ASCE STANDARD

ANSI/
ASCE/T&DI
21.2–08

Automated People Mover Standards—Part 2

Vehicles
Propulsion and Braking

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 21.2-08

American Society of Civil Engineers

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Published by the American Society of Civil Engineers

Library of Congress Cataloging-in-Publication Data

Automated people mover/American Society of Civil Engineers.
p. cm.
ISBN 0-7844-0873-4
1. Personal rapid transit. I. American Society of Civil Engineers.

TA1207.A95 2006
625.4—dc22

2006017165

Published by American Society of Civil Engineers
1801 Alexander Bell Drive
Reston, Virginia 20191
www.pubs.asce.org

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ISBN 13: 978-0-7844-0964-0
ISBN 10: 0-7844-0964-1
Manufactured in the United States of America.

16 15 14 13 12 11 10 09 08 1 2 3 4 5

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
ANSI/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 between five to ten years.

This Standard is Part 2 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 2 contains sections covering vehicles, propulsion, and braking.

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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ACKNOWLEDGMENTS

The American Society of Civil Engineers (ASCE) acknowledges the devoted efforts of the Automated People Mover Standards Committee under the Codes and Standards Committee. This group comprises individuals from many backgrounds, including consulting engineering, research, transit agencies, airports, transit system design and manufacturing, education, government, regulatory agencies, and private practice.

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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The following Working Group Leaders are especially acknowledged for their efforts in drafting specific sections of the standard and shepherding them through the consensus process:

WG1—General, Robert Good; Reaffirmation, Thomas McGean and Charles Martin
WG2—Definitions, Edward S. Neumann; Reaffirmation, Thomas McGean and Charles Martin
WG7—Vehicles, Robert Good and Frank Culver; Reaffirmation, Frank Culver with Redjean Clerc, Yves Clarissou, and Paul Didrikson
WG9—Propulsion and Braking, Jimmy E. Fletcher, Paul Wyss, and Frank Culver; Reaffirmation, Jimmy E. Fletcher

ASCE Staff support was provided by Jon Esslinger with Phillip Mariscal. Michael Shumack provided Configuration Control and Web site support. Support for our membership mailings and communication was provided by Frank Culver and Lawrence Smith. Web site support was provided by Atlanta Hartsfield International Airport. Support for meetings was provided by BAA United Kingdom; Berger/Abam Engineers; Bombardier Transportation; Booz Allen Hamilton; Conductix; Dallas/Fort Worth International Airport; Denver International Airport; Doppelmayr Cable Car; Greater Toronto Aviation Authority; Horton Automatics; Japan Overseas Rolling Stock Corporation; KBR; Lea+Elliott; Mitsubishi Heavy Industries; Becky Perry and Lawrence Smith; Slattery Skanska; Sumitomo; Tampa International Airport; *The Queens Courier*; Washington Group International; and Walt Disney Enterprises

CONTENTS

Automated People Mover Standards—Part 2

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 2 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 prior to 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 completely 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 specific citations of the following documents are incorporated by reference in this standard.

ACGIH: American Conference of Government Industrial Hygienists, 1330 Kemper Meadow Drive, Cincinnati, OH 45240; phone (513) 742-2020.

ACGIH Publication #7 DOC-648, *Whole Body Vibration: TLV Physical Agents,* 7th Edition Documentation (cited in 7.7.3.2)

NOTE: An equivalent source for the above is ISO 2631/1-1985, *Evaluation of Human Exposure to Whole Body Vibration*, which is no longer supported by or available from the ISO but may be purchased from the IHS Standards Store, 15 Inverness Way East, Englewood, CO 80112; phone (303) 792-2181 ext. 1950.

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

ANSI S1.4–1983 (R2006), *Specification for Sound Level Meters* (cited in 7.7.4)

ANSI/ASME B15.1-2000, *Safety Standard for Mechanical Power Transmission Apparatus* (cited in 8.5)

ANSI B77.1-2006, *Passenger Ropeways—Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors, Safety Requirements* (cited in 8.2.2)

ANSI Z26.1-1996, *American National Standard, Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways* (cited in 7.9)

ASHRAE: American Society of Heating, Refrigeration and Air Conditioning Engineers, 1791 Tullie Circle NE, Atlanta, GA; phone (800) 527-4723.

2005 ASHRAE Handbook Fundamentals Volume, Chapter 28, Table 1 (cited in 7.7.1)

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

IEEE Std 32-1972 (revised 1990), *Standard Requirements, Terminology and Test Procedures for Neutral Grounding Devices* (cited in 7.12.5)

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, *National Electrical Code* (cited in 7.12)

NFPA 130-2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems* (cited in 7.10 and 7.12)

SAE: Society of Automotive Engineers International, SAE World Headquarters, 400 Commonwealth Drive, Warrendale, PA 15096-0001; phone (877) 606-7323 (U.S. and Canada), 1-724-776-4970 (outside U.S. and Canada).

SAEJ673-2005, *Automotive Safety Glasses* (cited in 7.9)

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): That subsystem within the automatic train control system which 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): That subsystem within the automatic train control system which provides the primary protection for passengers, personnel, and equipment against the hazards of operations conducted under automatic control.

Automatic Train Supervision (ATS): That subsystem within the automatic train control system which 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 which is 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 automatic train supervision 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 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: An 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 Section 7.4.4.1.1, as Lateral Loads, Vertical Loads, and Longitudinal Loads.

Overspeed: Train speed which 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, then 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 which is deemed acceptable by the hazard resolution process (see ANSI/ASCE/T&DI 21-05, Section 3.1.2, Hazard Resolution Process).

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

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 where 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 which is essential to operational completeness of a system.

System: A composite of people, procedures, facilities and/or equipment which 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 simulated 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 which can operate alone or which comprises one of the basic building blocks of a train.

Zero Speed: A specified speed below which Automatic Train Control considers a train to be stopped.

7. VEHICLES

This section provides standards for Automated People Mover (APM) vehicles. These APM standards have been developed for vehicle cruise speeds up to 100 km/h (60 mph). They may be applied to higher speed systems at the discretion of the user; however, professional engineering judgment is needed with regard to suitability for such higher speed applications.

7.1 VEHICLE CAPACITY AND LOAD

Vehicle passenger "design capacity" shall be defined in number of persons, by the owner, based upon the owner's preferred comfort standards.

