APTA STANDARDS DEVELOPMENT PROGRAM
STANDARD
American Public Transportation Association
1300 I Street, NW, Suite 1200 East, Washington, DC 20006

APTA PR-CS-S-034-99, Rev. 3
First Published: Oct. 14, 1999
First Revision: Sept. 28, 2003
Second Revision: June 11, 2006
Third Revision: June 18, 2020

Passenger Rail Equipment Safety Standards (PRESS) Construction and Structural Working Group

Design and Construction of Passenger Railroad Rolling Stock

Abstract: This standard contains structural and crashworthiness requirements for railroad passenger equipment of all types, including locomotive-hauled equipment, MU and cab cars, and non-passenger-carrying power cars and locomotives.

Keywords: analysis, collision post, corner post, strength, stress, structure test, severe deformation

Summary: This standard contains structural design requirements for passenger rail equipment. The standard is intended to consider the forces applied to the carbody and truck structures during collisions, derailments, and other emergencies.

Scope and purpose: This standard shall apply, unless otherwise indicated, to new railroad passenger equipment of all types, including locomotive-hauled, MU cars, and cab cars and non-passenger-carrying power cars and locomotives that are intended for use on the general railroad system of the United States. Passenger equipment designed with crash energy management features are no longer covered by this standard. The purpose of this document is to provide minimum structural standards and to improve the crashworthiness of passenger-carrying rail vehicles.

Table of Contents

List of Figures and Tables

Participants

The American Public Transportation Association greatly appreciates the contributions of **Gabriel Amar, Michael Burshtin, Paul Callaghan, Michael Carolan, Joshua Coran, Nathaniel Eckman, Jeffrey Gordon, Robert Jones, Joseph Kenas, Dominique LeCorre, Frank Maldari, Eloy Martinez, Ronald Mayville, Mehrdad Samani, Narayana Sundaram, Gerhard Schmidt, Ben Spears, Mike Trosino, Rudy Vazquez, and Martin Young,** who provided the primary effort in drafting this document.

At the time this standard was completed, the working group included the following members:

Eloy Martinez, LTK Engineering Services, *Chair*
Mehrdad Samani, LTK Engineering Services, *Vice Chair*
Martin Young, Sound Transit, *Secretary*

Gabriel Amar, *Systra*
Enrique Arroyo-Rico, *Alstom*
Danny Bailey, *DCTA*
Jeffrey Bennett, *DDOT*
Evelyne Berthomme, *Alstom*
Allen Bieber, *STV*
Martin Bigras, *Bombardier*
Robert Bocchieri, *ARA*
Michael Burshtin, *Amtrak*
Paul Callaghan, *Transport Canada*
Gordon Campbell, *Crosslinx*
Luiz Cano Fernandez, *Alstom*
Bruce Cardon, *UTA*
Michael Carolan, *Volpe Center*
Mike Cook, *LTK*
Robert Cook, *SCRRA*
Joshua Coran, *Talgo*
Sean Cronin, *Metra*
Richard Curtis, *Curtis Engineering*
Felipe Czank, *Alstom*
Nathaniel Eckman, *LTK*
Shaun Eshraghi, *Volpe Center*
Steve Finegan, *SNC Lavalin*
Christian Forstner, Seisenbacher
Tom Freeman, *Intl. Name Plate*
Andre Gagne, *Bombardier*
Gene Germaine, *Kustom Seating*
Michael Gill, *SNC Lavalin*
Garrett Goll, *Voith*
Robert Gonzales, *Mid Region Council of Govts*
Jeffrey Gordon, *Volpe Center*
Glenn Gough, *Siemens*
Hugues Gregoire, *Bombardier*
Yosi Grunberg, *SNC Lavalin*
Tony Gutierrez, *Siemens*
Dong Keun Ha, *SCRRA*
Dongni Han, CRRC
Nicholas Harris, *LTK*
Jason Hesse, *STV*
Ritch Hollingsworth, *LTK*
Karina Jacobson, *Volpe Center*
Paul Jamieson, *Atkins*
Robert Jones, *Stadler*
Larry Kelterborn, *LDK Advisory*
Joseph Kenas, *Bombardier*
Steven Kirkpatrick, *ARA*
Peter Lapre, *FRA*
Paul Larouche, *Bombardier*
Dominique Le Corre, *Alstom*
Ana Maria Leyton, *Transport Canada*
Patricia Llana, *Volpe Center*
William Luebke, *Kustom Seating*
Francesco Maldari, *LIRR*
Amy Mayes, *Knorr*
Ronald Mayville, *SGH*
James Michel, *retired Amtrak*
Dimitar Mihaylov, *NCTD*
Tomoyuki Minami, *JRC*
Travis Nelson, *LTK*
Juergen Neudorfsky, *Seisenbacher*
Steve Orzech Jr., *Freedman Seating*
Chase Patterson, *Voith*
Thomas Peacock, *Atkins*
Gary Petersen, *TransLink*
Anand Prabhakaran, *Sharma & Assoc.*
Denis Robillard, *Baultar*
Steven Roman, *LTK*
Mehrdad Samani, *LTK*
Brian Schmidt, *Altamont Corridor Express*
Gerhard Schmidt, *Siemens*
Martin Schroeder, *Jacobs*
Frederic Setan, *Alstom*
Kristine Severson, *Volpe Center*
Melissa Shurland, *FRA*
Nick Sorensen, *UTA*
Benjamin Spears, *LTK*
Jeremy Spilde, *Metro Transit*
Laura Sullivan, *VOLPE*
Lukasz Szymsiak, *VIA Rail Canada*
Michael Trosino, *Amtrak*
Rudy Vazquez, *Amtrak*
Doug Warner, *Herzog*
Cliff Woodbury, *LTK*
Leonard Woolgar, *Baultar*

