surface of the concrete.

At-Grade OCS Support Poles

- Electrical continuity of reinforcing steel within support pole foundations shall be established to provide an adequate means for dissipating any leakage current from the contact wire and, where applicable, the messenger wire. The following minimum provisions shall be included with design:
    - The outermost layer of vertical reinforcing steel within the concrete foundation shall be tack welded at all intermediate vertical lap joints and to reinforcing bar

collector rings (two) installed at the top and bottom of the reinforcing bar cage.
    - A copper cable shall be connected between the base of the catenary support pole and the foundation reinforcing steel. The cable shall be thermite welded or brazed to the support pole and routed in such a manner that it will not be susceptible to damage during construction or after installation is complete.
    - The copper cable shall be sized based upon anticipated fault current and fault clearing time.
- Different electrical continuity requirements may be necessary depending on the actual reinforcing configuration for the support pole foundations.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.

OCS Poles on Aerial Structures. OCS poles located on aerial structures shall include either of the following minimum set of provisions, depending on the type of aerial structure.

- Where the aerial structure includes welded deck reinforcing steel connected to a ground electrode system, electrically interconnect the OCS support poles on the structure and connect these poles to the ground electrode system.
    - Cabling used to interconnect the poles and the ground electrode system shall be sized based upon anticipated fault current and fault clearing time.
    - The cabling shall be routed in conduit and terminated in junction boxes or test cabinets that also house wires from the deck reinforcing steel and the ground electrode system.
    - Cabling shall be designed to allow for connection of interconnected OCS poles along the aerial structure to all ground electrode systems installed with a particular aerial structure.
- Where the aerial structure has welded deck reinforcing steel but does not include a ground electrode system, electrically connect the OCS support poles to the welded deck reinforcing steel.
    - Provide a copper cable from each OCS support pole to the deck reinforcing steel. The copper cable shall be sized based upon anticipated fault current and fault clearing time.

- Thermite weld or braze the cable to the OCS support pole and preferably to the nearest transverse collector bar installed in the aerial structure deck.
  - Where it is not practical to connect an OCS pole directly to a transverse collector bar, because of excessive distance or other factors, connect the pole to a local transverse reinforcing bar using a copper cable and weld the transverse reinforcing bar to at least three upper layer longitudinal reinforcing bars in the deck.
- All copper to steel weld locations (bond cables) shall require coating with a cold applied, fast drying mastic consisting of bituminous resins and solvents.

10.3.2.3 Utility Structures

All piping and conduit shall be non-metallic, unless metallic facilities are required for specific engineering purposes. There are no special provisions required if nonmetallic materials are used.

<u>Metallic Facilities (System wide)</u>

- Pressure or non-pressure piping exposed within crawl spaces or embedded in concrete inverts shall not require special provisions.
- Pressure piping that penetrates station walls shall be electrically insulated from the external piping to which it connects, wall reinforcing steel, and from watertight wall sleeves.

<u>Metallic Facilities (Shop)</u>

All reinforcing steel, structural steel, and rails within the shop building shall be electrically connected to a common grounding grid.

- All pressure piping within the shop building or perimeter of the shop foundation or foundation slab shall have the following minimum provisions:
  - Designed to be run above or within the foundation slab. Below slab installations must be reviewed on an individual basis to determine the need for special measures.
  - Electrical insulation from interconnecting pressure piping located outside the shop building or perimeter of the foundation/foundation slab. Locate insulating devices above grade or inside the building, in lieu of burying directly.

- Electrical insulation from watertight wall/floor sleeves and wall reinforcement.
- Electrical connection to the shop common ground grid at sufficient locations, such that there will be only negligible potential differences between the piping and grounding network during fault and normal conditions.

Metallic Facilities (Yard)

- All buried pressurized piping shall meet the criteria of Section 10.2.0 and include the following minimum provisions:
  - Electrical continuity as described in Section 10.2.5.3.
  - Electrical insulation from interconnecting non-transit facilities and possibly additional insulation to establish discrete electrical units.
  - Test/access facilities installed at all insulated connections and at intermediate locations as determined during final design.
- Metallic fencing surrounding the yard perimeter shall be made electrically continuous and grounded.

10.3.3 Facilities Owned by Others

10.3.3.1 Replacement/Relocated Facilities

Corrosion control requirements for buried utilities installed by a utility owner/operator as part of transit construction shall be the responsibility of the individual utility owner/operator. Minimum stray current corrosion control criteria, when guidance is requested by the utility owner/operator, shall be in accordance with Section 10.3.3.2.

Relocated or replaced utilities, installed by transit contractors as part of contractual agreement between the transit agency and the utility, shall be installed in accordance with the utility owner specifications and shall include the following minimum provisions. These provisions are applicable to ferrous and reinforced concrete pressure piping. Other materials and structures will require individual review.

- Electrical continuity through the installation of insulated copper wires across all mechanical joints for which electrical continuity cannot be assured and shall be evaluated on a case by case basis.

- The requirement for electrical access to the utility structure via test facilities shall be evaluated on a case by case basis.
- The need for additional measures, such as electrical isolation, application of a protective coating system, installation of cathodic protection or any combination of the preceding, shall be based on the characteristics of the specific structure and to not adversely effect the existing performance within the environment.

10.3.3.2 Existing Utility Structures

The need for stray current monitoring facilities shall be jointly determined by RTD and the utility operators. If utilities require assistance, the following minimum provisions shall be suggested.

- Test facilities may be installed at select locations for the purpose of evaluating stray earth current effects during start-up and revenue operations. Guidelines for location of test facilities shall be as follows:
    - At all utility crossings with the system, and on structures that are within 300 feet and parallel to the system ROW.
    - At locations on specific utility structures that are within 300 feet of the system traction power substations.

10.3.3.3 Existing Bridge Structures

Stray current corrosion control for existing bridge structures shall be addressed by limiting earth current levels at the source (running rails). Meeting the criteria established in Sections 10.3.1.1, 10.3.1.2, 10.3.1.3, and 10.3.2.2 will provide the primary stray current control for these facilities.

10.4.0 MISCELLANEOUS CORROSION CONTROL CONSIDERATIONS (COATINGS)

Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied.

Coatings shall be able to demonstrate satisfactory gloss retention, color retention and resistance to chalking over their minimum life expectancies.

Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

10.4.1 Metallic-Sacrificial Coatings

Acceptable coatings for carbon and alloy steels for use in tunnels, crawlspaces, vaults or above grade are as follows:

- Zinc (hot-dip galvanizing [2 oz. per sq ft] or flame sprayed)
- Aluminum (hot-dip galvanizing [2 mil thickness] or flame sprayed)
- Aluminum-zinc
- Cadmium and electroplated zinc (sheltered areas only)
- Inorganic zinc (as a primer)

10.4.2 Organic Coatings

Organic coating systems shall consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s) and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, are as follows:

- Aliphatic polyurethanes
- Vinyl copolymers
- Fusion-bonded epoxy polyesters, polyethylenes and nylons
- Acrylics, where not exposed to direct sunlight
- Alkyds, where not exposed to direct sunlight
- Epoxy as a primer where exposed to the atmosphere or as the complete system where sheltered from sunlight

10.4.3 Conversion Coatings

Conversion coatings, such as phosphate and chromate coatings shall be used as pretreatments only for further application of organic coatings.

10.4.4 Ceramic-Metallic Coatings (Cermets)

This hybrid-type coating system is acceptable for use on metal panels and fastening hardware.

10.4.5 Sealants

Seal all crevices with a polysulfide, polyurethane or silicone sealant.

10.4.6 Barrier Coating System

Use one of the following barrier coating systems where corrosion protection is needed but appearance is not a primary concern:

- Near white blast surface according to SSPC-SP 10. Follow with a three coat epoxy system.

- Commercial blast surface according to SSPC-SP 6. Follow with a two coat inorganic zinc and high build epoxy system.
- Near white blast surface according to SSPC-SP 10. Follow with a three coat epoxy zinc, high build epoxy system.
- Apply all coatings according to manufacturer's specifications.

Use one of the following barrier coating systems where corrosion protection and good appearance are needed.

- Near white blast surface according to SSPC-SP 10. Follow with a three coat inorganic zinc, high build epoxy, and polyester urethane system.
- Near white blast surface according to SSPC-SP 10. Follow with a three coat vinyl system.
- Commercial blast surface according to SSPC-SP 6. Follow with a three coat epoxy zinc, high build epoxy, and polyester urethane system.
- Commercial blast surface according to SSPC-SP 6. Follow with a three coat epoxy zinc, high build epoxy, and acrylic urethane system.
- Apply all coating according to manufacturer's specifications.

10.5.0 QUALITY CONTROL TESTING

10.5.1 Electric Continuity

The electrical continuity of reinforcement and utility structures is required by the design criteria. The requirements for determining the proper electrical characteristics of these structures shall be incorporated into the design of the structure. The following paragraphs establish the guidelines for developing the quality control test procedures for electrical continuity.

- All structures that are to be made electrically continuous shall be tested for electrical continuity, compared to theoretically based criteria, and meet or exceed the accepted criteria.
- Incorporate a specific set of test procedures and acceptance criteria to be followed for the electrical continuity testing into the project specifications.
- Incorporate selection criteria for the test entities to perform the quality control testing including the qualifications of the agency, personnel requirements and equipment requirements. A minimum of 5 years of experience performing this work is required.
- Incorporate specific reporting requirements for the electrical continuity testing.

10.5.2 Cathodic Protection

The application of cathodic protection on the underground utility structures is required by the design criteria. The requirements for determining proper application of cathodic protection include the verification of electrical continuity (Section 10.5.1) and verification of cathodic protection compliance with industry standards (NACE International). The following paragraphs establish the guidelines for developing the quality control test procedures for verification of proper cathodic protection levels.

- All structures that are required to have cathodic protection shall be tested in accordance with NACE International RP0169.
- A test plan shall be submitted by the testing agency to be approved by the RTD.
- Incorporate specific reporting requirements for the cathodic protection testing.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 5 years of experience performing this work is required.

10.5.3 Coatings

The quality control measures required for the verification of proper application and handling vary greatly depending on the coating type. The following guidelines establish general procedures for the quality control testing.

- Coatings shall be tested in accordance with the manufacturer's recommendations and in accordance with NACE International Recommended Practices.
- A quality control test plan shall be required for the application and testing of all coated surfaces. The test plan shall address the allowable coating thickness measurements, adhesion requirements, hold points for test, test procedures to be used in the quality control process, and the reporting and acceptance requirements for each specific type of coating system being used.
- All shop coated surfaces shall first be tested, witnessed, and accepted at the coating facility. Additional field quality control hold points shall be required.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 10 years of experience performing this work is required.

10.5.4 Track-to-Earth Resistance Testing

The track-to-earth resistance of the running rails is the primary barrier for the control of stray current discharge from the negative system. The requirements for conducting this testing are as follows:

- Incorporate a specific set of test procedures and acceptance criteria to be followed for the track-to-earth testing into the project specifications.
- Incorporate selection criteria for the testing entities to perform the quality control testing including the qualifications of the agency, personnel requirements, and equipment requirements. A minimum of 10 years of experience performing this work is required.
- Incorporate specific reporting requirements for the track-to-earth resistance testing.

SECTION 11 – OPERATIONS FACILITY

Due to the unique nature of LRT operations facilities, each facility will be designed separately. Depending on the site, functions, and operational requirements of each facility, an individual program must be created to meet the needs of RTD operational requirements.

SECTION 12 - FARE COLLECTION EQUIPMENT

SECTION 12 - FARE COLLECTION EQUIPMENT

12.0.0 GENERAL

The Fare Collection System shall consist of Ticket Vending Machines (TVMs), a Central Data Collection & Information System (CDCIS), Stand Alone Validators (SAVs), spare parts, special tools, test equipment, documentation, training, technical assistance and warranty as part of the System. The TVMs and SAVs shall be designed for outdoor installation in an un-sheltered environment, including precipitation, sun glare, heat and solar loading. Any equipment supplied and/or installed, that is not housed in an environmentally controlled enclosure shall be rated to operate in the environmental conditions of the Denver Metro area.

It is required that the TVMs and SAVs (Fare Collection Equipment) shall be service proven. The System shall be of materials that are new and free of defects and which conform to the requirements of the Technical Specification.

12.1.0 AUTOMATED FARE COLLECTION

- All platforms shall have provisions for free-standing Ticket Vending Machines (TVMs) and future Ticket Validators.
- RTD shall determine the number of initial machines and future provisions.
- Weather protection shall be provided for each machine unless otherwise approved by RTD.
- All TVMs shall be protected from direct sunlight onto the screen.

12.2.0 TICKET VENDING MACHINES

In general, TVMs shall be designed to sell tickets and passes to RTD's customers by coins, bills or credit/debit cards. TVMs shall be capable of printing and issuing different tickets, passes, mag cards, smart cards, RFID cards or combination thereof from within the same housing. The design of the TVMs shall be based on simple, clear and reliable construction, and modular components to make them easy to use and maintain.

