ASME RT-1–2020
(Revision of ASME RT-1–2015)

Safety Standard for Structural Requirements for Light Rail Vehicles and Streetcars

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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Two Park Avenue • New York, NY • 10016 USA

Date of Issuance: August 31, 2020

The next edition of this Standard is scheduled for publication in 2025. This Standard will become effective 6 months after the Date of Issuance.

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The American Society of Mechanical Engineers
Two Park Avenue, New York, NY 10016-5990

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FOREWORD

On March 18, 1998, The American Society of Mechanical Engineers (ASME) formed the Standards Committee on Rail Transit Vehicles.

The Standards Committee on Rail Transit Vehicles develops and maintains standards that cover safety, functionality, performance, and operability requirements, as well as mechanical systems, components, and structural requirements for rail transit vehicles. Rail transit includes heavy rail and light rail, and excludes freight, commuter, high-speed, or any other rail operations under the jurisdiction of the Federal Railroad Administration.

The Standards Committee is responsible for developing a series of safety standards within its charter under the designation of RT. The purpose of the RT standards is to provide the rail transit industry with safety standards that address vehicle mechanical systems, components, and structural requirements that enhance public safety. Principles, recommendations, and requirements included in these standards promote good engineering judgment as applied in designing rail transit vehicles for safety. The standards are subject to revisions that are the result of Committee consideration of factors such as technological advances, new data, and changing environmental and industry needs.

Both SI (metric) and U.S. Customary units are used in this Standard, with the latter placed in parentheses. These units are noninterchangeable and, depending on the country as well as industry preferences, the user of this Standard shall determine which units are to be applied. Parameters are derived from IEEE/ASTM SI 10-1997 or the latest revision, with U.S. Customary units noted in parentheses.

The 2015 edition was approved by the American National Standards Institute on September 9, 2015, and designated as ASME RT-1–2015.

The 2020 edition has been revised in its entirety in part to reflect industry adoption of performance-based acceptance criteria where possible; to provide new definitions for vehicle carbody structural elements that are subject to crashworthiness performance criteria; and to update performance criteria in consideration of changing conditions within the rail transit industry. This revision was approved as an American National Standard on May 8, 2020 and designated as ASME RT-1–2020.

ASME RTV COMMITTEE
Rail Transit Vehicle

(The following is the roster of the Committee at the time of approval of this Standard.)

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General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions or a case, and attending Committee meetings. Correspondence should be addressed to:

Secretary, RTV Standards Committee
The American Society of Mechanical Engineers
Two Park Avenue
New York, NY 10016-5990
http://go.asme.org/Inquiry

Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Interpretations. Upon request, the RTV Standards Committee will render an interpretation of any requirement of the Standard. Interpretations can only be rendered in response to a written request sent to the Secretary of the RTV Standards Committee.

Requests for interpretation should preferably be submitted through the online Interpretation Submittal Form. The form is accessible at http://go.asme.org/InterpretationRequest. Upon submittal of the form, the Inquirer will receive an automatic e-mail confirming receipt.

If the Inquirer is unable to use the online form, he/she may mail the request to the Secretary of the RTV Standards Committee at the above address. The request for an interpretation should be clear and unambiguous. It is further recommended that the Inquirer submit his/her request in the following format:

Subject: Cite the applicable paragraph number(s) and the topic of the inquiry in one or two words.

Edition: Cite the applicable edition of the Standard for which the interpretation is being requested.

Question: Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. Please provide a condensed and precise question, composed in such a way that a "yes" or "no" reply is acceptable.

Proposed Reply(ies): Provide a proposed reply(ies) in the form of "Yes" or "No," with explanation as needed. If entering replies to more than one question, please number the questions and replies.

Background Information: Provide the Committee with any background information that will assist the Committee in understanding the inquiry. The Inquirer may also include any plans or drawings that are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in the format described above may be rewritten in the appropriate format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

Moreover, ASME does not act as a consultant for specific engineering problems or for the general application or understanding of the Standard requirements. If, based on the inquiry information submitted, it is the opinion of the Committee that the Inquirer should seek assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

ASME procedures provide for reconsideration of any interpretation when or if additional information that might affect an interpretation is available. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME Committee or Subcommittee. ASME does not “approve,” “certify,” “rate,” or “endorse” any item, construction, proprietary device, or activity.

Attending Committee Meetings. The RTV Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the RTV Standards Committee.

INTRODUCTION

Safety of light rail transit operations is a system characteristic. As do all transportation options in a given corridor, this operation has certain risks, including collision with another vehicle. The risks are mitigated by the design of the signal system and other system elements, by operating and maintenance procedures, and by the design of the vehicle. Risks are further mitigated by the elimination of grade crossings and the provision of safety barriers. Active safety systems on the vehicle include train control, communication, and propulsion and braking subsystems. The carbody, if properly designed, may be considered a passive safety device, and this Standard is intended to address the performance of the carbody in collisions. This Standard draws from existing requirements and best practices for the design of the carbody of light rail vehicles. It also considers recent developments in the design of rail carbody structures intended to optimize the performance of the structure under the conditions of an overload, as may occur during a collision. This measure is commonly identified as crash energy management (CEM). The intent of CEM is to better manage the dissipation of the portion of the energy from a collision that can reasonably be expected to be absorbed by the deformation of the carbody. CEM design, when appropriately applied, may reduce risk of injuries to occupants of the light rail vehicle due to loss of survivable volume and due to secondary collisions of occupants with the car interior. Specific portions of the carbody are designed for controlled deformation and energy absorption, and are located in the structure so as to limit the damage to, and acceleration of, occupied volumes of the light rail cars. For multiple-unit operation, distributing structural energy absorption through the train has been shown to be beneficial. This Standard requires the incorporation of CEM principles in the design of light rail vehicles.

