ASME RT-2–2021
(Revision of ASME RT-2–2014)

Safety Standard for Structural Requirements for Heavy Rail Transit Vehicles

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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The American Society of Mechanical Engineers
Two Park Avenue • New York, NY • 10016 USA

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This Standard will be revised when the Committee approves the issuance of a new edition. This Standard will become effective 6 months after the Date of Issuance.

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The American Society of Mechanical Engineers
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FOREWORD

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

The RTV Standards Committee develops and maintains standards that cover safety, functional, performance, and operability requirements, as well as mechanical systems, components, and structural requirements for RTVs. RTVs include streetcars, conventional subway (rapid) transit rail vehicles, and light rail vehicles and excludes freight, commuter, high-speed, or any other rail vehicles under the jurisdiction of the Federal Railroad Administration.

The RTV 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, so as to 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 the Committee's consideration of factors such as technological advances, new data, and changing environmental and industry needs.

Both SI 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 the "Standard for Use of the International System of Units (SI): The Modern Metric System," IEEE/ASTM SI 10-1997, or the latest revision.

The first edition of ASME RT-2 was approved by the American National Standards Institute (ANSI) in 2008. A revised edition was approved by ANSI in 2014.

ASME RT-2–2021 is a complete revision of the 2014 edition. Following its approval by the RTV Standards Committee and ASME, ASME RT-2–2021 was approved by ANSI on November 30, 2021.

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 heavy rail transit operations, like all rail vehicles, is a system characteristic. As do all transportation options in a given corridor, the operation of rail vehicles has certain risks, including derailment and collision with another vehicle. The risks are mitigated by the design of the signal system and other systems 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 vehicle 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 for the design of the carbody of heavy rail transit vehicles. It also considers recent developments in the design of rail carbody structures intended to optimize the structure performance under the conditions of an overload, such as might occur during a collision. This topic is commonly identified as crash energy management (CEM). The intent of CEM is to better manage the dissipation of the portion of the energy of 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 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. This Standard requires the incorporation of CEM principles in the design of heavy rail transit vehicles. For multiple unit operation, distributing structural energy absorption through the train has been shown to be beneficial.

ASME RT-2–2021
SUMMARY OF CHANGES

Following approval by the ASME RTV Committee and ASME, and after public review, ASME RT-2–2021 was approved by the American National Standards Institute on November 30, 2021.

This Standard has been revised in its entirety.

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SAFETY STANDARD FOR STRUCTURAL REQUIREMENTS FOR HEAVY RAIL TRANSIT VEHICLES

1 SCOPE

The objectives of the passive safety requirements described in this Standard are to reduce the risk to passenger injury and damage to equipment resulting from collision accidents by providing a means of protection when all 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, 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 impacts between the occupants and vehicle interior, beyond limiting vehicle acceleration and consequential secondary impact velocity of passengers colliding with interior surfaces.

1.1 Subjects Not Addressed by This Standard

There are several design considerations related to safety that are not addressed, such as, but not limited to

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

1.2 Effective Date

This Standard applies to newly constructed heavy rail transit vehicles for transit passenger service ordered 6 months following the date of issuance of this Standard 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.

antitelescoping plate: a single structural member that spans the full width of the carbody at the top of the end frame, that is attached to the tops of the collision and corner posts, and is designed to transmit the collision and corner post top reaction loads to the carbody sides.

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

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.

car: see *heavy rail transit vehicle*.

carbody: the main load-carrying structure above all truck suspension units. It includes all components that are connected to this structure and contribute directly to its strength, stiffness, and stability.

collision posts: a set of two full-height structural posts located at each end of the carbody, extending from the bottom of the underframe structure up to a structural shelf or an antitelescoping plate. 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. The use of a collision wall is intended to provide a collision performance equivalent to a collision post design.

consist: a set of vehicles forming a complete train.

corner posts: a set of two full-height structural posts located at the outside corners of the passenger compartment or at the extreme corners of the carbody, extending from the bottom of the underframe structure up to an anti-telescoping plate and to the roof at the top of the side frame at its intersection with the roof. Corner posts can be an assembly of several structural members, provided that the required performance is met.

coupler system: a system comprised of the coupler head, drawbar, draft gear, and attachments to the carbody, permitting the connection between vehicles or trains.

