ASCE STANDARD

ANSI/
ASCE/T&DI
21.3–08

Automated People Mover Standards—Part 3

Electrical
Stations
Guideways

This document uses both the International System of Units (SI) and customary units

ASCE

Approved American National Standard
ANSI

T&DI
Transportation and Development Institute

ASCE STANDARD ANSI/ASCE/T&DI 21.3-08

American Society of Civil Engineers

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STANDARDS

In 2003, the Board of Direction approved the revision to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by the Society. All such standards are developed by a consensus standards process managed by the Society's Codes and Standards Committee (CSC). The consensus process includes balloting by a balanced standards committee made up of Society members and nonmembers, balloting by the membership of the Society as a whole, and balloting by the public. All standards are updated or reaffirmed by the same process at intervals not exceeding five years.

The following standards have been issued:

ANSI/ASCE 1-82 N-725 Guideline for Design and Analysis of Nuclear Safety Related Earth Structures
ASCE/EWRI 2-06 Measurement of Oxygen Transfer in Clean Water
ANSI/ASCE 3-91 Standard for the Structural Design of Composite Slabs and ANSI/ASCE 9-91 Standard Practice for the Construction and Inspection of Composite Slabs
ASCE 4-98 Seismic Analysis of Safety-Related Nuclear Structures
Building Code Requirements for Masonry Structures (ACI 530-02/ASCE 5-02/TMS 402-02) and Specifications for Masonry Structures (ACI 530.1-02/ASCE 6-02/TMS 602-02)
ASCE/SEI 7-05 Minimum Design Loads for Buildings and Other Structures
SEI/ASCE 8-02 Standard Specification for the Design of Cold-Formed Stainless Steel Structural Members
ANSI/ASCE 9-91 listed with ASCE 3-91
ASCE 10-97 Design of Latticed Steel Transmission Structures
SEI/ASCE 11-99 Guideline for Structural Condition Assessment of Existing Buildings
ASCE/EWRI 12-05 Guideline for the Design of Urban Subsurface Drainage
ASCE/EWRI 13-05 Standard Guidelines for Installation of Urban Subsurface Drainage
ASCE/EWRI 14-05 Standard Guidelines for Operation and Maintenance of Urban Subsurface Drainage
ASCE 15-98 Standard Practice for Direct Design of Buried Precast Concrete Pipe Using Standard Installations (SIDD)
ASCE 16-95 Standard for Load Resistance Factor Design (LRFD) of Engineered Wood Construction
ASCE 17-96 Air-Supported Structures
ASCE 18-96 Standard Guidelines for In-Process Oxygen Transfer Testing
ASCE 19-96 Structural Applications of Steel Cables for Buildings
ASCE 20-96 Standard Guidelines for the Design and Installation of Pile Foundations
ANSI/ASCE/T&DI 21-05 Automated People Mover Standards—Part 1
ASCE/T&DI 21.2-08 Automated People Mover Standards—Part 2
ANSI/ASCE/T&DI 21.3-08 Automated People Mover Standards—Part 3
ANSI/ASCE/T&DI 21.4-08 Automated People Mover Standards—Part 4
SEI/ASCE 23-97 Specification for Structural Steel Beams with Web Openings
ASCE/SEI 24-05 Flood Resistant Design and Construction
ASCE/SEI 25-06 Earthquake-Actuated Automatic Gas Shutoff Devices
ASCE 26-97 Standard Practice for Design of Buried Precast Concrete Box Sections
ASCE 27-00 Standard Practice for Direct Design of Precast Concrete Pipe for Jacking in Trenchless Construction
ASCE 28-00 Standard Practice for Direct Design of Precast Concrete Box Sections for Jacking in Trenchless Construction
ASCE/SEI/SFPE 29-05 Standard Calculation Methods for Structural Fire Protection
SEI/ASCE 30-00 Guideline for Condition Assessment of the Building Envelope
SEI/ASCE 31-03 Seismic Evaluation of Existing Buildings
SEI/ASCE 32-01 Design and Construction of Frost-Protected Shallow Foundations
EWRI/ASCE 33-01 Comprehensive Transboundary International Water Quality Management Agreement
EWRI/ASCE 34-01 Standard Guidelines for Artificial Recharge of Ground Water
EWRI/ASCE 35-01 Guidelines for Quality Assurance of Installed Fine-Pore Aeration Equipment
CI/ASCE 36-01 Standard Construction Guidelines for Microtunneling
SEI/ASCE 37-02 Design Loads on Structures During Construction
CI/ASCE 38-02 Standard Guideline for the Collection and Depiction of Existing Subsurface Utility Data
EWRI/ASCE 39-03 Standard Practice for the Design and Operation of Hail Suppression Projects
ASCE/EWRI 40-03 Regulated Riparian Model Water Code
ASCE/SEI 41-06 Seismic Rehabilitation of Existing Buildings
ASCE/EWRI 42-04 Standard Practice for the Design and Operation of Precipitation Enhancement Projects
ASCE/SEI 43-05 Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities
ASCE/EWRI 44-05 Standard Practice for the Design and Operation of Supercooled Fog Dispersal Projects
ASCE/EWRI 45-05 Standard Guidelines for the Design of Urban Stormwater Systems
ASCE/EWRI 46-05 Standard Guidelines for the Installation of Urban Stormwater Systems
ASCE/EWRI 47-05 Standard Guidelines for the Operation and Maintenance of Urban Stormwater Systems
ASCE/SEI 48-05 Design of Steel Transmission Pole Structures

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FOREWORD

The Board of Direction approved revisions to the ASCE Rules for Standards Committees to govern the writing and maintenance of standards developed by ASCE. All such standards are developed by a consensus standards process managed by the ASCE Codes and Standards Committee (CSC). The consensus process includes balloting by a balanced standards committee, and reviewing during a public comment period. All standards are updated or reaffirmed by the same process at intervals of between five and ten years.

This standard is Part 3 of the four-part Automated People Mover Standards, which establish the minimum set of requirements necessary to achieve an acceptable level of safety and performance for an Automated People Mover (APM) system. An APM is defined as a guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way.

Parts 1, 2, and 3 cover requirements for design of an APM system while Part 4 covers requirements for an APM in passenger operation. Part 3 contains sections covering electrical, stations, and guideways.

The ASCE Automated People Movers Standards Committee has been developing these standards since 1991. The committee comprises individuals from many backgrounds, including consulting engineering, research, transit agencies, airports, transit system design and manufacturing, education, government, and private practice.

This standard establishes the minimum set of requirements necessary to achieve an acceptable level of safety and performance for an APM system. As such, it may be used in the safety certification process. The overall goal of this standard is to assist the industry and the public by establishing standards for APM systems.

This standard has no legal authority in its own right but may acquire legal standing in one or more of the following ways:

1. Adoption by an authority having jurisdiction.
2. Reference to compliance with the standard as a contract requirement.
3. Claim by a manufacturer or manufacturer's agent of compliance with the standard.

This standard will be beneficial to transportation engineers, civil engineers, safety engineers, and contractors of APM systems. Anyone who owns, operates, builds or maintains, designs, tests, insures, oversees, or certifies APMs or other innovative technology transit systems such as magnetic levitation, air cushion, and monorail systems will also benefit from the standard.

This standard has been prepared in accordance with recognized engineering principles and should not be used without the user's competent knowledge for a given application. The publication of this standard by ASCE is not intended to warrant that the information contained therein is suitable for any general or specific use, and ASCE takes no position respecting the validity of patent rights. The user is advised that the determination of patent rights or risk of infringement is entirely their own responsibility.