Each TVM shall be equipped to:

- Accept U.S. nickel ($.05), dime ($.10), quarter ($.25), and post-1978 dollar ($1.00) coins; RTD 0.0650 Token; U.S. one dollar, five dollar, ten dollar, twenty dollar, and fifty dollar bills; and provide for future acceptance of credit/debit cards as payment;
- Provide change in the fewest number of coins as required;
- Respond to customer's choice of action;
- Issue tickets and passes;
- Register the number of media of each type and price range issued and total value of fare media sold;
- Indicate malfunctions of the unit; and

- Include complete on-line TVM network capability with remote TVM status monitoring, automatic polling for sales information, a complete audit and accounting system, ability to remotely command TVMs to reset and self-diagnose, ability to remotely modify operating parameters such as fare tables and ticket print layouts, and optionally process all credit/debit card authorizations.

12.3.0 MODULARITY

Each TVM shall be a self-contained machine, complete with its own cabinet and mounting stand or base, and having integral light fixtures to illuminate the control face. Each TVM shall consist of a bill processing unit, coin processing unit, credit card processing unit (optional), debit card PIN pad (optional), display and information unit, change maker, ticket and pass issuing unit, key pad and function keys, power supply, and processing and control unit, all located within a self-contained unit. Each of the basic functions within the machine shall be performed by modular components which readily permit field replacement of inoperative modules to return the machine to service in minimal time. Control and power connections shall be made via plug-in connections. Modules shall not be directly hard wired together and/or into the TVMs. The individual module shall be fixed in the unitized frame with fast latching devices and be secured by locks against unauthorized removal, where required.

12.4.0 CODE REQUIREMENTS

TVMs shall be designed to comply with all applicable local or national design codes, ordinances, and standards existing at the time of procurement. Listed below are the principal applicable codes:

- National Electric Safety Code, American National Standard C2, latest edition
- National Electric Code, National Fire Protection Association ANSI/NFPA 70, latest edition
- Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG), latest edition
- Underwriters Laboratories UL-751, “Vending Machines,” latest edition
- International Electrotechnical Commission standard 529 (IEC529)

12.5.0 DESIGN LIFE

The entire TVM shall be designed for a minimum service life of 10 years of normal operation in the Denver metropolitan area. All equipment shall be designed to operate seven days per week, twenty-four hours per day.

12.6.0 OPERATING ENVIRONMENT REQUIREMENTS

The TVMs shall be capable of operating without shelter over an ambient temperature range of -15°F to 110°F. In the summer, direct sunlight conditions will cause cabinet temperature to rise considerably above ambient, in excess of 155°F. All equipment shall be capable of operating in relative humidity from 30% to 70% over the ambient temperature range given above. This shall include periods of condensation and wind-driven rain, freezing rain and snow. Equipment enclosures shall comply with International Electrotechnical Commission standard 529 (IEC529) level IP34 or equivalent.

12.7.0 ELECTRICAL

The TVMs shall be designed to accept standard 3-wire, 115 volt, single phase, 60 Hz power. Each machine shall be powered by a separate 20-amp circuit protected by circuit breaker. In addition, each TVM shall provide its own circuit protection.

All equipment shall be designed to tolerate 10% fluctuation in line voltage without any damage or service interruption. Breaks in the voltage (below 10% of the source voltage) or supply interruptions shall cause an orderly shutdown of the TVM.

Voltage transient suppression shall be provided where necessary. Each TVM shall include a protection system capable of withstanding transients of 3.0 kV peak pulse with a total energy of 1000 joules without damage, improper operation or shutdown. The functional status of any such surge and transient suppressor circuitry must be visible at all times when the outer door is open.

12.8.0 PASSENGER ACCESS

All functional controls, coin slots, bill slots, ticket slots and ticket and coin return bins shall be compliant with current Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities (ADAAG).

The TVM display shall use dark characters on a light background. Characters shall be at least 0.75 inches tall and be of sufficient contrast to make them easily readable in all ambient light conditions, including total darkness and direct sunlight. The TVM display shall utilize technology suitable for the environment and shall provide a viewing angle of least 45° from perpendicular in all directions. High-contrast raised lettering at least 0.625 inches high shall be used to label all controls, pushbuttons, coin and bill slots, and the ticket/coin return bin. All such labels shall also utilize standard Braille characters.

The TVM shall, on demand of the patron, provide audible voice instructions. The voice system shall utilize either stored human speech or synthesized speech using AT&T Natural Voices Software or approved equal. The messages shall be stored in digital form for operation and be modifiable by RTD. Context-sensitive voice messages shall provide, in audio form, the information shown on the TVM display or otherwise conveyed by the TVM. RTD will have final say in how the TVM looks and operates.

12.9.0 CONSTRUCTION/EQUIPMENT ENCLOSURE

The TVMs shall be designed to operate in unsheltered locations.

The overall dimension of an installed TVM shall not exceed 80 inches (height) by 38 inches (width) by 25 inches (depth). The equipment enclosure for the TVMs shall be of stainless steel with an unpainted random-orbital finish. The cabinet shall have a leveling base which shall accommodate the station platform surface slope. Mounting shall be by means of stainless steel bolts imbedded in concrete.

Frames shall be provided for graphic panels on the front of the TVM as required for explaining the operation of the TVM. The top of the TVM shall slant at least 5° downward and to the rear of the TVM to prevent any accumulation of rain. The interior of the equipment shall be designed to allow easy and safe access to service equipment and sub-assemblies.

12.10.0 MAINTAINABILITY AND ACCESSIBILITY

In the design of the TVMs, greatest emphasis shall be put on reliable operation of all components and equipment over their economic life, and to the minimization and simplification of scheduled and unscheduled maintenance tasks.

Equipment shall be modular in design to permit rapid field replacement of malfunctioning modules.

These units shall combine the advantages of relatively simple mounting and accessibility for maintenance. Adequate space shall be available to fit keys; to grasp, lift and turn internal components; and to remove and replace units, components, connections, and ticket stock. The weight of the units that must be lifted during servicing, except coin and bill vaults, and coin storage units when full, shall not exceed 37 pounds. Guide rails shall be provided to facilitate the removal of the modules. Adequate space for the use of tools shall be available as required. For ease of service, all electrical connections between components and sub-assemblies shall be established by means of coupling to allow rapid removal of a component and/or sub-assembly from the TVM.

12.11.0 SAFETY

The interior of the TVM shall be similarly free of sharp edges or other hazards that may cause injury to maintenance personnel. Particular attention shall be given to protecting blind persons who may explore the exterior surface with their fingers.

The exterior panels and control shall be grounded to prevent electrical leakage or static charge.

12.12.0 SECURITY

Access to the interior of the equipment enclosures and to the cash vaults shall be restricted on a "need to gain access" basis as approved by RTD.

The arrangement of modular mechanical and electrical components and money containers shall be such that normal maintenance, including change-out of defective modules, shall neither require removal of, nor access into, the coin and bill containers.

TVM location shall be coordinated with CCTV camera angles to ensure the TVM is viewed by a camera.

12.13.0 AESTHETIC REQUIREMENTS

TVMs shall be designed with all controls and customer interface display and inputs on a common front face of the enclosure. Suitable graphics shall be provided explaining the operation of the TVM.

12.14.0 PROTECTION AGAINST VANDALISM AND BURGLARY

For protecting against vandalism and burglary for each TVM, the following requirements shall be met:

- All latches shall be secure and robust
- All external screws and hinges must be covered
- Security locks with profile catches must be used
- Locks must be drill resistant, mounted flush with the outside surface of the door
- The door must be locked with at least a three-point latching device with a bascule bolt and hook bar, or equivalent tools
- Overlapping doors must be constructed with a joining gap equal to or less than 2 mm
- Reinforcement must be provided at positions where there is danger of burglary
- The display screen must be protected by a fixed, transparent shield

Each TVM shall be equipped with a signaling and alarm system. TVMs shall be capable of surviving a kick or punch from a large adult acting in an irrational manner (acceleration pulses of 5 gravities peak value with approximate duration of 10 milliseconds along each of three mutually perpendicular axes) while the equipment is operating.

The signaling and alarm system shall be equipped with an electronic or mechanical siren capable of emitting a sound level of at least 110 dB(A) measured at a distance of three feet with the door open. This siren shall sound whenever unauthorized entry is detected or when severe impacts to the front door are detected.

An internal momentary contact switch, hidden inside the TVM but readily accessible, shall permit an authorized technician to trigger a "silent" alarm. When activated, this switch shall cause the TVM to notify the central computer system and/or SCADA, but not activate the siren.

12.15.0 CENTRAL DATA SYSTEM

All TVMs shall communicate over the most efficient communications medium available to a centrally located data system. The fare collection equipment shall report status, events, alarms, and other information when necessary. All fare collection equipment shall also be able to receive information from the central computer to update fare structures, ticket print layouts, patron display information, operating parameters, and to be remotely commanded to perform certain diagnostic exercises.

While the central data system will be installed in the revenue shops, remote workstations shall provide users access to the data for queries, report generation and status information.

One or more such workstations shall be at the maintenance facility.

12.15.1 Data Networking

Data communications shall be provided in a hierarchical network, with a central control computer at the top level, an Ethernet switch at the middle level, and the TVMs at the lowest level.

All TVMs shall be networked back to the central computer via Ethernet. RTD will make available one 10/100 Mbps Ethernet port at each station for communications over RTD's IP-based network between the station and the revenue shop.

Ethernet switches, cabling and connectors shall be provided by the Contractor to communicate between the TVMs and the RTD provided communications network. An SNMP capable, managed Ethernet switch shall be provided at the station with enough ports to accommodate twice the original number of TVMs.

All outdoor cabling shall be suitable for outdoor/wet installations. For cable runs greater than 75 meters fiber optic cabling and transceivers (suitable for the environmental conditions it is installed in) shall be provided. For shorter distances CAT 5 or 5e cabling is sufficient.

Five RU of rack space will be provided by RTD in the communications room for installation of the fare collection communications equipment.

12.15.2 Central Computer

The central computer shall be an IBM-compatible PC, suitably configured for the intended application. The computer shall be of a dual-server architecture, with the second server in a "hot" spare configuration.

To facilitate reduced maintenance costs the central computer shall be of the same manufacturer as used by RTD's corporate IT group.

12.15.3 Application Software

Application software shall permit the computer to simultaneously communicate with several stations, two or more users (on remote computers), and up to two financial clearing houses for credit/debit card authorizations should such an option be exercised. Application software shall utilize menu or icon-driven user interfaces. All access to application software shall be under strict password control.

12.15.4 Database Software

All transaction, event, sales, accounting, maintenance and other records shall be maintained in a commercially available relational database manager such as Ingress, Informix or Oracle. The database manager software shall be of the most recent version available at the time the system enters factory system testing.

12.15.5 Report Generation

The central computer system shall generate reports that shall enable RTD to analyze the fare collection system, revenues, trends, maintenance activities, security status and so on. All reports shall be available on demand, spanning any range of data stored (such as by date, station, TVM, ticket type, event type, etc.). Based on user selection, the computer system shall also generate reports automatically at programmed intervals (such as daily, weekly, monthly and quarterly).

In addition to those reports to be provided with the system, the computer system shall enable RTD to customize existing reports and create new reports using Structured Query Language (SQL) commands available from the relational database manager.

All reports shall be available locally on the computer screen, printed to any available printer, or on any other workstation networked to the central computer.

The system shall also provide line graphs, bar charts, pie charts and other common data presentation methods to represent summarized data.

12.15.6 System Status and Security Monitoring

The central computer system shall receive status information from the TVMs when by the unit. All event information shall be stored on the central computer and depending on the priority of the event, displayed on the central computer screen.

Alarm information, such as intrusion alarms, out of service conditions and other high priority events shall be displayed without delay regardless of other activities in progress on the computer system.

The central computer shall also periodically poll all stations for status, to insure that all station network interfaces (master TVM or station computer) are functioning properly.

The central control computer system shall maintain a current understanding of the complete system status and permit authorized workstation operators to view the status of all equipment by station and by individual component.

The abilities to place an individual TVM in service and out of service, cause a TVM to perform self-diagnostics, and reset the TVM shall also be provided from the central computer system.

The central computer system shall also monitor the status of connections to the clearinghouses for credit/debit card authorizations should such an option be exercised. In the event that all communication with the clearing house(s) is lost, the central computer shall inform the TVMs that credit card transactions are temporarily unavailable, and the TVMs shall act accordingly. Upon restoration of communication with the clearing house(s), the central computer shall so inform the TVMs.

12.15.7 Configuration Management

All configuration parameters of the TVMs shall be alterable remotely from the central computer system, including date and time, fare tables, security access codes, ticket printing formats, passenger display messages, in-service/out-of-service times, accepted types of credit/debit cards, etc.

