Public Review Draft
August 2021

Proposed Revisions
for
ASME RT-2-20XX
Revision to
ASME RT-2-2014
Safety Standard for Structural Requirements for Heavy Rail Transit Vehicles

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Proposed Revision to RTV-2, Safety Standard for Structural Requirements for Heavy Rail Transit Vehicles:

Proposed ASME RT-2–20XX
(Revision of ASME RT-2–2014)

Safety Standard for Structural Requirements for Heavy Rail Transit Vehicles
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 the vehicle interior, beyond limiting vehicle acceleration and consequential secondary impact velocity of passengers colliding with interior surfaces.

40.3 Subjects Covered by This Standard

This Standard applies to carbodies of newly constructed heavy rail transit vehicles for transit passenger service. It defines requirements for the incorporation of passive safety design concepts related to the performance of the carbodies of heavy rail transit vehicles in conditions such as collisions, so as to enhance passenger safety, and limit and control damage.

40.4 Subjects Not Addressed by This Standard

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

40.5 Effective Date

This Standard applies to carbodies of newly constructed heavy rail transit vehicles for transit passenger service ordered 180 days 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 the anticlimber of an opposing vehicle or otherwise coupled or not vehicle 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.
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.
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 in the side frame arranged below the passenger side windows, 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, and the side cameras and mirrors.
car: see heavy rail transit vehicle.
carbody (heavy rail): the heavy rail vehicle body consists of 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. Mechanical or electrical equipment and other mounted parts are not considered part of the carbody, though their attachment brackets are.
closing speed: the relative speed of a vehicle to another object or vehicle at the time of initial impact.
collision posts (heavy rail transit): 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 anti-telescoping 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 structural assembly in the end frame that spans the full width of the carbody and is attached to the corner posts, and is designed to transmit collision reaction loads to the carbody sides. The use of a collision wall is intended to provide collision performance equivalent to a collision post design.
consist: the makeup or composition of the individual units of a train, generally by number and type of vehicle, a set of vehicles forming a complete train.
corner posts (RT-2): 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 assembled to each other provided that the required performance is met.
coupler load: The dynamic load needed to fully collapse a coupler such that its physical retraction stroke is maximized.
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). The controlled crushing and energy absorption functions are typically assigned to special carbody structural members in the structural energy absorption zone that are designed to crush in a predictable and stable manner over a distance that depends on the design of the member and the desired amount of energy absorption. The use of supplementary energy absorbing element(s) may be specified.
crashworthiness (RT-2): 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.
the ability of a carbody to manage the energy of a collision while maintaining structural integrity, so as to minimize injury to occupants.
end frame (RT-2): at the coupler ends, the end frame consists of structure inboard of and supporting the anti-telescoping posts at the juncture of the front end and side frames, collision posts located at the approximate one-third points of the end frame width, the end structural shelf or transverse beam, and sheathing connected to the structural framing members. Structure inboard of the extreme ends of the vehicle that typically supports includes the corner posts, or collision posts, or collision wall.
gangway corner post: a structural post located at the extreme corners of the carbody, at the carbody end(s) where a full-width gangway is to be installed, extending from the bottom of the underframe structure up to the level of the roof rail.
end sill compression load (buff load): longitudinal compressive (longitudinal) force applied at the ends of the vehicle carbody, usually at the anti-telescoping posts.
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.
gangway high-strength corner post: a structural post typically located at the extreme corners of the carbody, at the thenon-cab carbody end(s) of the leading and intermediate cars in a train, typically found in open gangway.
designs, replacing the need for collision posts where a full-width gangway is installed, extending from the bottom of the underframe structure up to the level of the roof rail. [SM2][B3]

**Heavy rail transit vehicle:** a 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.

**Occupied volume:** means 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 connection—connected passageway spanning a full-width opening between adjacent vehicles providing a walkway that allows passengers to freely move between vehicles without the use of end doors.

**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:**
- for design, 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 after the load is released.
- for testing, a condition resulting from a stress greater than the 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 after the load is released.
- 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: an elastic-plastic finite element analysis (FEA) analysis for the relevant load case shows the affected areas to be small within 1% plastic strain; the overall structure does not take a permanent set beyond its initial dimensions; no visual permanent deformation can be found via visual inspection; and, 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, etc.), 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 \(a_i\) \(i=1\) an n-point moving average is a new data sequence \(s_i\) \(i=n+1\) defined by computing the arithmetic means of n-point blocks.

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

**Structural energy absorption zone:** a zone, typically located at the ends of the carbody, designed for controlled deformation or crush when the carbody is loaded beyond its elastic capacity, while the integrity of the remaining carbody is maintained.

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

**Structural shelf (heavy rail transit):** 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. A horizontal structural member installed at the cab end of the vehicle, located between the collision post and the corner post on each side, at a height equivalent to the bottom of the windshield.

**Survival volume:** is the portion of the occupied volume that shall be preserved during the collision.

**Telescoping (RT-2):** 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.
(h) **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).

(i) **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/m² (100 lb/ft²).[8,4]

(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/m² (100 lb/ft²).

**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.

### 4.3 INTEROPERABILITY

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

This section covers geometric compatibility and crush mechanism design considerations for different vehicles operating on the same routes of the subject transit system.

#### 4.9.3.1 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 all vehicle types 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.

The coupler system shall be of a "shearback" design, to permit the couplers to collapse during a collision so as to allow engagement of the anticlimbers. See section 6 for additional requirements.