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 includes 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.

heavy rail transit vehicle: typically an electrically propelled, bidirectional vehicle, capable of multiple unit operation, and designed for rapid, high-level boarding and discharging of passengers. The vehicle is operated on a mode of rail rapid transit generally characterized by fully grade-separated construction on exclusive rights of way, with station platforms at the floor level of the vehicles. These systems are commonly referred to as subways or metros.

high-strength corner post: a structural post typically located at the extreme corners of the carbody, at the noncab ends of the leading and intermediate cars in a train, typically found in open gangway designs, replacing the need for collision posts, extending from the bottom of the underframe structure up to the level of the roof rail.

occupied volume: the volume of the heavy rail transit vehicle 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.

open gangway: a flexible, semi-permanent, connected passageway spanning a full-width opening between adjacent vehicles providing a walkway that allows passengers to freely move between vehicles.

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

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) an elastic–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) no visual permanent deformation can be found via visual inspection

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

principal structural element: an element that contributes significantly to resisting the loads specified for the identified structure (e.g., carbody, collision post, corner post) and whose integrity is essential in maintaining the overall structural integrity of the vehicle and preservation of occupied volume. Principal structural elements shall be agreed to by the customer and manufacturer.

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.

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

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 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: see *heavy rail transit vehicle*.

vehicle vertical loads:

(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).

(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).

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

yield strength: the stress published by 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 vehicles of different design operating on the same routes of the subject transit system.

3.1 Anticlimber and Coupler Interface

Each heavy rail transit vehicle shall incorporate an anticlimber at each end of the vehicle. The height and design of the anticlimber and coupler on new heavy rail transit vehicles shall be compatible with existing heavy rail transit vehicles that are operated on the same routes of the subject transit system. 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. 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.

3.2 Multiple Unit Operation

All combinations of vehicles to be operated within a train shall be considered in assessing the effect of multiple unit operation in a collision.

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 strength of connections between structural members for all structural loading requirements outlined in Table 4-1 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 Table 4-1 but increased in magnitude to the maximum load that can be resisted by the structure, as determined by observing that further increase in deflections will result in a decrease in the load capable of being carried by the structure. References to sheathing in Table 4-1 refer only to structurally related (load-carrying) sheathing.

4.1 Welding

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

4.2 Articulation

An articulation, if used, shall include structure to meet the requirements of section 5.

4.3 Design Parameter Tolerance

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, including the bolster if used, to the carbody shall be provided, with strength levels in accordance with section 5. The trucks shall remain attached to the

Table 4-1 Structural Load Requirements for Heavy Rail Transit 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	Minimum of 890 kN (200,000 lb), applied in the longitudinal (inward) direction on the end sill or anticlimber. Vehicle loaded to ready-to-run weight.	No permanent deformation of any structural member or structural sheathing, with the possible exception of the energy absorption elements
3	Coupler anchorage compression structural load (see section 6)	Carbody structure shall support the maximum dynamic load needed to fully collapse a coupler such that its physical retraction stroke is maximized.	No permanent deformation of any structural member or structural sheathing
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 wall shear	Load equal to the end sill compression load, applied to each collision post separately or applied to the collision wall at the approximate one-third points across the width of the vehicle in the longitudinal (inward) direction *(a)* Load application direction variation shall be within 15 deg on either side of the 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 wall elastic	Load equal to 33% of end sill compression load positioned at 450 mm (17.75 in.) above the top of underframe, applied to each collision post simultaneously or applied to the collision wall at the approximate one-third points across the width of the vehicle in the longitudinal (inward) direction *(a)* Load application direction variation shall be within 15 deg on either side of the 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 connections
7	Collision post elastic–plastic Collision wall elastic–plastic	Load applied per the elastic design load case (see Item 6 applied to single post or collision wall) beyond the elastic design load, until the post or wall achieves a permanent deflection at the back of the side of the post or wall, directly behind load location point, equal to 65 mm (2.5 in.). The deformation is to be measured after the load is removed and relative to a reference frame connecting the top and bottom of the post or wall back surface.	The load shall remain above the elastic design load. There shall be no complete separation of the posts or loss of integrity of the wall from its connecting structure.