SAFETY STANDARD FOR STRUCTURAL REQUIREMENTS FOR LIGHT RAIL VEHICLES AND STREETCARS

1 SCOPE

The objective of the passive safety requirements in this Standard is to reduce the risk of passenger injury and damage to equipment resulting from collision accidents by providing a means of protection when other possibilities of preventing an accident have failed. In the event of a collision, application of this Standard provides protection for the occupants of new designs of crashworthy vehicles through the preservation of structural integrity and reducing the risk of overriding and limiting decelerations. This Standard does not extend to the design of the vehicle interior structures that may help reduce injury risk caused by impact between the occupants and the vehicle interior, beyond limiting vehicle acceleration and consequential secondary impact velocity of passengers colliding with interior surfaces. In addition, this Standard provides measures for design of light rail vehicles (LRVs) and streetcars with the goal of reducing risks to street vehicles and pedestrians when involved in collisions.

1.1 Subjects Not Addressed by This Standard

There are several design considerations related to safety that are not addressed in this Standard, such as the following:

(a) structural repairs
(b) fatigue
(c) corrosion
(d) fire protection
(e) interior vehicle design
(f) emergency egress from vehicle
(g) inspection and maintenance
(h) operator seat belt

1.2 Effective Date

This Standard applies to newly constructed light rail vehicles and streetcars for transit passenger service ordered 180 days following the date of issuance of this Standard that is issued by the Rail Transit Vehicle (RTV) Standards Committee and ASME.

2 DEFINITIONS

This Standard relies, where practical, on terms already in use by ASME, the American Public Transportation Association (APTA), and the Institute of Electrical and Electronics Engineers (IEEE). For the purposes of this Standard, the following definitions apply:

anticlimber: a structural member or mechanism located at each end of the vehicle used to engage an opposing vehicle, coupled or not, to resist relative vertical travel between the two carbodies during a collision.

articulation: a rotating connection at the intermediate ends of carbody sections to allow negotiation of tracks with various vertical and horizontal profiles.

average collision acceleration: the longitudinal acceleration of each car-module of the vehicle computed using a 100 ms simple moving average over the duration of the collision event and averaged over each car-module.

belt rail: a longitudinal structural member of the carbody located on each side of the carbody below the passenger side windows. The distance between opposite belt rails often establishes the overall width of the carbody, exclusive of the side door thresholds, side cameras, and mirrors.

carbody: the car-module body comprising its main load-carrying structure above all truck suspension units. It includes all components and structural articulation parts that contribute directly to its strength, stiffness, and stability.

car-module: a fully assembled vehicle section that spans between couplers, articulating joints, or a coupler and an articulation. A module may be supported by a truck or may be suspended between two articulations without a truck.

collision posts: a set of two structural posts located at each end of the carbody, extending from the bottom of the underframe structure up to the structural shelf. Collision posts may be made of several structural members assembled to each other, provided that the required performance is met. They are located at the approximate one-third points across the width of the vehicle and are forward of the seating position of any passenger or crew person. An alternative to collision posts is a collision wall.

collision wall: a structure at the leading end of the vehicle spanning the area between the structural shelf, corner posts, and top of the underframe.

corner posts: a set of two full-height structural posts located at or near the two corners at one end of the carbody, extending from the bottom of the underframe structure up to the roof structure. Corner posts can be an assembly of several structural members assembled to each other provided that the required performance is met.

coupler system: a system that comprises the coupler head, drawbar, draft gear, and attachments to the carbody, permitting the connection between light rail vehicles or streetcars. The coupler system may be permanently extended in position, or of the folding/retractable type often stored behind a frangible cover or energy absorbing bumper system.

crash energy management (CEM): a method of design and manufacture of vehicles that enhances crashworthiness by assigning certain structural members or components of the carbody and the coupler system the task of absorbing a portion of the collision energy in a controlled manner (see *energy absorption zone*).

crashworthiness: capability of a vehicle structure to protect occupants from injury or fatality in the event of a collision between trains or between trains and obstacles.

end frame: structure inboard of the extreme ends of the vehicle that typically supports the corner posts, collision posts, or collision wall.

end sill compression load (buff load): longitudinal compressive force applied at the ends of the carbody.

energy absorption zone: a zone, typically located at the ends of the vehicle, designed for controlled deformation or crush, while the integrity of the remaining structure outside this zone is maintained.