#### 4.10.03.2 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.

### 6.1 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 of the end frame for Items 6 through 11 in Table 1 shall exceed the ultimate load-carrying capacity of the weakest member joined. For these load cases, the ultimate load-carrying capacity is established defined by applying the load at the location and in the direction specified in Table 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 1 refer only to structurally related (load carrying) sheathing.
<table>
<thead>
<tr>
<th>Item</th>
<th>Type of Load</th>
<th>Specified Load on Carbody</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vehicle vertical - Maximum carbody weight</td>
<td>Evenly distributed carbody volume capacity load not including trucks</td>
<td>Stress not to exceed 65% of the any carbody structural member yield strength and no loss of local stability.</td>
</tr>
<tr>
<td>2</td>
<td>End sill compression</td>
<td>Minimum load 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.</td>
<td>No permanent deformation of any structural member or structural sheathing with the possible exception of the energy absorption elements.</td>
</tr>
<tr>
<td>3</td>
<td>Coupler anchorage compression structural load (see section 6)</td>
<td>Load of 110% of the maximum possible (commonly called the disconnect or release load) produced by the coupler load, as defined in section 6 applied in longitudinal inward direction. Carbody structure shall support the maximum dynamic load needed to fully collapse a coupler such that its physical retraction stroke is maximized. Maximum possible dynamic load from the coupler. This load is commonly called the disconnect or release load, produced by the coupler load as defined in section 6, applied in the longitudinal (inward) direction.</td>
<td>No permanent deformation of any structural member or structural sheathing.</td>
</tr>
<tr>
<td>4</td>
<td>Coupling impact</td>
<td>Coupling at a vehicle closing speed of 8 km/h (5 mph).</td>
<td>No permanent deformation of any structural member or structural sheathing not including the anticlimber.</td>
</tr>
<tr>
<td>5</td>
<td>Coupler anchorage tensile load</td>
<td>Loads shall meet the required subject transit system duty as specified in (see section 6).</td>
<td>No permanent deformation of any structural member or structural sheathing.</td>
</tr>
<tr>
<td>6</td>
<td>Collision post shear load</td>
<td>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.</td>
<td>No permanent deformation of any structural member or structural sheathing. Ultimate strength of any. Stresses in the carbody structure and collision post not to be exceeded less than ultimate strength.</td>
</tr>
<tr>
<td>76</td>
<td><strong>Collision post load (elastic–design load)</strong></td>
<td>Loads equal to 33% of the end-sill load applied to each post, with both posts loaded simultaneously up to 15 deg on either side of the longitudinal inward direction 450 mm (17.75 in.) above the top of the underframe. 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 over a surface area of the collision post in the longitudinal (inward) direction.</td>
<td>No permanent deformation of any structural member, structural sheathing, or structural connections.</td>
</tr>
<tr>
<td>82</td>
<td><strong>Collision post load (elastic–plastic design load)</strong></td>
<td>Load applied per the elastic design load case (see Item 6 above 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 1/3 the longitudinal depth of the post. 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. Loads applied per the elastic design load case (see Item 7 above applied to a single post) beyond the elastic design load, until the center of the post has deflected at least one-third of its full depth measured at the middle of the post from a line connected between the top and bottom of the post when initially unloaded.</td>
<td>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.</td>
</tr>
<tr>
<td>98</td>
<td><strong>Corner post shear loads</strong></td>
<td>Two loads, applied separately, to one post at the top of the underframe, one load equal to 25% 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.</td>
<td>Stress in the carbody structure and corner post to be less than ultimate strength. No permanent deformation of any structural member, structural sheathing, or structural connections.</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td></td>
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<tr>
<td>Load application direction variation permitted within 15 deg on either side of the longitudinal (inward) or 15 deg on either side of transverse (inward).</td>
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</tr>
<tr>
<td>(a) 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.</td>
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<tr>
<td>100 (a) Corner post loads (elastic-design load)</td>
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<tr>
<td>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.</td>
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<tr>
<td>Load application direction variation permitted within 15 deg on either side of the longitudinal (inward) or 15 deg on either side of transverse (inward).</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(a) 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.</td>
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<tr>
<td>Load applied per the elastic design load case (see Item 9 above 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 1/3 the longitudinal depth of the post. 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.</td>
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<tr>
<td>Loads applied per the elastic design load case [see Item 10(a) above] beyond the elastic design load, until the center of the post has deflected at least one-third of its full depth measured at the middle of the post from a line connected between the top and bottom of the post when initially unloaded.</td>
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<tr>
<td>The load shall remain above the elastic design load. The connections between the corner post and all other structural members have not separated. 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.</td>
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<tr>
<td>1111 Structural shelf</td>
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<tr>
<td>Load equal to 7.5% of the end sill compression load at any point in the longitudinal inward direction.</td>
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<tr>
<td>Area of load application shall not exceed 250 mm x 150 mm (10 in. x 6 in)</td>
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<tr>
<td>No permanent deformation of any structural member, structural sheathing, or structural connections.</td>
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<tr>
<td>Section</td>
<td>Description</td>
<td>Load Details</td>
<td>Observations</td>
</tr>
<tr>
<td>---------</td>
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</tr>
<tr>
<td>12</td>
<td>Anticlimber</td>
<td>Load equal to the end sill compression load applied at the vehicle centerline in the longitudinal inward direction, in combination with separately applied vertical (upward and downward) load (with one less rib than total) of 334 kN (75,000 lb).</td>
<td>No permanent deformation of any structural member or structural sheathing. Some localized deformation of the anticlimber is permitted.</td>
</tr>
<tr>
<td>13-12</td>
<td>Side wall load, at side sill</td>
<td>Load of 178 kN (40,000 lb) applied in the transverse inward direction at the side sill, and distributed along an area of 2.4 m x 150 mm (96 in. x 6 in.) including the doorways.</td>
<td>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.</td>
</tr>
<tr>
<td>14-13</td>
<td>Side wall load, at belt rail</td>
<td>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 x 150 mm (96 in. x 6 in.) not including the doorways.</td>
<td>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.</td>
</tr>
<tr>
<td>15-14</td>
<td>Roof, in rollover condition</td>
<td>Vehicle shall be able to rest upon its roof.</td>
<td>Structural damage in occupied areas limited to roof sheathing and roof framing members.</td>
</tr>
<tr>
<td>16-15</td>
<td>Roof, concentrated load</td>
<td>Load of 1,330 kN (300 lb) spaced over an area of 380 mm x 330 mm (15 in. x 13 in.). Separately applied loads anywhere on roof structure.</td>
<td>No permanent deformation of any structural member or structural sheathing.</td>
</tr>
<tr>
<td>17-16</td>
<td>Truck-to-carbody attachment</td>
<td>(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 heaviest truck.</td>
<td>(a) Not to exceed ultimate strength in the attachment mechanism. Stress in the attachment mechanism to be less than ultimate strength. (b) Not to exceed yield strength in the attachment mechanism.</td>
</tr>
<tr>
<td>18-17</td>
<td>Gangway corner post shear</td>
<td>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. Load application direction variation permitted within 15 deg on either side.</td>
<td>No permanent deformation of any structural member, structural sheathing, or structural connections.</td>
</tr>
</tbody>
</table>
| Section | Gangway corner post loads  
|---------|--------------------------------------------------|
| **1918** | Gangway corner post loads  
| **elastic design 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.  
Load application direction variation 
permitted within 15 deg on either 
side of the longitudinal (inward) 
or 15 deg on either side of 
transverse (inward). 
The applied load area shall not 
exceed 250 mm (10 in.) in width 
or 150 mm (6 in) in height 
measured from the top of end 
frame. |
| **2019** | Gangway corner post loads  
| **elastic-plastic design load** | Load applied per the elastic design 
load case (see Item 18 above) 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 1/3 the 
longitudinal depth of the post. The 
deflection 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. |
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

The 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 conditions 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 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 loading 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, for the intermediate ends of the train, where operation shall take place while being connected to another like vehicle, 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 anti-climbing, 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 for collision posts, except for in Table 1, Items 5, 6, and 7. In lieu of, and as an intended equivalent to Table 1, Item 7, the collision wall shall be capable of absorbing a minimum of 95 kJ (70,000 ft-lbs of energy) undergoing a maximum deformation up to 6 in. For intermediate carbody ends between like vehicles and not designed for configuration at the ends of a train, for the intermediate ends of the train, where operation shall take place while being connected to another like vehicle, the function of a collision wall may be relocated to the corner of the end frame with strength equivalent to become a high-strength corner post.