Galiane Yergeau, *VIA Rail Canada*
Theresa Zemelman, *RVBA*
Steven Zuiderveen, *FRA*

Project team
Nathan Leventon, *American Public Transportation Association*
Narayana Sundaram, *American Public Transportation Association*

Introduction

This introduction is not part of APTA PR-CS-S-034-99, Rev. 3, "Design and Construction of Passenger Railroad Rolling Stock."

This standard is divided into five sections: "Materials," "Structural safety and crashworthiness requirements," "Design loads and practices," "Analysis," and "Tests". The "Materials" section provides basic requirements for the types of structural materials typically used in passenger railcars, as well as requirements for incorporating other materials into the railcar design. The "Design loads and practices" section provides structural requirements for ensuring a crashworthy carbody design. Separate requirements are provided for cab ends and non-cab ends of various types of passenger equipment, including cab cars, MU cars, coaches and non-passenger-carrying locomotives. Special considerations, such as articulated units, low-level boarding, and non-flat-end cabs, are addressed in these requirements. The minimum levels of analysis and testing required to demonstrate conformance with this standard are also provided. The "Analysis" and "Test" sections contain recommended practices for performing the elastic and plastic analyses and tests required by the "Design loads and practices" section. An informative Appendix A provides information on the history of the structural requirements in this standard.

APTA recommends the use of this document by:

- individuals or organizations that operate rail transit systems;
- individuals or organizations that contract with others for the operation of rail transit systems; and
- individuals or organizations that influence how rail transit systems are operated (including but not limited to consultants, designers and contractors).

Design and Construction of Passenger Railroad Rolling Stock

1. Materials

1.1 Austenitic stainless steel

Where austenitic stainless steel is required for structural use, it shall be in accordance with APTA-PR-CS-S-004-98.

1.2 High-strength low-alloy steel (HSLA)

Where HSLA steel structural shapes, plates, and bars are required, such parts shall, as a minimum, conform to ASTM A588. Plate may alternatively conform to ASTM A572, ASTM A1066, ASTM A514, ASTM A710 or EN-10025. General requirements for delivery of HSLA shapes, plates and bars shall be as required by ASTM A6.

Cold- and hot rolled HSLA sheet and strip shall, as a minimum, conform to the requirements of ASTM A606. Sheet and strip may alternatively conform to ASTM A1011. General requirements for delivery of HSLA sheet and strip shall be as required by ASTM A568 or ASTM A749, as applicable.

Welded HSLA steel shall develop minimum 15 ft-lbf (20 J) Charpy V-notch impact strength in the coarse grain heat-affected zone (CGHAZ) 1 mm from the fusion area at −20 °F (−30 °C).

Other HSLA steels that meet or exceed these minimum requirements may be used by agreement between the Manufacturer and the Purchaser. In any case, HSLA steels shall be applied strictly in accordance with the governing ASTM International or equivalent specification.

1.3 Aluminum

Where aluminum is required for structural use, it shall be in accordance with APTA-PR-CS-S-015-99.

1.4 Other materials

Materials other than those discussed in this standard may be used by agreement between the Manufacturer and the Purchaser. The Manufacturer and the Purchaser shall agree on the criteria for determining that alternative materials meet the strength and performance goals of this standard.

2. Structural safety and crashworthiness requirements

Unless otherwise stated, AW0 (empty, ready-to-run) weight shall be assumed for the load conditions defined in this section.

2.1 Static end-compression strength (49 CFR 238.203)

2.1.1 Passenger equipment without pushback couplers

Passenger equipment without pushback couplers shall meet the following end compression strength requirements:

a) Carbody structure shall be designed to resist a minimum static end-compression load of 800,000 lbf (3560 kN), applied longitudinally on the centerline of draft to the coupler or drawbar anchor of an empty, ready-to-run carbody.
b) For all equipment except non-passenger-carrying locomotives, carbody structure shall also be designed to resist a minimum end-compression load of 500,000 lbf (2224 kN) applied over an area not exceeding 6 in. (152 mm) high by 24 in. (610 mm) wide, centered vertically and horizontally on the underframe end sill or buffer beam construction.

2.1.2 Passenger equipment with pushback couplers

Passenger equipment with pushback couplers shall meet the following end compression strength requirements:

a) Carbody structure shall be designed to resist a minimum static end-compression load of 800,000 lbf (3560 kN), applied longitudinally on the centerline of draft to the coupler or drawbar anchor of an empty, ready-to-run carbody.
b) Carbody structure shall also be designed to resist a minimum end-compression load of 800,000 lbf (3560 kN) applied over an area not exceeding 6 in. (152 mm) high by 24 in. (610 mm) wide, centered vertically and horizontally on the underframe end sill or buffer beam construction.
c) The coupler or drawbar pushback load shall not exceed 800,000 lbf (3560 kN), including the operation of all energy-absorbing features. Reference APTA-PR-CS-RP-019-12 for recommended practices for pushback couplers.