light rail vehicle (LRV): vehicle that operates on a light rail transit system and is not part of mainline railroads. Light rail vehicles are capable of boarding and discharging passengers at track/street level or elevated curbs and platforms. The light rail vehicle is a mode of rail transit characterized by its ability to operate on exclusive rights-of-way, shared street running, and through roadway grade crossings (see also *streetcar*).

occupied volume: the volume of the light rail vehicle or streetcar where passengers or crewmembers are normally located during service operation, such as the operating cab and passenger seating and standing areas. The entire width of a vehicle's end compartment that contains a control stand is an occupied volume. An articulation or gangway is typically not considered occupied unless there are seats.

override: the behavior of end-to-end colliding vehicles such that one vehicle vertically rides above the other resulting in unintended crush deformations. Overriding can lead to telescoping intrusion of car-modules.

permanent deformation: a condition resulting from a stress greater than the minimum yield strength of the material, or where the material has deformed to the extent that it will not return to its original shape or position within 0.2% after the load is released. Localized stresses above yield are allowable, provided

(a) a plastic finite element analysis (FEA) for the relevant load case shows the affected areas to be small within 1% plastic strain.

(b) the overall structure does not take a permanent set beyond its initial dimensions.

(c) the structure continues to function as designed to meet the requirements of this Standard.

simple moving average: an arithmetic mean over a prescribed block of time or for a set number of digital data points, sequentially applied over a digital data set. Given a sequence of N data points, $(a_i)_{i=1}^{N}$ an n-point moving average is a new data sequence, $(s_i)_{i=1}^{N-n+1}$ defined by computing the arithmetic means of n-point blocks.

$$s_i = \frac{1}{n} \sum_{j=i}^{i+n-1} a_j$$

streetcar: a category of transit vehicle similar to LRV that operates mainly at street level in road traffic, typically operating up to a maximum speed of 70 km/h (44 mph).

structural sheathing: the parts of the exterior covering of the carbody that are used as structural components of the vehicle and included in the stress analysis.

structural shelf: the structural member in the end frame that spans the full width of the carbody and is attached to the collision posts and corner posts below the window sill, which is designed to transmit the collision post reaction loads to the carbody sides.

survival volume: the portion of the occupied volume that shall be preserved during the collision.

telescoping: the intrusion of one vehicle into another in a collision.

train: one or more vehicles coupled together.

ultimate strength: the maximum load-carrying capability of a structure for a load applied at a specified location and direction. For further deformation of the structure, the load capable of being supported will be less than this maximum load.

vehicle: a complete light rail vehicle or streetcar that contains all the minimum system requirements for operation. The vehicle may comprise multiple car-modules that are connected by articulation joints, allowing passage of passengers between the car-modules while in service.

vehicle vertical load: a force due to gravity acting on the vehicle. The following vehicle vertical loads apply to this Standard:

(a) ready-to-run load: the weight of a vehicle that is service ready with all mounted components, including full operating reserves of lubricants, windshield fluid, etc., but without any crew or passenger load.

(b) seated load: ready-to-run load plus the crew and all passenger seats occupied with average weight per person of 79.5 kg (175 lb).[1]

(c) carbody volume capacity load: a seated load plus all available standee areas occupied with a standee density that results in a floor pressure of 488.4 kg/m^2 (100 lb/ft^2).[1]

NOTE: An alternate occupant weight based upon specific service conditions, such as service to airports and use of luggage racks, may be specified.

vertical load: a force due to gravity (see also *vehicle vertical load*).

yield strength: the stress value published by the American Society for Testing and Materials (ASTM) for the specified material and grade. If the material used is not covered by an ASTM specification or another specification, the minimum yield strength for design shall be as guaranteed by the material supplier.

3 INTEROPERABILITY

This section covers geometric compatibility considerations for collisions between different vehicles operating on the same routes of the subject transit system.

3.1 Anticlimber and Coupler Interface

Each light rail or streetcar vehicle shall incorporate an anticlimber at each end of the vehicle. The anticlimber shall be designed for engagement between vehicles to mitigate override or telescoping in a collision, including any condition of failed or deflated suspension elements. The anticlimber may be integrated into a front bumper system designed to absorb low impact collision energy without major damage to the cab end. In such cases, the coupler, if provided, may be folded or retracted behind a bumper cover of a design that shall not impede engagement of anticlimbers between colliding vehicles. In the event of a collision with another rail vehicle, the coupler system shall include a feature that will permit engagement of anticlimbers. See section 6 for additional requirements. Design of the vehicle leading end structure shall not interfere with proper engagement or operation of the vehicle anticlimber system. Geometric compatibility does not mandate coupling between vehicles of different designs.

[1] Smith, S. and Schroeder, M.P., P.E., "Changes in Rider Anthropometrics and the Effect on Railcar Design," Rail Conference, American Public Transportation Association, Philadelphia, PA, June 4, 2013.