4.8 Requirements for Open-Gangways Equipped Vehicles
For heavy rail vehicles using an open gangway design, the open gangway as defined provides a passage width between cars that prevents the common location of collision posts. Where full-width open gangways are installed, the car end structure does not have center collision posts to not impede passenger flow between vehicles by the nature of their 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 car bodies fitted with open full-width gangways, but not applied to ends of cars at the end of a consist. See configuration below:

Gangway configuration:
- Cab end
- Gangway end

The cab end must comply with the requirements for the collision posts, corner posts, or collision walls as applicable requirements per Items 65 through 1010 in Table 1. The open-gangway end must comply with the high-strength corner gangway corner post requirements per Items 17 through 20 in Table 1.

Since the carbody ends with open-gangways are only located in the middle of the train and are not subjected to high acceleration loading seen by leading cab cars, they will not be subjected to head-on, cab end to cab end, collisions. The relative velocity between two gangway-equipped cars coupled together will be less than in the case of a head-on collision between two colliding cab ends. Therefore, the longitudinal load requirements for the gangway high-strength corner posts are lower than for the cab end collision posts.

In a crash scenario of a gangway equipped train, the energy will be absorbed by the cab end structure and the couplers between each car in the consist. A gangway’s functionality connects the relative dynamic motions between vehicles, and as a result, does not enable a design to have built-in, energy absorption features of significant capacity. Gangways between vehicles constituting flexible connections are assumed to be unoccupied and therefore excluded from the global vehicle shortening requirements of Section 9.3(f).

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

(a) The open gangway attachment points to the carbody end frame shall comply with Table 1, Item 20, Equipment attachments.
(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 interfere with the design function of the drawbar coupler, energy absorber elements, or the anticlimbers. The minimum length of compressed gangway components shall be taken into account.

4.9 Crashworthiness

The crashworthiness performance shall achieve the following objectives:

(a) Minimize the loss of occupied volume resulting from structural collapse or structural penetration.
(b) 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.
(c) 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.

(a) 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.

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minimize the loss of occupant volume resulting from structural collapse or structural penetration.

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.

The crashworthiness performance is specified by a series of collision scenarios and acceptable outcomes.

**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. This scenario can be achieved with replaceable or recoverable energy absorbing element(s).

**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.

**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 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 2 are met.

The carbody shall be constructed in accordance with the following:

- minimize the possibility of injury to occupants during a collision from such causes as the detachment of parts of the carbody or falling equipment mounted in the ceiling or on the roof.
- minimize the loss of occupant volume resulting from structural collapse or structural penetration.
- provide for a progressive controlled collapse of energy absorption zones of the carbody structure.

- Structural energy absorption zones typically located at the outer ends of the carbody structure shall be activated prior to crush of other carbody structures, following the sequence and magnitude of collapse as specified in Table 1 and para. 9.3.
- Structural collapse shall not commence until the end sill compression load identified in Item 2 of Table 1 has been exceeded. The end sill compression is the minimum allowable value for the initiation of crushing, with the exception of the energy absorption in Zone 1. The design end sill compression load shall be selected based on the CEM and collision survivability plan per section 8.
- The operator’s cab door and seat shall be designed to allow quick emergency egress of the operator into the passenger compartment. Armrests on the operator’s seat shall fold back or be easily movable to permit easy egress, and the cab-to-passenger compartment door shall open outward from the cab.

Table 1 further specifies required design loads and strengths of structural elements such as collision posts and corner posts, side wall strength, end sill compression strength, and equipment attachment to protect passengers and operators from structural penetration 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 requirements in Table 1 that are met.
45 DESIGN LOADS and ASSESSMENT CRITERIA REQUIREMENTS

This section defines load requirements used to assess the structural design of heavy rail vehicle carbodies, with respect to safety of the occupants. Table 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 weightloads 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 1 does not contain 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 should consider industry accepted fatigue analyses and criteria, such as should have generous safety margins and should consider the safety of maintenance and operation personnel; specification of operational loads should consider a generally accepted fatigue method 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; and infrequent exceptional loads such as rerailing recovery and emergency braking should be assessed to ensure damage does not result from their application.

This section defines load requirements to be used for the design of heavy rail transit vehicles, including static loads representing normal and exceptional conditions. The structure of the carbody shall be completely assembled with the loads of all equipment included before the specified loads are applied. Each specified force shall be applied over the minimum area necessary to limit local yielding or buckling, with its center of action at the location specified. In Table 1, where no permanent deformation is required, localized plastic deformation is permitted, provided it has no effect on the structural integrity of the complete carbody. Tables 1 and 2 do not contain all loads necessary to ensure the structural integrity of a carbody. Additional loads should be considered. Maintenance loads should have generous safety margins and should consider the safety of the maintenance and operation personnel. Specification of operational loads should consider a generally accepted fatigue method and criteria, such as AWS D1.1/D1.1M, to assess repeated loading from propulsion, braking, and track features. Infrequent exceptional loads such as re-railing recovery and emergency braking should be assessed to ensure damage does not result from their application.

4.6 Crashworthiness

The carbody shall be constructed in such a way as to

a) minimize the possibility of injury to occupants during a collision from such causes as the detachment of parts of the carbody or falling equipment mounted in the ceiling or on the roof
b) minimize the loss of occupant volume resulting from structural collapse or structural penetration
c) provide for a progressive controlled collapse of energy absorption zones of the carbody structure

Structural energy absorption zones shall be located at the ends of the carbody structure and shall be activated prior to crush of other carbody structures, following the sequence and magnitude of collapse as specified in Table 1 and para. 9.3. Table 1 further specifies required strengths for structural elements such as collision posts and corner posts to protect passengers and operators from structural penetration and loss of occupant volume in the event of a collision with another vehicle or obstruction. Other requirements in Table 1 specify design criteria for vehicle anticlimbing protection in vehicle-to-vehicle collisions, and carbody rollover strength. Section 10 describes the analytical and test principles used to verify that the requirements in Table 1 that are met.

4.7 Jacking and Hoisting Loads

4.8 The loading conditions and the margins of safety of stresses below yield strength shall be specified (see Table 1).

56 COUPLER SYSTEM
The design of the coupler system, including drawbars, draft gear, and 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 recoverable-regenerative or nonrecoverable 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 the release mechanism, which shall allow the coupler system to retract a sufficient distance to permit the carbody anticlimbers to engage. If the collision forces energy are 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 intended operation. The coupler system, after activation of the primary (first shear mechanism) compression overload, shall be capable of absorbing the tension forces encountered when towing.

The coupler system at all times shall be supported in a safe manner 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.

### STRUCTURAL MATERIALS

Minimum material property values as defined by a material specification or standards stated in 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


#### 7.2 Low Alloy High Tensile Steel

Structural use of low alloy high tensile (LAHT) steel shall be in accordance with the requirements of para. 4.2 of American Public Transportation Association (APTA) Safety Standard SS-C&S PR-CS-S-034-99, latest edition, Section 4.2, Standard for the Design and Construction of Passenger Railroad Rolling Stock, or equivalent.

#### 7.3 Aluminum


#### 7.4 Static Strength

The limiting static material properties shall be as given in the referenced material standard. When other standards are used, the equivalency shall be demonstrated between these standards and the referenced material standards.
7.5 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 analytic and test principles of Crash Energy Management (CEM) be applied, including the use of analytical tools to verify that the carbody structural design and CEM features are stable and crush or deform during crushing as intended. Analysis for the purpose of Evaluation of the load cases specified in para. 4.29 and Table 2 shall be performed using time-dependent, large deflection computer simulations. Validation of the crush behavior by test shall be performed only if specified.