2.1.3 Acceptance criteria

a) Static end-compression strength shall be verified by analysis and testing.
b) The acceptance criterion for each design load case shall be no permanent deformation in the carbody structure.
c) It is recommended that highly localized yielding or elastic buckling, which does not otherwise compromise the ability of the affected structure to meet the requirements of this standard and of the corresponding contract technical requirements, be permitted on a case-by-case basis as agreed by the Manufacturer and Purchaser.
d) When overloaded in compression, the body structure of passenger equipment shall be designed, to the maximum extent possible, to fail by buckling or crushing, or both, of structural members rather than by fracture of structural members or failure of structural connections.

2.2 Transverse strength requirements

2.2.1 General

The transverse strength requirements of this section shall apply to MU cars, cab cars, other cars and cabs of non-passenger-carrying locomotives.

2.2.2 Side strength

2.2.2.1 Side structure framing and sheathing

2.2.2.1.1 Framing (49 CFR 238.217[a])

The sum of the section moduli in cubic inches (cubic millimeters) about a longitudinal axis, taken at the weakest horizontal section between side sill and roof rail, of all posts on each side of the car located between the body corner posts shall be not less than 0.30 cu. in. (16.4 mm^3) multiplied by the distance in feet (millimeters) between the centers of end panels, and by the ratio of 32,000 psi (221 MPa) to the yield strength of the material used.

The sum of the section moduli, in cubic inches (cubic millimeters) about a transverse axis, taken at the weakest horizontal section between side sill and roof rail, of all side frame posts, braces and pier panels, to the extent they exist, on each side of car located between body corner posts shall be not less than 0.20 cu. in. (11.0 mm^3) multiplied by the distance in feet (millimeters) between the centers of end panels, and by the ratio of 32,000 psi (221 MPa) to the yield strength of the material used.

The section modulus for each post about each specified axis shall be calculated independently at the centroid of that post. The sum of the section moduli of all posts on each side of the car about the specified axis is calculated independently for the left and right sides of the car by adding the section moduli for all posts on the respective side of the car. This summation is to be repeated on each side of the car for each specified axis. The weakest horizontal section for each axis is the horizontal plane where the sum of the section moduli for all posts on the same plane is the lowest about that axis.

The center of an end panel shall be considered as the point midway between the center of the body corner post and the center of the adjacent side post.

2.2.2.1.2 Sheathing (49 CFR 238.217[b])

Outside sheathing of mild steel, with minimum 32,000 psi (221 MPa) yield strength, when used flat without reinforcement (other than side posts) in a side frame, shall not be less than ⅛ in. (3 mm) nominal thickness. Reinforcements and/or materials of higher yield strengths may be used to meet this requirement, provided that the sum of the shear capacity (0.577 × Area × Yield) of the reinforced structure, based on the yield strength of the material, is equivalent to the shear capacity of a ⅛ in. (3 mm) thick plate with a 32,000 psi (221 MPa) yield strength.

2.2.2.2 Side loads

2.2.2.2.1 Rollover (49 CFR 238.215 [a])

Except for switcher-cab locomotives, carbody structures shall be designed to rest on their sides, uniformly supported by the roof rail at the top of the side frame, by the side sill at the bottom of the side frame and, if a multilevel car, the longitudinal member at the edges of intermediate floors. The allowable stress shall be the lesser of one-half yield and one-half the critical buckling stress. Structural analysis shall be performed to demonstrate compliance with this requirement.

Switcher-cab locomotives shall be designed to provide a survivable volume in the operator’s cab with the locomotive lying on its side. Analysis shall show that the locomotive is capable of lying on its side supported along the length of the side sill and at the roof line by structure or major components most likely to contact the ground in a rollover incident where the unit comes to rest on its side. Under the action of the resulting applied load, deformation of cab structure shall be permitted as long as a survivable volume is maintained in the operator’s cab.

2.2.2.2.2 Side impact

Vehicle body structures shall be designed to resist an inward-directed load of 40,000 lbf (178 kN) applied to the bottom cords (“side sill”) and, except for non-passenger-carrying locomotives, 7,000 lbf (31 kN) applied below the side window(s). These loads shall be applied separately over an area 6 in. (152 mm) high by 8 ft (2.4 m) long at the weakest section along the length of the car. For multilevel vehicles, the 40,000 lbf (178 kN) requirement applies to the mezzanine and lower levels separately, and the 7,000 lbf (31 kN) requirement applies to each level separately.

The connection of the side frame to the roof and underframe shall be designed to support these loads.

The allowable stress shall be the lesser of the yield strength and the critical buckling strength, with local yielding of the side sheathing at the belt rail and the side sill allowed. In addition, in door pocket areas where door panel guideways compromise the strength of the affected members, it shall be permissible for the structure outboard the guideway to crush inward and bear on the inboard structure of the underframe in resisting the required loads.

At doorways, regardless of width, including doorways greater than 8 ft (2.4 m) wide, an assumption that all cases of the load spanning the door opening are represented by one-half the required load applied to and resisted by each of the major posts at the edges of the door opening shall be permitted.

Structural analysis shall be performed to demonstrate compliance with this requirement.