12.16.0 SCADA INTERFACE

The TVMs shall report simple status and alarms conditions to RTD's SCADA system via dry contacts. The conditions and the responses are:

- TVM Intrusion Alarm (unauthorized entry) & (impact sensor activated)
- TVM/SAV Maintenance Alarm (inclusive of all maintenance alarms)
- TVM Revenue Service Alarm (inclusive of all revenue service)
- Silent Alarm. Activated (opened) whenever the silent alarm is initiated

The SCADA circuits shall be wired to the TVM relays so that any cable fault (such as intentional cutting the wire, forcible removal of the TVM or just a simple break in the cable) would be detected as an alarm. The TVM/SAV Maintenance Alarm should also be constantly powered (in the closed position) so that any loss of power will open the relay and trigger the alarm. In cases where there are multiple TVMs at a station, one TVM shall be designated as the Master TVM. The other TVMs shall have their SCADA contacts terminated in the Master TVM. The Master TVM will report to the SCADA system one master alarm per location.

SECTION 13 - LIGHT RAIL VEHICLE

SECTION 13 - LIGHT RAIL VEHICLE

13.1.0 GENERAL

This chapter describes the characteristics of the new RTD light rail vehicle (LRV). The new vehicle will be physically and functionally similar to the existing LRV, with changes and improvements as listed below. The designation “SD100/SD160", when used below, refers to the existing vehicles. The designation "LRV", "vehicle", "car", when used below, refers to the new vehicle.

The LRV will be operated on all tracks designated for light rail use of the RTD system and will be operated in-train with the SD100/SD160.

Refer to RTD document "Light Rail Vehicle Specifications, group III, June 30, 1997 Edition" for specification requirements for the SD100/SD160.

The following acronyms are used herein:

AWO Maximum empty vehicle operating weight: 97,000 lb

AW1 Full seated load of 77 persons (passengers plus operator), plus AWO: 108,858 lb

AW2 Standees at 4 persons per m^2 suitable standing space per passenger, 90 persons minimum, plus AW1: 122,718 lb

AW3 Standees at 6 persons per m^2 of suitable standing space per passenger, minimum 136 persons, plus AW1: 129,802 lb

AW4 Standees at 8 person per m^2 suitable standing space per passenger, minimum 180 persons, plus AW1: 136,578 lb

13.1.1 Vehicle Type

The LRV is a single-articulated, six-axle, standard floor low entry car. There are eight passenger doorways, four per side directly across from one another.

Each end of the car has a fully equipped operator's position. Vehicles are capable of multiple unit operation in consists of up to four cars. The anticipated service life of the vehicle is 30 years.

13.1.2 Seating Arrangement

The vehicle will have a minimum of 64 passenger seats, including those designated as flip-up for disabled patrons.

The predominant seating arrangement will be stainless steel pedestals or cantilevered, transverse back-to-back seats. Flip-up seats may be arranged longitudinally.

13.1.3 Elderly and ADA Accessibility

The LRVs, in conjunction with platform configuration, shall comply with the ADA Accessibility Guidelines.

13.1.4 Compatibility

The LRV will be fully compatible with all aspects of the RTD system, including the SD100/SD160, maintenance facilities, clearances, ADA accessibility and operating requirements. It is expected that any LRV that is compatible with the SD100/SD160 must also be compatible with other LRVs that RTD uses in service that may be a different model. The following compatibility requirements will be as follows.

The LRV, when coupled with an SD100/SD160, will be electrically, mechanically and functionally compatible with the SD100/SD160. The LRV will automatically match the performance of the SD100/SD160 when in-train with an SD100SD160, regardless of the location of the SD100/SD160 relative to the LRV.

When not coupled to an SD100/SD160, the LRV shall provide the performance listed below. The LRV anti-climber height and design will match the SD100/SD160.

13.1.5 Winter and Airborne Debris

All vehicle systems must be designed to function under conditions of snow, ice and freezing rainstorms including airborne debris such as leaves, plant seeds, grass cuttings, etc., that may be encountered in the Denver metropolitan area.

13.1.6 Environmental Conditions

Normal operation of the vehicles in the Denver metropolitan area environment shall not in any way impair the performance or useful life. Typical environmental characteristics in the Denver metropolitan area are:

- Ambient temperature - 30° F to +110° F
- Relative humidity 8% to 100% and condensing conditions
- Maximum Rainfall in 24 hrs. 6.5 in.
- Maximum wind speed 80 mph

- Maximum snowfall in 24 hrs. 18.5 in.
- Freezing rain and ice conditions 1 time/yr.
- Elevation 6000 ft.

13.2.0 GENERAL VEHICLE REQUIREMENTS

13.2.1 Dimensions

13.2.1.1 Carbody Dimensions

TABLE 13A – CARBODY DIMENSIONS

Maximum length of car over coupler faces	24536 mm (80.5 ft.)
Maximum width of car at widest point (excluding mirrors)	2692 mm (8.83 ft.)
Maximum roof-mounted equipment height, exclusive of pantograph, above top of rail (TOR) with new wheels and car at AWO	3810 mm (12.5 ft.)
Nominal coupler vertical centerline height above TOR, car at AWO, with new wheels	605 mm (23.82 ft.)
Maximum floor height above top-of-rail (AWO)	991 mm (39 in.)
Minimum interior ceiling height, finished floor to finished ceiling, on vehicle centerline, except at articulation	2032 mm (6.70 ft.)
Minimum door bottom clearance above top-of-rail (AWO)	260 mm (10.25 in.)
Minimum side door clear opening width with doors fully opened	1237 mm (48.7 in.)
Minimum clear side door height from finished floor	2007 mm (6.58 ft.)
Minimum width of cab door opening	622 mm (24.5 in.)
Minimum height of cab door opening	905 mm (6 ft. 3 in.)
Minimum double seat width	889 mm (35.0 in.)
Minimum seat to wall offset	25.4 mm (1 in.)
Minimum aisle width	660 mm (26.0 in.)
Minimum plus seat thickness, seat pitch	762 mm (20.0 in.)

13.2.1.2 Pantograph Dimensions

TABLE 13B – PANTOGRAPH DIMENSIONS

Pantograph operating height	Maximum: 7000 mm (22.97 ft.)
Dynamic conditions any car weight AWO to AW4, and with new to fully worn wheels minimum	4200 mm (13.78 ft.)
Pantograph lockdown height	3786 mm (12.42 ft.)
Collector head width over horns	1980 mm (6.50 ft.)
Minimum collector head carbon shoe length	1370 mm (4.49 ft.)

The pantograph shall be of a service proven design requiring a minimum of modifications to allow for special operating conditions in Denver.

13.2.1.3 Wheel Dimensions

a. Profile: The car builder shall develop a wheel profile that supports the vehicles operating

b. Diameter

New, nominal: 720 mm (28.35 in)

Fully worn (condemning limit): 660 mm (25.98 in)

c. Nominal back-to-back dimension: 1365 mm (4.48 ft)

13.2.1.4 Truck Dimensions

Variations are permitted, subject to shop hoist and clearance requirements.

a. Nominal truck spacing, centerline-to-centerline:

7720 mm (25.33 ft)

13.2.2 Weights

- The AWO car weight will not exceed 1650 kg per meter of length (1106.4 lbs/ft), measured over the coupler faces.

- The AWO car weight at the center truck is within the range of 25% to 35% of the total car weight.

- The difference in car weight between motor trucks will not exceed 900 kg (1984.2 lbs).

- Wheel load on one side of a truck will not differ by more than 3% from the load on the opposite wheel at AWO.

13.2.3 Curves and Grades

The vehicle shall operate over:

Minimum horizontal curve radius	25 m (82.0 ft)
Minimum vertical curve radius, crest	250 m (820.2 ft)
Minimum vertical curve radius, sag	350 m (1148.3 ft)
Maximum gradient	7%

13.2.4 Clearances

13.2.4.1 General

Maximum normal dynamic roll angle:	2.5 degrees
Maximum dynamic role angle, failed suspension:	4 degrees

13.2.4.2 Undercar Clearances

Vertical undercar clearance is defined from TOR with the maximum suspension deflection and car body roll, minimum vertical curve radius and fully worn wheels.

Minimum vertical clearance under floor mounted equipment shall be 102 mm (4.0 in).

Minimum vertical clearance truck mounted equipment shall be 76 mm (3.0 in).

With the above conditions and with any radius curve, clearances between truck components and the car body shall be no less than 38 mm (1.5 in).

13.2.4.3 Dynamic Envelop and Station Platform Interfaces

The station platform interface shall be as described in Sections 4.2.4.3.b and 5.4.1.

13.2.5 Catenary Voltages

The vehicle, and all vehicle systems, will operate normally at any catenary voltage between 525 Vdc and 925 Vdc, except where indicated otherwise.

No vehicle equipment will generate voltages in excess of 900 Vdc into the catenary system. The SD100/SD160 can operate continuously between 525 Vdc - 900 Vdc.

13.2.6 Performance

All car systems will provide the indicated performance at all line voltage levels between 525 Vdc and 925 Vdc with the nominal voltage rating of 750 Vdc, except the braking systems, which will function at any line voltage down to 0 Vdc.

Acceleration

For vehicle loads from AWO to AW2, and all speeds from 0 to 40 km/h (25 mph), an acceleration of 1.34 m/s (3.0 mphps) will be provided. Time to reach 90 km/h (56 mph) shall be no greater than 35 seconds.

At loads above AW2, the acceleration may be reduced proportionally by the ratio of AW2 to the actual car weight.

13.2.6.1 Service Brake Requirements

Braking will be comprised of a combination of dynamic, regenerative and disc braking. The term "electric braking" will be used to mean dynamic and/or regenerative braking.

Braking efforts on each of the three trucks will be apportioned according to the vehicle weight distribution at each truck.

For vehicle weights up to AW2, motor truck braking will be entirely electric braking. For vehicle weights above AW2, motor truck disc braking will supplement the electric brake. Center truck braking will be via friction disc brakes.

On the motor trucks, friction braking will be automatically blended with electric braking to provide the requested effort.

For all vehicle weights from AWO to AW3, and at all speeds from 0 to 90 km/h (56 mph), an instantaneous service brake deceleration of 1.56 m/s ± 10% (3.5 mphps) will be provided. For vehicle weights above AW2, and speeds greater than 72 km/h (45 mph), electric braking may be tapered to no less than 1.0 m/s (2.2 mphps), with the remaining effort provided by motor truck friction discs.

For vehicle weights above AW3, brake rates shall be proportional to the ratio of AW3 to the actual car weight.

Electric brake fade shall not occur above 8 km/h (5 mph).

In the event of electric brake failure, maximum train speed will be automatically limited to not less than 56 km/h (25 mph). Under this restricted speed condition, the disc brakes shall be capable of providing the above service brake rate, with a ±20% tolerance, without damage to any equipment or brake pads.

13.2.6.3 Emergency Braking Requirements

For brake entry speeds equal to or greater than 50 km/h (31 mph), the minimum emergency brake rate, at all weights up to AW4, shall meet or exceed the values calculated by the following equation:

$$R_{AV} = -0.006v + 2.5$$

Where R_{AV} is the average emergency braking rate in m/s and v is the brake entry speed in km/h.

The maximum emergency braking rate shall not exceed the minimum rates by more than 30%.

For brake entry speeds greater than 25 km/h (15 mph) and less than 50 km/h (31 mph), the average emergency brake rate shall be a minimum of 2.2 m/s (5.0 mphps) and shall not exceed this rate by more than 30%.

For brake entry speeds of less than 25 km/h (15 mph), the instantaneous emergency brake rate after the rate has built up shall be a minimum of 2.2 m/s (5.0 mphps) and the maximum rate shall follow the characteristics of the magnetic track brake.

13.2.6.4 Parking Brake

The parking brake system shall hold an AW4 vehicle on a 7% grade indefinitely.

13.2.6.5 Speed Characteristics

Minimum balancing speed:	90 km/h (56 mph)
(AWO to AW2, level tangent track)	
Balancing speed on a 5% uphill grade:	65 km/h (40 mph)
(AWO to AW2, tangent track)	

Minimum safe operating speed:	105 km/h (65 mph)

(Fully worn wheels)

The vehicle shall be capable of continuous operation at low speeds of 8 km/h (5 mph) or less. A regulated speed control shall provide a constant speed for car wash and similar activities. This function will be selectable at the master controller, and shall be initially set at 5 km/h (3 mph).

13.2.6.6 Mode Change Dead Times

Mode change dead times will not exceed the following:

Power to Brake	300 ms
Power to Coast	300 ms
Coast to Brake	300 ms
Coast to Power	300 ms
Brake to Power - below 3 mph	300 ms
Brake to Power - above 3 mph	600 ms

13.2.6.7 Jerk Limits

Changes in acceleration or deceleration shall be limited to a fixed rate of change (jerk limit) of 2.0 m/s^3 +10% (4.5 mph/s^2) unless the command signal changes at a lower rate.

Emergency brake applications shall not be jerk limited.

13.2.7 Spin/Slide Correction

A system shall be provided to detect and correct wheel spin and slide on each car whether random or synchronous on an individual truck basis both in acceleration and braking.