A CEM and collision survivability strategy shall be developed that is compliant with the criteria provided in section 5, para. 9.3, and other specified requirements. The carbody vehicle shall be designed to crush and absorb energy in a controlled manner when subjected to end collision loads that exceed its static load capability. The design shall be based on the CEM structural energy absorption zones per the scenarios specified in Table 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. The design shall be based on the requirements of Table 2. A CEM and collision survivability strategy shall be developed that is compliant with the criteria provided in section 5, para. 9.3, and other specified requirements 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 vehicles are involved in collisions. The specifications do not address all the considerations that may need to be examined in light of vehicle design and operating variances. For example, users of this Standard may need to conduct further crashworthiness analyses that address a variety of factors including collisions with incompatible vehicle equipment strength or geometry, or conditions of the coupler engagement during collisions.

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 for purchaser and supplier to agree on a compatibility plan to ensure performance-based scenarios are applicable.

ANALYSIS

In a collision, interior equipment within the occupied volume shall remain securely fastened. An analysis shall be provided for such interior equipment that weighs greater than 11.3 kg (25 lbs) (typically: 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 weighing greater than 67.8 kg (150 lbs) shall be analyzed. Equipment attachments shall be of sufficient strength to support equipment under loading specified by Item 47.20 in Table 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 47.20 of Table 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.
Structural analysis of the carbody, and of supports for equipment weighing over 30 kg (66 lb), shall be performed.

For any portion of the proposed design which 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 shall be provided.

9.1 Structural Sketch Renderings

A structural sketch where specified renderings shall be provided in order to clearly define the primary carbody structure in advance of formal stress analysis and structural drawings. The structural sketch 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 cross-sections of the structural members, showing the shape, dimensions, material, and thickness of each member, shall be included. The members and the connections shown shall include, to the extent used in the particular design, the typical side frame and door frame posts; end, side, draft, and center sills; belt rail, top, and roof rails; collision and corner posts; anti-telescoping plate; bolsters, floor beams, and cross bearers; roof carlines and purlins; roof sheathing or corrugation; and side frame sheathing and/or corrugation.

9.2 Linear Elastic 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:

- Sketch of the item to be analyzed, with dimensions, applied forces, and other boundary conditions
- Drawing references
- Material properties
- Allowable stress
- Detailed stress results and analyses
- Conclusions

The carbody stress analysis, based upon the structural sketch, shall consist of a linear-elastic Finite Element Analysis (FEA) using a recognized computer FEA code, supplemented by a manual stress analysis. The results of the linear 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. For all linear-elastic load cases, the elastic stability of plates, webs, and flanges shall be calculated for members subject to compression and shear.

The purpose of the manual analysis shall be to examine details of the carbody (such as weld connections, welded and/or bolted joints, fatigue conditions, and column and plate stability) that are not readily handled in the FEA. The format and content of the manual analyses:
shall include the following as a minimum:

- Title
- Sketch of the item to be analyzed with dimensions, applied forces, and other boundary conditions
- Drawing references
- Material properties
- Allowable stress
- Detailed stress analyses
- Conclusions

### Table 2 Crashworthiness

<table>
<thead>
<tr>
<th>Type of Load</th>
<th>Specified Load on Carbody</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collision Scenario 1 – coupler impact</td>
<td>Collision of two ready-to-run loaded trains, one traveling at 8 km/h (5 mph) and one vehicle stopped. Couplers in coupling position. Additional scenario conditions are defined in para. 9.3.1 (a, c-d).</td>
<td>No permanent deformation of any structural member, sheathing or connection, with the possible exception of the element used to absorb the energy of the collision. This element can be either recoverable or replaceable.</td>
</tr>
<tr>
<td>Collision Scenario 2 – safe speed</td>
<td>Collision of two ready-to-run trains, one traveling at 24 km/h (15 mph) and one stopped. Additional scenario conditions are defined in para. 9.3.1 (a-e).</td>
<td>Acceptance criteria defined in para. 9.3.2 (a-k)</td>
</tr>
<tr>
<td>Collision Scenario 3 – structural integrity</td>
<td>Collision of two ready-to-run trains, one traveling at 40 km/h (25 mph) and one stopped. Additional scenario conditions are defined in para. 9.3.1 (a-e).</td>
<td>Acceptance criteria defined in para. 9.3.3 (a-k)</td>
</tr>
</tbody>
</table>

Scenario 1: Two ready-to-run trains, one traveling at 24 km/h (15 mph) into a stopped train, passengers and survival brakes applied on both trains space in operating cab, at full service rate per scenario in para. 9.3 per para 9.3.

Scenario 2: Two ready-to-run trains, one traveling at 40 km/h (25 mph) into a stopped train, passengers, per para. 9.3, brakes applied on both trains at full service rate, per scenario in para. 9.3.
The purpose of the manual analysis shall be to examine details of the car body (such as weld connections, welded and/or bolted joints, fatigue conditions, and column and plate stability) that are not readily handled in the FEA. The format and content of the manual analyses shall include the following as a minimum:

- **Title**
- Sketch of the item to be analyzed with dimensions, applied forces, and other boundary conditions
- Drawing references
- Material properties
- Allowable stress
- Detailed stress analyses
- 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 the 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 2 and Sections 9.3.1, 9.3.2, 9.3.3, and 9.3.4.

#### 9.3.1 Collision Conditions

Train crashworthiness analysis simulation conditions are as follows:

- a moving train colliding into a stopped, braked train (wheel/rail friction coefficient of 0.45) of identical design using the train initial velocities and loading conditions identified in Table 2, occurring on level tangent track.
  
  (a) A vertical height offset between colliding vehicles as specified in Table 2. Items 2 and 3 only, with the stopped train in the lower (below nominal) height position that shall be modeled achieved by vertical offset movement of the track.

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

- 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 Section 9.3.1 and Table 2 shall conform to the following criteria for any train:

- (a) The energy shall be absorbed by recoverable or easily replaceable elements.
- (b) No permanent deformation to any vehicle structural member, or side sheathing.
- (c) 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 Section 9.3.1 and Table 2 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.
- (c) All vehicles remain upright and in line during and after the collision.
(d) Truck remain attached to the vehicles (vertical movement of vehicles remains permissible during the collision).

(e) Global shortening of vehicle length due to plastic deformation of the vehicle structure from a collision is limited to 1% over any 4.57 m (15 feet) of the occupied volume (not including the operating compartment). Highly localized plastic deformation of the occupied volume not affecting the ability of the structure to meet the requirements of this Standard shall be allowed. The 4.57 m (15 ft) of the passenger occupied volume length located at the end of the vehicle closest to the point of collision may reduce in length up to 2%.

(f) Operator’s compartment shall maintain a survival volume for the operator’s seat area and shall control collapse to maintain an egress path.