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This standard was prepared through the consensus standards process by balloting in compliance with procedures of ASCE's Codes and Standards Activity Council. Those individuals who serve on the Automated People Mover Standards Committee are:

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WG1—General, Robert Good; Reaffirmation, Michael Shumack and Thomas McGean

WG2—Definitions, Edward S. Neumann; Reaffirmation, Thomas McGean

WG12—Electrical, Joseph Abbas; Reaffirmation, Joseph Abbas with Alex Inserto

WG4—Stations, William Hathaway, J. Sam Lott, Jimmy Fletcher, and Thomas McGean; Reaffirmation, Jimmy Fletcher with William Hathaway

WG8—Guideways, Reuben Beebe, David Campbell, Jimmy Fletcher, Robert Griebenow, Jim Harper, J. Sam Lott, and William Hathaway; Reaffirmation, Robert Griebenow with William Hathaway

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CONTENTS

Automated People Mover Standards—Part 3

1. GENERAL

1.1 SCOPE

This standard has been divided into four parts to expedite the approval and release process as well as to facilitate ease of use. This document constitutes Part 3 of the standard.

Parts 1, 2, and 3 cover a minimum set of requirements for design of an Automated People Mover (APM) with an acceptable level of safety and performance.

Part 1 consists of:

1. General
2. Operating Environment
3. Safety Requirements
4. System Dependability
5. Automatic Train Control (ATC)
6. Audio and Visual Communications

Part 2 consists of:

1. General
7. Vehicles
8. Propulsion and Braking

Part 3 consists of:

1. General
9. Electrical
10. Stations
11. Guideways

Part 4 is a minimum set of requirements for maintaining an acceptable level of safety and performance for an APM in passenger operation. Part 4 consists of:

1. General
12. Security
13. Emergency Preparedness
14. System Verification and Demonstration
15. Operations, Maintenance, and Training
16. Operational Monitoring

The APM Standards all use SI units with equivalent English units provided in parentheses.

1.2 EXISTING APPLICATIONS

Existing installations and projects in progress before the effective date of this standard need not comply with the new or revised requirements of this edition, except where specifically required by the authority having jurisdiction. Existing APMs, when removed and reinstalled, shall be classified as new installations.

1.3 NEW APPLICATIONS

New installations begun after the effective date of this standard shall comply with the new or revised requirements of this edition.

1.4 REFERENCE STANDARDS

The following documents or portions thereof are incorporated by reference in this standard:

AASHTO: American Association of State Highway and Transportation Officials, Suite 249, 444 North Capitol Street NW, Washington, DC 20001; phone (202) 624-5806.

AASHTO LRFD Bridge Design Specifications, 4th edition, 2007 (cited in 11.9.1, 11.9.2, and 11.9.3)

AASHTO Standard Specifications for Highway Bridges, 17th edition, 2002 (cited in 11.9.1, 11.9.2, and 11.9.3).

ASCE: American Society of Civil Engineers, 1801 Alexander Bell Drive, Reston, VA 20191; phone (703) 295-6163.

ANSI/ASCE/T&DI 21-05, *Automated People Mover Standards—Part 1* (cited in 9.1.3, 9.1.4, 9.1.4.2, 9.1.5, 9.2.3, 9.2.4, 9.2.5, 9.2.6, 9.2.8, 9.2.9, 9.5, 10.2, 10.2.1, 10.2.2, 10.2.3, 10.3, 10.5.1, 10.5.2, 11.1, 11.2, 11.3, 11.3.3, 11.8.1, 11.8.3, and 11.9.1)

ASCE/T&DI 21.2-08, *Automated People Mover Standards—Part 2* (cited in 9.1.4, 9.1.8, 10.1.1, 10.2.1, 10.2.2, 10.2.3, 11.8 11.8.1, and 11.9.3)

ANSI: American National Standards Institute, Customer Service, 25 West 43rd Street, 4th floor, New York, NY 10036; phone (212) 642-4980.

ANSI B77.1-2006, *Passenger Ropeways, Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors—Safety Requirements* (cited in 11.0)

ANSI Z97.1-2004, *Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test* (cited in 10.2.1 and 10.2.2)

ANSI 117.1-2003, *Guidelines for Accessible and Useable Buildings and Facilities* (cited in 11.5)

ASTM: American Society of Testing Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959; phone (610) 832-9585.

ASTM D635-06, *Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position* (cited in 9.3.6)

ASTM C1036-06, *Standard Specification for Flat Glass* (cited in 10.2.1 and 10.2.2)

ASTM C1048-04, *Standard Specification for Heat Treated Flat Glass* (cited in 10.2.1 and 10.2.2)

Code of Federal Regulations: U.S. Government Printing Office, Superintendent of Documents, 732 North Capitol Street NW, Washington, DC 20401; phone (202) 512-1800.

16 CFR 1201, *Consumer Product Safety Commission Standard on Architectural Glazing Materials* (cited in 10.2.1 and 10.2.2)

IEEE: Institute of Electrical and Electronics Engineers, Inc., 3 Park Avenue, New York, NY 10016-5997; phone (800) 678-4333.

IEEE Standard 242, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems*, Section 1.0, First Principles (cited in 9.1.3)

IEEE Standard 519-1992, *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems* (cited in 9.2.3)

IEEE Standard 142-1991 (ANSI C114.1-1991), *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems* (cited in 9.1.4.1)

NACE: National Association of Corrosion Engineers, 1440 South Creek Drive, Houston TX 77084; phone (281) 228-6200.

NACE Standard RP0169-2002, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems* (cited in 9.1.2)

NFPA: National Fire Protection Association, Customer Service Department, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101; phone (800) 344-3555.

NFPA 70, 2005 edition, *National Electrical Code* (cited in 9.1.4.2, 9.2.9, and 9.4)

NFPA 101, 2006 edition, *Life Safety Code* (cited in 10.4)

NFPA 130, 2007 edition, *Fixed Guideway Transit and Passenger Rail Systems* (cited in 9.1.1, 9.2.9, 10.4, 10.5.2, 10.5.3, 11.1, 11.3, 11.3.1, 11.3.2, 11.3.3, 11.4, 11.5, 11.6, and 11.7)

1.5 DEFINITIONS

Automated People Mover (APM): A guided transit mode with fully automated operation, featuring vehicles that operate on guideways with exclusive right-of-way.

Automatic Train Control (ATC): The system for automatically controlling train movement, enforcing train safety, and directing train operations. ATC includes subsystems for automatic train operation (ATO), automatic train protection (ATP), and automatic train supervision (ATS).

Automatic Train Operation (ATO): The subsystem within the ATC system that performs any or all of the functions of speed regulation, programmed stopping, door and dwell time control, and other functions otherwise assigned to the train operator.

Automatic Train Protection (ATP): The subsystem within the ATC system that provides the primary protection for passengers, personnel, and equipment against the hazards of operations conducted under automatic control.

Automatic Train Supervision (ATS): The subsystem within the ATC system that monitors and manages the overall operation of the APM system and provides the interface between the system and the central control operator.

Bogie: The bogie consists of the elements which transmit lateral, longitudinal, and vertical loads between the guideway and the carbody. Bogies are also referred to as “trucks”.

Braking, Emergency: Irrevocable braking to a complete stop at a rate never less than the minimum guaranteed rate.

Braking, Service: Braking of vehicle motion at a rate regarded as comfortable for repeated use in service stopping and/or slowing.

Carbody: The structural body shell, enclosing the passenger compartment(s).

Central Control: That location where ATS is accomplished for the entire transit system; the train command center

Central Control Operator: Any person authorized to operate the APM system from central control.

Consist: The makeup or composition (number and specific identity) of a train of vehicles.

Cosmetic Damage: Damage that does not impair system function, performance, safety, or structural integrity.

Dwell Time: The total time the train services the station, measured as the time from the door open command to the time the doors are closed and locked.

Dynamic Sign: A sign on which the messages can be changed.

Fail-Safe: A characteristic of a system or its elements whereby any failure or malfunction affecting safety will cause the system to revert to a state that is known to be safe.

Failure: Inability to perform an intended function.

Free Field: An isotropic, homogeneous sound field that is free from all bounding surfaces.