Total passenger area shall be all of the area available to seated and standing passengers. The definition of standee floor area is the total passenger area less 0.42 m^2 (4.5 ft^2) for each nonremovable or nonstowable seat position. For calculating the loads imposed by passengers seated on benches, 0.45 m (18 in.) of width shall be allocated for each seated passenger unless otherwise established by the seat design.

The following loadings are established for APM vehicles:

AW0: Weight of an empty vehicle, ready to be operated, but without passengers.

AW1: Design load shall be AW0 plus a force of 712 N (160 lb) per passenger, multiplied by the design capacity.

AW2: Maximum operating load shall be AW0 plus 712 N (160 lb) multiplied by the maximum number of passengers that the vehicle is permitted to transport, if limited by load weigh systems designed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.3, ATC System Fail Safe Design. Otherwise, AW2 shall be equal to AW3 for the brake system design; for the propulsion system design, AW2 shall equal AW3 or, alternatively, AW2 for propulsion shall be determined by simulation of the worst-case anticipated load profile along the alignment.

NOTE: This definition of AW2 is intended to define AW2 as the maximum load which can be encountered by a moving vehicle. AW3 is the maximum load which can be encountered by a stationary vehicle. In the absence of a load weigh system designed in accordance with the fail-safe design principles of ANSI/ASCE/T&DI 21-05, Section 3.3, AW2 and AW3 will be the same.

AW3: The crush load shall be AW0 plus 5,120 N/m^2 (107 lb/ft^2) multiplied by the standee floor area, plus 712 N (160 lb) per seat multiplied by the number of nonremovable or nonstowable seats.

If luggage racks are provided, a luggage load of 2870 N/m^2 (60 lb/ft^2) shall be considered for both AW2 and AW3.

All operating vehicle subsystem design requirements that are not safety-related shall meet loading requirements from AW0 to AW1. All conditions affecting safety, including automatic train protection, emergency braking, propulsion duty cycle, and clearances, shall meet loading requirements from AW0 to AW2. Structural design shall be in accordance with 7.4.

7.2 VEHICLE DYNAMIC ENVELOPE

The vehicle dynamic envelope is defined as the space occupied by the dynamic outline of the transit vehicle under normal operating conditions and probable combinations of vehicle failures. The dynamic envelope shall also consider the effect of manufacturing, construction, installation and maintenance tolerances, and the effects of normal wear of wheels or tires and other components.

The dynamic envelope shall include, but not be limited to, the overhang on curves, effects of chording, vehicle speed, suspension characteristics and failures, and applicable external forces, such as wind, acting upon the vehicle or other system equipment. The dynamic envelope shall also include a margin of 90 cm (36 in.) for passenger limbs for those vehicles that permit passenger limbs to extend through windows or other openings.

The risk of any part of the vehicle extending outside its dynamic envelope under failure conditions shall be assessed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.4, Table 1, Risk Assessment, and the risk classification shall be assessed to be neither “unacceptable” nor “undesirable.”

7.3 CLEARANCE IN STATIONS

Slow-speed people movers are defined as those particular site applications where all vehicles travel no more than 32 km/h (20 mph) at any location on their route during normal operation.

For slow-speed people movers, when the vehicle is stopped in a station with the doors open for boarding, the horizontal gap between the station platform and the vehicle door threshold shall be no greater than 25 mm (1.0 in.), and the height of the vehicle floor shall be within $\pm$12 mm (0.5 in.) of the platform height under all normal static load conditions from AW0 to AW1.

For all other people movers (such as those not covered by the “slow speed” definition above), the horizontal gap as defined above shall be no greater than 50 mm (2.0 in.) and the height of the vehicle floor shall be within $\pm$15.5 mm (0.625 in.) of the platform height under all normal static load conditions from AW0 to AW1.

7.4 VEHICLE STRUCTURAL DESIGN

The vehicle supplier shall perform a complete structural analysis of the body structure, suspension/guidance elements, and equipment mounts.

7.4.1 Structural Analysis

The structural analysis shall identify the design loads, and include evaluation of:

1. Strength of primary structural members of the body structure and suspension/guidance elements.
2. Strength of load-bearing joints, connections, and equipment mounts.
3. Flexural and torsional deformation of the vehicle structure.
4. Tipping stability.
5. Crashworthiness.

7.4.2 Previous Structural Analysis

A previous structural analysis may be used, provided that it is updated as needed to account for:

1. Pertinent changes in environmental or operating conditions which affect design loading.
2. Pertinent engineering changes in the vehicle dimensions, materials, or manufacturing processes.
3. Experience from prior installation.

7.4.3 Structural Design Life

The vehicle structure shall be designed to operate in passenger service, with recommended maintenance, for at least 20 years while meeting the specified system operating criteria, unless explicitly specified otherwise by the owner.

7.4.4 Structural Design Criteria

Structural design criteria are as follows.

7.4.4.1 Design Loads

Design loads for the vehicle structural elements shall be defined in terms of operating loads and worst-case loads.

7.4.4.1.1 Operating Loads Operating loads (those loads which occur repeatedly during normal system operation) are defined as follows:

1. *Lateral load:* A reversing force under normal speed operation over the alignment equal to the centrifugal force to be experienced by a vehicle loaded to AW1, plus the load resulting from an additional reversing acceleration of no less than 0.1 g for a vehicle loaded to AW1.
2. *Vertical load:* The vertical load from an AW1 loaded vehicle, plus the load resulting from a reversing acceleration of no less than 0.2 g for a vehicle loaded to AW1.
3. *Longitudinal load:* A reversing longitudinal load caused by normal acceleration or braking operation but no less than the load resulting from a reversing acceleration of 0.1 g applied to an AW1 loaded vehicle.

All of the above loads shall be assumed to be distributed as they would be applied in passenger service. Loads attributed to the unsprung mass shall be considered based on vehicle and suspension dynamics. Grade and super-elevation shall be considered where appropriate.

Actual loads, measured over a route duplicating all site geometry and operating speeds, shall be permitted in place of the above operating loads.

The vehicle operating stress ranges resulting from the above loads shall not exceed 0.75 of the material allowable fatigue stress range from an accepted industry standard considering a 97.5% lifetime survival probability for the structural design life per 7.4.3.