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

Item	Type of Load	Specified Load	Acceptance Criteria
8	Corner post shear	25% of the end-sill compression load, applied to each corner post over a surface area of the corner post in separate longitudinal and transverse directions *(a)* Load application direction variation shall be within 15 deg on either side of the 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
9	Corner post elastic	Two loads, applied separately, to one post 450 mm (17.75 in.) above the top of the underframe, one load equal to 12% of the end sill compression load applied in the longitudinal inward direction, and a second load equal to 6% of the end sill compression load applied in the transverse inward direction *(a)* Load application direction variation shall be within 15 deg on either side of the 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.	No permanent deformation of any structural member, structural sheathing, or structural connections
10	Corner post elastic–plastic	Load applied per the elastic design load case (see Item 9 applied to single post) beyond the elastic design load, until the post achieves a permanent deflection at the back of the side of the post, directly behind load location point, equal to 50 mm (2 in.). The deformation is to be measured after the load is removed and relative to a reference frame connecting the top and bottom of the post back surface.	The load shall remain above the elastic design load. There shall be no complete separation of the posts, its connection to the underframe, and its connection to either the roof structure or at the antitelescoping plate.
11	High-strength corner post shear	Two loads, applied separately, to one post at the top of the underframe, one load equal to 70% of the end sill compression load applied in the longitudinal inward direction, and a second load equal to 25% of the end sill compression load applied in the transverse inward direction *(a)* Load application direction variation shall be within 15 deg on either side of the 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.	No permanent deformation of any structural member, structural sheathing, or structural connections

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

Item	Type of Load	Specified Load	Acceptance Criteria
12	High-strength corner post elastic load	Two loads, applied separately, to one post 450 mm (17.75 in.) above the top of the underframe, one load equal to 45% of the end sill compression load applied in the longitudinal inward direction, and a second load equal to 6% of the end sill compression load applied in the transverse inward direction *(a)* Load application direction variation shall be within 15 deg on either side of the 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 structural member, structural sheathing, or structural connections
13	High-strength corner post elastic–plastic load	Load applied per the elastic design load case (see Item 12 applied to single post) beyond the elastic design load, until the post achieves a permanent deflection at the back of the side of the post, directly behind load location point, equal to 50 mm (2 in.). The deformation is to be measured after the load is removed and relative to a reference frame connecting the top and bottom of the post back surface.	The load shall remain above the elastic design load. The connections between the corner post and all other structural members have not separated.
14	Structural shelf	7.5% of the end sill compression load 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 shall be within 15 deg on either side of longitudinal (inward).	No permanent deformation of any member, structural sheathing, or connection
15	Side wall, at side sill	178 kN (40,000 lb) applied in the transverse inward direction at the side sill and distributed along an area of 2.4 m × 150 mm (96 in. × 6 in.), including the doorways	No permanent deformation of any structural member or structural sheathing. Some localized deformation of the side wall profile in the area of the load application is permitted.
16	Side wall, at belt rail	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 sharp edges or protrusions of vehicle structure within the vehicle interior.
17	Roof, in rollover condition	Vehicle shall be able to rest upon its roof.	Structural damage in occupied areas limited to roof sheathing and roof framing members
18	Roof, concentrated	1.330 kN (300 lb) spaced over an area of 380 mm × 330 mm (15 in. × 13 in.), applied anywhere on roof structure	No permanent deformation of any structural member or structural sheathing
19	Truck to carbody attachment	*(a)* 667 kN (150,000 lb) applied on the truck in the horizontal plane through the center of truck rotation *(b)* a vertical load of two times the weight of the truck	*(a)* stress in the attachment mechanism to be less than ultimate strength *(b)* not to exceed yield strength in the attachment mechanism

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

Item	Type of Load	Specified Load	Acceptance Criteria
20	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

carbody when the vehicle is raised unless first intentionally detached. The ultimate strength of the attachment mechanism in the horizontal plane (ultimate horizontal strength) 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 constraints nor upon bolster anchor rods.

4.6 Collision and Corner Posts

Collision posts are required in end frames to protect the occupants at the end of the train, normally a cab end, from the severity of a collision with another train. For intermediate carbody ends between like vehicles and not designed for configuration at the ends of a train, the function of a collision post may be relocated to the corner of the end frame to become a high-strength corner post. The design of the high-strength corner post shall include features that prevent anticlimbing, provide strength resistance against override, and exhibit a distributed load transfer into the car structure along its length, including the roof level end-frame to end-frame reaction at the roof to side frame structural connection.

4.7 Collision Wall

A collision wall may be substituted for collision posts provided it meets all of the same performance requirements as required in Table 4-1, Items 5 through 7. For intermediate carbody ends between like vehicles and not designed for configuration at the ends of a train, the function of a collision wall may be relocated to the corner of the end frame with strength equivalent to a high-strength corner post.