Guideway: A track or other riding surface (including supporting structure) that supports and physically guides transit vehicles specially designed to travel exclusively on it.

Hazard: An existing or potential condition that can result in an accident.

Headway: The time separation between two trains, both traveling in the same direction on the same guideway, measured from the time the head end of the leading train passes a given reference point to the time the head end of the train immediately following passes the same reference point.

Interlock: An arrangement of control elements so interconnected that their operations must succeed each other in proper sequence.

Jerk: The time rate of change of acceleration or deceleration.

MTBHE: Mean time between hazardous events. (ANSI/ASCE/T&DI 21-05, Section 3.4, Table 3-1)

Operating Loads: Definitions of operating loads are presented in ASCE/T&DI 21.2-08, Section 7.4.4.1.1, as lateral loads, vertical loads, and longitudinal loads.

Overspeed: Train speed that is in excess of the speed limit as defined for the relevant point on the guideway.

Overtravel: Continued movement of a train beyond a specified stopping point.

Passenger Compartment: If a vehicle is divided into separate areas between which passengers are either unable or not permitted to move, each such area is defined as a passenger compartment. If the vehicle is not so divided, the entire carbody is the passenger compartment.

Permissive Decision: Granting permission or authority for the system or a part of the system to enter any state other than the safe state.

Risk: A measure of the severity and likelihood of an accident.

Safe State: System state that is deemed acceptable by the hazard resolution process (ANSI/ASCE/T&DI 21-05, Section 3.1.2).

Safety Critical: A designation placed on a system, subsystem, element, component, device, or function denoting that satisfactory operation of such is mandatory to mitigate unacceptable and undesirable hazards as defined in ANSI/ASCE/T&DI 21-05, Section 3.4, Table 3-1.

Separation: The distance between the adjacent ends of two trains traveling along the same guideway, as measured along the guideway centerline.

Shall: In this standard, the word “shall” denotes a mandatory requirement.

Should: In this standard, the word “should” denotes a recommendation.

Slow-Speed People Movers: Defined as those particular site applications in which all vehicles travel no more than 32 km/h (20 mph) at any location on their route during normal operation.

Subsystem: A major functional subassembly or grouping of items or equipment that is essential for operational completeness of a system

System: A composite of people, procedures, facilities, and/or equipment that are integrated to perform a specific operational task or function within a specific environment.

System Dependability: The overall set of criteria used to measure the performance of an operating system in terms of reliability, maintainability, and availability.

System Safety: The application of engineering and management principles, criteria, and techniques to optimize all aspects of safety within the constraints of operational effectiveness, time, and cost throughout all phases of the system life cycle.

Tabletop drill: A simulation/theoretical drill where personnel carry out their functions by discussion.

Train: A consist of one or more contiguous vehicles combined into an operating unit.

Vehicle: The smallest unit that can operate alone or that comprises one of the basic building blocks of a train.

Zero Speed: A specified speed below which ATC considers a train to be stopped.

9. ELECTRICAL EQUIPMENT

9.1 GENERAL

The following requirements shall apply to all APM electrical equipment.

9.1.1 Safety

Passengers, operations and maintenance personnel, and emergency response personnel shall be protected from contact with voltages that could result in injury or death.

Blue light stations shall be provided as defined in Section 6.2.7, *Fixed Guideway Transit and Passenger Rail Systems*, NFPA 130, 2007 edition.

9.1.2 Corrosion Control

To avoid deterioration of buried metallic structures, stray current protective measures shall maintain stray earth currents within acceptable ranges by maintaining a minimum negative return rail to ground isolation resistance per 9.3.8 and complying with the requirements of *Control of External Corrosion on Underground or Submerged Metallic Piping,* NACE Standard RP0169-2002. For direct current (DC) traction systems, a means for testing shall be provided on all electrically bonded system structures to measure and monitor stray currents.

When required, cathodic protection shall consider the presence of anaerobic bacteria, the need for mutual protection schemes, limitations of cathodic potential inaccessibility after construction is completed, and a means for testing.

9.1.3 Electrical System Protection

Automatic protection of fault, overcurrent, reverse current, overvoltage, undervoltage, lockout, ground fault, and phase sequence, as applicable to alternating current (AC) or direct current (DC) power distribution systems, shall be provided. The protection system shall be selective, i.e., all protective devices shall be coordinated so that any fault or overcurrent condition results in tripping of the smallest isolatable portion of the system and as per the recommendations of Section 1.0, First Principles, of IEEE Standard 242-2001, *Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.*

Phase imbalance and other relays susceptible to harmonics shall include harmonic filters to permit application of the most sensitive recommended settings. All equipment and circuits shall be surge- and ground-fault protected.

The system shall incorporate a ground-fault circuit interrupter or other device intended for the protection of personnel. The ground-fault device shall functionally de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds some predetermined value. This activation current value shall be less than that required to operate the overcurrent protective device of the supply circuit. Automatic tripping of any circuit breaker shall have an indication and trigger an alarm at Central Control. Lightning protection shall be provided in accordance with ANSI/ASCE/T&DI 21-05, Section 2.1.4.

9.1.4 Grounding

This section provides requirements for grounding of the APM system. Additional grounding requirements associated with equipment operations are contained in ASCE/T&DI 21.2-08, Section 7.12.5.

Grounding systems shall protect equipment from damaging voltages and currents and be designed to prevent electrical shock hazards. The focus of the requirements contained herein is safety, and additional grounding requirements for protection of microprocessor devices or other equipment shall be considered as required. Electrical hazards shall be assessed through a hazard analysis performed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.

9.1.4.1 Traction Power Grounding

A non-current-carrying ground rail shall be provided to afford proper continuous grounding of the vehicle. This ground resistance to earth shall not exceed 5 ohms when measured in accordance with *IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems*, IEEE Standard 142-1991, Section 4.4.

For DC traction power distribution systems, the current-carrying return shall have no more that one single-point ground on the APM system. Cathodic protection shall be provided at this single-point ground to protect other structures and utilities in the regions of the ground.

Under conditions of worst-case operating current and/or vehicle fault current, the traction power grounding system shall not permit a voltage (touch potential) greater than 60 volts to appear anywhere on the vehicle when measured between earth ground and the vehicle or any adjacent station platform, metallic enclosure, or metallic guideway structure. Also, under conditions of worst-case fault current, the system shall not permit a voltage of greater than 60 volts to appear on any enclosure when measured between the enclosure and its connection to the grounding electrodes in the substation.

For DC traction power distribution systems, deletion of the non-current-carrying ground rail may be considered if an alternative approach provides equivalent protection from leakage currents and electrical system faults. In this case, substations shall be provided with access to the negative bus for stray current monitoring, and the voltage, referenced to ground, in the main line negative return rails shall not exceed 60 volts. The voltage, referenced to ground, in the yard negative return rails shall not exceed 10 volts.

Maintenance shop tracks shall be electrically grounded to the shop building and shop grounding system. Shop tracks shall be electrically insulated from storage yard tracks. For DC single-point ground systems, the shop building ground shall be separated from the yard and mainline ground systems.

Temporary paralleling is allowed during train transition between shop tracks and yard or storage tracks.

9.1.4.2 Facilities and Structure Grounding

Grounding shall be provided for fixed facilities and structures in accordance with the *National Electrical Code*, NFPA 70, 2005 edition, Article 90-2, Subsection B. Grounding shall consist of a ground mat under the station or facility and shall be composed of a buried grid-and-rod system. Interconnection with steel piling and steel reinforcement shall be provided. A hazard analysis shall address the safety of electrical grounds during emergency evacuation situations per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

9.1.5 Redundancy

Sufficient redundancy shall be designed into the power distribution system so that no single-point electric power failure will preclude operations of the APM system. Degraded modes of operation are permitted. Failure of critical elements of the power distribution system shall be annunciated as specified in ANSI/ASCE/T&DI 21-05, Section 5.3.2.2.