(g) Operator’s compartment seat(s) when positioned at its median position, has a minimum of 305 mm (12 in.) clearance from the front and side edges of the seat extending from floor to ceiling, except for operator control consoles, walls, bulkheads, or side structures normally designed to be within the 355 mm (14 in.) envelope space around the seat (survival volume), which must not further intrude more than 51 mm (2 in.) toward the operator seat.

(h) Vertical (floor-to-ceiling) height of the operating compartment is not reduced by more than 20% after the collision.

(i) Operator shall have a clear accessible exit path from the operator’s compartment through the operator’s compartment door or doorway exit to the passenger compartment. The operator’s compartment door shall remain operable or an alternative method of egress through the doorway provided.

(j) Deformation in the door-operating area anywhere in the vehicle shall not prohibit emergency evacuation.

(k) Upper limit on the magnitude of average collision acceleration\(^1\) is 5 g for any car, and

(l) Structural crush of occupied volume shall not commence until the end sill compression load identified in Item 2 of Table 1 has been exceeded. The end sill compression load is the minimum allowable value for the initiation of crushing, with the exception of damage to energy absorption elements allowed in Scenario 1. The design end sill compression load may be increased based on the CEM and collision survivability strategy per Section 8.

The following criteria applies to open-gangway applications:

(m) For vehicles with open gangways, the open-gangway shall not interfere with the crash capability of the vehicle structure.

(n) For vehicles with open gangways, the gangway structure shall prevent penetration of sharp edges or objects into the open gangway volume and minimize lateral or vertical intrusions that could obstruct movements of occupants.

### 9.3.4 Collision Acceptance Criteria – Scenario 3

The results of the simulation for Collision Conditions and Scenario 3 as referenced in Section 9.3.1 and Table 2 shall conform to the following criteria for any train:

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

(b) Progressive structural crush begins and is retained at car ends to maintain stability in occupied zones.

\(^1\) Average collision acceleration is to be computed at a sample rate of no less than 1 kHz and processed using a simple moving average with a length in time (block) of 100 ms. Alternatively, and similarly, average collision acceleration may be computed from the change in velocity over a length in time (block) of 100 ms. Upper limit on average collision acceleration is the largest car acceleration magnitude for any block of the processed data.
(c) all vehicles remain upright and in-line during and after the collision (vertical movement of vehicles remains permissible during the collision).
(d) trucks remain attached to the vehicles.
(e) Passengers and operator have a clear egress path.
(f) Structural crush of occupied volume shall not commence until the end sill compression load identified in Item 2 of Table 1 has been exceeded. The end sill compression load is the minimum allowable value for the initiation of crushing, with the exception of damage to energy absorption elements allowed in Scenario 1. The design end sill compression load may be increased based on the CEM and collision survivability strategy per section 48.
(g) upper limit on the magnitude of average collision acceleration¹ (footnote 1) is \( 7.5 \text{ms}^2 \) for any car.

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The following criteria applies to open gangway applications:

(h) For vehicles with open gangways, the gangway shall not interfere with prevent the energy absorption or anti-climbing function of the vehicle crash CEM structure.

For vehicles with open gangways, the gangway structure shall prevent penetration of sharp edges or objects into the open gangway volume and minimize lateral or vertical intrusions that could obstruct movements of occupants.

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The crashworthiness analysis shall be performed using a nonlinear large deformation explicit finite element software program such as LS-DYNA, ABAQUS, or equal. Lumped mass features may be used in the finite element model to represent vehicle structure and mass located away from the crush zone rearward of the first vehicle and the adjacent passenger area.

The simulation results shall be provided in various forms including video animation, static displays of video frames, graphs of force deflection versus time, graphs of vehicle acceleration versus time, and energy balance data. The video animation and graphical documentation of results shall demonstrate progressive crush response and the ability of the structure to maintain survivability space required for operator and passengers. The force deflection curves shall show the crush response of the floor and structure where force is measured at the interface between the sub-end structure and the passenger compartment. The acceleration history for each vehicle of the consist shall be determined by a method that computes the global vehicle acceleration. Energy data shall be included to demonstrate conservation of momentum, conservation of energy balance, and minimization of computational energy loss such as might be caused by computational element deformation (commonly referred to as hourglass energy).

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9.3.1 Collision Scenario

(b) The vehicle-to-vehicle crashworthiness analysis simulation scenarios, as referenced in Table 2, shall conform to the following conditions unless as noted otherwise in Table 2:

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The crashworthiness analysis simulations shall:
- a moving train colliding into a stopped train of similar design using the vehicle initial velocities and loading conditions be a moving train colliding into a stopped train, using the vehicle load-condition, initial velocity, and brake application status identified in Table 2.
- collide trains contain a vertical height offset of 2 inches measured at the anti-climbers at the colliding ends between lead vehicles, with the stopped vehicle
in the lower (below nominal) height position.

— Both trains shall be of similar design, and consist of the maximum number of cars used in operation.

— The simulation shall be initiated with sufficient time prior to impact to allow gravitational and braking loads to develop. The collision shall occur on level tangent track.

— The coupler and/or end covers shall be configured in a typical service condition.

(c) Note: Additional simulations may be required based on interoperability requirements of considerations identified in Section 3.

9.3.2 Collision Acceptance Criteria - Scenarios 1 and 2

— The results of the simulation of Collision Scenario 1 and 2 of Table 2 shall conform to the following criteria for any vehicle or car of the train:

— The vehicle interactions do not exhibit override or telescoping responses.

— Progressive structural crush begins at vehicle ends.

— All vehicles remain upright and in line during and after the collision.

— Trucks remain attached to the vehicles.

— The relative difference in elevation between the underframes of the colliding and connected vehicles does not change by more than 102 mm (4 in).

— The tread of any wheel of any vehicle does not rise more than 102 mm (4 in) above the top of rail.

— Maximum crush displacement of either colliding vehicle does not differ more than 25% from the average maximum crush displacement of both vehicles.

— Survivable volumes must be retained in the passenger and operator compartments.

— Global shortening of vehicle length due to plastic deformation from a collision is limited to 1% over any 4.57 m (15 feet) of the occupied volume (not including the operating compartment). Highly localized plastic deformation of the occupied volume not affecting the ability of the structure to meet the requirements of this Standard shall be allowed. The 4.57 m (15 ft) of the passenger occupied volume length located at the end of the vehicle closest to the point of collision may reduce in length up to 2% (3 in).

— The operator compartment seat(s), when positioned at its nominal forward position, has a minimum of 305 mm (12 in) clearance from the front and side edges of the seat extending from floor to ceiling, except for operator control consoles, walls, bulkheads, or side structures normally designed to be within 305 mm (12 in) envelope space around the seat, which must not further intrude more than 51 mm (2 in.) toward the operator seat.

— The vertical (floor-to-ceiling) height of the operating compartment is not reduced by more than 20% after the collision.

— The operator must have a clear accessible exit path through the operator’s compartment and through the operator’s compartment door or doorway exit. The operator’s compartment doors used for exiting the operator’s compartment must remain fully operable.

— Some local plastic deformation is allowed; however, deformation in the door operating areas anywhere in the vehicle shall not infringe on their emergency escape operation.