3.2 LRV and Streetcar Leading End Design for Protection of Street Vehicles

For light rail vehicles and streetcars operating in urban environments sharing roadways and crossings, the design of the leading end of the vehicle shall incorporate a contoured geometry shape extending across the width of the vehicle, enclosing open area spaces to encourage deflection of struck objects from the path of the LRV/streetcar and to minimize entrapment, override, and penetration of automobiles and light trucks. Sharp corners and protruding shapes of the contoured geometry design shall be minimized. A bumper, coupler enclosure, pilot beam, skirting, and/or alternative structures may be used to achieve these objectives.

The bottom of the car end structures as described in para. 3.1, with nominal floor height conditions, shall not be greater than the larger of 250 mm (10 in.) above the top of rail or the minimum allowable by the dynamic operating envelope.

The leading end design shall take into account collision compatibility with automotive construction.

NOTE: Side structures for typical automobiles and light trucks are designed for load-bearing reinforcement at a height above the roadway surface ranging from 250 mm to 635 mm (10 in. to 25 in.). Matching the leading end geometry and structural design of the LRV/streetcar to this height reduces the likelihood of LRV/streetcar penetration into passenger compartments of these vehicles, thus reducing injury propensity. See SAE Paper No. 1999-01-0071 (section 11).

4 STRUCTURAL REQUIREMENTS

The carbody shall withstand the maximum loads consistent with the operational requirements and achieve the required service life under normal operating conditions. The carbody and vehicle design shall be based on the design load requirements specified in section 5. The capability of the structure to meet these requirements shall be demonstrated by calculation and/or appropriate proof-of-design testing. The vehicle is assumed to be of double-end design with an operating cab at either end. If the vehicle is of single-end design, the rear of the vehicle should be of equivalent design, and in a collision, should respond in the same manner as the front end.

The strength of connections between structural members for all structural loading requirements outlined in Tables 4-1 and 4-2 shall exceed the ultimate load-carrying capacity of the weakest member joined. For these load cases, the ultimate load-carrying capacity is defined by applying the load at the location and in the direction specified in Tables 4-1 and 4-2 but increased in magnitude to the maximum load that can be resisted by the structure, as determined by observing that further increase in deflection will result in a decrease in the load capable of being carried by the structure. References to sheathing in Tables 4-1 and 4-2 refer only to structurally related (load carrying) sheathing.

4.1 Welding

Design of welded structures shall be in accordance with AWS D15.1 or AWS D1.1/D1.1M for steel and AWS D1.2/D1.2M for aluminum, or equivalent.

4.2 Articulation

The articulation shall include structure to meet the requirements of section 5.

4.3 Design Parameter Tolerances

The allowable stresses for the loads specified in section 5 shall consider the limiting cases of dimensional tolerances, manufacturing processes, workmanship, and other manufacturing effects.

4.4 Demonstration of Strength and Structural Stability

It shall be demonstrated by analysis (section 9) and/or tests (section 10) that the requirements of section 5 are achieved.

4.5 Truck-to-Carbody Attachment

A mechanism for attaching the completely assembled truck to the carbody, including a bolster if used, shall be provided, with strength levels in accordance with section 5. The strength of the attachment mechanism loaded in the vertical direction shall be as specified to secure the entire truck to the carbody when the vehicle is raised unless first intentionally detached. The strength of the attachment mechanism loaded longitudinally in a horizontal plane shall be as specified to secure the entire truck to the carbody during collisions at any possible position of the truck in its vertical suspension travel. This shall include the condition of the vehicle raised off the track with the truck hanging from the vehicle and shall not depend upon external vertical loading nor upon bolster anchor rods. The strength of the attachment mechanism loaded laterally in a horizontal plane shall be as specified to secure the entire truck to the carbody during collisions of roadway vehicles with the side of the light rail vehicle or streetcar.

4.6 Crashworthiness

(a) The crashworthiness performance shall achieve the following objectives:

(1) minimize the possibility of injury to occupants during a collision from such causes as parts detaching from the carbody or equipment falling from the ceiling or roof

(2) minimize the loss of occupant volume resulting from structural collapse or structural penetration

(3) provide for a progressive controlled collapse of energy absorption zones of the carbody structure prior to crush of other carbody structures, while limiting the average collision acceleration

(b) The crashworthiness performance is specified by the following collision scenarios and acceptable outcomes:

(1) Scenario 1 (Low-Speed Collision). This is a relatively low-severity frontal collision between two LRVs or two streetcars. This scenario can be achieved with replaceable or recoverable energy absorbing element(s). The coupler system, if of the folding or retractable type, may or may not be deployed into its extended position as per normal operation.

(2) Scenario 2 (Safe-Speed Collision). This is a significant collision speed impact between two like LRVs or streetcars. It is indicated as the safe-speed collision because in this scenario, all the protection measures for the operator and passengers are fulfilled. These protection measures include minimal reductions in the occupied volumes and limits on average collision acceleration.

(3) Scenario 3 (Structural Stability Collision). This is a severe collision speed impact between two like LRVs or streetcars and is intended only to evaluate structural stability.

(4) Scenario 4 (Collision With Street Vehicles). This collision limits the damage to the LRV or streetcar in collisions with street vehicles and provides a level of protection to the occupants of the street vehicles.