NOTE: The service availability requirements in ANSI/ASCE/T&DI 21-05, Section 4.3 assume fully available primary power.

9.1.6 Design Life

Transformers, rectifiers, and all wiring and cables shall have a design life of 30 years unless explicitly specified by the owner. Power rails and all other non-consumable equipment shall have a design life of 15 years unless explicitly specified by the owner.

9.1.7 Voltage Regulation

The power distribution system shall be designed to maintain, under normal operating conditions, voltage regulation at a level such that specified system performance is met. Voltage regulation shall also ensure that the service life of the various motors onboard the vehicles is not degraded.

9.1.8 Capacity

The equipment, including feeder cables and power rails, shall be sized to withstand the peak loads encountered during start-up, normal, degraded, and recovery modes of operation of the ultimate fleet of vehicles planned for the system. The traction power substation equipment and associated power distribution wiring and equipment shall have a design duty cycle rating based on these operating conditions for vehicles loaded to an AW2 capacity, as defined in ASCE/T&DI 21.2-08, Section 7.1.

If the APM system is expected to grow in phases, not all equipment need be provided initially. However, the design should accommodate the future addition of equipment as the system is expanded.

9.2 TRACTION POWER SUBSTATION EQUIPMENT

Substation equipment shall be designed with the following interfaces and performance criteria.

9.2.1 Interfaces with the Local Utility Company

All electrical connections and equipment shall properly interface with the local utility company.

9.2.2 Power Factor

The system power factor, when averaged over any two-hour period, shall be at least 0.8 in lagging power factor conditions and shall not permit leading power factor conditions. This value may be achieved by the use of power factor correction equipment where necessary. The power factor shall be measured at the point of interface between the electric utility and the APM system. Coordination with the local utility company shall occur during system design.

9.2.3 Harmonics

The power conversion equipment and load elements within the system shall be designed so that the voltage distortion limits, at the point of common coupling between the electrical utility and the APM system, conform to the guidelines set forth in Table 11.1 of *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems,* IEEE Standard 519-1992. Electromagnetic background and radiation shall be in conformance with ANSI/ASCE/T&DI 21-05, Sections 2.1.8 and 2.2.3.

9.2.4 System Monitoring and Alarms

Indicating instruments shall be installed within each substation to display voltage, current, and power demands. Abnormal conditions shall be transmitted as an alarm to the Central Control per ANSI/ASCE/T&DI 21-05, Sections 5.3.2.2 and 5.3.3.3. As a minimum, the following conditions shall result in an alarm:

Overvoltage	Switchgear Local Mode (see 9.2.7)
Undervoltage	Overtemperature
Overcurrent	Loss of Phase
Ground Fault	Fire or Smoke

All transformers and rectifiers shall be provided with overtemperature sensors that activate alarms at the Central Control and cause automatic shutdown of the affected equipment at the preset temperature. Alarms shall be transmitted first at impending overtemperature; then with critical overtemperature accompanied by equipment shutdown.

9.2.5 Power Regeneration Equipment

Traction power regeneration may be specified. If specified, the system shall make efficient use of train regeneration capability. The system shall be designed to accommodate the worst-case overvoltage conditions associated with power regeneration at maximum vehicle speeds, loading, and train length. Provisions for regeneration shall prevent excessive voltage from being returned to the utility power source. If power regeneration is specified, the hazard of regenerating power into the de-energized power rail shall be analyzed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

9.2.6 Remote Monitoring and Control

The traction power substation shall be remotely monitored and controlled through the ATS system (see ANSI/ASCE/T&DI 21-05, Section 5.3.2.2 and Section 5.3.3.2, item 11). Monitoring shall include data logging (see ANSI/ASCE/T&DI 21-05, Section 5.3.3.4). All commands for power application and removal shall be logged, with time stamp.

9.2.7 Local Control

The power distribution equipment shall include provisions for local control (open/close) of the switchgear in addition to the remote control provisions cited above. Each separate switchgear element shall have a lockout switch allowing local control of the switchgear, locking out remote control when in local mode. Local mode shall be annunciated at Central Control.

9.2.8 Restoring Power

The power distribution equipment shall allow the main switchgear at the power substation to be closed both from Central Control and locally at the traction power substation, to re-energize the substation. Restoration of power shall be done in accordance with operational procedures.

Automatic reclosing of power distribution equipment shall be permitted only after thorough hazard analysis in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1. If implemented, the design shall provide for reclosing only when line testing verifies that the short-circuit condition does not exist.

9.2.9 Substation Facilities

Substation facilities and the structure housing the power distribution equipment shall be provided in accordance with the *National Electrical Code,* NFPA 70, 2005 edition. Traction power substation equipment shall provide its own auxiliary and control power.

A fire protection system shall be provided to detect the presence of and contain fire. Traction power substation design may be considered in combination with station design to provide fire-rating compliance, as approved by local fire authorities. Traction power substations shall comply with the requirements of Section 5.2.3.2 of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, and of ANSI/ASCE/T&DI 21-05, Section 5.3.3.3.2, Facility Fire and Intrusion Alarms.

9.3 WAYSIDE POWER COLLECTION

As the interface to onboard power collection equipment, wayside power collection equipment shall be provided in accordance with the following sections.

9.3.1 Guideway Mounted Power Distribution

The system providing power to the vehicle shall use rigid power rails or other means. The power rail system consists of the power rails, fastening means, expansion joints, protective covers, and other hardware. Power rails shall be electrically insulated from each other and from adjacent structures, as determined by the operating voltage. The location and method of mounting the power rails shall include consideration of the operating dynamic envelope of the vehicles.

The power rail system shall be sized for its current/voltage drop requirements and to provide structural strength for appropriate support spacing. The power rail system shall not be damaged by the electromagnetic forces developed during short-circuit conditions.

9.3.2 Power Zones

Where the power distribution system is sectionalized, the power feeding arrangements shall include sufficient flexibility to allow each section of the guideway to be powered even if power is removed from adjacent sections, so that degraded-mode operation can continue under failure conditions or maintenance outages. Power zones shall be coordinated with the blue light station design (see 9.1.1).

A single vehicle shall be able to bridge power gaps between zones to provide a continuous electrical supply at all times that the APM system is operational. An exception shall be made when two adjacent zones are electrically incompatible, in which case a non-bridgeable isolating gap shall be provided. A means shall be provided to prevent the accidental energizing of an unpowered section of guideway (e.g., during maintenance) which could be caused by bridging a power gap with a vehicle.

9.3.3 Splice Joint Requirements

The power rails and splice plates shall provide positive and rigid splice joints. The length, cross-sectional area, and profile of the splice plate or plates shall be designed to provide adequate heat dissipation surfaces to limit heat rise increases to no greater than 2°C (3.5°F) above the power rail temperature at its operating capacity.

9.3.4 Expansion Joints/Sections

Expansion joints/sections shall be provided to accommodate the thermal expansion and contraction of the power rails caused by changes in ambient temperature, heat rise of the conductor caused by electrical load, solar radiation effect, and guideway movement.

The expansion joint/section slider assembly shall be able to withstand electromagnetic forces encountered during short-circuit conditions. All jumpers providing electrical continuity shall have capacity equal to or greater than the power rail capacity.

9.3.5 Power Rail Transitions

If there are breaks in the guideway power rail, means shall be provided to facilitate smooth engagement and disengagement of current collector shoes at the train's rated speed.

9.3.6 Insulators

The surface of the insulating material shall be smooth, hard, UV-resistant, and rated either self-extinguishing or nonburning per ASTM D635-06, *Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position*.

Power conductor rails shall be protected from inadvertent contact.

9.3.7 Mounting

Power rails, if used, shall be solidly supported to prevent lateral or vertical motion, while allowing longitudinal movement necessary for thermal expansion.