Efficiency shall be at least 90% in acceleration and in braking for adhesion levels above 5%.

13.2.8 No-Motion Detection

Apparatus shall be provided to detect all vehicle motions down to and including 3 km/h (1.9 mph).

13.2.9 Duty Cycle Rating

The car shall be capable of continuous operation on any of RTD lines without exceeding the continuous rating of any equipment, under the following conditions:

- A constant AW2 load
- A dwell time of 10.0 seconds at each stop
- Acceleration and braking at maximum rates
- Operation to maximum track speeds
- A 30 second layover at each end of the line

In addition, one train with an AW3 load shall be capable of pushing or towing another train of equal length with an AW3 load from the point of failure to the next station, where passengers would be unloaded, and then continue with both trains at AWO load to the end of the line, at reduced performance, without damage or reduction in equipment life. The point of failure shall be considered to be at the farthest location on the line from either end of the line such that the worst load is imposed on the equipment. The train will be dispatched to the nearest end of the line. The train operating in this condition would be operated as a special equipment movement with no passenger station stops after the first and would slow down only as normally required by other traffic, signals, and civil requirements. Maximum speed may be reduced, by rulebook, to not less than 30 mph.

13.2.10 Electromagnetic Emissions

The vehicle will not produce disruptive electrical interference affecting its own equipment, existing or proposed RTD wayside equipment or other LRVs.

13.2.10.1 Radiated Emission Limits

- From 0.01 MHZ to 30 MHZ, the maximum permissible interference limit shall not exceed 20 dB above the limit of Figure 22 (RE05) of MIL-STD-461 A.
- From 30 MHZ to 88 MHZ, the maximum permissible interference limit shall be 58 dB above one p,V/m/MHZ bandwidth.
- From 88 MHZ to 1000 MHZ, the maximum permissible interference limit shall be 68 dB above one p,V/m/MHZ bandwidth.

13.2.10.2 Conductive Emission Limits

- From 0 Hz to 40 Hz, 10 A maximum.
- From 40 Hz to 120 Hz, 1 A maximum.
- From 120 Hz to 320 Hz, 10 A maximum.
- Above 320 Hz, the emissions limit then follows a smooth curve through 10 A at 320 Hz, 0.08 A at 2 kHz, 0.016 A at 4 kHz and 0.0046 A at 7 kHz.

13.2.10.3 Inductive Emission Limits

The inductive emissions shall be limited to a maximum of 20 millivolts, rms, rail-to-rail, at all frequencies between 20 Hz and 20 kHz.

13.2.11 Noise

Interior noise shall not exceed the following:

- Vehicle stationary: 65 dBA

Windows and doors closed, all auxiliaries operating simultaneously under normal operating conditions

- Vehicle operating: 70 dBA

Car operating on any line at any speed except in tunnels

Exterior noise, measured 15 m (49.21 ft) from the centerline of the track, 1.5 m (4.92 ft) above the ground, shall not exceed the following:

- Vehicle stationary: 65 dBA
- Vehicle operating on tangent track: 75 dBA

13.2.12 Shock and Vibration

Vibrations anywhere on the vehicle floor, walls, ceiling panels and seat frames shall not exceed the following:

- Below 1.4 Hz: Maximum deflection (peak to peak): 2.5 mm
- 1.4hz to 20 Hz: Peak acceleration: 0.01 g
- Above 20 Hz: Peak velocity: C

All vehicle equipment shall withstand the following:

- Car-body-mounted components:
  - Vibrations up to 0.4g peak to peak, at frequencies up to 100 Hz
  - Impact loads of 2g lateral, 3g vertical and 5g longitudinal
- Truck-frame-mounted components:
  - Vibrations up to 4g peak to peak at frequencies up to 100 Hz
  - Impact loads up to 20g each applied individually on any major axis
- Truck-axle-mounted components:
  - Vibrations up to 10g peak to peak at frequencies up to 100 Hz
  - Impact loads up to 50g each applied individually on any major axis

13.2.13 Ride Quality

The rms acceleration values shall not exceed the "4-hour, reduced comfort level (vertical)" and "2.5 hr, reduced comfort level (horizontal)" boundaries derived from Figure 2a (vertical) and Figure 3a (horizontal) of ISO 2631 over the range of 1 Hz to 80 Hz, for all load conditions AWO to AW3.

13.2.14 Flammability and Smoke Emissions

All materials used in the construction of the car shall meet the requirements of NFPA 130 Sections 4.1, 5.2, 5.4 and 5.6.

The floor structural assembly shall meet a 30-minute minimum endurance rating if tested in accordance with ASTM E 119. The ceiling structural assembly shall meet a 15-minute minimum endurance rating if tested in accordance with ASTM E 119.

13.2.15 Reliability

Actual reliability will be based on actual car mileage divided by the average schedule speed on RTD's system, which is approximately 40 km/h (25 mph).

The indicated requirements apply to all unscheduled maintenance activities resulting from equipment failures, whether occurring in revenue service or not.

Individual car systems will meet the following reliability requirements:

MTBF = Mean time between failures

Sub-System	MTBF (hrs)
• Car body & Appointments (including seats, windows, flooring, cab appointments, etc.)	4,000
• Propulsion and Electric Braking (including all drive train components)	4,000
• Friction Braking (including track brakes and sanders)	3,500
• Communications (including destination signs)	7,500
• Passenger Doors and Controls (including ramps)	2,500
• Lighting	20,000
• Electrical (apparatus not included in other systems)	5,000
• HVAC	6,000
• Couplers & Draft Gear	15,000
• Trucks & Suspension	10,000

13.2.16 Maintainability

The vehicle will be designed to minimize Mean Time to Repair (MTTR). The quantitative maintainability goal for the vehicle shall result in an overall MTTR of 1.8 hours. This shall be the weighted average of the MTTR of the key system elements as listed below. Diagnostic time shall be included in MTTR.

Sub-System	MTTR (hours)
• Car body & Appointments (including seats, windows, flooring, cab appointments, etc.)	2.13
• Propulsion and Electric Braking (including all drive train components)	1.77
• Friction Braking (including track brakes and sanders)	1.94
• Communications (including destination signs)	0.82
• Passenger Doors and Controls (including ramps)	0.84

•	Lighting	0.50
•	Electrical (apparatus not included in other systems)	1.50
•	HVAC	2.12
•	Couplers & Draft Gear	1.50
•	Trucks & Suspension	1.57

13.3.0 CAR STRUCTURE AND INTERIOR

The primary car structural material will be low-alloy, high-tensile (LAHT) steel.

The structure will withstand a 2g load applied longitudinally at the anticlimber without permanent deformation. Collision posts and similar structures above the floor will resist penetration by objects impacting above the anti-climber.

13.3.1 Seats

Seats will be of two varieties: lateral fixed 2 person seats, or flip-up 2 person seats arranged laterally or longitudinally.

All seat frame materials visible to the public will be brushed stainless steel. Non-visible frame materials may be painted mild steel.

Seat cushions will be replaceable insert type.

13.3.2 Wheel Chair Accommodations

Wheel chair accommodations will be provided in accordance with ADA Accessibility Guidelines.

Space for a minimum of two wheelchairs shall be allocated near the operators cab. A stop request tape switch shall be located in this area.

Passenger seats at designated wheelchair areas shall be flip-up type.

13.3.3 Elderly and ADA Accessible Ramps

Each front doorway, nearest the operators cab, will be fitted with a manually operated ramp and bridge plate.

When deployed, the ramps will completely cover the step well, and the bridge plate will rest on the wayside platform.

The status of the ramp will be indicated by limit switch to other vehicle systems.

13.3.4 Windows

The windshield will be one piece laminated clear safety glass meeting FRA Type 1 requirements.

The passenger and door windows will be laminated, tinted, safety glass meeting ANSI Type 1 requirements.

The passenger side windows will be one piece without an openable portion.

13.4.0 COUPLER

The coupler will be an automatic, tight-lock, electrical coupler, which is mechanically and electrically compatible with the existing Scharfenburg/Voith coupler.

The coupler will employ an energy absorption feature that will absorb kinetic energy and prevent car structure damage until the anti-climbers mate.

13.5.0 OPERATOR'S CAB

The general arrangement of the operator's cab shall be similar to the SD100/SD160 cab, with changes and improvements as noted.

- All cab features will be located and dimensioned to accommodate RTD operators in the size range of the 5th to 95th percentile of U.S. males and females.
- The operator's seat will be fully adjustable via electric or manual controls.
- Each sidewall of the cab will include a sliding window. Adjustable shades will be provided for the windshield and both side windows.
- A dual glass, electrically or manually adjustable, mirror will be provided on each side of the cab, viewable through the side windows. Each glass of the mirror will be independently adjustable.

13.6.0 PASSENGER DOORS

The door system shall be outward folding, bi-parting doors or plug doors similar in configuration to the SD100/SD160 doors. Door operators will be electric.

Each door will include a dedicated, microprocessor-based, controller. The controller will respond to external commands, monitor door positions and status, and provide diagnostic and status information to portable test units (PTUs). Basic door operating parameters will be adjusted via the PTU.

Front doors will be operable independently of the other side doors for ADA accessibility.

All door control units will be linked together with a serial data connection such that the status of all doors may be monitored at a single location in the vehicle.

13.7.0 HEATING VENTILATION AND AIR CONDITIONING (HVAC)

Each car half will include a separate, unitized, roof-mounted HVAC unit. Each HVAC unit will function independently of the other, including logic and thermostat controls.

Compressor fluid will be R-22 or R-134a.

The vehicle will include floor heaters to supplement the heat provided by the HVAC units.

13.8.0 LIGHTING

All vehicle lighting will operate from the car's LVPS.

Except for interior passenger lighting, headlights, roof lamps and cab ceiling lights, all lights shall be LED based.

Interior passenger lighting will be via two continuous rows of fluorescent light fixtures along the length of the passenger compartment, except in the articulation. Illumination levels at 840 mm above the floor at any seat will be 375 lux, minimum. Illumination levels on the floor anywhere in the vehicle will be 215 lux, minimum. High-frequency inverter ballasts will power the fluorescent fixtures.

The fluorescent fixture adjacent to each doorway, as well as other specified light fixtures, will be powered directly from the battery to provide emergency lighting during LVPS failure.

13.9.0 ELECTRICAL

13.9.1 Transients

A roof-mounted MOV-type lightning arrester will provide over-voltage protection meeting minimum IEC 1287-1 requirements.

All vehicle equipment will be protected against transient voltages whether generated externally or internally, independent of the lightning arrester.

All equipment capable of generating electrical transients will include suppression devices.

13.9.2 Auxiliary Power Supply

Low Voltage Power System: 28 Vdc

AC Power Supply: 208/120 Vac RMS, 3 phase, 4 wire, 60 Hz.

The vehicle will provide 3-phase 208 Vac power from a static inverter operated from the catenary. Low voltage DC circuits will operate at 28 Vdc, provided by a static converter (LVPS) operated from the catenary. The LVPS and AC inverter may share enclosures, but will have limited common components.

The LVPS will also provide battery charging.

13.9.3 Battery

A 20-cell, nickel cadmium battery will provide back-up low voltage power in the event of LVPS failure. The battery will be sized to carry emergency loads for 1 hour.

13.9.4 Miscellaneous

A pantograph will be provided on each vehicle, mounted such that the head is located over the center truck.

HV circuit protection will be provided by roof-mounted high-speed circuit breaker (HSCB). All other high voltage circuits will be protected by fuses mounted beneath the floor, except as noted below.

Provision will be included to reset the HSCB with a discharged battery. For this purpose, a roof-mounted fuse may provide HV to the inverter/LVPS.

All non-HV circuits will be protected by circuit breakers. All motors on the vehicle will be 3-phase, AC motors.

The quantity of commands and indications for the LRV are expected to exceed the spare pin count on the SD100. As such, many commands and indications not common with the SD100 will be carried via serial and/or multiplexed signals on SD100 spare trainlines.

13.10.0 PROPULSION/ELECTRIC BRAKES

The propulsion equipment will be configured as two independent IGBT-based inverter system, one for each motor truck.

Motortrucks will be configured as bi-motor, parallel drive. Traction motors will be self-ventilated squirrel cage AC motors designed and tested to IEEE Standards 11 and 112, or IEC 349-2. Traction motors will be configured as TEFC or WP Type 1 per NEMA MG1.

The propulsion equipment will provide electric brake effort signals to the friction brake system for blending. The propulsion equipment will provide spin/slide control independent of the friction brake system.

Each propulsion inverter will include a line filter and line contactor for EMI control and isolation from the catenary, respectively. The line contactors will open during emergency braking. The propulsion equipment will provide regenerative braking whenever the overhead catenary is receptive. In the case when the overhead catenary is not receptive to regenerative braking, the rheostatic braking resistors shall be capable of handling 100% of the load with out damage.