Tables 4-1 and 4-2 further specify required design loads and strengths of structural elements such as collision posts and corner posts, side walls, end sills, and equipment attachments to protect passengers and operators from structural penetration, free-flying objects, and loss of occupant volume in the event of a collision with another vehicle or obstruction.

Section 10 describes the test principles used to verify that the crashworthiness requirements in Tables 4.6-1 and 4.6-2 are met.

5 DESIGN LOADS AND ASSESSMENT CRITERIA

This section defines load requirements that assess the structural design of light rail and streetcar vehicle carbodies, with respect to safety of the occupants. Tables 4-1 and 4-2 list the loading conditions and assessment criteria; Table 4-1 lists the requirements to assess passive safety for light rail vehicles based on structural loading cases, and Table 4-2 similarly for streetcars. The structure of the carbody shall be completely assembled with the loads of all equipment included before the specified loads as applicable are applied. Each specified load or force shall be applied over the minimum area necessary to prevent local yielding or buckling with its center of action at the location specified. Where no permanent deformation is specified, localized plastic deformation is permitted, provided it is shown by

Table 4-1 Structural Load Requirements for Light Rail Vehicles

Item	Type of Load	Specified Load	Acceptance Criteria
1	Vehicle vertical	Evenly distributed carbody volume capacity	Stress not to exceed 65% of any carbody structural member yield strength, and no loss of local stability
2	End sill compression	Load of 400 kN (90,000 lb) applied on the end sill in the longitudinal (inward) direction of the carbody at ready-to-run weight	No permanent deformation of any structural member or structural sheathing, with the possible exception of the Scenario 1 energy absorption elements
3	Coupler anchorage compression	Carbody structure shall support the maximum dynamic load needed to fully collapse and release a coupler such that its physical retraction stroke is maximized	No permanent deformation of any member, structural sheathing, or connection
4	Coupler anchorage tensile	Loads shall meet the required duty as specified in section 6	No permanent deformation of any structural member or structural sheathing
5	Collision post shear (collision posts or protective collision wall structures)	Load equal to the end sill compression load, applied to each collision post separately over a surface area of the collision post in the longitudinal (inward) direction, or applied to a collision wall structure over a surface area of the wall at two separately located lateral positions at 30% of the end frame width relative to either side of vehicle longitudinal centerline *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height measured from the top of end frame	Stresses in the carbody structure and collision post to be less than ultimate strength
6	Collision post elastic (collision posts or protective collision wall structure)	Load of 133 kN (30,000 lb) positioned at 380 mm (15 in.) above top of anticlimber applied to each collision post simultaneously over surface areas of the collision posts, or applied simultaneously to collision wall structure areas in two locations symmetrically positioned laterally at 30% of the end frame width relative to either side of vehicle longitudinal centerline *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height centered on the point of loading	No permanent deformation of any member, structural sheathing, or connection

Table 4-1 Structural Load Requirements for Light Rail Vehicles (Cont'd)

Item	Type of Load	Specified Load	Acceptance Criteria
7	Corner post shear	Load of 133 kN (30,000 lb) applied to each corner post (or corner structure) over a surface area of the corner post in separate longitudinal (inward) and transverse (inward) directions *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) or 15 deg on either side of transverse (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height measured from the top of end frame	Stress in the carbody structure and corner post to be less than ultimate strength
8	Corner post elastic load	Load of 67 kN (15,000 lb) positioned at 380 mm (15 in.) above top of end sill applied to each corner post (corner structure) over a surface area of the corner post in separate longitudinal (inward) and transverse (inward) directions *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) or 15 deg on either side of transverse (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height centered on the point of loading	No permanent deformation of any member, structural sheathing, or connection
9	Structural shelf	Load of 67 kN (15,000 lb) applied at any point in the longitudinal (inward) direction *(a)* area of load application shall not exceed 250 mm × 150 mm (10 in. × 6 in.) *(b)* load direction variation permitted within 15 deg on either side of longitudinal (inward)	No permanent deformation of any member, structural sheathing, or connection
10	Side wall at side sill	Load of 178 kN (40,000 lb) applied in transverse (inward) direction at the side sill, and distributed along an area of 2.4 m × 150 mm (96 in. × 6 in.), not including the doorways	No permanent deformation of any member, structural sheathing, or connection. Localized deformation of the side wall profile in the area of the application is permitted.
11	Side wall at belt rail	Load of 44 kN (10,000 lb) applied in the transverse (inward) direction at the belt rail, and distributed along an area of 2.4 m × 150 mm (96 in. × 6 in.), not including the doorways.	No more than 75 mm (3 in.) of permanent structural deformation into the vehicle interior. This load shall not result in edges or protrusions of vehicle structure within the vehicle interior.
12	Roof, concentrated load	Load of 1.330 kN (300 lb) spaced over area of 380 mm × 330 mm (15 in. × 13 in.)	No permanent deformation of any member, structural sheathing, or structural connection.