9.3.8 Power Rail to Earth Resistance

Each conducting power rail of the guideway power distribution system shall have a minimum in-service effective resistance to earth of 1 megohm per 300 m (1 megohm per 1,000 ft) under all conditions.

For DC supply systems, negative return elements shall be designed to have a minimum in-service effective rail resistance to earth of 500 ohms per 300 m (1,000 ft) for a single track.

9.3.9 Power and Ground Rail Heating

Power and ground rail heating, if required, shall be provided with sufficient heat for local anticipated icing conditions. The heating system shall be segmented with each segment independently controlled.

9.4 PASSENGER STATION ELECTRICAL EQUIPMENT

Station equipment shall be designed so that housekeeping power and lighting distribution are provided from one location. Station communications and alarms, emergency lighting, and signage shall have back-up power. Typical loads to be supplied by the facilities electrical substation include ATC, uninterruptible power supply (UPS), communications, and other station equipment. The facilities electrical substation shall be designed in accordance with the *National Electrical Code*, NFPA 70, 2005 edition.

9.5 UNINTERRUPTIBLE POWER SUPPLY

Equipment requiring power, in the event that primary power is unavailable, shall be supported by UPS devices. Uninterruptible power shall be provided for at least the following functions:

- ATC (per ANSI/ASCE/T&DI 21-05, Section 5)
- Communications (all audio and visual, per ANSI/ASCE/T&DI 21-05, Section 6)
- Fire and other appropriate safety and security equipment
- Power distribution system control power at the substation

UPS equipment shall be sized to provide for all of the above functions for a period determined in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis.

10. STATIONS

The areas of the station addressed by this section include APM equipment spaces and passenger boarding and alighting platforms.

10.1 DISABLED PERSONS ACCESS REQUIREMENTS

This section presents disabled access requirements for the APM interface between the vehicle floor edge and the station platform edge. The specific requirements presented in this section focus on those areas applicable to the vehicle–platform gap and detectable warnings, and do not address those considered "architectural" concerns.

NOTE: Disabled access in the United States is subject to the *Americans with Disabilities Act of 1990,* and applicable federal regulations should be consulted.

10.1.1 Vehicle–Platform Gap

The vertical and horizontal vehicle–platform gap requirements are presented in ASCE/T&DI 21.2-08, Section 7.3.

10.1.2 Detectable Warning Strip

The platform edge between the guideway and station, if not protected by platform edge barriers, shall have a detectable warning. Such detectable warnings shall be 0.6 m (2 ft) wide and run the full length of the unprotected platform.

NOTE: In accord with the above, platform edges protected per items 1 or 2 of 10.2 do not require detectable warning strips. For item 3 of 10.2, detectable warning strips are required only at openings in the platform. For item 4 of 10.2, detectable warning strips are required to run the full length of the platform edge.

Detectable warning strips shall consist of raised truncated domes with a nominal diameter of 23 mm (0.9 in.), a nominal height of 5 mm (0.2 in.) and a nominal center-to-center spacing of 60 mm (2.35 in.) and shall contrast visually with adjoining surfaces, either light-on-dark or dark-on-light.

The material used to provide contrast shall be an integral part of the walking surface. Detectable warnings used on interior surfaces shall differ from adjoining walking surfaces in resiliency or sound-on-cane contact.

10.2 PLATFORM EDGE PROTECTION

A means of platform edge protection shall be provided to protect people from the potential hazard of being struck by a moving train or moving elements within the guideway, falling from the platform, shock, or electrocution.

Acceptable means of platform edge protection include the following:

1. *Intrusion prevention* through full-height solid barriers and automatic horizontal sliding doors (see 10.2.1).
2. *Intrusion control* through barriers with a minimum height of 1.1 m (42 in.), and automatic horizontal sliding doors or gates (see 10.2.2).
3. *Intrusion detection* in association with platform edge barriers (minimum height 1.1 m [42 in.]), with openings located at the doors of stopped vehicles. The openings shall be provided with an intrusion detection device that monitors the opening in the railings (see 10.2.3).
4. *Intrusion detection* using a system located in the guideway or along the platform edge for the entire station length of the platform (see 10.2.3).
5. Any other method that provides acceptable protection as approved by the authority having jurisdiction over the system and as demonstrated by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

For conditions in which a fall of more than 1.5 m (5 ft) from the station platform is possible, either intrusion prevention per item 1 or intrusion control per item 2 shall be required (see also 10.2.1 and 10.2.2).

For conditions in which passengers can extend limbs from vehicles through windows or other openings (reference ASCE/T&DI 21.2-08, Section 7.2), the means of platform edge protection shall be analyzed for these risks by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

10.2.1 Intrusion Prevention System

An intrusion prevention system consisting of station platform edge barriers and their associated doors, when provided, shall meet the following requirements:

1. Platform edge doors shall be compatible with the requirements of ANSI/ASCE/T&DI 21-05, Section 5.2.2, with height equal to or greater than that of the vehicle door opening.
2. The platform edge barriers, door assembly, supporting tracks, and linkages shall withstand a force of 1,110 N (250 lb) applied at right angles to and approximately at the center of a panel, distributed over an area of approximately 10 cm × 10 cm (4 in. × 4 in.) without permanent deformation or binding of the door mechanism. Platform edge barriers and their associated doors shall also be designed to withstand wind loads and buffeting forces when applicable.

3. If glass is used in station platform edge barriers or platform doors, the glass shall comply with the requirements of *Standard Specification for Flat Glass*, ASTM C1036-06; *Standard Specification for Heat Treated Flat Glass*, ASTM C1048-04; *Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test,* ANSI Z97.1-2004; and *Consumer Products Safety Commission Standard on Architectural Glazing Materials*, Code of Federal Regulations, 16 CFR 1201. Markings as specified in ANSI Z97.1 shall be on each separate piece of glass and shall remain visible after installation.
4. Platform edge doors shall comply with ANSI/ASCE/T&DI 21-05, Sections 5.1.10 and 5.1.11, and all applicable requirements of ASCE/T&DI 21.2-08, Section 7.8 regarding locking, closing forces, obstruction detection, and emergency egress. A keyed platform side-lock release shall be provided to allow authorized access to the guideway for maintenance and evacuation purposes. Moreover, to avoid any injury, the kinetic energy of the moving parts (door leaf and all pieces of equipment mechanically coupled to it) shall be limited to 10 J (88.5 in. lb), computed for the average door speed. The average door closing speed shall be calculated by measuring the time required for the leading edge of the door to travel from a point 25 mm (1 in.) away from the open jamb to a point 25 mm (1 in.) away from the point of closure of the doors. Demonstration of compliance by test in lieu of calculation may be provided.
5. Initiation of platform edge door closing shall be annunciated by audio and visual warning signals, as specified in ANSI/ASCE/T&DI 21-05, Section 6.3.2.
6. The space between the platform doors and the vehicle doors shall be designed to prevent door closure when passengers are in the space between the vehicle doors and the platform doors, unless the gap is less than 130 mm (5 in.) from the platform level up to 1.1 m (42 in.) above the platform level.
7. Vehicle and station platform door opening and closure shall be coordinated per ANSI/ASCE/T&DI 21-05, Section 5.2.3.