— Maximum vehicle acceleration of 5 g.
2.3.3 Collision Criteria—Scenario 3

The results of the simulation of Collision Scenario 2 of Table 2 shall conform to the following criteria for any vehicle or car of the train:

(d) shall demonstrate the following:
   - The vehicle interactions do not exhibit override or telescoping responses.
   - Progressive structural crush begins at vehicle ends.
   - All vehicles remain upright and in line during and after the collision.
   - Trucks remain attached to the vehicles.
   - The relative difference in elevation between the underframes of the colliding and connected vehicles does not change by more than 102 mm (4 in).
   - The tread of any wheel of any vehicle does not rise more than 102 mm (4 in.) above the top of rail.
   - Maximum crush displacement of either colliding vehicle does not differ more than 25% from the average maximum crush displacement of both vehicles.
   - Survivable volumes must be retained in the passenger and operator compartments.
   - The operator must have a clear accessible exit path through the operator’s compartment and through the operator’s compartment door or doorway exit. The operator’s compartment doors used for exiting the operator’s compartment must remain fully operable.
   - Some local plastic deformation is allowed; however, deformation in the doors and operating areas anywhere in the vehicle shall not infringe on their emergency escape operation.

Maximum vehicle acceleration of 7.5 g.

(f) The vehicle interactions do not exhibit overriding or telescoping responses.

(g) Average vehicle deceleration shall be 7.5 g or less.

(h) All vehicles must remain upright and in line during and after the collapse. Trucks must remain attached to the vehicles.

(i) Global vehicle shortening shall be no more than 1% over any 4.6 m (15 ft) of the occupied volume (not including the operating compartment). Highly localized plastic deformation of the occupied volume not affecting the ability of the structure to meet the requirements of this Standard shall be allowed. The 4.6 m (15 ft) of the occupied volume length located at the end of the vehicle may reduce in length up to 2%.

(j) The operating compartment seat shall have a minimum of 30.5 cm (12 in.) of survival space from the edges of the seat where there is no intrusion, and a clear path from the seat to exit the operating compartment after the collision.

(k) The vertical (floor to ceiling) height of the operating compartment shall not be reduced by more than 20% after the collision.

(l) The relative difference in elevation between the underframes of the colliding and connected vehicles does not change by more than 101.6 mm (4 in.

(m) The tread of any wheel of the vehicles shall not rise more than 101.6 mm (4 in.) above the top of rail.

(n) The simulation results shall be provided in various forms including video animation, static displays of video frames, graphs of force deflection versus time, graphs of vehicle acceleration versus time, and energy balance data. The video animation and graphical documentation of results shall demonstrate progressive crush response and the ability of the structure to maintain
Certain proof of design tests shall be performed in order to demonstrate the strength and stability required by this Standard. It is not necessary to carry out all tests if there are appropriate verification data in existence from previous tests on a similar structure and correlation between the test and calculation has been established. Tests shall be carried out to verify any significant changes to the design or to the performance requirements. There is no need to repeat the tests if the production location is later changed, provided that there is no significant change in the design or manufacturing process of the carbody.

The specific objectives of the tests are to verify the strength of the carbody, and the articulation system, if used, when subjected to the specified loads, to verify that no permanent deformation is present after removal of specified loads, and to validate analytic models and determine the accuracy of the analyses for load cases not tested. The test program shall comprise, as appropriate, the static simulation of selected design cases, measurements of actual stresses with electric resistance strain gauges or other suitable techniques, and measurement of the structural deformation under loads.

One of the first carbodies produced shall be tested to verify compliance of the design of the carbody with this Standard. The carbody shall be structurally complete, including flooring if used as part of the primary carbody structure, but shall exclude such items as exterior and interior trim, windows, doors, seats, lights, insulation, interior lining, or any other materials that will obscure any structural member of the carbody from view. Underfloor, roof, and ceiling-mounted apparatus shall be installed or equivalent weights distributed at their respective locations. If weights are used, attachment fasteners shall duplicate the proposed designs.

For any portion of the design that is based on a service proven vehicle, data from previous tests to satisfy the corresponding portion of these requirements may be provided.

The test procedure should include, as a minimum, the drawings, sketches, tables and other descriptions which provide a description of the test load equipment, the location of each point that a load or reaction is applied to the specimen, a table showing the load applied at each load point for each test increment, and the location of each load, strain, and deflection measuring device. The force of the testing machine shall be measured by a load cell or equivalent device that is independent of the equipment producing the applied force.

Proof Load Tests
1.1 Proof Load Tests

1.2 Test Procedures. — Tests shall be conducted on a bare carbody, following its manufacture, that shall be ballasted or otherwise loaded with properly distributed \textit{weightload} equivalent to the weight of a fully assembled ready-to-run vehicle. The tests shall be carried out in a test fixture that allows for the application of reaction forces at the points where they would occur during operation. The carbody shall be equipped with strain measuring \textit{devices instrumentation} in locations which will allow estimation of maximum stresses for comparison with predicted by the stresses from analysis, in areas of stress concentration factors as determined by the stress analysis or finite element analysis. The following measurements of strain and structural deflection shall be measured-recorded during tests:

1.3(a) the strain at critical points, including windows and doors, corners, side sills, corner and collision posts, structural shelf, and other areas
1.3(b) diagonal dimensions at window and door openings
1.3(c) residual deflection, if any
1.3(d) residual strain, if any

To stabilize the vehicle structure, the carbody shall be preloaded before the load tests in a manner as agreed upon between the customer and the manufacturer. Following stabilization, the maximum force loading identified in Section 5, shall then be cyclically applied and reapplied incrementally at least twice. Results from the last loading cycle shall be used for evaluation by the customer. The customer shall approve the results of the last test. These tests shall verify that there is no permanent deformation to the carbody or individual elements when subjected to the loads identified in Section 5.

10.3.1 Vertical Load

10.3.1.1 Test Description. — The carbody, supported on trucks or a simulation, shall be subjected to a vertical load test. To account for the stresses already existing due to weight of the bare carbody structure itself, a test load is to be applied in two steps:

\textbf{Step 1}: A uniformly distributed test load equivalent to the bare carbody structure weight is to be applied with both strain gauge and deflection readings taken.

\textbf{Step 2}: A test load equal to the maximum carbody weight specified in Table 1, Item 1 minus the bare carbody structure weight shall be applied in a minimum of four evenly spaced increments. The test load may be applied by means of weights or jacks, but shall be distributed in proportion to the distribution of weight in the finished vehicle. The carbody shall be unloaded in the increments in which it was loaded, in reverse order. Strain gauge and deflection readings shall be taken at each load increment.

\textit{Test Description} — The carbody, supported on trucks or a simulation thereof, shall be subjected to a vertical load test. Consideration should be given to the stresses already existing due to weight of the bare carbody structure itself.

A test load equal to the vertical load specified in Item 1 of Table 1 shall be applied in a minimum of four evenly spaced increments. The test load may be applied by means of weights or jacks, but shall be distributed in proportion to the distribution of weight in the finished vehicle. The carbody shall be unloaded in the increments in which it was loaded, in reverse order. Strain gauge and deflection readings shall be taken at each load increment.