7.4.4.1.2 Worst-Case Loads Worst-case loads are defined as follows.

1. *Lateral load:* A lateral load equal to the greater of the following:
   (a) A maximum force under either maximum normal or manual speed operation over the proposed alignment equal to the maximum centrifugal force to be experienced by a vehicle loaded to AW2, under worst-case overspeed conditions subject to automatic train protection, plus the force resulting from an additional acceleration of 0.1 g, plus a lateral wind load normal to the side of the vehicle body per ANSI/ASCE/T&DI 21-05, Section 2.1.2, Wind.
   (b) A survival wind load, as specified in ANSI/ASCE/T&DI 21-05, Section 2.1.2, Wind, normal to the side of the stationary vehicle body, plus the lateral load component from the worst-case combinations of guideway super-elevation and vehicle load from AW0 to AW3.
2. *Vertical load:* A vertical load equal to the greater of the following:
   (a) An AW3 loaded vehicle, or
   (b) An AW2 loaded vehicle ± the force resulting from a reversing acceleration of 0.2 g.
3. *Longitudinal load:* The largest longitudinal load resulting from dragging of brakes due to any single-point failure on an AW2 loaded train, plus applicable wind loads as specified in ANSI/ASCE/T&DI 21-05, Section 2.1.2.
4. Any other applicable worst-case loads, including (but not limited to) tire scrubbing (cornering) and wheel locking.

All of the above loads shall be assumed to be distributed as they would be applied in passenger service. Loads attributed to the unsprung mass shall be considered based on vehicle and suspension dynamics. Grade and super-elevation shall be considered where appropriate.

Stresses resulting from all worst-case possible combinations of the above loads applied to a train, including a load factor of 1.5, shall not exceed the material yield strength of any structural element or connection.

Under a combined maximum vertical load and an end load applied horizontally to the end structure of the vehicle equivalent to AW0, stresses in the principal framing members shall not be greater than the yield strength of the associated structure.

Any roof area intended to be traversed by personnel shall be capable of supporting a point load of 1,110 N (250 lb) over a 15 cm × 10 cm (6 in. × 4 in.) area, without permanent deformation. The portions of the roof intended to support personnel shall also support a uniform load of 1440 N/m^2 (30 lb/ft^2) without permanent deformation.

The floor load shall be based upon an AW3 loading condition. The floor shall be capable of withstanding a point load of 712 N (160 lb) over a 13-mm- (0.5 in.)-diameter circle.

Each seat pan, seat structure, and attachments to the structure shall support, without permanent deformation, a 2,160 N (485 lb) vertical load applied uniformly at each seating position.

Wheelchair areas shall be considered as 76 cm × 122 cm (30 in. × 48 in.), with a weight of 2,670 N (600 lb).

Stanchions shall be rigidly attached at their ends, rattle-free, and shall withstand a horizontal load, in any direction, of 890 N (200 lb) applied at the vertical midpoint.

Doors, supporting tracks, and linkages shall withstand a force of 980 N (220 lb) applied at right angles to and approximately at the center of a panel, and shall be distributed over an area of approximately 10 cm × 10 cm (4 in. × 4 in.), without permanent deformation or binding of the door mechanism.

7.4.4.2 Jacking and Lifting

Jacking and lifting loads shall be considered in the design of the vehicle structure.

Adequate attachment points shall be provided, as required for handling the vehicle. Jacking pads shall be provided if jacking is required. The vehicle structure design shall consider jacking and handling loads, using vehicle weight as AW0, per 7.1. Expected jacking and lifting loads shall not exceed material yield strength of any structural members, including a load factor of 1.5.

7.4.4.3 Material Properties

Documentation showing the as-delivered properties of the materials used in the vehicle structure, including fasteners and welds, shall be available. This shall include at least the guaranteed minimum yield and ultimate strengths, elongation, and Young's modulus data for each material, in the form of test reports certified by the manufacturer, along with allowable fatigue stress assumptions for each material.

7.4.4.4 Paints, Coatings, and Protection of Metals

The structure shall be protected by finish coating systems so that it does not sustain corrosion damage during its structural design life per 7.4.3 when maintained as specified.

7.4.4.5 Allowable Stress

Reduction in allowable stresses shall be made due to stress concentrations and the effects of welded or bolted connections and castings, or if the failure of a component could result in unacceptable and/or undesirable hazard conditions per ANSI/ASCE/T&DI 21-05, Section 3.4 Table 1, Risk Assessment.

7.4.4.6 Deformation

Elastic deformations occurring under any loading conditions per 7.4.4.1 shall not interfere with normal and/or safe operation of the vehicle or any of its subsystems, including door operation.

7.4.4.7 Structural Joints and Connections

Joining with welds and fasteners shall be performed in accordance with an applicable standard. Bonding, including chemical and thermal adhesion, shall be performed in accordance with proven, documented manufacturer's or industry procedures or standards.

7.4.4.8 Tipping Stability

The vehicle shall be stable under the worst-case combination of loads per 7.4.4.1.2. No vehicle guideway friction effects shall be included in computing vehicle stability.

7.4.4.9 Crashworthiness

As applicable, the vehicle/train shall be capable of withstanding collisions with other vehicles or trains and/or end-of-track overtravel protection device as specified below.

As applicable, the vehicle and overtravel protection device shall have anti-climbing capability in a collision to prevent one vehicle in a train from climbing another, or an overtravel protection device. This may be provided by capture to the guideway or by vehicle design in a manner that limits vertical movement.

7.4.4.9.1 Vehicle/Vehicle Collision The collision at any speed up to 5 km/h (3 mph) of either end of a moving train with another AW2 loaded train of any length, parked on a level guideway with its brakes released (not applied), shall not cause damage to the vehicles of either train. This requirement shall be met for any condition of the moving train between the shortest length train at AW0 and a maximum length train at AW2.

7.4.4.9.2 Vehicle/Overtravel Protection Device Collision The vehicle under any possible loading conditions or train configuration, except pushing or pulling with another vehicle or train, shall be capable of withstanding a collision with the end-of-track overtravel protection device at the maximum impact speed attainable under automatic control at that specific location (ANSI/ASCE/T&DI 21-05, Section 5.1.5, Overtravel Protection), and a maximum deceleration rate of 1.2 g with only cosmetic damage to the train.

The vehicle or train, under any possible loading condition or train configuration, including pushing or pulling with another vehicle or train, shall not leave the guideway during a collision with the overtravel protection device for speeds at which the train can be driven under manual control not subject to Automatic Train Protection (ATP) as defined in ANSI/ASCE/T&DI 21-05, Section 1.5. In this collision event, the integrity of the passenger compartment shall be maintained.