13.11.0 TRUCKS

Trucks will be of proven design, and may be inboard or outboard bearing. Suspension components will be selected to provide a stable and comfortable ride at all vehicle speeds without excessive track or wheel wear.

Primary suspension will be coil spring or rubber elements. Secondary suspension will be coil spring.

Each of the three trucks will provide a load signal to the propulsion and braking systems. Load leveling will not be provided.

Wheels will be resilient types, similar to Bochum 54, with external shunts.

Provision for floor height adjustment to compensate for wheel wear and suspension variation will be provided on each truck.

13.12.0 FRICTION BRAKE

The friction brake equipment will be comprised of hydraulic disc brakes, track brakes and sanders.

Hydraulic disc brakes will be provided on each axle of each truck. The size and quantity of each axles discs will be selected to provide the thermal capacity as defined by the performance requirements. A dedicated hydraulic power unit, each with a dedicated electronic controller, will independently control each truck's disc brakes.

Each electronic control will independently monitor trainlined input commands and local vehicle conditions, as well as the status of its own components, and provide diagnostic and status outputs to a PTU.

Each truck will be provided with two track brakes.

Each motor truck will be provided with sand nozzles for each wheel, with controls arranged to deposit sand only in front of the leading axle of each motor truck.

13.13.0 COMMUNICATIONS

The LRV communication equipment will be comprised of on board train radios, public address (PA) and passenger emergency intercom (PEI). It shall function with a passenger information system, which includes all signs and communication systems. Closed Circuit Television (CCTV) equipment shall also be provided for LRV interior video surveillance.

Radios will be commercial units functionally compatible with the existing RTD radio system, and integrated into the cab console.

The public address system will allow one-way communication between the operator and passengers via the interior and or exterior speakers.

A passenger emergency intercom system will allow two-way communication between individual passengers and the operator. Each vehicle will have 2 intercom stations. A passenger will hail the operator by pressing a button on the station, which sounds a tone in the cab. The operator establishes, and controls, the communication link.

The Automatic Announcement System (AAS) will control all pre-recorded audible announcements. The audio messages will be stored in digital form, and played over the PA system. All functions of the AAS will be trainline.

The PA and AAS will be configured as two independent systems, each system will have a dedicated amplifier.

Destination or route designations will be displayed on the end and side signs. The end and side destination signs will be LED or LCD. The operator will enter the route into a control head via a route ID number. The route ID will determine the sequencing of messages, or other information entered by the train operator.

A Central Control Unit (CCU) will control all portions of the communication system, except for train radio. The train radio will interface with the CCU but in the event of CCU failure the radio will remain functioning.

13.14.0 TWC, ATS AND EVENT RECORDER

This section establishes the requirements for the vehicle Train-to-Wayside Communications (TWC) system, Automatic Train Stop (ATS) system and Event Recorder. The Contractor shall furnish and install all carborne TWC, ATS, and event recorder equipment as described in the following sections. The TWC, ATS and event recorder systems shall be service proven and compatible with RTD's present equipment and operations.

13.14.1 Train to Wayside

The vehicle shall be equipped with a TWC system that is the same or compatible with the Philips Vetag TWC system, represented in the United States by VAPOR Corporation of Chicago, Illinois. The TWC transponders (VAPOR part no. 28836123) mounted at both ends on the center line of the carbody, approximately 10 feet from the end of the coupler. The TWC system uses a wayside interrogator to excite a wayside loop antenna with approximately 0.1 A, at frequencies between 80 kHz. and 120 kHz.

The Vehicle TWC equipment shall be furnished and installed to provide for the accurate transmission of a 19-bit data message from the carborne transponders. The wayside interrogator shall process the following information from the LRVs via the wayside loop antennas:

Active cab:

- Train Number (00-99) 7 bits
- Route Number (00-99) 7 bits
- Stationary Pre-empt/Activation button in cab 1 bit
- Cancel (route) button in cab 1 bit
- Spare 3 bits

Intermediate (inactive) cabs (for multiple-unit consists only):

- Car Number (000-999) 10 bits
- Active Cab (off for intermediate cab) 1 bit
- End-of-train (off for intermediate cab) 1 bit
- Spare 7 bits

Trailing (rear-end, end-of-train, inactive) cab:

- Car Number (000-999) 10 bits
- Active Cab (off for trailing cab) 1 bit
- End-of-train (on for trailing cab) 1 bit
- Spare 7 bits

13.14.2 Automatic Train Stop

Each cab of each LRV shall be equipped with a service proven Automatic Train Stop (ATS) System which shall automatically place the car into an irretrievable braking mode should the Train Operator attempt to pass a red wayside signal. The ATS system consists of both, carborne receiving and control equipment and wayside transmitting equipment. The carborne portion shall consist of two receiving magnets, two car-switching (control) units, a cab control panel in each cab and the necessary brake interface while the wayside portion consists of a transmitting magnet.

The carborne ATS equipment shall function with the existing wayside ATS equipment on the RTD LRT system.

Vehicle ATS equipment shall be installed to be effective only in the normal direction of traffic on a given track and not be effective for reverse movement. In order to prevent a Train Operator from attempting to avoid an ATS trip, by placing a forward moving train into reverse or OFF, the ATS system shall remain active for 20s after the reverser has been moved from forward into neutral or reverse and after the key switch has been placed in OFF.

The ATS equipment shall be interconnected with the car propulsion equipment and braking systems such that only the ATS equipment associated with the active cab of a car shall be activated in the direction of forward travel. The ATS system shall not be functional when a car is operated in the reverse direction of travel from a given cab.

Each cab shall be equipped with the following ATS control equipment:

- Trip Counter
- Key-By Counter
- "ATS Bypass" indicator lamp
- "ATS Trip" indicator lamp
- "ATS Reset" switch
- "ATS Key-By" switch

13.14.3 Event Recorder

Each LRV shall be provided with a service proven, fully electronic data recorder system, which shall store times, speeds, distances traveled and both analog and digital events as described further below. The event recorder shall be a self-contained unit with data storage and retrieval capabilities. Unless explicitly stated otherwise, the event recorder shall comply with the requirements of IEEE 1482.1, "Standard for Rail Transit Vehicle Event Recorders."

13.15.0 MATERIALS AND WORKMANSHIP

All equipment employed in the construction of these LRVs shall be designed and manufactured to recognized U.S. or international standards for heavy industrial applications. Material and workmanship shall be in accordance with the stated specification or description, unless written approval for substitution is obtained.

13.16.0 TESTING

The complete car and its apparatus shall undergo a comprehensive test program to substantiate required design and performance characteristics. The contractors test plans, procedures and reports are subject to review and approval by RTD. Comprehensive design conformance, production conformance and routine acceptance tests and test procedures are required.

13.17.0 QUALITY ASSURANCE

The Contractor shall plan, establish and maintain a quality assurance program. The elements of the Contractor's quality assurance program shall be required of all entities within the Contractor's organization and all subcontractors.

13.18.0 TECHNICAL PUBLICATION AND USER EDUCATION

Manuals, integrated schematics, narratives and training are to be provided under the particular LRVs contract. They shall include but not limited to:

- Operating Manuals
- Running Maintenance and Servicing Manuals
- Heavy Repair Maintenance Manuals
- Integrated Schematics and Narratives
- Tools and Test Equipment Maintenance Manuals
- Illustrated Parts Catalogs

Durable "oil proof" pages and binders shall be required per RTD's requirements.

13.19.0 SUPPORT EQUIPMENT

The Contractor shall provide all support equipment necessary for maintaining, troubleshooting, testing, repairing, calibrating and inspecting all carborne equipment. This shall include equipment for the support of shop repair and overhaul activities, for on-board inspection and testing and for maintaining and updating all deliverables.

- Common Tools
- Gauges and Special Tools
- Portable Test Equipment
- Bench Test Equipment
- Repair Data
- Workstations
- Bar Coding Equipment
- Spare Parts

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SECTION 14 – SYSTEM SAFETY AND SYSTEM SECURITY

SECTION 14 – SYSTEM SAFETY AND SYSTEM SECURITY

14.1.0 GENERAL

The CRT design shall address system elements according to the requirements of the applicable standards listed. Should any standard or requirement conflict, the most stringent standard shall apply. In accordance with RTD's System Safety and System Security Program Plan, RTD's Executive Safety and Security Committee must review and accept all CRT design and any subsequent changes or modifications. The RTD Project Manager and/or Design Engineer shall present design reviews to the RTD Executive Safety and Security Committee for acceptance as design milestones are reached. Additionally, any deviation from RTD's design criteria must be approved by RTD's Executive Safety and Security Committee.

Standards, specifications, regulations, design handbooks, safety design checklists and other sources of design guidance will be reviewed for pertinent safety design requirements applicable to the system. The design shall establish criteria derived from all applicable information. Some general system safety design requirements are:

- Identified hazards shall be eliminated or associated risk shall be reduced through design, including material selection or substitution. When potentially hazardous materials must be used, such materials selected shall pose the least risk throughout the life cycle of the system.
- Hazardous substances, components and operations shall be isolated from other activities, areas, personnel and incompatible materials.
- Equipment shall be located so that access during operations, servicing, maintenance, repair or adjustment minimizes personnel exposure to hazards (e.g. hazardous chemicals, high voltage, electromagnetic radiation, cutting edges or sharp points).
- Risk resulting from excessive environmental conditions (e.g. temperature, pressure, noise, toxicity, acceleration and vibration) shall be minimized.
- Risk resulting from human error in system operation and support shall be minimized as part of the design effort.
- In the case of risk from hazards that cannot be eliminated, alternatives that will minimize such risk shall be considered. (e.g. interlocks, redundancy, fail safe design, system protection, fire suppression and other protective measures, such as clothing, equipment, devices and procedures.)
- Power sources, controls and critical components of redundant subsystems shall be protected by physical separation or shielding, or by other suitable methods mutually agreeable to the design and RTD.
- When alternate design approaches cannot eliminate the hazard, safety and warning devices and warning and cautionary notes shall be provided in assembly, operations, maintenance and repair instructions, and distinctive markings shall be provided on hazardous components, equipment and facilities to ensure personnel and equipment protection. These shall be standardized in accordance with commonly accepted commercial practice or, if none exists, normal procedures. Where no such common practice exists, the design shall propose the method or methods to be used to RTD for review and approval. The design shall provide all warnings, cautions and distinctive markings proposed to RTD for review and comment.

The severity of personnel injury or damage to equipment as a result of a mishap shall be minimized.

Software controlled or monitored functions shall ensure minimal initiation of hazardous events or mishaps.

Design criteria shall not include inadequate or overly restrictive requirements regarding safety. Where there is appropriate supporting information, recommend new safety criteria as required.

14.2.0 APPLICABLE STANDARDS

The design shall be in accordance with the following standards. Should the standards requirements conflict, the most stringent requirement shall apply.

TABLE 14-A – STANDARDS

Document	Title	Required (R) Guidance (G)
49 CFR 659	State Safety Oversight of Fixed Rail Guideways	R
CCR 723-14	Standards for Rail Fixed Guideway Systems	R
49 CFR 51, 201, 202, 205, 207, 209, 211, 213, 241	Federal Railroad Administration	G
National Fire Protection Association (NFPA) 130	Standard for Fixed Guideway Transit Systems	R
NFPA 101	Life Safety Code	R
Latest Revision	Americans with Disabilities Act	R
	Uniform Fire Code	R
	Local jurisdiction fire and building codes	R
Latest Revision	RTD's System Safety and System Security Program Plan	R
Latest Revision	RTD Safety Certification Program	R
Latest Revision	RTD's CRT Design Criteria Manual	R
MIL-STD-882D	Military Standard 882D	G
NFPA 70	National Electric Safety Code	R

Document	Title	Required (R) Guidance (G)
U.S. Department of Transportation (DOT), FTA, latest revision	Transit Threat Level Response Recommendation	G
U.S. Department of Transportation (DOT), FTA, November 2002	Handbook for Transit Safety and Security Certification	R
U.S. Department of Transportation (DOT), January 2000	Hazard Analysis Guidelines for Transit Projects	G
29CFR1910	Federal Occupational Safety and Health Standards (General Industry)	R
29CFR1926	Federal Occupational Safety and Health Standards (Construction Industry)	R
Transit Cooperative Research Program (TCRP) Report 17	Integration of Light Rail transit into City Streets	G
MIL-STD-1472D	Human Engineering Design Criteria for Military Systems, Equipment and Facilities	G
U.S. Department of Transportation (DOT), November 2004	Transit Security Design Considerations	R

14.3.0 DEFINITION OF SAFETY CONDITIONS

14.3.1 Unacceptable Conditions

The following safety critical conditions are considered unacceptable. Positive action and implementation verification is required to reduce the risk to an acceptable level.

- Single component failure, common mode failure, human error or design features, which could cause a mishap of catastrophic or critical severity.
- Dual independent component failures, dual human errors or a combination of a component failure and a human error involving safety critical command and control functions, which could cause a mishap of catastrophic or critical severity.
- Generation of hazardous ionizing/non-ionizing radiation or energy when

no provisions have been made to protect personnel or sensitive subsystems from damage or adverse effects.