2.3 End frame

The strength requirements for the collision posts and the supporting structure are defined in Section 2.3.1 and for the corner posts and supporting structure in Section 2.3.2. These strength requirements are intended to ensure that all connections to the carbody supporting structure of the collision and corner posts be designed to resist failure as the posts undergo plastic bending.

If the end frame has an anti-telescoping plate (A-T plate), then the effects of the A-T plate on the roof-post connection shall be considered.

2.3.1 Collision posts

2.3.1.1 General

This standard outlines the minimum structural design requirements for collision posts at the ends of occupied vehicles. The end of a vehicle that is designed to lead a train must protect occupants of that vehicle from the intrusion of objects the train has struck in a collision. As such, higher strength requirements are necessary for the lead ends of such vehicles.

The requirements of this standard are intended to result in an energy-absorbing end structure above the underframe. Therefore, requirements for collision posts in the following sections include the ability of the post to absorb a significant amount of energy by undergoing severe deformation without failure of the post or its connections during an overloading condition.

2.3.1.2 Non-passenger-carrying locomotives

2.3.1.2.1 Cab-end collision posts

Cab-ends of non-passenger-carrying locomotives and non-cab ends of locomotives with a hostler station shall have structural collision posts meeting the requirements outlined in this section.

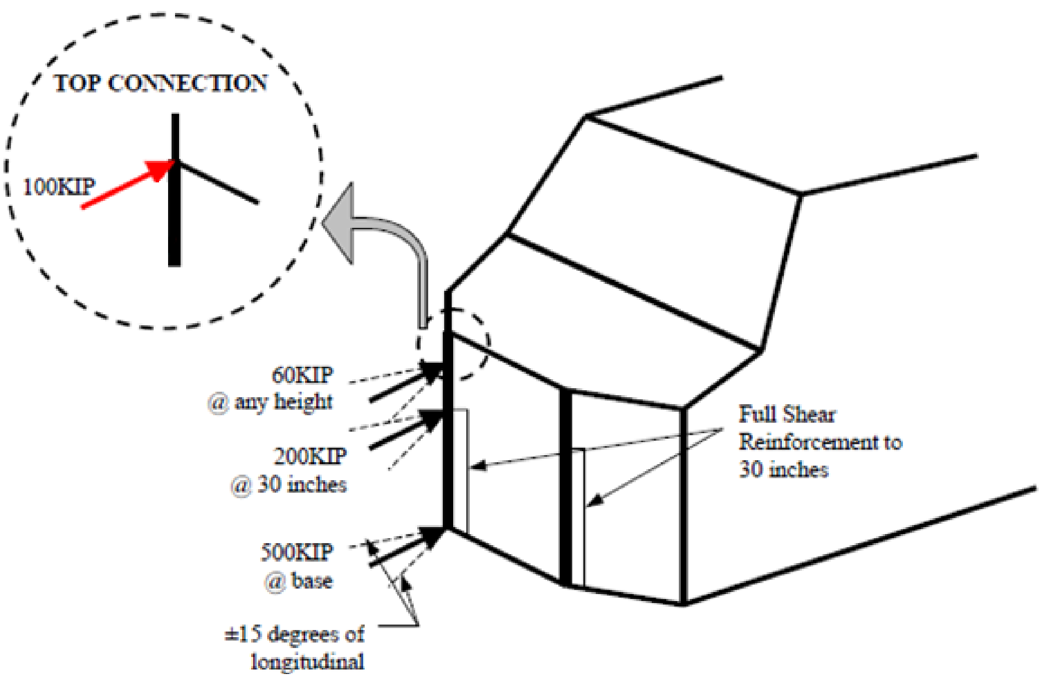
There shall be two collision posts extending from the underframe to a height within 6 in. (152 mm) from the bottom of the windshield, or alternatively at least 24 in. above the finished cab floor. They shall be located at the approximate one-third points across the width of the vehicle and shall, in their entirety, be forward of the seating position of any crew member. Each collision post, acting together with the supporting carbody structure, and intervening connections shall resist each one of the following horizontal inward loads individually applied at any angle within 15 deg. of the longitudinal axis (see **Figure 1**):

a) Minimum 500,000 lbf (2224 kN) applied at a point even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is depth of the post times the thickness of the webs).
b) Minimum 200,000 lbf (890 kN) applied at a point 30 in. (762 mm) above the top of the underframe, without exceeding the ultimate strength.
c) Minimum 60,000 lbf (267 kN) applied anywhere along the post, including the top connection, above the top of the underframe, without permanent deformation of the post or supporting structure.
d) The top connection of the collision post (at the roof structure or the structure below the windshield, whichever applies) shall be designed to resist each of the following individually applied ultimate loads:
    - 100,000 lbf (445 kN) longitudinal shear load

The top connection loads specified in d) above are to be used to design the strength of the connections and not the supporting structure.

The area properties of the collision posts, including any reinforcement required to provide the specified 500,000 lbf (2224 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 30 in. (762 mm) above the top of the underframe.

FIGURE 1
Schematic of Collision Post Loads for Non-Passenger-Carrying Locomotive



Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CWB code, or equivalent recognized standard.

2.3.1.2.2 Non-cab-end collision posts

Non-passenger-carrying locomotives that do not have a hostler station at the non-cab end or "B" end of the locomotive are not required to have structural collision posts.