Table 4-1 Structural Load Requirements for Light Rail Vehicles (Cont'd)

Item	Type of Load	Specified Load	Acceptance Criteria
13	Truck-to-carbody attachment	Separately applied loads as follows: *(a)* a longitudinal load produced from the collision scenarios referenced in section 8. Alternatively, a longitudinal load equivalent to 5 times the weight of a truck applied through the center of gravity of the truck. *(b)* a load as specified in Item 10 above, with two wheels on the opposite side of the truck fixed laterally at the wheel flanges at the height of the rail. *(c)* a vertical load of 2 times the weight of the truck. All above accelerations shall be applied in combination of −1 g vertical	*(a)* Truck shall remain attached. *(b)* Truck shall remain attached. *(c)* Yield strength in the attachment mechanism shall not be exceeded.
14	Equipment attachments	Separately applied acceleration loadings of *(a)* ±5 g, applied in the longitudinal direction *(b)* ±2 g, applied in the transverse direction *(c)* ±3 g, applied in the vertical direction All above accelerations shall be applied in combination of −1 g vertical	

Table 4-2 Structural Load Requirements for Streetcars

Item	Type of Load	Specified Load	Acceptance Criteria
1	Vehicle vertical	Evenly distributed carbody volume capacity load	Stress not to exceed 65% of any carbody structural member yield strength, and no loss of local stability
2	End sill compression load	Load of 300 kN (67,500 lb) applied on the end sill in the longitudinal (inward) direction of the carbody at ready-to-run weight	No permanent deformation of any structural member or structural sheathing, with the possible exception of the Scenario 1 energy absorption elements
3	Coupler anchorage compression load	Carbody structure shall support the maximum dynamic load needed to fully collapse and release a coupler such that its physical retraction stroke is maximized	No permanent deformation of any member, structural sheathing, or connection
4	Coupler anchorage tensile load	Loads shall meet the required duty as specified in section 6	No permanent deformation of any structural member or structural sheathing
5	Collision post shear load (collision posts or protective collision wall structures)	Load equal to the end sill compression load, applied to each collision post separately over a surface area of the collision post in the longitudinal (inward) direction, or applied to a collision wall structure over a surface area of the wall at two separately located lateral positions at 30% of the end frame width relative to either side of vehicle longitudinal centerline *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height measured from the top of end frame	Stresses in the carbody structure and collision post to be less than ultimate strength
6	Collision post elastic load (collision posts or protective collision wall structure)	Load of 100 kN (22,500 lb) positioned at 380 mm (15 in.) above top of anticlimber applied to each collision post simultaneously over surface areas of the collision posts, or applied simultaneously to collision wall structure areas in two locations symmetrically positioned laterally at 30% of the end frame width relative to either side of vehicle longitudinal centerline *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height centered on the point of loading	No permanent deformation of any member, structural sheathing, or connection

Table 4-2 Structural Load Requirements for Streetcars (Cont'd)

Item	Type of Load	Specified Load	Acceptance Criteria
7	Corner post shear load	Load of 100 kN (22,500 lb) applied to each corner post (or corner structure) over a surface area of the corner post in separate longitudinal (inward) and transverse (inward) directions *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) or 15 deg on either side of transverse (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height measured from the top of end frame	Stresses in the carbody structure and corner post to be less than ultimate strength
8	Corner post elastic load	Load of 50 kN (11,250 lb) positioned at 380 mm (15 in.) above top of end sill applied to each corner post (corner structure) over a surface area of the corner post in separate longitudinal (inward) and transverse (inward) directions *(a)* load application direction variation permitted within 15 deg on either side of longitudinal (inward) or 15 deg on either side of transverse (inward) *(b)* the applied load area shall not exceed 250 mm (10 in.) in width nor 150 mm (6 in.) in height centered on the point of loading	No permanent deformation of any member, structural sheathing, or connection
9	Structural shelf	Longitudinal load of 50 kN (11,250 lb) applied at any point in the longitudinal (inward) direction *(a)* area of load application shall not exceed 250 mm × 150 mm (10 in. × 6 in.) *(b)* load direction variation permitted within 15 deg on either side of longitudinal (inward)	No permanent deformation of any member, structural sheathing, or connection
10	Side wall load at side sill	Load of 178 kN (40,000 lb) applied in transverse (inward) direction at the side sill, and distributed along an area of 2.4 m × 150 mm (96 in. × 6 in.), not including the doorways	No permanent deformation of any member, structural sheathing, or connection. Localized deformation of the side wall profile in the area of the application is permitted.
11	Side wall load at belt rail	Load of 44 kN (10,000 lb) applied in the transverse (inward) direction at the belt rail, and distributed along an area of 2.4 m × 150 mm (96 in. × 6 in.), not including the doorways	No more than 75 mm (3 in.) of permanent structural deformation into the vehicle interior. This load shall not result in edges or protrusions of vehicle structure within the vehicle interior.
12	Roof, concentrated load	Load of 1.330 kN (300 lb) spaced over area of 380 mm × 330 mm (15 in. × 13 in.)	No permanent deformation of any member, structural sheathing, or structural connection

Table 4-2 Structural Load Requirements for Streetcars (Cont'd)