- Packaging or handling procedures and characteristics which could cause a mishap for which no controls have been provided to protect personnel or sensitive equipment.
- Hazard level categories that are specified as unacceptable.

Unacceptable hazardous conditions will be identified according to the hazard resolution matrix. Hazard classification at this level is a formal process for determining which hazards are acceptable, acceptable with review by management staff, undesirable or unacceptable. Hazard severity is a subjective measure of the worst credible mishap resulting from personnel error, environmental conditions, design inadequacies and/or procedural efficiencies for system, subsystem or component failure or malfunction. Hazard probability is defined as the probability that a specific hazard will occur during the planned life expectancy of the system element, subsystem or component. The categories of hazard severity, hazard probability and their definitions follow:

Hazard Severity Definition

- Catastrophic – Death or system loss
- Critical – Severe injury, severe occupational illness or major system damage
- Marginal – Minor injury, minor occupational illness or minor system damage
- Negligible – Less then minor injury, occupational illness or system damage

Hazard Probability Definition

- Frequent – Likely to occur frequently; continuously experienced
- Probable – Will occur several times in the life of an item; will occur frequently in fleet/inventory
- Occasional – Likely to occur sometime in the life of an item; will occur several times in fleet inventory
- Remote – Unlikely but possible to occur in the life of an item; unlikely but can be expected to occur in fleet/inventory
- Improbable – So unlikely, it can be assumed occurrence may not be experienced; unlikely to occur, but possible in fleet

The following table (of the RTD System Safety and System Security Program Plan) demonstrates the relationship between severity and probability to define an unacceptable hazardous condition.

TABLE 14-B – HAZARD RESOLUTION MATRIX

	Catastrophic (I)	Critical (II)	Marginal (III)	Negligible (IV)
Frequent (A)	Unacceptable	Unacceptable	Unacceptable	Acceptable/WR
Probable (B)	Unacceptable	Unacceptable	Undesirable	Acceptable/WR
Occasional (C)	Unacceptable	Undesirable	Undesirable	Acceptable
Remote (D)	Undesirable	Undesirable	Acceptable/WR	Acceptable
Improbable (E)	Acceptable/WR	Acceptable/WR	Acceptable/WR	Acceptable

Acceptable/WR means acceptable with management review.

14.3.2 Acceptable Conditions

The following approaches are considered acceptable for correcting unacceptable conditions and will require no further analysis once controlling actions are implemented and verified.

- For non-safety critical command and control functions; a system design that requires two or more independent human errors, or that requires two or more independent failures, or a combination of independent failure and human error.
- For safety critical command and control functions; a system design that requires at least three independent failures, or three human errors or a combination of three independent failures and human errors.
- System designs which positively prevent errors in assembly, installation or connections which could result in a mishap.
- System designs, which positively prevent damage propagation from one component to another or prevent sufficient energy propagation to cause a mishap.
- System design limitations on operation, interaction or sequencing that preclude occurrence of a mishap.
- System designs that provide an approved safety factor or fixed design allowance which limit, to an acceptable level, possibilities of structural failure or release of energy sufficient to cause a mishap.
- System designs that control energy build-up which could potentially cause a mishap (fuses, relief valves, electrical explosion proofing, etc.).
- System designs in which component failure can be temporarily tolerated because of residual strength or alternate operating paths so that operations can continue with a reduced but acceptable safety margin.

- System designs that positively alert the controlling personnel to a hazardous situation for which the capability for operator reaction has been provided.
- System designs which limit/control the use of hazardous materials.

14.4.0 HAZARD IDENTIFICATION, ANALYSIS, AND RESOLUTION

The Design Engineer shall develop and implement a Hazard Identification, Analysis, and Resolution process in accordance with the minimum criteria outlined in this section and 49 CFR 659. The purpose of hazard analysis and resolution during the design and engineering phase of the project is several fold: to minimize or eliminate potential hazards; support early hazard identification; integrate safe operating procedures into system design and service; and provide for constant and continuous safety evaluation and assessment.

The Design Engineer shall use the requirements established in the following documents:

- 49 CFR 659 using the APTA Guideline's Hazard Resolution Matrix (American Public Transit Association, Manual for the Development of Rail Transit System Safety Program Plans, Checklist Number 7);
- Military Standard 882D (MIL-STD-882D); and
- Hazard Analysis Guidelines for Transit Projects, January 2000, U.S. Department of Transportation.

Subsequent to performing the initial hazard analysis, the Design Engineer shall recommend resolution or mitigation factors to reduce the classification of identified hazards and reclassify identified hazards considering the recommended resolution.

In applying resolution to identified hazards, the Design Engineer shall utilize the following system safety precedence:

- design for minimum risk;
- incorporate safety devices;
- provide warning devices; and
- Develop procedures and training.

14.5.0 PRELIMINARY HAZARD ANALYSIS (PHA)

The Preliminary Hazard Analysis (PHA) activity is the engineering function, which is performed to identify the hazards and their preliminary casual factors of the system in development. The hazards are formally documented to include information regarding the description of the hazard, casual factors, the effects of the hazard, and preliminary design considerations for hazard control by mitigating each cause. Performing the analysis includes assessing hazardous components, safety-related interfaces between subsystems, environmental constraints, operation, test and support activities, emergency procedures, test and support facilities, and safety-related equipment and safeguards.

The analysis also provides an initial assessment of hazard severity and probability of occurrence. The probability assessment at this point is usually subjective and qualitative. To support the tasks and activities of a safety effort, the "causes" of the root hazard must be assessed and analyzed. These causes should be separated in four separate categories:

- Hardware initiated causes
- Software initiated causes
- Human error initiated causes
- Human error causes that were influenced by software input to the user/operator

The Design Engineer shall conduct a PHA process for the project design. PHA work shall begin upon project initiation and continue throughout the project. The Design Engineer shall provide PHA progress reports according to a mutually agreeable schedule. The Design Engineer shall provide a draft and final PHA report on the preliminary engineering. Subsequent to the preliminary engineering, the Design Engineer shall conduct a draft and final PHA report on the final design.

The PHA document itself is a living document, which must be revised and updated as the system design and development progresses. It becomes the input document and information for all other hazard analyses performed on the system.

14.6.0 SAFETY CERTIFICATION

Safety certification is the process of verifying that system elements comply with a formal list of safety requirements. The requirements are defined by design criteria, contract requirements, applicable codes and industry safety standards. The Design Engineer shall develop a preliminary list of safety certifiable items and associated design requirements based on the preliminary engineering. The safety certification process shall apply to all elements of the system. Separate programs shall be developed, for light rail, for commuter rail and for BRT, as appropriate.

The Design Engineer shall identify those system elements and design standards to comply with the major steps in the safety certification process. These steps are implemented beginning with system design and continue through the start of revenue operation.

- Define and identify those safety-critical system elements to be certified.
- Define and identify those security-related elements to be certified.
- Define and develop a Certifiable Items List (CIL).
- Identify safety and security requirements for each certifiable item.
- Verify and document design compliance with the safety and security requirements.

The Design Engineer shall define and identify certifiable items relating to the elements listed in the following table.

Safety Certifiable Elements (minimum)

1. Systems Elements
    - Rail Vehicles
    - Traction Power (TES-TPSS, TPDS, TPFS, OCS, catenary)
    - Overhead Contact System (OCS)

Train Signals

Communications - Central Control System (CCS)

Comm- Supervisory Control & Data Acquisition (SCADA)

Ticket Vending Machines (TVM)

Maintenance Vehicles

Signaling - Train Control

Track

Fire Protection & Suppression Systems

Auxiliary Vehicles

Grade Crossing Fixtures & Traffic Control System

Emergency Response Equipment

Intrusion Detection System

Signage

Tunnel Ventilation Control System (if req.)

2. Facility Elements

Tunnel

Structures

Track

Each Station

Each at grade crossing

Each at grade crossing within each station

Yard and Shops

Garages/Parking Lots

Each Park-n-Ride

Control or Dispatch Center

Maintenance Facility

Art in Transit

3. Security Elements

Video Surveillance (CCTV)

Parking Structure design

Park-n-Ride design

Incorporation of Crime Prevention Through Environmental Design (CPTED) applied to entire design

Station design

Emergency Telephones (and Radio)

Lighting – Stations, patron areas, park-n-Rides

Security of stairwells and elevators

Access Control

Portal Protection

Each certifiable item shall have an associated checklist or verification form consisting of a minimum of two major sections with the following minimum requirements.

<u>Section 1 -- Design Requirements and Design Verification</u>

The Design Engineer shall Identify and define each certifiable item, design requirement(s), requirement source, applicability, and provide name and signature of person and Design Engineer responsible for identifying element and defining requirements. The Design Engineer shall separately verify design requirements and provide name and signature of person and Design Engineer responsible for concurrence for design review. For each certifiable item, the Design shall define a basis from which to judge compliance with safety requirements.

The Design Engineer shall verify that design complies with identified requirements and supporting documentation, and shall provide name and signature of person responsible and Design Engineer responsible for design verification.

<u>Section 2 -- Construction Verification</u>

The Design Engineer shall supply a signature section on the form or checklist for future verification that construction complies with design through inspection, testing and the provision of documentation to serve as evidence that construction complies with design.

14.7.0 RIGHT-OF-WAY FENCING AND BARRIERS

Right-of-Way (ROW) fencing and/or barriers shall be provided along the entire CRT alignment. The fencing and barriers shall be designed to address the following:

- act as a safety barrier to prevent vehicles, trucks, and other highway/roadway users from accidentally entering the CRT envelope;
- shall be of sufficient height to prevent trespass;
- shall be designed to prevent debris and roadway snow removal activity (snow plows throwing slush, ice and other debris) from entering rail envelope and transit station areas; and
- shall incorporate safety considerations on elevated sections with respect to fall protection and providing adequate space for maintenance-of-way workers.

There may be areas where different fencing or barriers may be more appropriate and aesthetic. In these areas, the fencing and/or barrier design shall be determined on a case by case basis and the design shall be accepted by the RTD System Safety Project Manager. The following table describes ROW conditions and the corresponding fencing and barrier requirements. The design shall conform to the requirements contained in the table. For any situation not specifically defined in the table, the fencing and/or barrier design shall be determined on a case by case basis and the design shall be approved by the RTD System Safety Project Manager. These requirements shall be applied regardless of the horizontal or vertical distance from the rail ROW to the adjacent property use. This includes, but is not limited to horizontal and vertical distances between the automobile traffic lane and the rail ROW where state or federal regulations may not require barrier or fence protection. Where different types of fencing/barriers connect, e.g. at-grade to elevated transition points, or at-grade to retaining wall transition points, the design shall accommodate a seamless transition accommodating the integrity of the fence/barrier. For example, a section of ROW may have a three foot jersey barrier with a six foot fence (total height nine feet) that meets up to a three foot MSE wall with a three foot fence (total height six feet). The fencing shall be designed so it tapers from the higher requirement to the lower requirement and meets the performance requirement of this section. No gaps between transitions are allowed. For example, if the fencing/barrier terminates at a bridge monument, the fencing shall be attached to the monument.

TABLE 14-C – ROW FENCING AND BARRIERS

ROW	Description		Barrier Height and Type	Fence Height and Type	Total Height
Semi-Exclusive & Exclusive ROW	Highway 55mph automobile speed	ROW at Grade	5' concrete	5' (2" mesh) (1)	10'
		ROW below Grade	5' concrete	5' (1" mesh) (1)	10'
		Station Platform (51" above T.O.R.)	5' concrete	7' (1" mesh) (1)	12'
	Roadway 35-45 mph automobile speed	ROW at Grade	3' concrete	3' (2" mesh)	6'
		ROW below grade	3' concrete	6' (1" mesh) (1)	9'
		Station Platform (51" above T.O.R.)	5' concrete	7' (1" mesh) (1)	12'
		Roadway and Sidewalk	3' concrete	5' (1" mesh) (1)	8'
	Bridges	Highway over CRT	5' concrete	5' (1" mesh) (1)	10'
		Roadway over CRT	3' concrete	6' (1" mesh) (1)	9'
Shared ROW	Automobile speeds less than 35mph	Residential street running 25 - 35 mph	18" ballast curb/wall	4' (1)	5' 6"
		Down town street running < 25mph	6" curb	N/A	6"
		Bike Path	N/A	4'	4'

(1) Note: Exact fence height, type and mesh size shall be determined by site-specific hazard analysis taking into account all factors including protection of the overhead catenary system and patron safety relating to snow plows & snow removal operations. Final design shall be approved by the RTD System Safety Project Manager.

14.8.0 EMERGENCY ACCESS/EGRESS, STATION DESIGN, AND WALKWAYS

The design shall include emergency access and egress points along the alignment per NFPA 130 requirements. The design shall identify emergency access and egress locations and shall provide a list or matrix of the necessary elements to be provided at each exit, such as lighting, signage, lock hardware, intrusion detection, and other elements as required by NFPA 130 and local jurisdictions. The design shall incorporate a preliminary emergency evacuation plan and diagrams for the corridor, including each station, identifying primary and secondary evacuation routes and points of safety.