10.2.2 Intrusion Control System

An intrusion control system, when provided, shall include barriers with a minimum height of 1.1 m (42 in.) and automatic horizontal sliding doors or gates, and shall meet the following requirements:

1. Doors or gates shall be compatible with the requirements of ANSI/ASCE/T&DI 21-05, Section 5.2.2, with height at least equal to that of the associated barriers.
2. The platform edge barriers, door or gate assembly, supporting tracks, and linkages shall withstand a force of 1,110 N (250 lb) applied at right angles to the panel and 1 m (3.3 ft) above floor level, distributed over an area of approximately 10 cm × 10 cm (4 in. × 4 in.), without permanent deformation or binding of the door or gate mechanism.
3. Where glass is used in barriers, doors, or gates, the glass shall comply with the requirements of *Standard Specification for Flat Glass*, ASTM C1036-06; *Standard Specification for Heat Treated Flat Glass*, ASTM C1048-04; *Safety Glazing Materials Used in Buildings—Safety Performance Specifications and Methods of Test,* ANSI Z97.1-2004; and *Consumer Products Safety Commission Standard on Architectural Glazing Materials*, Code of Federal Regulations, 16 CFR 1201. Markings as specified in ANSI Z97.1 shall be on each separate piece of glass and shall remain visible after installation.
4. Doors or gates shall comply with ANSI/ASCE/T&DI 21-05, Sections 5.1.10 and 5.1.11, and all applicable requirements of ASCE/T&DI 21.2-08, Section 7.8 regarding locking, closing forces, obstruction detection, and emergency egress. A keyed platform side-lock release shall be provided to allow authorized access to the guideway for maintenance and evacuation purposes. Moreover, to avoid any injury, the kinetic energy of the moving parts (door leaf and all pieces of equipment mechanically coupled to it) shall be limited to 10 J (88.5 in. lb), computed for the average door speed. The average door closing speed shall be calculated by measuring the time required for the leading edge of the door to travel from a point 25 mm (1 in.) away from the open jamb to a point 25 mm (1 in.) away from the point of closure of the doors. Demonstration of compliance by test in lieu of calculation may be provided.
5. Door or gate closing shall be annunciated by audio and visual warning signals, as specified in ANSI/ASCE/T&DI 21-05, Section 6.3.2.
6. The space between the doors or gates and the vehicle doors shall be designed to prevent closure when passengers are in the space between the vehicle doors and the doors or gates, unless the gap is less than 130 mm (5 in.).
7. Vehicle and station platform door opening and closing shall be coordinated per ANSI/ASCE/T&DI 21-05, Section 5.2.3.

8. Openings or spaces between elements of the door, gate, or barrier shall be designed such that a 100-mm- (4-in.)-diameter sphere will not pass through. Fences and gates shall be constructed to inhibit contact with the vehicle per ASCE/T&DI 21.2-08, Section 7.2.

10.2.3 Intrusion Detection System

If provided, an intrusion detection system shall be capable of detecting the intrusion of a sphere 0.3 m (1 ft) in diameter or larger weighing 9 kg (20 lb) or more, falling or otherwise passing from the platform to the guideway at any open location, at a height between platform level and 1.1 m (42 in.) above the platform surface.

When activated, the detection system shall initiate:

1. Command for appropriate braking for trains entering or approaching the station as determined by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.
2. Command to stop any moving apparatus on the guideway exposed to potential contact by the intruder (for example, drive ropes) in the vicinity of the detected intrusion.
3. An alarm to Central Control.

The procedures used to reset the detection system and to restore traffic after an intrusion detection shall be analyzed through a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

10.3 EVACUATION OF MISALIGNED TRAINS

A means shall be provided to allow egress from a misaligned train onto the station platform. Such means shall meet the requirements of 11.3. Where auxiliary egress doors or gates are used, a latching mechanism shall be provided on the guideway side to allow passengers to exit onto the platform. Permissible misalignment shall be per ANSI/ASCE/T&DI 21-05, Section 5.2.2.

10.4 EMERGENCY LIGHTING AND VENTILATION

For APM station platforms located within airport terminals or office, retail, entertainment, or other such buildings, the station lighting and ventilation shall be in accordance with local building codes, as applicable, and *Life Safety Code,* NFPA 101, 2006 edition, Sections 7.9 and 9.2. For interpretation of such building codes, the APM platforms shall be treated, for lighting and ventilation issues only, as elevator lobbies. (Refer also to 10.5.1, Fire Detection.)

For free-standing stations dedicated to the APM system, the station emergency ventilation and emergency lighting provisions shall comply with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 5.3 and 5.6, respectively. Lighting fixtures shall be designed as vandal-resistant.

10.5 FIRE PROTECTION

A fire protection system shall be provided. Station design may be considered in combination with platform doors to provide fire-rating compliance, as approved by local fire authorities.

10.5.1 Fire Detection

All stations and associated equipment rooms shall be provided with smoke and/or heat detection and alarm devices that shall be annunciated on a fire monitoring display in Central Control. Upon activation of a smoke or fire alarm, appropriate automatic or operational procedures shall be implemented to address the hazards associated with fire or smoke as required by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

10.5.2 Fire Containment

Station platform barriers and doors, if intended to serve as a fire barrier, shall comply with the requirements of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 5.2.3.2 and 5.2.3.3. The fire separation of all stations shall be based on an engineering analysis of potential fire exposure hazards conducted in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis.

10.5.3 Fire Suppression

A fire suppression system, if specified by the authority having jurisdiction, shall comply with local building codes and/or *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition.

11. GUIDEWAYS

The requirements given in this section apply to all rigid guideways: elevated, at-grade, and underground.

Systems suspended by wire rope or cable are addressed by the requirements given in *Passenger Ropeways, Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors—Safety Requirements,* ANSI B77.1-2006.

The guideway shall be designed and constructed in such a way that the ride quality criteria and the vehicle clearance restrictions are met along the entire alignment. The guideway shall be designed to support all loads and forces associated with vehicles, vehicle interfaces, the environment, and any other facilities affixed to the guideway.

11.1 BLUE LIGHT STATIONS

Blue light stations shall be provided as defined in 9.1.1; in ANSI/ASCE/T&DI 21-05, Section 6.1.2; and in *Fixed Guideway Transit and Passenger Rail Systems*, NFPA 130, 2007 edition, Section 6.2.7 and Section 10.4.1 in its entirety.

11.2 INTRUSION PROTECTION AND DETECTION

The system shall be designed to protect against unauthorized persons or foreign objects entering the vehicle dynamic envelope. This protection shall be in the form of fencing or other suitable barriers, as determined by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

Where deemed appropriate from the hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, intrusion detection devices shall be provided to alert the system to unauthorized access.

11.3 EMERGENCY EVACUATION AND ACCESS

The APM guideway emergency evacuation and access shall be designed in accordance with the requirements of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.2.1, 6.2.2, and 6.2.3. In addition, the APM guideway shall meet the following two stipulations:

1. Under *Fixed Guideway Transit and Passenger Rail Systems* NFPA 130, 2007 edition, Section 6.2.1 regarding evacuation of passengers from a disabled train, guidance and control by authorized personnel shall involve voice communication by the Central Control Operator, and such involvement shall be sufficient to meet the intent of Section 6.2.1.
2. If any passenger activates the door release within any vehicle, creating a condition allowing passengers to exit the vehicle onto the guideway or its associated emergency walks, or other suitable means of evacuation, passengers shall be protected, as determined by a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1. Hazards shall include making contact with an energized power rail or any other device of dangerous electrical potential and entering any portion of the guideway where other vehicles are still moving.

All station or guideway doors that do not provide emergency egress shall be so identified and clearly labeled “Not an Exit.” Emergency egress doors shall not be locked on the inside at any time. Emergency exits shall have the capability of being readily opened from the outside by the fire department or other rescue personnel.

11.3.1 Tunnel Guideway

Emergency exits shall comply with the requirements of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.2.1. and 6.2.2 This includes doors, exit hatches, and emergency lighting. When interpreting NFPA 130 requirements, a “point of safety” shall be defined as an enclosed fire exit that leads to a public way or safe location outside the structure, or an at-grade point beyond any enclosing structure, or another area that affords adequate protection for passengers.

11.3.2 Surface Guideway

For an at-grade or any unroofed structure other than elevated structures, the emergency access and egress should comply with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.2.1. and 6.2.3.1.

11.3.3 Elevated Guideway

Elevated structures are all structures not defined in this standard as surface or underground structures. For elevated structures, the emergency access and egress should comply with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.2.1 and 6.2.3.2.