2.3.1.2.3 Alternative requirements for cab-end collision posts (49 CFR 238 Appendix F)

As an alternative to the requirements of Section 2.3.1.2.1, cab ends may be designed to meet the Alternative Requirements for Collision Posts provided in Appendix F to 49 CFR 238. The collision scenario shall involve a vehicle at AW0 (empty, ready-to-run weight) and an object with a recommended weight of 10,000 lbs. (4536 kg). The impact speed shall be adjusted to achieve a minimum impact energy of 135,000 ft-lb (0.18 MJ). The object weight may be adjusted to achieve higher impact speeds with the same impact energy, as agreed by the Purchaser and Manufacturer.

Conformance with the requirements of this section shall be demonstrated through analysis. The dynamic analysis shall be validated against the required quasi-static elastic-plastic testing of the front-end structure.

2.3.1.3 Cab cars

2.3.1.3.1 Cab-end collision posts (49 CFR 238.211[c])

Except as allowed by Section 2.3.1.3.2, cab ends of flat-end cab cars shall have structural collision posts meeting the requirements outlined in this section. There shall be two full-height collision posts extending from the underframe to the cant rail or roofline. They shall be located at the approximate one-third points across the width of the vehicle and shall, in their entirety, be forward of the seating position of any crew member or passenger.

Each collision post, acting together with the supporting carbody structure, and intervening connections shall resist the horizontal inward loads defined in sections a), b), and c) below, individually applied at any angle within 15 deg. of the longitudinal axis (see **Figure 2**). Analysis shall be performed to demonstrate compliance with all of the following requirements. A load distribution device may be used between the loading ram and post that is not greater than 6 in. (152 mm) high and wide enough to distribute the load directly into the post webs, but not more than 36 in. (914 mm) wide.

a) Minimum 500,000 lbf (2224 kN), applied such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post. If manual calculations are used for analysis, they shall be based upon the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs. The load shall be applied exclusively to the collision post and may not be applied to any part of the underframe structure.
b) Minimum 200,000 lbf (890 kN) applied centered at a height of 30 in. (762 mm) above the top of the underframe, without exceeding the ultimate strength of the post or supporting structure.
c) Minimum 60,000 lbf (267 kN) applied at any height along the post, including the top connection, above the top of the underframe, without permanent deformation of the post or supporting structure.
d) Each collision post shall be capable of absorbing a minimum of 135,000 ft-lb (0.18 MJ) of plastic energy when loaded longitudinally, centered at a height of 30 in. (762 mm) above the top of the underframe. At the moment that the collision post has absorbed this minimum energy:
    - The post shall not permanently deflect more than 10 in. (254 mm) into the operator's cab or passenger seating area.
    - There shall be no complete separation of the post, its connection to the underframe, or its connection to either the roof structure or A-T plate (if used).

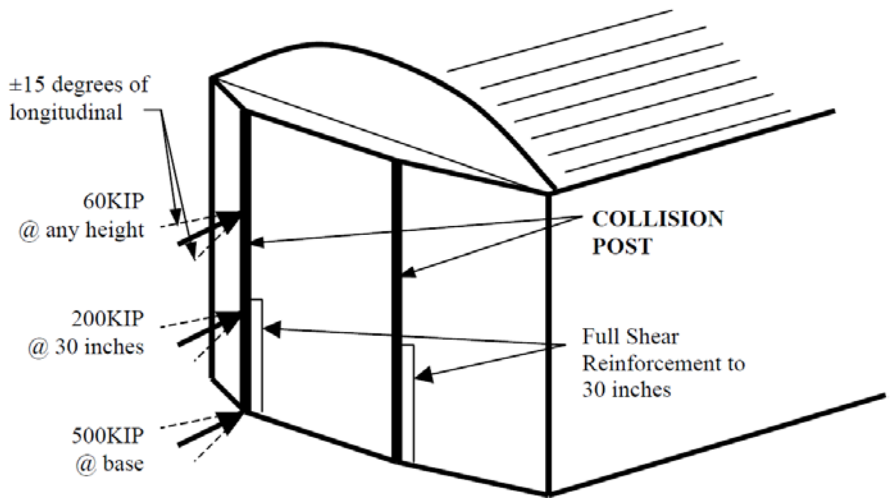
Testing shall be performed to demonstrate compliance with paragraph d) above.

The area properties of the collision posts, including any reinforcement required to provide the specified 500,000 lbf (2224 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 30 in. (762 mm) above the top of the underframe.

Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CWB code, or equivalent recognized standard.

FIGURE 2

Schematic of Collision Post Loads for the Cab End of Cab Cars



2.3.1.3.2 Alternative requirements for cab-end collision posts (49 CFR 238 Appendix F)

As an alternative to the requirements of Section 2.3.1.3.1, cab ends may be designed to meet the Alternative Requirements for Collision Posts provided in Appendix F to 49 CFR 238. The collision scenario shall involve a vehicle at AW0 (empty, ready-to-run weight) and an object with a recommended weight of 10,000 lbs. (4536 kg). The impact speed shall be adjusted to achieve a minimum impact energy of 135,000 ft-lb (0.18 MJ). The object weight may be adjusted to achieve higher impact speeds with the same impact energy, as agreed by the Purchaser and Manufacturer.