\textbf{10.3.1.2 Test Criteria.} — The test results shall verify the following:

\textbf{10.3.1.2(a)} Stresses are in accordance with the requirements of section 5.
\textbf{10.3.1.2(b)} Vertical deflection readings plotted against applied load do not vary by more than ±7.5\% from a straight line, with one end point at the origin and the other at the point that represents the measured deflection for the specified section 5 load. Vertical deflection readings plotted against load do not
10.3.2 Carbody Compression Loads

10.3.2.1 Test Description.

The carbody, supported on trucks or simulation equivalent supports to allow longitudinal movement, shall be subjected to compression load tests. The carbody shall be ballasted or otherwise loaded with properly distributed weights load equivalent to the weight of a fully assembled ready-to-run vehicle. Test loads equal to those specified in Table 1, Items 2, 3, and 4 shall be individually applied. The test loads shall be applied horizontally at the anticlimber on the carbody longitudinal centerline, or to the coupler anchorage as is appropriate for the test being performed. Test loads applied to the anticlimber shall be applied over a contoured area not exceeding 91,200 sq. mm (144 sq. in.) and no wider than 600 mm (23.6 in.). No allowance shall be made for the camber of the carbody. Cushioning by means of soft metal sheets shall by means of conformable sheet material may be provided to assure uniform bearing of the applied load. The test load application equipment (e.g., hydraulic rams) shall be configured in such a manner that the "humping" deformation behavior of the car shell structure during the compression loading does not transfer any portion of the car shell weight from the trucks or simulated supports to the load application equipment. It is recommended that measures be taken in the test setup to prevent binding of the loading rams in the test article as the compression load is applied. The test loads shall be applied with incrementally increases, and shall include at least one return to a load not greater than 9 kN (2,025 lb) after attaining not less than 80% of the required maximum load.

10.3.2.2 Test Criteria.

The test results shall verify the following:

(a) Strain readings plotted against applied load do not vary by more than ±7.5% from a straight line, with one end point at the origin and the other at the point that represents the measured deflection for the specified section 5 load.

(b) Maximum stresses calculated from strain readings in any structural element do not exceed the allowable stresses approved prior to starting the test program as part of the stress analysis.

(c) Recorded residual vertical deflection between the carbody bolsters following removal of the specified section 5 load does not exceed 1.0 mm (0.04 in.).

(d) Recorded residual carbody transverse width and/or opening diagonal changes in dimensions following removal of the specified section 5 load do not exceed 1.0 mm (0.04 in.).

(e) Indicated residual strains at strain gauges on principal structural elements following removal of the specified section 5 load do not exceed 60 microstrain including instrumentation error. Indicated residual strains at strain gauges on principal structural elements following removal of the applied loads should not exceed 5% of the yield strength divided by the elastic modulus of the material to which the strain gauge is attached. Higher residual strains may be permitted based upon further investigation (e.g., consideration of instrumentation error and boundary condition variations).

(f) Carbody deflection, as measured during the vertical load tests under a car volume capacity load, shall not be more than the design camber in the side sill at any point between the carbody bolsters.

(g) There are shall be no visual permanent deformations, fractures, cracks, or separations in the carbody. Any broken welds shall be analyzed to determine if the failure is the result of either inadequate weld quality or from over stress before repair or redesign of the area. The repaired or redesigned structure shall be and retested.
10.3.3 Collision Post and Corner Post Loads: Elastic Design Loads Behavior

10.3.3.1 Test Description.
- The ability of the collision posts, corner posts, and associated supporting structures to resist the elastic design loads specified in Table 1 (or worse-case as agreed to by customer and manufacturer) shall be tested. The placement of the applied loads shall be for the worst-case condition. The test loads may be applied to one end (cab) of a structurally complete carbody or, as an alternate, a separate end frame section may be constructed and tested. If the alternate method is chosen, the test element shall simulate to the maximum extent possible, the location, the degree of fixity, and magnitude and direction of reactions of the supporting carbody. Cushioning by means of soft metal sheets shall by means of conformable sheet material may be provided to assure uniform bearing of the applied load.

10.3.3.2 Test Criteria.
- The test results shall verify the following:

10.39.3.1(a) Indicated residual strains at strain gauges on principal structural elements following removal of the applied loads do not exceed 5% of the yield strength divided by the elastic modulus of the material to which the strain gauge is attached. Higher residual strains may be permitted based upon further investigation (e.g., consideration of instrumentation error and boundary condition variations).

(a) Indicated residual strains at strain gauges on principal structural elements following removal of the maximum load do not exceed 60 microstrain including instrumentation error.

(c) There shall be no visual permanent deformations, fractures, cracks, or separations in the carbody. Any broken welds shall be analyzed to determine if the failure is the result of either inadequate weld quality or from overstress before repair or redesign of the area. The repaired or redesigned structure shall be and retested.
10.3.4 Collision and Corner Post Loads: Elastic–Plastic Design Loads

Behavior

10.3.4.1 Test Description.

The ability of the collision and corner posts and associated supporting structural members to resist the elastic-plastic design load specified in Table 1, Item 8 shall also be tested, in order to demonstrate the ductility of the collision posts. The placement of the applied load shall be as specified in Table 1, Items 7 and 10. It is recommended that the test loads be applied to a special test article consisting of an end frame and sufficient carbody to provide a representative support condition. Cushioning by means of soft metal sheets shall be provided to assure uniform bearing of the applied load.

10.3.4.2 Test Criteria.

10.39.4.1 The test results shall verify the following:

(a) The load remains above the elastic design load.

(b) The connections between the collision posts and all other structural members have not separated.

(c) The posts have deflected a minimum of one-third of their required depth specified in Table 1.

10.3.5 Gangway High-Strength Corner Post Design Loads

No elastic-plastic test on the gangway corner post is required provided a valid correlation between the calculations and the destructive test is proven by the post elastic-plastic load test per Item in Table 1. Should no valid correlation exist, the procedural requirements of Section 10.3.4, Collision Post Loads: Elastic–Plastic Design Loads, then shall apply.

The ability of the high-strength corner post and associated supporting structures to resist the elastic-plastic design loads specified in Table 1, Item 13 may be tested, if specified by the customer. The placement of the applied load shall be as specified in Table 1, Item 13.

10.3.6 Collision Wall Loads: Elastic-Plastic Loads

In lieu of meeting the requirements of Table 1, item 7, the collision wall with its supporting car body structure shall be capable of absorbing a minimum of 70,000 ft-pounds of energy prior to, or during structural deformation by withstanding a frontal impact with a rigid object in accordance with all of the following requirements:

- The striking surface of the object shall be centered at a height of 30 in above the top of the underframe.
- The striking surface of the object shall have a width of no more than 36 in and a diameter of no more than 48 in.
- The center of the striking surface shall be offset by 19 in laterally from the center of heavy rail transit vehicle.
- Only the striking surface of the object interacts with the collision wall.
- As a result of the impact, there shall be no more than 6 in of longitudinal permanent deformation into the occupied volume.
- There shall also be no complete separation of the post or of the collision wall, its connection to the underframe or of its supporting car body structure.
- The nominal weights of the object and the cab car or MU locomotive, as ballasted, and the speed of the object may be adjusted to impart the minimum of 70,000 ft-pounds of energy to be absorbed.