Passenger egress from elevated guideways shall comply with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.2.1 and 6.2.3.2. An acceptable “other suitable means” to using an elevated emergency walkway shall be a means that evacuates the maximum number of passengers who can be in a maximum-length train to a point of safety within no more than 15 minutes from the time the evacuation is initiated. The means and duration shall be subject to a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

11.4 FIRE PROTECTION

For tunnels, the fire protection provisions of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Section 6.5 shall apply. Tunnel construction materials shall comply with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Sections 6.3.1.1.1, 6.3.1.1.2, and 6.3.1.1.3.

A fire suppression system, if specified by the authority having jurisdiction, shall comply with local building codes and/or *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition.

11.5 SIGNAGE

Signage shall be provided along the guideway and in the adjacent right-of-way to inform passengers, operating personnel, and emergency services personnel of features that may be critical for safe evacuation or to minimize the severity of a life-threatening incident and to enhance system operation.

The types and location of signs shall comply with the requirement of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, including Sections 6.2.6, 6.2.8, and 6.2.9. Where not otherwise specified, *Guidelines for Accessible and Usable Buildings and Facilities,* ANSI 117.1-2003 should be consulted for signage lettering size, color, and contrast. In addition, the following types of signage shall be provided:

Emergency Exit—The emergency evacuation route to the point of safety shall be provided with the following signage: (a) direction to nearest exit (signs spaced no more than 30m [100 ft] apart); (b) designation of exit; (c) instructions for using the exit; and (d) warning sign of potential hazards in the exit area. Emergency exit signage shall be visible at all times.

Power Section—The boundaries of each power section shall be clearly marked.

Location Information—Location information shall be provided on, and visible from, the guideway at intervals of no more than 100 m (325 ft).

Exposed Power-Delivery Device—Clearly visible signs shall be provided to warn of hazard greater than 50 volts presented by exposed power rails or other exposed power-delivery devices, in accordance with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Section 6.2.6.2. Signs shall be provided on the guideway at station locations and at intervals of no more than 30 m (100 ft) along the guideway.

11.6 EMERGENCY LIGHTING AND VENTILATION

For underground systems, lighting provisions shall be in accordance with *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Section 6.2.5. Underground systems shall comply with the ventilation requirements of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Section 6.3.3.2.9.

For elevated and at-grade systems, the egress route shall have a level of illumination of no less than 2.7 lux (0.25 ft-candles).

11.7 EMERGENCY POWER SUPPLY

For underground systems, the power supply for emergency ventilation provisions of *Fixed Guideway Transit and Passenger Rail Systems,* NFPA 130, 2007 edition, Section 6.3.3.2.9 shall apply.

11.8 GUIDEWAY ALIGNMENT

The guideway shall be designed and constructed in accordance with vehicle ride quality criteria per ASCE/T&DI 21.2-08, Section 7.7.3.

Horizontal alignment may consist of any combination of straight (tangent) sections, spiral transitions, and curved sections.

The effects of centrifugal forces, superelevation, ride comfort criteria, and the related limitation of operating speed shall be considered in establishing the guideway horizontal alignment. Vehicle turning restrictions shall also be considered.

Vertical alignments may also consist of any combination of straight sections, spiral transitions, and curved sections. The effects of centrifugal forces, ride comfort criteria, and vehicle geometric limitations to vertical curve radius (crest and trough) shall be considered in establishing guideway vertical alignment.

When the vehicle is stopped at a station, the guideway shall be designed so that the vehicle floor shall not be inclined by more than 1% in any direction with respect to a horizontal plane.

When the vehicle is stopped at any other location along the guideway, (a) the angle at which the vehicle floor is inclined laterally shall not exceed 12% with respect to a horizontal plane, and (b) the angle at which the vehicle floor is inclined longitudinally shall be limited by the normal longitudinal limits for maximum sustained acceleration, including the effects of grade per ASCE/T&DI 21.2-08, Section 7.7.3.1.1.

11.8.1 Clearances

The vehicle dynamic envelope per ASCE/T&DI 21.2-08, Section 7.2 shall be separated from any other vehicle dynamic envelope on an adjacent trackway by at least 100 mm (4 in.).

Nonstructural system components that provide less clearance shall be permissible subject to a hazard analysis per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

The vehicle dynamic envelope shall be separated from any fixed structure by at least 100 mm (4 in.). Station platform edges and APM system equipment that are designed to physically interface with the vehicles are excluded from this requirement.

The maximum allowable clearance between the vehicle threshold and the station platform edge shall be per ASCE/T&DI 21.2-08, Section 7.3.

If the vehicle is designed to come in contact with the platform edge under normal operating conditions, the platform edge shall be designed so that the vehicle ride quality criteria given in ASCE/T&DI 21.2-08, Section 7.7.3 are met, except that the jerk limit in all directions shall be 0.1 g/sec for standing passengers.

If the vehicle dynamic envelope is such that the vehicle may come in contact with the platform edge under failure conditions, the platform edge and/or vehicle shall be designed to allow no more than cosmetic damage to the vehicle when the vehicle impacts the platform edge while operating at design speed.

11.8.2 Operating Equipment Interfaces

The guideway shall provide support and guidance to passenger vehicles and service vehicles throughout the APM system. The design of the guideway shall accommodate all elements of the APM system that are to be installed on the guideway.

11.8.3 Drainage

If the guideway design is such that water may accumulate on the surfaces, provisions shall be made in the design for draining the water. The drainage system shall route the water to a location acceptable to all local, state, and national codes and regulations and shall not cause drainage water or hazardous accumulations of snow or ice to fall onto pedestrian or vehicular paths.

In cases in which a drainage system is included in the design of the guideway, surfaces shall be sloped toward the drains with a minimum 1% slope (excluding the running surface as long as provisions are made for minimizing water accumulation on the running surface).

The drainage system shall be designed to operate in all environmental conditions per ANSI/ASCE/T&DI 21-05, Section 2.1.

11.9 STRUCTURAL CRITERIA

The guideway for an APM shall comply with the following structural design requirements and the applicable requirements in local codes.

11.9.1 Loads and Forces

The guideway shall be designed for the following loads and forces, with appropriate consideration of point loads, distributed loads, and inter-related loads that occur for a specific technology's suspension, propulsion, and entrainment characteristics.

Dead Load—The dead load shall consist of the maximum weight of all permanent structures, including the weight of permanently fastened material and equipment.

Live Load—The live load shall consist of the weight of the applied load of one or more maximum-length, crush-loaded trains under normal and failure conditions, including any specified push/pull retrieval capability, plus any additional service and emergency equipment included in the system that might be brought out on the guideway for maintenance or during failures. Multiple trains shall be considered if the guideway supports multiple lanes. The weight of the applied load of passengers on the emergency walkway(s), if provided, also shall be considered. Crush load shall consider both a static AW3 load and a dynamic AW2 load.

NOTE: Load imbalance and the potential for future increases in AW2/AW3 should be considered in the design.

Walkway Load—Live load on service or emergency walkways shall be at least 4.0 kPa (85 lb/ft^2). The total live load transferred from the walkway to the guideway need not exceed the total weight of evacuated passengers.

Dynamic, Vibratory, and Impact Forces—The ratio of vehicle crossing frequency (VCF) to span fundamental frequency (SF) shall be computed for each span, where:

VCF is defined as the number of spans crossed per second by a vehicle; computed as vehicle speed in meters/second [feet/second] divided by span length in meters [feet]).

SF is defined as the lowest guideway natural frequency excited by vertical train loading on the span; computed based on guideway dead load mass and guideway structural stiffness properties.

Vehicle frequency (VF) is defined as the lowest natural frequency of a vehicle excited by vertical loading.

For values of VCF/SF less than 0.2, the minimum dynamic load allowance (I) applied to the vertical live load shall be 0.1.