7.4.4.10 Mounted Equipment and Attachments

Bogie- and carbody-mounted equipment and attachments shall be designed to withstand the worst-case and operating loads associated with that equipment.

7.5 COUPLING

If coupling between vehicles is used, it shall meet the following requirements.

7.5.1 Mechanical Design

Couplers shall be slack-free and shall allow coupling and uncoupling of trains anywhere on the system, including within any maintenance facilities or storage yards. A positive lock shall ensure that the coupler, once engaged, cannot release without prior release of this lock.

Coupling shall be accomplished by moving vehicles under manual control or using an automatic process, and shall not require the placement of an individual in the area between vehicles while either vehicle is in motion.

7.5.2 Electrical/Control

Automatic coupling shall meet all requirements of ANSI/ASCE/T&DI 21-05, Section 3, Safety Requirements, and Section 5.1, Automatic Train Protection (ATP) Functions. Mechanical couplers shall not be used as an electrical ground or a means to transmit current between vehicles.

7.5.3 Coupler Interfaces

For manually coupled vehicles, all required electrical, pneumatic, and hydraulic coupling connections shall be made automatically during a mechanical coupling event, or made manually following such an event. These connections may be disconnected automatically or manually prior to a mechanical uncoupling event. Fully automatic coupling shall not require manual intervention to accomplish electrical, pneumatic, or hydraulic connections.

Electrical connections between coupled vehicles shall include circuit and shield grounds as appropriate. Electrical coupling shall prevent incorrect alignment of electrical connections and shall have weather- and moisture-resistant protection for contacts when not in use.

High-voltage circuits shall not be trainlined between vehicles which may be coupled or uncoupled.

Hydraulic and pneumatic trainlines between vehicles shall have valves to shut off the lines when not coupled to another vehicle. If more than one hydraulic or pneumatic trainline is required, they shall be configured so that misconnection is not possible.

7.6 SUSPENSION AND GUIDANCE

Where pneumatic tires are used, failure of a tire to maintain proper pressure shall not result in a condition that allows damage to the vehicles, electrical system, or guideway, or present a hazard to passengers per ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis. Similarly, loss of levitation elements shall also not result in such conditions.

7.7 PASSENGER COMFORT

This section describes the vehicle design areas that affect passenger comfort.

7.7.1 Heating and Air Conditioning

Heating and air conditioning are optional but, when provided, shall meet the following requirements. Design capacity, per 7.1, shall be used as the basis for vehicle cooling load calculation.

Local meteorological conditions are to be used in the heating and air conditioning system analysis as defined in ASHRAE 1% day (summer), and ASHRAE 99% day (winter) per Chapter 28, Table 1, *2005 ASHRAE Handbook Fundamentals Volume.*

Cooling capacity shall be calculated to include the following heat loads:

1. Carbody conduction
2. Duct gains
3. Forced fresh air per 7.7.2
4. Lighting
5. Passengers
6. Solar radiation
7. Miscellaneous interior.

NOTE: Miscellaneous interior loads shall include heat gains from control equipment, communications equipment, and other onboard equipment.

With doors closed, the heating and air conditioning system shall maintain the vehicle interior temperature at an owner-specified set temperature and with a relative humidity not exceeding 60%.

The heating and air conditioning control system shall be fully automatic, allowing automatic control in cooling, ventilation, or heating modes without manual intervention. All heating and air conditioning system controls shall be inaccessible to passengers. The system shall maintain temperature uniformity within the passenger space with doors closed, at steady state, of ±2°C (4°F). Also, the air discharged from vents shall have minimum and maximum air temperatures of 5°C and 50°C (40°F and 120°F) respectively.

Solar loading shall be based on local summer conditions and calculated for typical solar exposure on the vehicle.

Filtration shall be provided at the evaporator supply duct or interface.

7.7.2 Ventilation

Proper ventilation shall be provided on all vehicles. Fresh air shall be provided for passengers at a rate no less than 15 m^3 per hour (9 cfm) per passenger at design capacity, and shall continue to operate at a rate no less than 9 m^3 per hour (5.3 cfm) per passenger under emergency conditions, including loss of guideway power, for a time period as determined by the Hazard Analysis performed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1. Fresh air ventilation shall also be filtered. Provision shall be made to allow for the controlled deactivation of emergency ventilation to prevent the infusion of smoke or fumes from under the cars.

7.7.3 Ride Quality

The vehicle shall produce a ride within the passenger comfort limits detailed in this section. Testing for verification of ride quality is to be done with vehicles at AW0 with not more than three test/observation personnel onboard with necessary test equipment.

Measurements shall be taken at the vehicle floor above the trucks, and at the geometric center of the vehicle floor.

7.7.3.1 Acceleration and Jerk Limits

Acceleration of the vehicle is dependent upon system design parameters, including civil design. As such, guideway geometric design shall be limited to the following sustained acceleration and jerk criteria. For both acceleration and jerk, values are given for vehicles with standing passengers and also for vehicles where only seated passengers are permitted.

7.7.3.1.1 Maximum Sustained Acceleration The accelerations introduced by guideway geometry and vehicle speed changes shall not exceed the limits stated in Table 2-1. "Sustained" refers to the nominal values, excluding random vibration effects above 0.5 Hz.

Table 2-1 includes limits for standing passengers and a column for seated passengers, showing higher allowable accelerations. The limits in the Seated column apply to those vehicles where provisions for standing passengers are not included, resulting in a vehicle interior where all passengers are seated. Where the design allows for standing passengers, the limits in the Standing column shall be used.

Lateral, vertical, and longitudinal accelerations are as measured by an inertial accelerometer mounted on the vehicle floor. The vertical axis shall be perpendicular to the floor and the lateral axis shall be perpendicular to the direction of vehicle travel.

When grade effects are excluded from the sustained standing acceleration, it shall be limited to 0.13 g for normal longitudinal and 0.25 g for emergency longitudinal.

7.7.3.1.2 Maximum Jerk Rate Jerk is defined as the rate of change of sustained acceleration. The jerk limits in Table 2-2 must not be exceeded for speed changes and vertical and horizontal curves. Jerk during onset of emergency braking may exceed these limits.