These requirements are intended to be equivalent alternatives to the requirements of Table 1, item 7, and allow for the application of dynamic performance criteria.

10.4 Crash Energy Management Tests

10.4.1 Test Description

Test Description. Tests to validate the CEM design may include a series of tests of the
individual elements, testing of subassemblies, or testing the global structure. While it is recommended, as a minimum, to test each crush element, the actual validation of the global crush behavior may also require intermediate steps.

Element energy tests shall be performed on each element type to validate its design. While it is recommended that full-size elements be used during the testing, reduced scale replicas may be used.

Testing of the individual elements or the global structure may be done either dynamically or quasi-statically.

**Test Description.** Tests to validate the CEM design, if prescribed, may include a series of dynamic tests of the individual elements, subassemblies, or of the global structure. While it is recommended as a minimum to test each crush element, the actual validation of the global crush behavior may also require assembly testing.

10.4.2 Test Criteria.

These tests will demonstrate compliance with the CEM requirements in section 8.9.

10.410.5 Coupling-Coupler Impact Tests

(a) The coupler shall remain fully serviceable when subjected to coupling impacts up to the coupling speed requirements of Item 1 in Table 2.

(b) The coupler system shall be tested dynamically to determine the structural design coupler release loads. By analysis or test, the coulper will be shown to support collision loads through the coupler sufficiently past the point of release as required in Item 3 of Table 1.
<table>
<thead>
<tr>
<th>Item</th>
<th>Type of Load</th>
<th>Specified Load on Carbody</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vehicle vertical</td>
<td>Evenly distributed carbody volume capacity</td>
<td>Stress not to exceed 65% of the any carbody structural member yield strength and no loss of local stability.</td>
</tr>
<tr>
<td>2</td>
<td>End sill compression</td>
<td>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.</td>
<td>No permanent deformation of any structural member or structural sheathing, with the possible exception of the energy absorption elements.</td>
</tr>
<tr>
<td>3</td>
<td>Coupler anchorage compression structural load (see section 6)</td>
<td>Load of 110% of the maximum possible (commonly called the disconnect or release load) produced by the coupler load, as defined in section 6 applied in longitudinal inward direction. Carbody structure shall support the maximum dynamic load needed to fully collapse a coupler such that its physical retraction stroke is maximized.</td>
<td>No permanent deformation of any structural member or structural sheathing.</td>
</tr>
<tr>
<td>4</td>
<td>Coupler anchorage tensile</td>
<td>Loads shall meet the required duty as specified in Section 6</td>
<td>No permanent deformation of any structural member or structural sheathing.</td>
</tr>
</tbody>
</table>
| 5    | Collision post shear Collision wall shear | Load equal to the end sill compression load, applied to each collision post separately [BH6] or applied to the collision wall at the approximate one-third points across the width of the vehicle over a surface area of the collision post in the longitudinal (inward) direction.  
(a) Load application direction variation permitted shall be within 15 deg on either side of the longitudinal (inward) direction.  
(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 or structural connections. Stresses in the carbody structure and collision post to be less than ultimate strength. |
<p>| 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 | No permanent deformation of any member, structural. |
| 7 | Collision post elastic-plastic, Collision wall elastic-plastic | Load applied per the elastic design load case (see Item 6 above 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 1/2 the longitudinal depth of the post. 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, and its connection to the underframe, and its connection to either the roof structure or at the antitelescoping plate. |
| 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. | 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. | 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 above 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 $\frac{1}{3}$ the longitudinal depth of the post. 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. | No permanent deformation of any structural member, structural sheathing, or structural connections |
| 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. | No permanent deformation of any structural member, structural sheathing, or structural connections |</p>
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|   |   | **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.  
**The load shall remain above the elastic design load. The connections between the corner post and all other structural members have not separated.** |
| **13** | **High-strength corner post elastic-plastic load** | Load applied per the elastic design load case (see Item 1812 above 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)  
\[(SM10)\] \[rac{1}{3}\text{ the longitudinal depth of the post.}
\] 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.  
**No permanent deformation of any member, structural sheathing, or connection.** |
| **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 x 150 mm (10 in x 6 in)  
(b) Load direction variation shall be permitted 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 x 150 mm (96 in x 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 x 150 mm (96 in x 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** |
<p>| | | | |</p>
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<tbody>
<tr>
<td>18</td>
<td><strong>Roof, concentrated</strong></td>
<td>1.330 kN (300 lb) spaced over an area of 380 mm x 330 mm (15 in. x 13 in.), applied anywhere on roof structure</td>
<td>No permanent deformation of any structural member or structural sheathing</td>
</tr>
<tr>
<td>19</td>
<td><strong>Truck to carbody attachment</strong></td>
<td>(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</td>
<td>(a) Stress in the attachment mechanism to be less than ultimate strength. (b) Not to exceed yield strength in the attachment mechanism</td>
</tr>
<tr>
<td>1220</td>
<td><strong>Equipment attachments</strong></td>
<td>Separately applied acceleration loadings of: +5g applied in the longitudinal direction, +2g applied in the transverse direction, and +3g applied in the vertical direction</td>
<td>Stresses in the attachment mechanism to be less than ultimate strength. All above accelerations shall be applied in combination of -1g vertical</td>
</tr>
</tbody>
</table>
These tests shall serve to demonstrate that the vehicle can remain fully serviceable under coupling impacts up to the coupling speed requirements of Item 4 in Table 21.

### Table 2 - Crashworthiness for Heavy Rail Transit Vehicles

<table>
<thead>
<tr>
<th>Item</th>
<th>Type of Load</th>
<th>Specified Load / Condition</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Collision Scenario 1 — low speed</td>
<td>Collision of two ready-to-run loaded trains under conditions specified in 9.3.1 with moving train at an impact speed of 8 km/h (5 mph).</td>
<td>Acceptance criteria defined in para. 9.3.2</td>
</tr>
<tr>
<td>2</td>
<td>Collision Scenario 2 — safe speed</td>
<td>Collision of two ready-to-run loaded trains under conditions specified in 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.</td>
<td>Acceptance criteria defined in para. 9.3.3</td>
</tr>
<tr>
<td>3</td>
<td>Collision Scenario 3 — structural</td>
<td>Collision of two ready-to-run loaded trains under conditions specified in 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.</td>
<td>Acceptance criteria defined in para. 9.3.4</td>
</tr>
</tbody>
</table>

### REFERENCES

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AWS D1.1/D1.1M (latest edition), Structural Welding Code — Steel
AWS D1.2/D1.2M (latest edition), Structural Welding Code — Aluminum
AWS D15.1 (latest edition), Railroad Welding Specification for Cars and Locomotives
AWS D17.2/D17.2M (latest edition), Specification for Resistance Welding for Aerospace Applications
Publisher: American Welding Society (AWS), 8669 NW 36 Street, No. 130, Miami, FL 33166 (www.aws.org)
Publisher: Institute of Electrical and Electronics Engineers, Inc. (IEEE), 445 Hoes Lane, Piscataway, NJ 08854 (www.ieee.org)