Conformance with the requirements of this section shall be demonstrated through analysis. The dynamic analysis shall be validated against the required quasi-static elastic-plastic testing of the front-end structure.

2.3.1.3.3 Non-cab-end collision posts

The non-cab ends of cab cars shall have structural collision posts meeting the requirements of Section 2.3.1.4.

2.3.1.4 Coach car collision posts (49 CFR 238.211[a])

Coach cars shall have structural collision posts meeting the requirements outlined in this section. There shall be two full-height collision posts extending from the underframe to the cant rail or roofline. They shall be located at the approximate one-third points across the width of the vehicle.

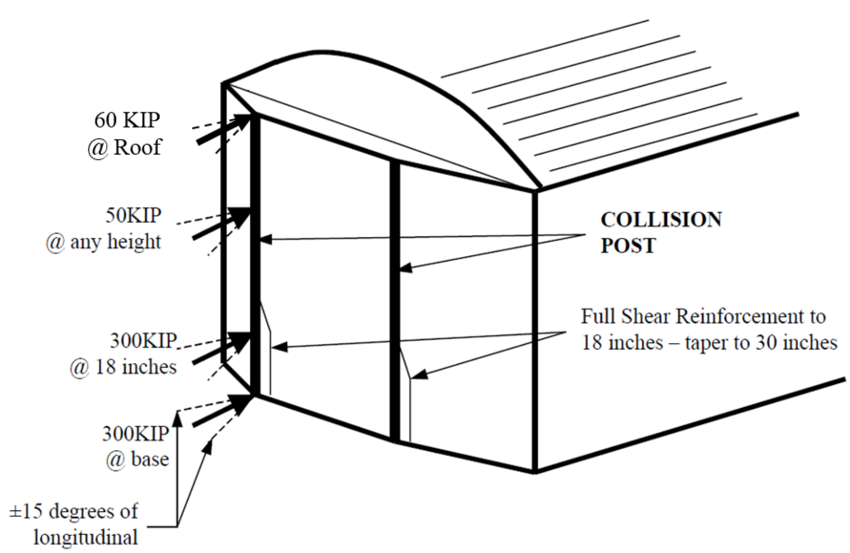
Each collision post, acting together with supporting carbody structure, and intervening connections shall resist each one of the following horizontal inward loads individually applied at any angle within 15 deg. of the longitudinal axis (see **Figure 3**). Analysis shall be performed to demonstrate compliance with all of the following requirements. Testing shall be performed to demonstrate compliance with the elastic portion of the following requirements. A load distribution device may be used between the loading ram and post that is not greater than 6 in. (152 mm) high and wide enough to distribute the load directly into the post webs, but not more than 36 in. (914 mm) wide.

a) Minimum 300,000 lbf (1334 kN), applied such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post. If manual calculations are used for analysis, they shall be based upon the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs. The load shall be applied exclusively to the collision post and may not be applied to any part of the underframe structure.
b) Minimum 300,000 lbf (1334 kN) centered at a height of 18 in. (457 mm) above the top of the underframe, without exceeding the ultimate strength of the post and supporting structure.
c) Minimum 50,000 lbf (222 kN) applied anywhere along the post, including the top connection, above the top of the underframe, without permanent deformation of the post and supporting structure.
d) Minimum 60,000 lbf (267 kN) applied such that the top of the load is even with the attachment to the roof structure, without exceeding the ultimate strength of the post or supporting structure. The load shall be applied entirely to the collision post and may not be applied in any part to the roof structure.
e) The collision posts shall be designed so that if overloaded longitudinally at a point 30 in. (762 mm) above the underframe, the post will fail beginning with bending or buckling in the post and the post will continue in the plastic bending mode until its ultimate capacity has been developed. The connections of the post to the supporting structure shall support the post at its ultimate capacity.

The area properties of the collision posts, including any reinforcement required to provide the specified 300,000 lbf (1334 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 18 in. (457 mm) above the top of the underframe and then taper to a point 30 in. (762 mm) above the top of the underframe.

Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CWB code, or equivalent recognized standard.

FIGURE 3
Schematic of Collision Post Loads for Coach Cars



2.3.1.5 Permanently and semi-permanently coupled articulated cars

If a car is to be used within a permanently or semi-permanently coupled articulated consist, and provided that the intercar coupling meets the climb, bypass and overturn requirements of Section 2.5 of this standard, the collision post requirements outlined above apply only to the ends of the assembly of units, not to each end of each unit so joined. The requirements of 49 CFR 238.211(d) for documentation and analysis apply to this configuration.

The structural requirements for the collision posts at the end of this assembly of units will depend on the configuration of the trainset. If the end of the assembly of units is a non-passenger-carrying locomotive or power car, then the requirements of Section 2.3.1.2.1 apply. If the end of the assembly of units is at the lead end of the trainset (i.e., similar to a cab car), then the requirements of Sections 2.3.1.3.1 or 2.3.1.3.2 apply. If the end of the assembly of units is not at the lead end of the trainset, then the requirements of Section 2.3.1.4 apply.

2.3.2 Corner posts

2.3.2.1 General

All passenger equipment shall have at each end of the vehicle two structural corner posts, located ahead of the occupied volume. The corner posts shall extend from the bottom of the underframe structure to the bottom of the roof structure.