Table 2-1. Maximum Sustained Acceleration

Direction	Standing	Seated
Lateral	±0.10 g	±0.25 g
Vertical[a]	±0.05 g	±0.25 g
Longitudinal Normal[b]	±0.16 g	±0.35 g
Longitudinal Emergency[b]	±0.32 g	±0.60 g

[a]This is with respect to a 1 g datum.
[b]Including effect of grade.

Table 2-2. Maximum Jerk Rate

Direction	Standing	Seated
Lateral	0.06 g/sec	0.25 g/sec
Vertical	0.04 g/sec	0.25 g/sec
Longitudinal	0.10 g/sec	0.25 g/sec

7.7.3.2 Human Response Testing

Ride quality, if testing is required, shall be measured on an empty vehicle, with not more than three test/observation personnel and necessary equipment, using a Bruel & Kjaer Type 2512 (or 2522) Human Response Vibration Meter (or equal) with a 4322 triaxial accelerometer (or equal). For any single station-to-station run (not including dwells), RMS accelerations between 1 and 80 Hz shall fall below the levels outlined in ACGIH Publication #7 DOC-648 (ACGIH 2001) using the 1-hour TLVs tabulated in Tables 1 and 2, with all acceleration values divided by 3.15.

NOTE: This produces the same values as in ISO 2631/1, 1985 *Evaluation of Human Exposure to Whole Body Vibration,* for 1-hour exposure to reduced comfort, and either reference may be used.

7.7.4 Noise Levels

The interior noise levels in Table 2-3 shall not be exceeded under the conditions defined with all auxiliary equipment operating. All noise measurements are to be taken in a free field environment, with no passengers (up to three test personnel permitted) in the vehicle. Interior noise levels shall be measured 1.5 m (5 ft) above the floor, above the suspension/running gear, and at the geometric center of the vehicle floor, using at least a Type II Instrument, as defined in ANSI Standard S1.4-1983 (ANSI R2006), and shall be set for fast or slow response as indicated.

Slow response shall be used for the vehicle stopped in the station, and fast response shall be used for noise testing with the vehicle in motion.

Noticeable pure tones are not permitted. A pure tone is defined to exist when one $\frac{1}{3}$-octave band exceeds the arithmetic average of the two adjacent bands by 4 dBA or more in the range of frequencies between 250 and 8,000 Hz. If an adjacent band contains a pure tone, the next closest band without a pure tone shall be used in its place. A noticeable pure tone shall be considered to exist when the $\frac{1}{3}$-octave band containing the pure tone contributes more than 1 dBA to the overall dBA level.

Exterior noise level limits are presented in ANSI/ASCE/T&DI 21-05, Section 2.2.1, Exterior Airborne Noise.

Table 2-3. Interior Noise Levels

Vehicle Condition	Noise Level
Vehicle stationary, doors shut	74 dBA
Vehicle moving up to 48 km/h (30 mph)	76 dBA
Vehicle moving above 48 km/h (30 mph)	79 dBA

7.7.5 Vibration

The interior of the vehicle shall be designed to avoid resonance of panels and other vehicle components. Equipment mounts shall be designed to minimize the transmission of vibration.

7.7.6 Passenger Compartment Provisions

The following sections describe general passenger compartment provisions.

7.7.6.1 Priority Seating Signs

Each vehicle shall contain sign(s) which indicate that certain seats are priority seats for persons with disabilities, and that other passengers should make such seats available to those who wish to use them.

Characters on required signs shall have a width to height ratio between 3:5 and 1:1, with a minimum character height (using an uppercase “X”) of 16 mm (0.625 in.), with wide spacing (generally, the space between letters shall be 1/16 the height of uppercase letters), and shall contrast with the background, either light on dark, or dark on light.

7.7.6.2 Interior Circulation, Handrails, and Stanchions

Handrails and/or stanchions shall be provided to assist safe boarding, onboard circulation, seating and standing assistance, and alighting by persons with disabilities.

Handrails, stanchions, and seats shall allow a route at least 82 cm (32 in.) wide so that at least two wheelchair or mobility-aid users can enter the vehicle and position the wheelchairs or mobility aids in the appropriate areas. Each handrail, stanchion, and seat shall have a minimum clear space of 76 cm × 122 cm (30 in. × 48 in.) so as not to unduly restrict movement of other passengers. Passenger compartments 6.7 m (22 ft) in overall outside length or less need provide only one wheelchair or mobility aid space. Space to accommodate wheelchairs and mobility aids may be provided within the normal area used by standees and designation of specific spaces is not required. Particular attention shall be given to ensuring maximum maneuverability immediately inside doors. Ample vertical stanchions from ceiling to seat back rails shall be provided. Vertical stanchions from ceiling to floor shall not interfere with wheelchair or mobility-aid user circulation and shall be kept to a minimum in the vicinity of doors. Stanchions and handrails immediately in the entrances and exits of the vehicle should be a visibly contrasting color to aid the visually impaired.

The diameter or width of the gripping surface of handrails and stanchions shall be 32 mm to 38 mm

(1.25 in. to 1.5 in.) and provide a minimum 76 mm (3 in.) knuckle clearance from the nearest adjacent surface.

7.7.6.3 Floor Surfaces

Floor surfaces on aisles, places for standees, and areas where wheelchair and mobility-aid users are to be accommodated shall be slip-resistant.

7.7.6.4 Materials and Fasteners

Materials used for the vehicle shall be vandal-resistant. Fasteners exposed to passenger access shall be tamper-resistant.

7.8 DOORS, ACCESS, AND EGRESS

Vehicles shall be equipped with automatically controlled, horizontally sliding doors for passenger entry and exit. Door openings shall be a minimum of 193 cm (76 in.) in height. The door width shall provide a minimum clear opening per ANSI/ASCE/T&DI 21-05, Section 5.2.2, Programmed Station Stop.

If doorways connecting adjoining cars in a multicar train are provided, such doorways shall have a minimum clear opening of 76 cm (30 in.).

Vehicle doors shall be considered to be in the closed position when the door opening is less than 9.5 mm (0.375 in.). A locking mechanism shall hold the door in the closed position.

Upon final closing, vehicle door control shall detect an obstruction of 25 mm (1 in.) or greater located at any point along the leading edges. When such obstruction is contacted, the door shall not lock and the interlocking requirements of ANSI/ASCE/T&DI 21-05, Section 5.1.11, Departure Interlocks, shall be met. Door closing forces shall not exceed 133 N (30 lb) for the full range of door motion, including the force exerted upon contact/detection. Door closing shall be annunciated by audio and visual warning signals, as specified in ANSI/ASCE/T&DI 21-05, Section 6.3.2, Stations.