Item	Type of Load	Specified Load	Acceptance Criteria
13	Truck-to-carbody attachment	Separately applied loads as follows: *(a)* a longitudinal load produced from the collision scenarios referenced in section 8. Alternatively, a longitudinal load equivalent to 5 times the weight of a truck applied through the center of gravity of the truck. *(b)* a load as specified in Item 10, with two wheels on the opposite side of the truck fixed laterally at the wheel flanges at the height of the rail. *(c)* a vertical load of 2 times the weight of the truck. All above accelerations shall be applied in combination of −1 g vertical	*(a)* Truck shall remain attached. *(b)* Truck shall remain attached. *(c)* Yield strength in the attachment mechanism shall not be exceeded.
14	Equipment attachments	Separately applied acceleration loadings of *(a)* ±5 g, applied in the longitudinal direction *(b)* ±2 g, applied in the transverse direction *(c)* ±3 g, applied in the vertical direction All above accelerations shall be applied in combination of −1 g vertical	Stresses in the attachment mechanism to be less than ultimate strength

Table 4.6-1 Crashworthiness for Light Rail Vehicles

Item	Type of Load	Specified Load/Condition	Acceptance Criteria
1	Collision Scenario 1 — low speed collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at an impact speed of 8 km/h (5 mph)	Acceptance criteria defined in para. 9.3.2
2	Collision Scenario 2 — safe speed collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at a speed of 24 km/h (15 mph) and trains vertically offset by 30 mm (1.18 in.) at mating anticlimbers of the colliding vehicles. Couplers in position for normal operation.	Acceptance criteria defined in para. 9.3.3
3	Collision Scenario 3 — structural stability collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at an impact speed of at 40 km/h (25 mph) and trains vertically offset by 30 mm (1.18 in.) at mating anticlimbers of the colliding vehicles. Couplers in position for normal operation.	Acceptance criteria defined in para. 9.3.4
4	Collision Scenario 4 — collision of LRV with street vehicle	Corner load of 100 kN (22,500 lb) applied in a direction normal to a surface point whose tangent is 45 deg as measured relative to the longitudinal centerline of the vehicle. The load shall be applied over a surface area along the bottom edge of the leading end structure measuring no greater than 250 mm (10 in.) vertically × 500 mm (20 in.) horizontally.	No permanent deformation of LRV structural elements with the possible exception of replaceable elements used to absorb the collision energy. Damage to decorative coverings or nonstructural elements is permissible.

Table 4.6-2 Crashworthiness for Streetcars

Item	Type of Load	Specified Load	Acceptance Criteria
1	Collision Scenario 1 — low speed collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at an impact speed of 8 km/h (5 mph).	Acceptance criteria defined in para. 9.3.2
2	Collision Scenario 2 — safe speed collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at a speed of 16 km/h (10 mph) and trains vertically offset by 30 mm (1.18 in.) at mating anticlimbers of the colliding vehicles. Couplers in position for normal operation.	Acceptance criteria defined in para. 9.3.3
3	Collision Scenario 3 — structural stability collision	Collision of two ready-to-run loaded trains under conditions specified in para. 9.3.1 with moving train at an impact speed of at 24 km/h (15 mph) and trains vertically offset by 30 mm (1.18 in.) at mating anticlimbers of the colliding vehicles. Couplers in position for normal operation.	Acceptance criteria defined in para. 9.3.4
4	Collision Scenario 4 — collision of streetcar with street vehicle	Corner load of 100 kN (22,500 lb) applied in a direction normal to a surface point whose tangent is 45 deg as measured relative to the longitudinal centerline of the vehicle. The load shall be applied over a surface area along the bottom edge of the leading end structure measuring no greater than 250 mm (10 in.) vertically × 500 mm (20 in.) horizontally.	No permanent deformation of streetcar structural elements with the possible exception of replaceable elements used to absorb the collision energy. Damage to decorative coverings or nonstructural elements is permissible.

analysis and/or test that it has no effect on the structural integrity of the complete carbody.

Tables 4-1 and 4-2 do not list all loads necessary to ensure the structural integrity of a carbody. Additional loads that may need to be considered include: loads associated with vehicle maintenance procedures such as jacking or hoisting to ensure the safety of maintenance and operation personnel; recurring operational loads that follow industry-accepted fatigue analyses and weld criteria, such as specified by AWS D1.1/D1.1M, to assess repetitive loading from propulsion, braking, and track features; and infrequent exceptional loads such as rerailing recovery and emergency braking to ensure damage does not result from their application.

6 COUPLER SYSTEM

6.1 Characteristics

The design of the coupler system including drawbars, draft gear, attachments to the carbody, and the carbody connection point shall respond to normal and overload conditions in a predictable manner. When deployed, the coupler system shall be capable of absorbing the compression and tension forces encountered in normal vehicle operation in a train, including coupling and uncoupling, without damage.

The coupler system shall also be designed with a release mechanism to respond to compressive overload conditions. The coupler system may also include a regenerative or nonregenerative energy absorption unit(s). In a collision, the draft gear elements and/or energy absorption unit(s) of the coupler shall compress, followed by activation of a release mechanism, which shall allow the coupler system to retract a sufficient distance to permit the carbody anticlimbers to engage. If the collision energy is sufficiently high such that compression continues following the full retraction of the coupler system, the coupler system shall not impede the CEM response of the carbody to overload conditions. The value of the release load shall satisfy the specific characteristics of the subject transit system's intended operation.