The requirements of this standard are intended to result in an energy-absorbing end structure above the underframe. Therefore, requirements for corner posts in the following sections include the ability of the post to absorb a significant amount of energy by undergoing severe deformation without failure of the post or its connections during an overloading condition.

2.3.2.2 Non-passenger-carrying locomotives corner posts

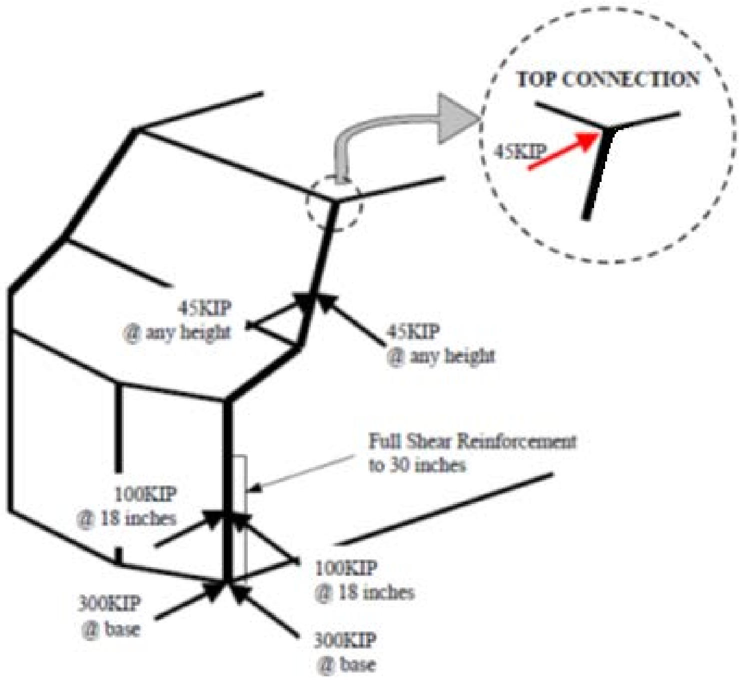
Cab ends of non-passenger-carrying locomotives and non-cab ends of locomotives with a hostler station shall have structural corner posts meeting the requirements outlined in this section. Each corner post, acting together with supporting carbody structure, and intervening connections shall resist each one of the following horizontal loads individually applied toward the inside of the vehicle in any direction from longitudinal to transverse (see **Figure 4**):

a) Minimum 300,000 lbf (1334 kN) applied at a point even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is depth of the post times the thickness of the webs).
b) Minimum 100,000 lbf (445 kN) applied at a point 18 in. (457 mm) above the top of the underframe, without permanent deformation.
c) Minimum 45,000 lbf (200 kN) applied anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or the supporting structure.
d) The connection of the corner post to the roof structure shall be designed to resist each of the following individually applied ultimate loads:
    - 45,000 lbf (200 kN) longitudinal shear load

The roof connection loads specified in d) above are to be used to design the strength of the connections and not the supporting structure.

The area properties of the corner post, including any reinforcement required to provide the specified 300,000 lbf (1334 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 30 in. (762 mm) above the top of the underframe.

FIGURE 4
Schematic of Corner Post Loads for Non-Passenger-Carrying Locomotive



Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CWB code, or equivalent recognized standard.

Corner posts in non-passenger-carrying locomotives with isolated cabs may be discontinuous at the boundary of the isolated cab but shall otherwise meet the requirements of this section for corner posts. A design incorporating discontinuous posts may require intermediate supports for the portions of the corner posts in the locomotive platform structure and in the isolated cab, and limit stops on the possible displacement of the isolated cab.

2.3.2.2.1 Alternative requirements for cab-end corner posts (49 CFR 238 Appendix F)

As an alternative to the requirements of Section 2.3.2.2, cab ends may be designed to meet the Alternative Requirements for Corner Posts provided in Appendix F to 49 CFR 238. The collision scenario shall involve a vehicle at AW0 (empty, ready-to-run weight) and an object with a recommended weight of 9,000 lbs. (4,082 kg). The impact speed shall be adjusted to achieve a minimum impact energy of 120,000 ft-lb (0.16 MJ). The object weight may be adjusted to achieve higher impact speeds with the same impact energy, as agreed by the Purchaser and Manufacturer.

Conformance with the requirements of this section shall be demonstrated through analysis. Where feasible, elastic–plastic testing of the front end structure shall be performed to validate the analysis results.

2.3.2.3 Cab cars

2.3.2.3.1 Cab-end corner posts (49 CFR 238.213[b])

The cab ends of cab cars shall have structural corner posts meeting the requirements outlined in this section. Each corner post, acting together with supporting carbody structure, and intervening connections shall resist the horizontal loads in paragraphs a), b) and c), individually applied toward the inside of the vehicle in any direction from longitudinal to transverse (see **Figure 5**). Analysis shall be performed to demonstrate compliance with all of the following requirements. A load distribution device may be used between the loading ram and post that is not greater than 10 in. (254 mm) high by 10 in. (254 mm) wide.