4.8 Open Gangways

For heavy rail vehicles using an open gangway design, the open gangway as defined provides passage width between cars that prevents the common location of collision posts by the nature of its design. As a result, the side corner posts at open gangway-equipped ends require higher strength criteria to provide the necessary passenger protection and loading resulting from collision events.

The design requirements for gangway corner posts shall apply only to ends of carbodies fitted with open gangways but not applied to ends of cars at the end of a consist (see Figure 4.8-1).

The cab end must comply with the requirements for collision posts, corner posts, or collision walls as applicable in Table 4-1. The open gangway end must comply with the high-strength corner post requirements per Items 11 through 13 in Table 4-1.

Open gangways are only located in the middle of the train and are not subjected to high acceleration loading seen by leading cab cars. Therefore, the longitudinal load requirements for the high-strength corner posts are lower than for the cab end collision posts.

Gangways between vehicles constituting flexible connections are excluded from the global vehicle shortening requirements of para. 9.3.

In the event of a collision, according to the scenarios defined in this Standard, the following criteria apply:

(a) The open gangway attachment points to the carbody end frame shall comply with Table 4-1, Item 20.

(b) The open gangway attachments shall withstand all forces imparted by the open gangway, including those resulting from negotiating all applicable track conditions on the system, loads from jacking, and lifting.

(c) The open gangway attachments shall withstand the carbody volume capacity load.

(d) The gangway system shall not prevent the design function of a drawbar coupler, energy absorber elements, or anticlimbers. The minimum length of compressed gangway components shall be taken into account.

4.9 Crashworthiness

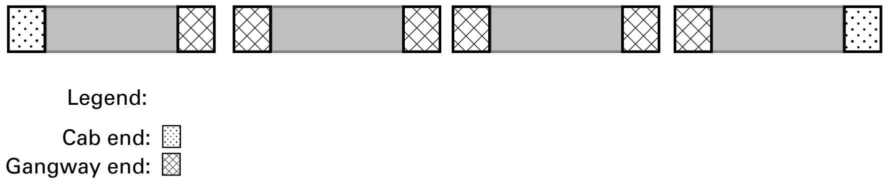
(a) The crashworthiness performance shall achieve the following objectives:

(1) minimize the loss of occupied volume resulting from structural collapse or structural penetration

(2) 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

(3) 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

Figure 4.8-1 Gangway Configuration



(b) Crashworthiness performance is specified by the following series of collision scenarios and acceptable outcomes:

(1) *Scenario 1 (Low Speed Collision).* The first collision scenario is a relatively low-severity frontal collision between two trains. Vehicle damage or CEM activation resulting from this collision is limited to replaceable or recoverable energy-absorbing element(s).

(2) *Scenario 2 (Safe Speed Collision).* This collision scenario is a significant collision speed impact between two like trains. It is indicated as the safe speed collision because it is the scenario where 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 collision scenario is a severe collision speed impact between two like trains. This scenario is intended only to evaluate structural stability.

Table 4-1 further specifies 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 occupied 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 Table 4.9-1 are met.

5 DESIGN LOADS AND ASSESSMENT CRITERIA

This section defines load requirements used to assess the structural design of heavy rail vehicle carbodies with respect to safety of the occupants. Table 4-1 contains the loading conditions and assessment criteria and the requirements to assess passive safety for heavy rail vehicles based upon structural loading cases. 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 analysis and/or test that it has no effect on the structural integrity of the complete carbody.

Table 4-1 does not contain all loads necessary to ensure the structural integrity of a carbody. Additional loads that may need to be considered include the following:

(a) loads associated with vehicle maintenance procedures, such as jacking or hoisting, to ensure the safety of maintenance and operation personnel

(b) recurring operational loads should consider industry accepted fatigue analyses and criteria, such as AWS D1.1/D1.1M, endurance limit or accumulated damage methods to assess repeated loading from propulsion, braking, and track features

Table 4.9-1 Crashworthiness for Heavy Rail Transit 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	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 40 km/h (25 mph) and trains vertically offset by 30 mm (1.18 in.) at mating anticlimbers of the colliding vehicles	Acceptance criteria defined in para. 9.3.4

(c) infrequent exceptional loads, such as rerailing recovery and emergency braking, should be assessed to ensure damage does not result from their application

6 COUPLER SYSTEM

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. 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), including portions that could be considered recoverable or easily replaceable. 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.