Each side of the passenger compartment having doors shall have at least one door which is manually operable from the exterior of the vehicle without powered assistance.

Provision shall be made for emergency vehicle evacuation, either using the regular doors or special emergency exits. It shall be possible to manually open the emergency exits from inside the vehicle without powered assistance with a force not to exceed 156 N (35 lb).

The emergency exit operating mechanism on the inside of the vehicle shall be conspicuously marked and designed to discourage unintentional operation. Simple operating instructions shall be posted. In some cases, there will be conditions when operation of an emergency exit could present a hazard. In such cases, a proper hazard resolution process per ANSI/ASCE/T&DI 21-05, Section 3.1.2, shall be undertaken.

7.9 WINDOWS

All vehicle glazing shall meet the requirements of SAE J673–2005, *Automotive Safety Glasses* (*Edge Treatment*) and ANSI Z26.1-1996, *American National Standard, Safety Code for Safety Glazing Materials for Glazing Motor Vehicles Operating on Land Highways.* All windows shall meet ANSI Z26.1-1996 item 3 tests for glass and glass laminates or item 4 tests for rigid plastics.

7.10 FIRE PROTECTION AND FLAMMABILITY

Incidence of fire shall be considered a Category I (catastrophic) hazard as defined in ANSI/ASCE/T&DI 21-05, Section 3.4, Table 3-1, Risk Assessment. Fire protection design shall meet all requirements of Chapter 8, NFPA 130-2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems*.

7.10.1 Material Selection

The materials used for vehicle construction shall comply with the requirements contained in Chapter 8, NFPA 130–2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems*. Oils and hydraulic fluids shall be flame-retardant, except as required for normal lubrication. Up to 0.02% of the empty vehicle weight (AW0) shall be exempted from these requirements.

7.10.2 Thermal Protection

Thermal protection shall be provided for electric motors either by thermal sensors or overcurrent sensors installed in the circuit.

7.10.3 Fire Extinguishers

Each passenger compartment shall be fitted with at least one 5-lb, Class ABC fire extinguisher per 75 AW1 passengers. Units shall be mounted in a visible and readily accessible location.

7.10.4 Smoke Detectors

Each passenger compartment shall have smoke detectors that, when activated, will annunciate an alarm in Central Control. There shall be a means to test the smoke detectors.

7.11 LIGHTING

Each vehicle shall be provided with interior and exterior lighting as described below.

7.11.1 Interior Lighting

Vehicle interiors shall be designed with lighting fixtures that are secure, rattle-free, and vandal-resistant. Fluorescent tubes or other powered fixtures shall be inaccessible to passengers. Diffusers of a material that is shatterproof shall be provided.

Under non-emergency operating conditions, interior lighting levels shall be a minimum of 54 lux (5 foot-candles) measured at the vehicle floor, including all doorways, and when the vehicle is stopped in the station, 215 lux (20 foot-candles) when measured 76 cm (30 in.) above the vehicle floor, with the exception of areas within 15 cm (6 in.) of a seat. Lighting shall be of a consistent level.

7.11.2 Emergency Lighting

Emergency lighting power is to be provided by vehicle-borne batteries capable of sustaining required levels of lighting for a time period as determined by the hazard analysis performed as specified in ANSI/ASCE/T&DI 21-05, Section 3.1.2.1.

The emergency lighting system shall provide minimum lighting levels per NFPA 130-2007, Section 8.8.3, Emergency Lighting, measured in the immediate area of the doors.

7.11.3 Directional Identification and Headlights

The front and rear of a vehicle or train shall be readily identifiable as such, and visible at all times.

Vehicles that can be operated manually onboard shall include headlights that shall provide sufficient illumination for forward visibility of at least 5 lux at 10 m (0.5 foot-candles at 33 ft).

7.12 ELECTRICAL SYSTEMS

Electrical wiring and equipment shall be inaccessible to passengers.

7.12.1 Propulsion Subsystem

Propulsion requirements are specified in Section 8.

7.12.2 Auxiliary Subsystem

The auxiliary subsystem shall provide for the distribution and conversion as required of collected power for purposes other than propelling the vehicle.

7.12.2.1 Low-Voltage Power

A low-voltage direct current (DC) source shall be provided for powering all onboard control circuits. It shall operate in conjunction with and may serve as the charger for a storage battery that has sufficient capacity to provide emergency power per 7.12.2.3. Storage batteries shall be mounted in a ventilated enclosure (if appropriate) isolated from the passenger compartment and meet NFPA 130-2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems,* Section 8.6.10, Battery Installation.

7.12.2.2 Protection Devices

All onboard circuits and devices of the auxiliary subsystems shall be protected from overload by circuit breakers, fuses, or other interrupt devices. All such devices shall be manufactured in accordance with NEMA standards or have demonstrated proven operation in same or similar service. The protection system shall be in accordance with practices of the NFPA 70-2005, *National Electrical Code*.

7.12.2.3 Emergency Power

Emergency power to critical subsystems shall be maintained when primary power is lost, for a time period as determined by a hazard analysis performed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1. Critical subsystems shall include communications, fresh air ventilation, emergency lighting (interior and exterior), and Automatic Train Protection.

7.12.3 Wiring

Vehicle wiring shall be unalloyed copper. Wiring shall be clearly marked in accordance with the vehicle electrical schematic for ease of identification in maintenance and troubleshooting. Minimum wire size shall be in accordance with NFPA 130-2007, *Standard for Fixed Guideway Transit and Passenger Rail Systems,* Section 8.6.8.2; cable and wire sizes in accordance with Section 8.6.8.3; and wiring methods in accordance with Section 8.6.8.4.

Control wiring shall be physically isolated from power wiring to prevent conducted electromagnetic interference (EMI) from interfering with system performance.

7.12.4 Power Collectors

If electrically powered from the wayside, each vehicle shall be provided with power collectors that are compatible with the characteristics of the power rail.