CRT station design shall meet the “Means of Egress” requirements for stations as identified in NFPA 130. The Design Engineer shall provide a draft and final Means of Egress Report for all stations documenting that station design meets or exceeds all criteria listed in NFPA 130. The report shall include all calculations, supporting documentation, engineering drawings and other information necessary to demonstrate compliance with NFPA 130. For calculation of occupant load, the Design Engineer shall use projected ridership figures or maximum trainload capacities if accurate projections are not available. Each station shall have a minimum of two main access/egress points remotely located from one another. There shall be sufficient exit lanes to evacuate the station occupant load, as defined in NFPA 130, from the station platform in 4 minutes or less. The maximum travel distance to an exit from any point on the platform shall not exceed 300 feet. Stations shall also be designed to permit evacuation from the most remote point on the platform to a point of safety in 6 minutes or less.

The design shall incorporate walkways as follows. An emergency/maintenance walkway shall be provided along structures. The walkway shall be above TOR at the track edge and shall be located at a horizontal distance from track centerline as determined by regulations plus appropriate Other Wayside Factors, and Running Clearance. The walkway shall have a minimum width of 30 inches. A walkway shall be provided adjacent to one side of every track. In certain instances, with prior approval from the RTD System Safety Project Manager, the walkway may be between two tracks to serve both. Walkways in underground CRT structures, bridges and flyovers regardless of length, shall consist of a solid type material that provides a smooth continuous walking surface (concrete, etc.). Walkways shall have a slip-resistant design and shall be constructed of noncombustible materials.

Along the trackway, walkways shall be provided in addition to the clearance envelope requirements per Section 4.2.4.2, it is required that space be provided for emergency/maintenance walkways adjacent to the trackway. The walkway envelope shall extend at least 2 feet-6 inches from the edge of the clearance envelope and shall extend to 6 feet-6 inches above the walkway. A walkway shall be provided adjacent to one side of every track. In certain instances, with prior approval from the RTD System Safety Project Manager, the walkway may be between two tracks to serve both. In either case the walkway shall permit unobstructed passage from which passengers can be evacuated. Crosswalks shall have a uniform walking surface at top of rail. Walkway continuity shall be maintained at special track sections (e.g., crossovers, pocket tracks, other special track sections). For walkway clearance calculations only, traction power poles shall not be considered a permanent obstruction. This requirement is not applicable to paved track sections in street ROW. Walkways shall be placed to allow passengers to evacuate a train at any point along the trainway so that they can proceed to the nearest station or other point of safety per NFPA 130 requirements.

14.9.0 GRADE CROSSINGS

The CRT design shall incorporate approaches that minimize hazards and risks to CRT, pedestrians, bicyclists and motor vehicle operators. The primary method to minimize grade crossing hazards is to eliminate at grade crossings or minimize the number of at grade CRT crossings. Pedestrian only and bicycle only at grade crossings are generally prohibited and will require a case by case evaluation and written RTD approval. The exceptions to this criteria are pedestrian and bicycle crossings at stations with paved track.

Where planning and design does not allow for the elimination of an at grade crossing, the following system safety precedence shall be applied: design for minimum risk, incorporate safety devices, and provide warning devices. A combination of active grade crossing warning devices and passive warning devices is preferred to solely using passive warning devices. Active warning devices include: gates, bells, flashing lights, and grade crossing indicators for train operators. Passive warning devices include signage and pavement markings.

Design of each at grade crossing shall be subject to the circumstances of that crossing and its relation to the transit corridor. In considering appropriate control and warning devices, consideration shall be given to the following: type of alignment (exclusive, semi-exclusive, or shared ROW); configuration and geometry of crossing (angled or mid-block crossing; operating speed of all users; line of sight of all users; pedestrian activity; school zone; and extreme surges (pedestrians and vehicles).

To enhance pedestrian and bicycle safety at crossings, consideration shall be given to the use of channeling. The purpose of channeling is to create a physical barrier that prevents or discourages persons from taking shortcuts or from crossing the track way in a risky or unauthorized manner. Effective channeling may be developed through the use of fencing, landscaping, bollard and chain, railing, sidewalks or other methods. In all cases, a channeling method that enhances sight lines to an approaching train shall be selected.

Additional elements that may improve pedestrian and bicycle safety at crossings include: swing gates, pedestrian barriers, and automatic pedestrian gates. The purpose of a swing gate is to slow persons who are hurriedly approaching the track way. Swing gate operation depends upon the judgment of the individual. It is not electrically interconnected into approaching train or vehicular traffic signal systems. Swing gates may be appropriate where:

- There is a high likelihood that persons will hurriedly cross the track way, or sight lines and distance are restricted, and
- Channeling or other barriers reasonably prevent persons from bypassing the swing gates, and
- Acceptable provisions for opening the gates by disabled persons can be provided.

Swing gates shall open away from the tracks. Pedestrians shall pull the gate to open it and enter the track way. Gates shall also permit quick exit from the track way, automatically close after use, and be light and easy to operate by all persons.

Pedestrian barriers are also intended to slow persons who are hurriedly approaching the track way. Major advantages of barriers are that there are no operating parts to maintain, and that disabled persons are less impeded. Pedestrian barriers may be appropriate where:

- There is a high likelihood that persons will hurriedly cross the track way, or sight lines and distance are restricted, and

- Channeling or other barriers reasonably prevent persons from bypassing the barriers, and
- Adequate space is available to accommodate installation.

Barrier positioning shall accommodate use by disabled persons and be positioned so persons are turned to face the nearest on-coming train prior to crossing the track way.

Automatic pedestrian gates prevent or discourage a pedestrian or bicyclist from crossing the track way when a train is approaching. Automatic pedestrian gates are electrically interconnected into and activated by the train signal system. Automatic pedestrian gates may be considered in situations where the use of swing gates and barriers may not be effective due to train speeds and severely limited sight distance.

All gated grade crossings shall have video surveillance per the requirements of Section 14.10.0 Video Surveillance. Each gated grade crossing shall have two cameras.

The Design Engineer shall prepare diagrams for swing gates and pedestrian bedstead barriers.

14.10.0 VIDEO SURVEILLANCE

The design shall incorporate video surveillance into the project. The video surveillance system shall be capable of transmitting real-time (30 frames per second per camera) video to RTD's Security Command Center via a fiber optic transmission backbone or other suitable transmission network. The design shall include all system elements including communication houses, transmission infrastructure, color cameras, and digital video recorders. The design shall incorporate video surveillance covering station platforms, emergency telephones, elevator waiting areas, stairwell entries, parking structures, pedestrian tunnels and pedestrian bridges. The minimum number of cameras to provide coverage of these transit elements is as follows.

TABLE 14D – MINIMUM CAMERA COVERAGE

Single level at grade station platform of 300 feet or less *		
Platform type	Fixed color camera	Pan-Tilt-Zoom color camera
Center platform	4	2
Side/ center platform	6	2
Side/Side platform	4	4
Triple platform (side with two centers)	10	3

*For stations with vertical circulation, the minimum number of cameras is as stated above plus: one fixed color camera per elevator waiting area per floor, one fixed color camera per stairwell entry per floor, and one fixed color camera per each emergency telephone.

*For stations greater than 300 feet in length additional cameras will be required. The exact number will be dependent on the station design.

TABLE 14E – PARKING STRUCTURE CAMERAS

Vehicle spaces	Vehicle entrance	Vehicle exit	Elevator waiting area*	Stairwell entrance area*	Emergency telephone*
1 camera per 35 vehicle spaces	1 camera per vehicle entrance lane	1 camera per vehicle exit lane	1 camera per waiting area per floor	1 camera per entrance area per floor	1 camera per emergency telephone

*Subject to approval by the RTD Security Systems Administrator, if the design accommodates a cluster of the elevator waiting area, stairwell entrance, and emergency telephone, a single camera may be used if the video coverage of all three elements is satisfactory.

**All parking structure cameras are color, pan-tilt-zoom.

TABLE 14F – PEDESTRIAN TUNNEL CAMERAS

Pedestrian Tunnel* (all cameras are color, pan-tilt-zoom, 4 cameras minimum per tunnel)	
1 camera focused on each portal entrance/exit (2 cameras)	1 camera inside each tunnel portal entrance/exit focused inside the tunnel (2 cameras)

*For tunnels in excess of 150 feet, additional cameras will be required. If a tunnel has a bend or turn, additional cameras will be required. The RTD Security Systems Administrator will determine the number of additional cameras necessary for coverage.

TABLE 14G – PEDESTRIAN BRIDGE CAMERAS

Pedestrian Bridge (all cameras are color, pan-tilt-zoom, 2 cameras minimum per bridge)
1 camera inside each bridge portal entrance/exit focused inside the tunnel

*For bridges in excess of 150 feet, additional cameras will be required. If a bridge has a bend or turn, additional cameras will be required. The RTD Security Systems Administrator will determine the number of additional cameras necessary for coverage.

Surface park-n-Rides will typically not have video surveillance installed for opening day. However, a minimum network of two, two-inch conduits with pull cords shall be provided as follows for future video installation; one for power and one for communications. As light poles are installed and trenching is done to supply power to these poles, these conduits, shall be installed at each light pole for security. These conduits are of sufficient size to hold any wiring that might be needed for camera installation. Poles in a common area, such as on an island, shall be wired in series (daisy chained). From each common area, the pole closest to the security room shall have a conduit run directly into the security room where the conduits shall stub up. The diameter of the conduit used for this run shall be sufficient to support all poles in that daisy chain. The conduit layout shall be designed to ensure that all poles, either directly or via daisy chain, stub up into the security room.

TABLE 14H – SURFACE PARK-N-RIDE CAMERAS

Surface park-n-ride			
Vehicle spaces	Vehicle entrance	Vehicle exit	Pan-tilt-zoom color camera*
1 fixed color camera per 25 vehicle spaces	1 pan-tilt-zoom color camera per vehicle entrance lane	1 pan-tilt-zoom color camera per vehicle exit lane	Minimum of 1 camera, than 1 camera per 250 spaces

*In addition to the network of fixed cameras, each park-n-Ride shall have a minimum of one pan-tilt-zoom color camera, then 1 additional camera per 250 vehicle spaces.

All camera locations will be presented to RTD's Security Systems Administrator for review and acceptance.

The video surveillance system shall be consistent with existing RTD equipment including digital video recorders, switches, routers, cameras and operating system. The system shall be capable of providing real time video (30 full frames per second per camera) at RTD's Security Command Center. The system shall record images consistent with RTD's existing system at 15 full frames per second per camera, and shall provide recorded archive storage of two weeks (14 days) at 15 full frames per second per camera.

14.11.0 EMERGENCY TELEPHONES

The design shall incorporate emergency telephones into the project. The emergency telephones shall be consistent with existing RTD units and meet performance requirements of RTD's existing emergency telephone network. The design shall incorporate emergency telephones covering station platforms, elevator waiting areas, stairwell entries, parking structures, park-n-Rides, pedestrian tunnels and pedestrian bridges. Emergency telephones shall be placed as follows.

TABLE 14I – EMERGENCY TELEPHONES AT STATIONS

Single level at grade station platform*	
Platform type	Emergency telephones
Center platform	1
Side/ center platform	1
Side/Side platform	2
Triple platform (side with two centers)	2

* For stations with vertical circulation, one additional emergency telephone shall be placed per floor.

TABLE 14J - EMERGENCY TELEPHONES AT PARKING STRUCTURES

Parking Structure	
Elevator waiting area*	Stairwell entrance area*
1 emergency telephone per waiting area per floor	1 emergency telephone per stairwell entrance area per floor (if two stairwells, then 2 ET's per floor, etc.)

Subject to approval by the RTD Security Systems Administrator, if the design accommodates the elevator waiting area and stairwell entrance being adjacent to one another, a single emergency telephone may be used for that location.

For surface park-n-Rides, a minimum of one emergency telephone shall be placed in the design, and then one additional emergency telephone per each 300 spaces.

If pedestrian overpasses or underpasses are incorporated into design, a minimum of one emergency telephone shall be provided for each overpass/underpass. If the overpass or bridge is isolated from other transit elements, additional emergency telephones may be necessary.

The emergency telephone when activated shall connect to 911 and also send notification and audible listening capability to RTD rail control and RTD Security Command Center.

Installed Emergency Telephones shall be constructed pursuant to a minimum NEMA 3R rating (see below) and be Underwriter Laboratory and FCC approved and ADA compliant. The phones shall draw power from the phone line and require no additional power line attachments. The phones shall be capable of off-site live monitoring of emergency conversations. The emergency phones shall be part of a networked management system that is operated by a PC, XP Windows compatible or newer. The software management system will:

- Establish an automatic connection with each phone on a prearranged schedule. Phones will be tested at least one time in every twenty-four hours. The connection shall be initiated either by the PC or the telephone.
- Print an exception report at designated intervals highlighting use and malfunctions.
- Archive and maintain all reporting both of normal functioning and malfunctions.
- Log and archive all call activity at each phone.
- Identify all call activity by date and time, type of activity, and location of data within memory.
- Establish Automatic Maintenance Monitoring which reports stuck buttons, power interruption, microprocessor testing, call interrupt, handset integrity and functioning, handset off hook notification and phone line current.