For values of VCF/SF greater than or equal to 0.2 but less than or equal to 0.3, the minimum dynamic load allowance (I) applied to the vertical live load shall be calculated as follows:

$$I = VCF/SF - 0.1$$

For values of VCF/SF greater than 0.3, a dynamic analysis shall be performed considering the dynamic properties of the guideway and the vehicles (VCF, SF, and VF). The dynamic analysis shall be used to determine guideway deflections, dynamic load allowances, and vehicle vertical accelerations. However, the dynamic load allowance (I) shall not be less than 0.2.

Centrifugal Force—The centrifugal force (CF) acting radially through the center of gravity of the vehicle on curved track shall be calculated as follows:

$$CF = V^2 LL/R \text{ (SI units) or}$$
$$CF = V^2 LL/32.2R \text{ (English units),}$$

where

V is the design speed for the particular curve in meters/second (feet/second);
LL is the vehicle live load in Newtons (pounds force); and
R is the radius of the curve in meters (feet).

The effects of superelevation on vertical and lateral loads shall be taken into account.

Longitudinal Force—The guideway shall be designed for maximum longitudinal forces caused by acceleration, service deceleration, and emergency deceleration, including grade effects, applied to the live loads. In addition, the guideway shall be designed for severe loads caused by suspension or propulsion system failure as determined from a hazard analysis in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

Steering Force—Forces from vehicle steering shall be applied to the guidance and running surfaces. The magnitude of these forces shall be based on the steering characteristics of a maximum-size AW2-size train, with consideration for abnormal steering. Steering force shall include forces caused by steering misalignment, hunting, and the difference between the direction of vehicle motion and the steering angle.

Buffeting Force—The effect of buffeting forces when a maximum-length train enters a narrow, closed passage shall be investigated and these pressures treated as a special condition of wind load for load combinations.

Thermal Force—Provisions shall be made in the structural design for stresses and deformations occurring from ambient temperature changes, radiant and solar heating, and radiation cooling in accordance with *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007*,* Section 3.12. Where applicable, stresses induced by heating provisions for ice and snow conditions and by differential movement of guideway elements shall be included. Special consideration shall be given to systems operating in a controlled environment.

Wind Loads—Wind loads on the elevated guideway only shall be computed and applied in accordance with *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007, Section 3.8. The maximum wind speed for survival as defined in ANSI/ASCE/T&DI 21-05, Section 2.1.2 shall be used. Both horizontal and vertical wind effects shall be considered.

Wind loads on the exposed areas of the vehicle in combination with the wind loads on the elevated structure shall be computed using the same method as used for the wind load on the structure. These loads shall be based on the maximum wind speed for manual operation as defined in ANSI/ASCE/T&DI 21-05, Section 2.1.2. Only horizontal wind effects on the vehicle need to be considered.

For systems in which empty vehicles are stored on the elevated guideway or parked on the elevated structure when the system is shut down, maximum wind speed for survival as defined in ANSI/ASCE/T&DI 21-05, Section 2.1.2 shall be used to calculate the wind effects on both the elevated structure and the vehicles.

Snow and Ice Loads—Loads resulting from freezing rain and from consolidation of snow on the guideway superstructure shall be included as appropriate, considering the environmental conditions per ANSI/ASCE/T&DI 21-05, Section 2.1.3, and the potential for build-up based on the configuration of the guideway.

Loads on the guideway caused by ice pressure or floating ice shall be computed and applied in accordance with Section 3.18 of *AASHTO Standard*

Specifications for Highway Bridges, 17th edition, 2002, or Section 3.11 of *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007.

Earth Pressure—Earth pressure shall be computed and applied in accordance with Section 3.20 of *AASHTO Standard Specifications for Highway Bridges,* 17th edition, 2002, or Section 3.7 of *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007.

Seismic Force—Seismic forces on elevated guideway shall be computed and applied in accordance with Section 3.10 of *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007, or Division 1-A of *AASHTO Standard Specifications for Highway Bridges,* 17th edition, 2002.

Seismic forces for underground structures must consider a site-specific analysis for ground shaking, fault rupture, regional tectonic movements, landslides, liquefaction, and differential consolidation of sediments. In areas where these design parameters are not available to the geotechnical/underground designer, a seismic hazard evaluation shall be conducted to assess the above risk and provide ground motions, site responses, and racking parameters for design of structures. For structural analysis, the earthquake loading may be applied as a distortion or racking, superimposed on the static loading conditions.

NOTE: For areas with high seismic activity, local codes and governing authorities should be consulted.

Stream Flow—Loads resulting from flowing water shall be computed and applied in accordance with Section 3.18 of *AASHTO Standard Specifications for Highway Bridges,* 17th edition, 2002, or Section 3.7 of *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007.

Highway Vehicle Collision—Columns located within a distance of 10 m (30 ft) from the edge of a roadway shall be protected with a structural traffic barrier or designed in accordance with Section 3.6.5 of *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007.

The possibility of overheight vehicles colliding with a guideway beam shall be considered for guideways with less than 5 m (16.5 ft) clearance over existing roadways.

Expansion—A continuously welded guide rail directly fastened to the guideway induces an axial force in the structure through the fastener restraint when the structure expands or contracts because of variations in temperature. The axial stress in the guide rail shall be considered because of movement of the structure. Correspondingly, where rail motion occurs, the relaxation of the rail stress must be analyzed to determine its effect on the structure. Rail motion may occur when:

1. Guide rail expansion joints are present.
2. Radial or tangential movements of the guide rail and guideway occur at curves.
3. A guide rail break occurs at low temperature.
4. Continuous guide rails cross structure joints.

Construction Loads—Loads caused by construction equipment and materials that may be imposed on the guideway structure during construction should be considered. Additionally, transient load effects during construction caused by wind, ice, stream flow, and seismic events should be considered commensurate with the expected duration of the particular construction stages.

Other Guideway Equipment Forces—The guideway loads and forces caused by attached wayside equipment such as propulsion cable, sheaves, linear induction motors, and guideway switches, as applicable, shall be considered.

11.9.2 Load Combinations

Loads and forces shall be investigated in combination as specified in Section 3.22 of the *AASHTO Standard Specifications for Highway Bridges,* 17th edition, 2002, or in Section 3.4 of the *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007, with the single exception that the live load factor in load combination "Group I," *AASHTO Standard Specifications for Highway Bridges*, shall be changed from 1.67 to 1.35.

NOTE: This live load factor has been reduced because the APM empty vehicle and passenger loads are known. The load magnitude uncertainty is therefore reduced relative to that of live loads on highway bridges. Therefore, the live load factor in the first load combination only of the *AASHTO Standard Specification for Highway Bridges* has been reduced.

11.9.3 Design and Analysis

Deflections and Tolerances—Guideway design and construction tolerances shall be coordinated with the system designer to achieve the ride quality requirements and clearance requirements of ASCE/T&DI 21.2-08, Section 7.7.3.

Fatigue—Fatigue design shall be in accordance with *AASHTO Standard Specification for Highway Bridges,* 17th edition, 2002, or *AASHTO LRFD Bridge Design Specifications,* 4th edition, 2007. The number of cycles of maximum stress range caused by AW1 operating loads to be considered in the design of the guideway (except for running and guidance elements) shall correspond to an infinite fatigue life. If a design life shorter than 50 years is explicitly specified by the owner, then the fatigue life may be reduced appropriately. Depending on the span lengths and the maximum train size, there may be multiple stress cycles associated with the passing of each train.

The running and guidance elements shall be designed, with recommended maintenance, for at least a 20-year life while meeting the specified system operating criteria, unless explicitly specified otherwise by the owner.

Structural Deformation and Settlement—All structural deformations, including differential foundation settlement, shall be considered in the structural behavior of the guideway and vehicle guidance provisions. The control of deformation to maintain acceptable ride comfort requirements per ASCE/T&DI 21.2-08, Section 7.7.3 shall be considered in the structural design of the guideway.

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