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 carbody 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 standards stated in the following sections shall be utilized. The limiting static material properties shall be as given in the referenced material standard. 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 or an 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 or an equivalent.

7.3 Aluminum

Structural use of aluminum and aluminum alloys shall be in compliance with APTA PR-CS-S-015-99 or an equivalent.

7.4 Nonmetallic Materials

If nonmetallic materials are being utilized, then 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 to verify that the structural design and CEM features are stable and crush or deform as intended. Evaluation of the load cases specified in para. 4.9 and Table 4.9-1 shall be performed using time-dependent, large deflection computer simulations. Validation of the crush behavior by test shall be performed if specified.

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 Table 4.9-1. 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 given within this Standard for CEM represent a basis for protecting passengers when trains are involved in collisions with like trains or with 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. It is recommended that the purchaser and supplier agree on a compatibility plan to ensure performance-based scenarios are applicable.

9 ANALYSIS

In a collision, interior equipment within the occupied volume shall remain securely fastened. An analysis shall be provided for such interior equipment of weight greater than 11.3 kg (25 lb), e.g., display panels, seats, fire extinguishers, luggage stowage racks, excluding interior liners, such as side and end walls, door pockets, ceiling-lining materials, and floors. All exterior equipment attached to the carbody of weight greater than 67.8 kg (150 lb) shall be analyzed. Equipment attachments shall be of sufficient strength to support equipment under loading specified by Item 20 in Table 4-1.

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 20 of Table 4-1. 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 corresponding portion of these requirements may be provided in lieu of new analyses or tests.

9.1 Structural Renderings

Structural renderings shall be provided in order to clearly define the primary carbody structure. The structural renderings 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 door frame posts; end, side, draft, and center sills; belt rail, top, and roof rails; collision and corner posts; antitelescoping plate; 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 finite element analysis, 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 as a minimum:

(a) load case description

(b) rendering of the item to be analyzed, with dimensions, applied forces, and other boundary conditions

(c) drawing references

(d) material properties

(e) allowable stress

(f) detailed stress results and analyses

(g) conclusions

9.3 Crashworthiness Analysis

A crashworthiness analysis shall be performed using a nonlinear, large-deformation explicit, time-dependent, finite element software program. The simulation results shall be provided in various forms, including video animation, static images of the calculated response, graphs of collision forces, displacements, accelerations, and energy balance data. The documentation of results shall demonstrate progressive crush response and the ability of the structure to maintain survival volume required for operator and passengers. The force deflection curves shall show the crush response of the front-end structure, where force is measured at the interface between the cab end structure and passenger compartment. The acceleration history for each car of the train shall be determined as defined by the average collision acceleration definition. Energy data shall be included to demonstrate conservation of momentum, conservation of energy, and minimization of computational energy loss such as might be caused by computational errors in element deformation.

The performance of the energy absorption components shall be validated by the collision conditions and scenarios specified in Table 4.9-1 and paras. 9.3.1 through 9.3.4.

9.3.1 Collision Conditions. Train crashworthiness analysis simulation conditions are as follows:

(a) A moving train colliding into a stopped, braked train (wheel/rail friction coefficient of 0.5) of identical design shall use the train initial velocities and loading conditions identified in Table 4.9-1 and occurring on level tangent track.

(b) A vertical height offset between colliding vehicles as specified in Table 4.9-1, Items 2 and 3 only, with the stopped train in the lower (below nominal) height position shall be modeled by a vertical offset movement of the track.

(c) Both trains shall be configured to the maximum train length used in operation.

9.3.2 Collision Acceptance Criteria: Scenario 1. The results of the simulation for collision conditions and Scenario 1 as referenced in para. 9.3.1 and Table 4.9-1 shall conform to the following criteria for any train:

(a) The energy shall be absorbed by a recoverable or an easily replaceable element.

(b) There shall be no permanent deformation to any vehicle structural member or side sheathing.

(c) There shall be no damage to vehicle equipment other than the recoverable or easily replaceable elements.

NOTE: This scenario is intended to maintain vehicle availability and reduce repair costs.

9.3.3 Collision Acceptance Criteria: Scenario 2. The results of the simulation for collision conditions and Scenario 2 as referenced in para. 9.3.1 and Table 4.9-1 shall conform to the following criteria for any train:

(a) Vehicle interactions do not exhibit override or telescoping responses.

(b) Progressive structural crush begins at vehicle ends.