The power collector shall function under all permissible vehicle dynamic/operating conditions as per 7.2, and the vehicle environmental operating conditions per ANSI/ASCE/T&DI 21-05, Section 2.1, Ambient Conditions. Fully redundant power collector assemblies shall be provided to ensure continuous power collection. Each of the redundant collector assemblies shall be sized to carry the entire vehicle root mean square (RMS) electrical load for an indefinite period of time when operating in a normal duty cycle at an AW2 load. It shall not be possible to apply shop power to the vehicle without electrically disconnecting the power collectors. The shop power connector, if provided, shall be protected from the environment and shall be intrinsically safe to prevent inadvertent touching of the stinger probe.

7.12.5 Grounding

Where the maximum voltage onboard the vehicle exceeds 48 volts RMS, the vehicle electrical system and body shall be positively grounded under all operating conditions, except as explicitly noted otherwise herein.

The carbody shall not be used to carry current for either the negative return of primary power or negative return of low-voltage power.

Electrical subsystem equipment enclosures are to be grounded with the grounding system in contact with the system ground rail at all times.

Grounding of equipment shall utilize direct bonding of the equipment enclosure to a carbody frame member by metal-to-metal contact between the two surfaces. Where direct bonding is not feasible, grounding conductors of sufficient cross-sectional area shall be used to limit the resistance across the bond to 0.0025 ohms and to carry lightning discharge current or fault current of the equipment. Bogie-mounted components shall be bonded to the bogie frame.

Negative return circuits shall be routed to a common negative bus which shall be isolated from the carbody and pass the Isolation Resistance Test of IEEE 32-1972 (revised 1990), *Standards Requirements, Terminology and Test Procedures for Neutral Grounding Devices*. A grounding cable with ample capacity for the service intended shall bond the negative bus to the negative return power collectors. If the non-current-carrying ground rail is not provided as permitted by ANSI/ASCE/T&DI 21.3-08, Section 9.1.4.1, fourth paragraph, then the negative return power collectors and the negative return plate may either be the same or separate from the ground plate and vehicle ground collectors. For alternating current (AC) systems, AC primary powered equipment shall have a separate non-current-carrying connection to a system ground plate connected to the system ground through grounding collectors compatible with the non-current-carrying ground rail required by ANSI/ASCE/T&DI 21.3-08, Section 9.1.4, Grounding.

The maximum direct current (DC) contact impedance in bolted connections in the vehicle traction circuit returns and other intentional circuit grounds shall not exceed 0.0025 ohms.

All load circuits connected to the low-voltage DC (LVDC) bus shall be two-wire with separate ground conductors connected to a common ground, or shall be equipped with a ground fault detection system if a floating (ungrounded) LVDC system is used. The low-voltage DC bus system enclosure shall be grounded to the carbody frame by means of a single removable ground strap through which no intentional current shall flow. The LVDC common ground, when isolated from the carbody, shall pass the Isolation Resistance Test (IEEE 32-1972, revised 1990). Individual branch circuit ground connections to the LVDC common ground shall permit circuit isolation to check circuit integrity. The LVDC common ground terminal shall be connected to the system ground rail at all times through collectors compatible with the ground rail requirements of ANSI/ASCE/T&DI 21.3-08, Section 9.1.4, Grounding.

8. PROPULSION AND BRAKING

The propulsion and braking system (PBS) shall consist of all those elements associated with train propulsion that respond to signals from the ATC system and/or manual controller to produce and adjust tractive effort and braking necessary for train acceleration, cruising, coasting, deceleration, and stopping. The PBS may be of the wayside or onboard type.

The PBS shall provide minimum required traction effort and required stopping distances based on the operating requirements and the hazard analysis and safety principles defined in ANSI/ASCE/T&DI 21-05, Section 3, Safety Requirements, and Section 5.1.2, Separation Assurance.

8.1 PROPULSION AND BRAKING SYSTEM RATING

The PBS shall be rated to provide traction and all train movement along the guideway, under specified loading per 7.1, and environmental conditions per ANSI/ASCE/T&DI 21-05, Section 2, Operating Environment, and to ensure motion control up to the maximum speed specified so that the acceleration, deceleration, and jerk rates are within acceptable passenger comfort limits per 7.7.3.

The PBS shall be thermally rated at AW2 load for the highest temperature per ANSI/ASCE/T&DI 21-05, Section 2.1.1, without degradation to equipment. The system shall also be rated for intermittent operating conditions including (if provided) towing, pushing, motor failures, or other specified conditions. Limits of stopping distance per ANSI/ASCE/T&DI 21-05, Section 5.1.2, Separation Assurance, shall be met. Multiple brakes or combinations of dynamic/regenerative braking with mechanical friction braking when used simultaneously, shall be applied in such a fashion as to not exceed the limits for deceleration and jerk constraints specified in 7.7.3, Ride Quality.

8.2 PROPULSION AND BRAKING METHODS

Vehicle or train propulsion/braking units of the onboard or wayside type may utilize any methods of propulsion/braking, including the following:

1. Adhesion propulsion
2. Tension member propulsion
3. Air flow propulsion
4. Electromagnetic drives.

These propulsion/braking methods imply specific requirements which are described in the following subsections.

Other methods of propulsion, if provided, shall also adhere to the applicable functional requirements herein.

Overheating of propulsion or braking elements shall be addressed in the hazard resolution process per ANSI/ASCE/T&DI 21-05, Section 3.1.2.

8.2.1 Adhesion Propulsion

Measures shall be taken, where necessary, to provide proper guideway running surface adhesion.

8.2.2 Tension Member Propulsion

Rope drives shall comply with ANSI B77.1-2006, *Passenger Ropeways—Aerial Tramways, Aerial Lifts, Surface Lifts, Tows and Conveyors, Safety Requirements,* Chapter 2, Sections 2.1.2.8, 2.1.2.9, 2.1.2.10, 2.1.2.11, and 2.1.4.1. For systems which use onboard emergency braking, have no rope splices, and operate on maximum slopes less than 15%, the requirements for minimum diameter of terminal sheaves (Section 2.1.2.8.2 of ANSI B77.1) shall be not less than 40 times the nominal diameter of the haul rope.

8.2.3 Air Flow Propulsion

Suitable devices must be incorporated to protect the public and the environment from any stray air emerging from the system along the guideway, the vehicles or train, and along the station platform areas.