Whether deployed or stowed behind a coupler cover, the coupler system shall at all times be vertically supported in a safe manner to prevent the coupler from falling onto the track. No portion of the carmodule or truck components shall hinder the coupler system during its full retraction.

7 STRUCTURAL MATERIALS

Minimum material property values as defined by a material specification or standard stated in paras. 7.1 through 7.4 shall be used. The limiting static material properties shall be as given in the referenced material standard as follows. When other standards are used, equivalency shall be demonstrated between these standards and the referenced material standards.

7.1 Austenitic Stainless Steel

Structural use of austenitic stainless steel shall be in accordance with APTA PR-CS-S-004-98, Rev. 1, Standard for Austenitic Stainless Steel for Railroad Passenger Equipment, or equivalent.

7.2 Low-Alloy High Tensile Steel

Structural use of low-alloy high tensile (LAHT) steel shall be in accordance with the requirements of APTA PR-CS-S-034-99, Rev. 2, Section 4.2, Standard for the Design and Construction of Passenger Railroad Rolling Stock, or equivalent.

7.3 Aluminum

Structural use of aluminum and aluminum alloys shall be in compliance with APTA PR-CS-S-015-99, Standard for Aluminum and Aluminum Alloys for Passenger Equipment Carbody Construction, or equivalent.

7.4 Nonmetallic Materials

If nonmetallic materials are utilized, this Standard shall be applied to the extent possible. Data from internationally accepted standards that represent the performance of the material may be applied pending demonstration of equivalency to a U.S. code or standard.

8 CRASH ENERGY MANAGEMENT (CEM)

To improve crashworthiness, this Standard requires that the principles of crash energy management (CEM) be applied, including the use of analytical tools and/or testing to verify that the structural design and CEM features are stable and will crush or deform as intended. Computer modeling analysis for the purpose of evaluation of load cases specified in para. 4.6 and Tables 4.6-1 and 4.6-2 shall utilize a time-dependent, large-deflection type model.

The vehicle shall be designed to crush and absorb energy in a controlled manner when subjected to end collision loads. The design shall be based on the CEM structural energy absorption zones per the scenarios specified in Tables 4.6-1 and 4.6-2. A CEM and collision survivability strategy shall be developed that is compliant with the criteria provided herein. The strategy shall define the specific features of the carbody that will provide the required zones of energy absorption.

NOTE: The specifications referenced in this Standard for CEM represent a basis for protecting passengers when vehicles are involved in collisions with like vehicles or obstacles. The specifications do not address all the considerations that may need to be examined inclusive of vehicle design and operating variances that may lead to incompatibility related to strength, geometry, or variations in the condition of coupler engagement during collisions.

9 ANALYSIS

In case of collision, interior equipment interfacing with occupants that may become loose within the occupied volume shall be securely fastened. An analysis shall be provided for such interior equipment that weighs over 11.3 kg (25 lb) (e.g., display panels, seats, fire extinguishers, luggage stowage racks) excluding the interior liners such as side and end walls, door pockets, ceiling-lining materials, and floors. All other equipment attached to the carbody (interior equipment not interfacing with occupants and exterior equipment) weighing over 67.8 kg (150 lb) shall be analyzed. Equipment attachments shall be of sufficient strength to support equipment under loading and acceptance criteria specified by Item 14 in Tables 4-1 and 4-2.

Equipment housed within a fixed compartment need not be analyzed provided it can be shown that contained equipment will not penetrate the walls of a fixed compartment when exposed to the specified acceleration loads in Item 14 in Tables 4-1 and 4-2. For any portion of the proposed design that is based on a service-proven vehicle, data from previous tests, historical data from operations or structural analyses as required to satisfy the applicable requirements may be provided in lieu of new analyses or tests.

9.1 Structural Illustrations

Structural illustrations shall be provided to clearly define the primary carbody structure. The structural illustrations shall include a side view, a top view showing one longitudinal half of the roof and one longitudinal half of the underframe, and typical carbody cross-sections, which may include side-frame and doorframe posts; end, side, draft, and center sills; belt rail, top, and roof rails; collision and corner posts; bolsters, floor beams, and cross bearers; roof carlines and purlins; roof sheathing or corrugation; and side-frame sheathing and/or corrugation.

9.2 Stress Analysis

The carbody stress analysis shall consist of a finite element analysis (FEA) using a recognized computer FEA code, supplemented as appropriate by manual stress analyses. The results of the stress analysis shall include calculated stresses, allowable stresses, and margins of safety for all structural elements at all design loading conditions required by this Standard. The stability of plates, webs, and flanges shall be calculated for members subject to compression and shear. For results that are not efficiently analyzed by FEA (such as weld connections, welded and/or bolted joints, and column and plate stability), manual stress analyses may be performed. The format and content of these analyses shall include the following at a minimum:

(a) load case description