NEMA 3R – Enclosures constructed for either indoor or outdoor use to provide a degree of protection to personnel against incidental contact with the enclosed equipment; to provide a degree of protection against falling dirt, rain, sleet, snow, and that will be undamaged by the external formation of ice on the enclosure. Phones will operate in a temperature range of -40˚C to +60˚C.

All emergency telephone locations will be presented to RTD's Security Systems Administrator for review and acceptance.

14.12.0 CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN

The design shall incorporate Crime Prevention Through Environmental Design (CPTED) strategies to the entire design. The purpose of CPTED is to minimize potential threats and vulnerabilities to the transit system, facilities and patrons and maximize safety and security through engineering and design. Good CPTED strategies include: maximizing visibility of people, parking areas, patron flow areas and building/structure areas; providing adequate lighting minimizing shadows; graffiti guards; Mylar shatter guard protection for glass windows; landscape plantings that maximize visibility; gateway treatments; decorative fencing; perimeter control; fencing; minimizing park-n-ride and parking structure access points; elimination of structural hiding places; open lines of sight; visible stairwells and elevators meaning the exterior walls are constructed of transparent material; and painting with light.

Examples of CPTED strategy include:

- Adequate lighting of all areas appropriate for their use including perimeter lighting in park-n-Rides so the edge of the park-n-Ride is illuminated the same as the rest of the park-n-Ride (refer to station design criteria for lighting levels).
- When using shrubs, use species with a maximum height or spread that will minimize visibility obstructions. The preliminary design shall be approved by RTD prior to final design and implementation.
- When using trees, use deciduous trees with branches no lower than six feet from ground surface.

The design shall incorporate CPTED strategies into the Threat and Vulnerability Analysis and Resolution process described in the following section, 14.13.0 Threat and Vulnerability Analysis and Resolution.

14.13.0 THREAT AND VULNERABILITY ANALYSIS AND RESOLUTION

The design shall incorporate a Threat and Vulnerability Analysis and Resolution process in accordance with the minimum criteria outlined in this section. A risk assessment is a comprehensive study of a system to identify those components most vulnerable to disruption or destruction and to assess the likely impact that such disruption or destruction would have on passengers, employees, and the RTD system. Threat and vulnerability analysis (TVA) work shall begin upon project initiation and continue throughout the project. The design shall incorporate TVA progress reports according to a mutually agreeable schedule. The design shall include a draft and final TVA report on the preliminary engineering. The TVA document itself is a living document, which must be revised and updated as the system design and development progresses. It becomes the input document and information for all other TVA performed on the system.

The process shall assign values to design elements based on their criticality to the transit system operations. The four level risk classification system listed below will be used to assess risk levels.

14.13.1 Severity Categories

See Section 14.3.1, Hazard Severity Definitions.

14.13.2 Transit Risk Assessment Levels

TABLE 14J - TRANSIT RISK ASSESSMENT LEVELS

Category	Characteristic
1	Loss of life, loss of critical information, loss of critical assets, significant impairment of mission, loss of system
2	Severe injury to employee or other individual, loss of information and physical equipment resulting from undetected or unacceptable mission delays, unacceptable system and operations unauthorized access, disruption
3	Minor injury not requiring hospitalization, undetected or delay in the detection of unauthorized entry resulting in limited access to assets or sensitive materials, no mission impairment, minor system and operations disruption
4	Less than minor injury, undetected or delay in the detection of unauthorized entry system or operations disruption

14.13.3 Probability Categories

TABLE 14K – PROBABILITY CATEGORIES

Category	Level	Specific Event
A	Certain	Possibility of Repeated Incidents
B	Highly Probable	Possibility of Isolated Incidents
C	Moderately Probable	Possibility of Occurring Sometime
D	Improbable	Practically Impossible

The design shall incorporate a risk and vulnerability assessment to determine any potential hazards or high-risk areas. The table below is an example of the type of assessment to determine risk and vulnerability.

TABLE 14L - ASSESSMENT OF RISK & VULNERABILITY (RAIL)

Public Transportation Assets	Criticality People	Criticality System
Transit Centers & Stations	High	Potentially High[2]

Rail		
Track/Track Structure/Signals	Low	Potentially High[2]
Cars	High [1]	
Maintenance Yards	Low	Medium
Switching Stations	Low	Medium
Electric Power		
Source for System	Medium	High
Substations	Low	Medium
Command Control Center	Low[3]	High
Revenue Collection Center	Low[3]	Medium
Bridges	Medium	Medium[2]
Tunnels	Medium	Medium[2]
Fans	Low	Medium
Vents	Low	Medium
Emergency Hatches	Low	Medium

TABLE 14M - ASSESSMENT OF RISK & VULNERABILITY (BUS)

Public Transportation Assets	Criticality People	Criticality System
Bus Terminals	High [1]	Potentially High[2]
Bus Vehicles	High [1]	Low
Bus Stops/Shelters	Medium	Low
Maintenance Garages	Low[3]	Medium
Fuel Storage Facility	Low	High
Command Control Center	Low[3]	High
Revenue Collection Center	Low[3]	Medium

[1]Depends on what time of day incident occurs. Greater impact would be experienced during rush hour than non-rush hours

[2]Depends on location in the system where an incident occurs. An incident at a crossover or main junction would have greater impact than one at an outlying station or track segment. Also depend on the alternatives available, such as redundancies, rerouting capabilities, and other factors.

[3]Affects employees only

The design process shall identify any threats that have been located. These identified threats could include,

- Criminal Activity
- Terrorism
- Natural disasters
- Emergency Response

Identified risks and hazards shall be resolved to acceptable levels. The matrix below provides a source for mitigating hazards based on frequency of occurrence and severity. The matrix condenses risk resolution into a table and prioritizes the risks that are evaluated.

TABLE 14N – SEVERITY OF LOSS

Assessed Rating	Probability of Loss	1 Catastrophic	2 Very Serious	3 Moderately Serious	4 Not Serious
A	Certain				
B	Highly Probable				
C	Moderately Probable				
D	Improbable				

	1A. 1B. 1C. 2A.	Unacceptable: Implement Countermeasures to Reduce
	2D. 2C. 2D. 3B.	Acceptable with Management Review
	3D. 4A. 4B. 4C.	Acceptable

The design shall present several options to the RTD in order to decrease the hazards located in the assessment. These options shall be based on the system security precedence:

- Design the system to eliminate the risk
- Design the system to control the risk

- Add safety or security devices to control the risk
- Add warning devices to control the risk, and
- Institute special procedures or training to control the risk.

14.14.0 PARK-N-RIDES, PARKING STRUCTURES, AND ENCLOSED UNDERGROUND OR BELOW GRADE TRANSIT FACILITIES

14.14.1 Surface park-n-Rides

In addition to the items already listed in this chapter, design for surface park-n-Rides shall consider safety and security of patrons and the protection of property. Park-n-Ride design shall incorporate good visibility throughout the park-n-Ride, and good visibility from surrounding streets into the park-n-Ride for patrols by law enforcement and security personnel.

The use of landscaping shall consider maximizing visibility and eliminating hiding places and shadows. Shrubs shall not impede visibility in height and trees shall bear no branches below 6 feet from ground surface. Evergreen trees shall only be used on a limited basis and shall be placed in such a manner that hiding spaces and visual obstructions are not created. Landscape placement shall be subject to approval by the RTD Security Systems Administrator.

Adequate and appropriate lighting is the single most effective deterrent for minimizing crime at park-n-Rides. Lighting shall be provided in accordance with the criteria provided in the stations chapter. The design shall address perimeter lighting by including placement of light poles around the perimeter of the park-n-Ride.

The control and design of park-n-Ride entrances and exits is important to maintaining security of park-n-Rides. Entrances and exits shall be limited to as few as practically possible to control access and egress from the park-n-Ride site and minimize the number of entrance and exit cameras. To compliment the effective use of video surveillance, traffic calming features (i.e. speed bumps) shall be considered at entrances and exits on a case-by-case basis to slow the vehicles as they enter and exit to allow adequate time for automobile license plates to be captured by video surveillance. Where speed bumps are used for these purposes, they shall include two speed bumps separated by one and one half standard vehicle lengths.

14.14.2 Parking Structures

In addition to the items already listed in this chapter, design for parking structures shall consider safety and security of patrons and the protection of property. Parking structure design shall incorporate good visibility throughout the structure, and good visibility from surrounding streets into the structure for patrols by law enforcement and security personnel. Walls inside the structure shall be limited to increase visibility and minimize hiding places throughout the structure. Openings in interior walls between levels or ramps shall be protected by mesh or chain link fencing. Openings in exterior walls at the ground level and at below grade level shall be protected by mesh, chain link fence or other treatment to prevent pedestrians from entering or exiting the structure through these openings.

The control and design of parking structure entrances and exits is important to maintaining security of the structures. Entrances and exits shall be limited to as few as practically possible to control access and egress from the structure and minimize the number of entrance and exit cameras.

Stairwell and elevator design shall maximize the interior visibility of the stairwell, elevator and elevator shaft. Materials of wall construction for these elements shall be transparent such as glass and allow visibility from at least three sides.

Each parking structure shall include a security room/office for security or law enforcement personnel.

Parking structures shall have minimum lighting levels of 10 foot candles.

14.14.3 Underground and Below Grade Transit Facilities

Enclosed, underground and below grade transit facilities present unique security design challenges. Design of these facilities shall maximize patron safety and security by the inclusion of counterterrorism measures. Each enclosed, underground or below grade facility shall be covered by video surveillance including: its perimeter; portals, entrances and exits; its interior; and fare vending areas. Patron station areas in these facilities shall be designed as paid fare zones. Thus, patron circulation design shall consider the availability to purchase fare media prior to entering the paid fare zones.

Where facilities serve more than one mode of transportation, the design shall incorporate a means to physically separate modal areas using automatic doors. Each modal area shall also have a separate ventilation system. This design shall allow one modal area to operate in the event of a major incident occurring in an adjacent modal area and prevent cross contamination.

Facility access control is an important aspect of design and shall be designed as follows. All access points (entrances and exits) to the facility and all interior doors shall be controlled by proximity reader access control. The proximity reader access control system shall be a Lenel system as currently installed at RTD facilities and shall be networked into the existing system. All access points or portals capable of accommodating a motor vehicle shall be equipped with automatic portal protection that will prevent unauthorized vehicles from entering the facility. The portal protection shall have a K-12 rating, shall include a guard shack, and shall be located at a minimum distance of 150 feet from the facility entry portal. Portals for train access shall include intrusion detection capable of distinguishing between an authorized train and any other unauthorized vehicle or person attempting to gain access through the train portal. Intrusion detection alarm notification shall be sent to rail central control and RTD Security Command Center. The facility design shall incorporate a means to establish a vehicle checkpoint at a minimum distance of 150 feet from each facility vehicle entry portal.

The design shall protect the facility from progressive collapse. In the event of an internal explosion, the design shall prevent progressive collapse due to the loss of one primary column. Column design shall consider sizing, reinforcement or protection so that the threat charge will not cause the column to be critically damaged.

Loading docks and shipping/receiving areas are prohibited in underground and below grade facilities. All deliveries shall be accommodated for at the exterior of the facility above grade.

Each enclosed, underground or below grade facility shall include a security room/office for security or law enforcement personnel.

14.15.0 PUBLICLY ACCESSIBLE RECEPTACLES

Publicly accessible receptacles are any receptacle with a void space that the public can access. Examples include but are not limited to trash receptacles, bike lockers, and newsracks. Placement of publicly accessible receptacles shall be subject to threat and vulnerability analysis and shall not be placed within 250 feet of a station, station area or patron gathering area for outside locations. An exception is the use of an explosion resistant trash receptacle. An explosion resistant trash receptacle shall be capable of containing an explosion of four (4) pounds of TNT or the C4 equivalent and shall be third party tested or certified. For enclosed areas, underground, or below grade transit stations, facilities, structures and tunnels, placement of publicly accessible receptacles is strictly prohibited. In parking structures, placement of publicly accessible receptacles is strictly prohibited.

14.16.0 CONFIGURATION MANAGEMENT

Any change or deviation to this design criteria must be approved by RTD's Executive Safety and Security Committee. All project design shall be reviewed and accepted through a signature process by the following personnel: Assistant General Manager, Rail Operations; Sr. Manager of Engineering; and Manager, Public Safety. The signature review and acceptance procedure shall be applied at each design phase or milestone. Any change to an accepted design, shall also be subject to a signature review and acceptance process by the same personnel.