8.3 BRAKING FUNCTIONS

The PBS shall provide the functions of service braking, emergency braking, and parking braking. Internal friction can serve as one or all of the braking methods if the minimum internal friction of the system under all conditions including unacceptable or undesirable hazards as defined in ANSI/ASCE/T&DI 21-05, Section 3.4, Table 3-1, Risk Assessment, is sufficient to meet the braking requirements of this section and ANSI/ASCE/T&DI 21-05, Section 5.1.2, Separation Assurance.

8.3.1 Service Braking

Service braking shall be applied to accomplish the requirements of ANSI/ASCE/T&DI 21-05, Section 5.2.1, Motion Control. Braking performance and braking capacity shall be sufficient to accommodate specified loading conditions without overheating under continuous operation.

8.3.2 Emergency Braking

It shall be possible to emergency brake, using friction-type braking only, using stored energy. Emergency braking shall be designed in accordance with ANSI/ASCE/T&DI 21-05, Section 3.2, Safety Principles, and shall have priority over any other method of braking.

The emergency braking system shall be capable of decelerating and stopping a vehicle or train, under the worst-case conditions of ANSI/ASCE/T&DI 21-05, Section 5.1.2, Separation Assurance, AW2 loading, and worst-case environmental conditions per Section 2.1 for a minimum of three repeated stops at the minimum cycle time for the system while meeting all of the requirements of ANSI/ASCE/T&DI 21-05, Section 5, Automatic Train Control.

If the emergency braking system has any elements in common with the service braking system, then the emergency braking system shall comply with the above stopping requirements after meeting all requirements for the service brake duty cycle. Braking performance must meet acceptable passenger comfort limits, conforming to the deceleration rates in 7.7.3, Ride Quality, and the speed limits imposed by ANSI/ASCE/T&DI 21-05, Section 5.1.4, Overspeed Protection.

Emergency braking shall be irrevocable (i.e., once the command is issued by the ATP for this braking to be applied, braking shall be continuous until the vehicles or train has come to a complete stop). The emergency braking system shall operate properly without wayside, vehicle, or propulsion power. The energy source for emergency brakes using electrical, pneumatic, or hydraulic power for actuation shall be redundant. The failure of any one energy source shall be detected according to the requirements of ANSI/ASCE/T&DI 21-05, Section 3.2, Safety Principles, and Section 3.3, ATC System Fail Safe Design, and shall not result in a braking capability less than that required by 5.1.2, Separation Assurance. Energy storage devices may be used to meet this redundancy requirement. In the event that failure of an energy source has been detected, a Priority 1 system alarm shall be transmitted to Central Control (ANSI/ASCE/T&DI 21-05, Section 5.3.3.3.1, System Alarms), and the train shall be removed from service.

Onboard emergency braking shall be provided for all APM systems except for systems with wayside emergency brakes. For these wayside-braked systems, in lieu of this requirement, a satisfactory Hazard Resolution Process may be provided per ANSI/ASCE/T&DI 21-05, Section 3.1.2, showing that no hazard will result and the vehicle or train can be stopped by other means within the required limits. If such braking is applied directly on the guideway or guideway-mounted rails, it shall provide gradual stopping of the vehicle or train without damaging the guideway, guideway rails, vehicles, or train when applied.

8.3.3 Parking Braking

The parking braking function shall be activated whenever the vehicle is parked and not in operation. The parking braking function shall be capable of holding an AW3-loaded train on the maximum grade, considering all environmental conditions, without application of guideway or vehicle-borne power for the maximum period of time required to evacuate passengers during a total system power failure. It shall be capable of holding an AW0-loaded train on the maximum grade for at least 24 hours and for an indefinite period thereafter with manual intervention permitted. AW0 and AW3 loads shall be as defined in 7.1.

The parking braking function may be provided by elements of the service and/or emergency brake equipment, provided that the requirements of ANSI/ASCE/T&DI 21-05, Section 3, Safety Requirements, are satisfied.

8.4 PROPULSION AND BRAKING SYSTEM COMPONENT DESIGN

The components of the PBS shall be designed for the service/application as defined in the subsections below.

8.4.1 Design Requirements

PBS components shall be designed to meet all relevant requirements of Section 7, Vehicles, and ANSI/ASCE/T&DI 21-05, Section 3.2, Safety Principles. In performing the Safety Evaluation Process outlined in Section 3, Safety Requirements, the APM manufacturer shall include the following:

1. Description of the PBS method, explaining the philosophy and principal components used.
2. Results and data of analytical computations and detail hazard analysis considering worst-case operating conditions.
3. Results of relevant tests conducted.

Wayside-type propulsion and braking unit equipment locations shall be considered as part of the guideway for purposes of measuring exterior airborne noise per ANSI/ASCE/T&DI 21-05, Section 2.2.1, item 3.

8.4.2 Service Requirements

Propulsion and braking components shall have service factors appropriate for the duty cycle per 8.1. For APM systems that require bidirectional operation, all components shall be rated for bidirectional use.

Friction brakes, excluding self-braking, shall incorporate a manual release mechanism. The tractive effort performance of the propulsion unit and the braking performance shall not degrade below the required values due to deterioration anticipated, according to ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis, within the specified service life.

8.5 INSTALLATION AND PROTECTION

All rotating power transmission components shall be guarded in accordance with ASME B15.1-2000, *Safety Standard for Mechanical Power Transmission Apparatus*. Equipment mounting shall permit access for proper maintenance and inspection.

Onboard-type propulsion and braking machinery shall be housed in a compartment separate from the passenger compartment.

Propulsion and braking machinery placed along the guideway or in stations shall be determined to be acceptable by analysis, according to ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis.

Building rooms housing machinery shall be protected to prevent unauthorized access. Such facilities shall have a permanently installed lighting system, adequate to perform routine maintenance and inspection.

8.6 CONTROLS AND INTERLOCKS

Propulsion and braking interlocking shall be according to ANSI/ASCE/T&DI 21-05, Section 5.1.13.

When emergency braking is applied, the propulsion power shall automatically be disconnected such that simultaneous propulsion and emergency braking cannot occur.

8.7 BRAKE TESTING

Periodic testing of emergency braking and any other braking system, as required, shall be performed at a frequency sufficient to verify compliance with ANSI/ASCE/T&DI 21-05, Section 3.1.2.1, Hazard Analysis.

Testing provisions shall be included by the system supplier as part of the operating and maintenance procedures.

As a minimum, the testing provisions shall specify the testing interval, testing equipment, connection procedures, pass/fail criteria, and modes of operation.

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