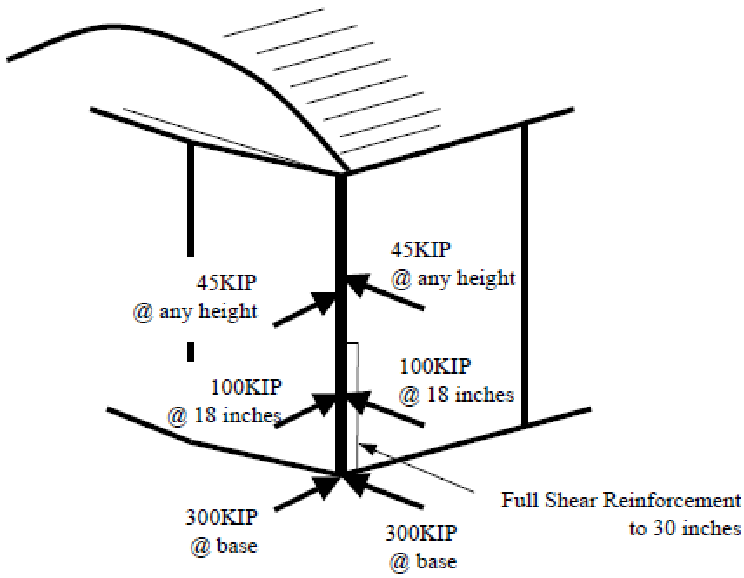
a) Minimum 300,000 lbf (1334 kN) applied such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post. If manual calculations are used for analysis, they shall be based upon the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs. The load shall be applied exclusively to the corner post and may not be applied to any part of the underframe structure.
b) Minimum 100,000 lbf (445 kN) centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.
c) Minimum 45,000 lbf (200 kN) applied anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or supporting structure.
d) Each corner post on a cab car shall be capable of absorbing a minimum of 120,000 ft-lb (0.16 MJ) of plastic energy when loaded longitudinally at a height of 30 in. (762 mm) above the top of the underframe. At the moment that the corner post has absorbed this minimum energy:
    - The post shall not permanently deflect more than 10 in. (254 mm) into the operator’s cab or passenger seating area.
    - There shall be no complete separation of the post, its connection to the underframe, structural shelf, sidewall structure, or its connection to either the roof structure or A-T plate (if used).

Testing shall be performed to demonstrate compliance with the elastic portion of paragraph d).

The area properties of the corner post, including any reinforcement required to provide the specified 300,000 lbf (1334 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 30 in. (762 mm) above the top of the underframe.

Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CWB code, or equivalent recognized standard.

FIGURE 5
Schematic of Corner Post Loads for Cab Ends of Cab Cars



2.3.2.3.2 Non-cab-end corner posts

The non-cab ends of cab cars shall have structural corner posts meeting the requirements outlined in Section 2.3.2.3.4.

2.3.2.3.3 Cab-end non-operator side of cab – alternate requirements (49 CFR 238.213(c))

Cab cars that use low-level passenger boarding at the non-operating side of the cab end and are unable to meet the requirements outlined in Section 2.3.2.3.1 shall meet the following alternate structural requirements for the corner post and the adjacent body corner post (post on the inboard side of the stepwell) at the non-operating side of the cab (see **Figure 6**). Analysis shall be performed to demonstrate compliance with all of the following requirements. Testing shall be performed to demonstrate compliance with the elastic portion of the following requirements. A load distribution device may be used between the loading ram and post that is not greater than 10 in. (254 mm) high by 10 in. (254 mm) wide.

2.3.2.3.3.1 Severe deformation

The corner post and the body corner post on a cab car shall be capable of absorbing a minimum of 120,000 ft-lb (0.16 MJ) of energy, in accordance with the following formula, when loaded longitudinally at a height of 30 in. (762 mm) above the top of the underframe:

$$E_{min} = ECP + EBCP$$

where: E_{min} = minimum total energy absorbed = 120,000 ft-lb (0.16 MJ)
ECP = energy absorbed by the corner post
EBCP = energy absorbed by the body corner post

At the moment the corner post fails to resist any further load due to complete separation of the post and/or its supporting structure, the corresponding energy absorbed by the corner post shall be calculated (ECP). The load shall then be applied to the body corner post to absorb the remaining energy (EBCP).

At the moment that the body corner post has absorbed the remaining minimum energy:

- The body corner post shall not permanently deflect more than 10 in. (254 mm) into the passenger seating area and,
- There shall be no complete separation of the body corner post, its connection to the underframe, sidewall structure, or its connection to either the roof structure or A-T plate (if used).

2.3.2.3.3.2 Corner post

The corner post of cab cars meeting the alternate requirements, acting together with supporting carbody structure, and intervening connections shall resist each one of the following horizontal loads individually applied toward the inside of the vehicle (see **Figure 6**):

a) Minimum 150,000 lbf (667 kN) applied longitudinally such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs). The load shall be applied exclusively to the corner post and may not be applied to any part of the underframe structure.
b) Minimum 30,000 lbf (133 kN) applied longitudinally centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.
c) Minimum 30,000 lbf (133 kN) applied longitudinally such that the top of the load is even with the attachment to the roof structure, without permanent deformation of the post or supporting structure. The load shall be applied entirely to the corner post and may not be applied in any part to the roof structure.
d) Minimum 20,000 lbf (89 kN) applied longitudinally anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or supporting structure.
e) Minimum 300,000 lbf (1334 kN) applied transversely such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs). The load shall be applied entirely to the corner post and may not be applied in any part to the underframe structure.
f) Minimum 100,000 lbf (445 kN) applied transversely, centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.
g) Minimum 45,000 lbf (200 kN) applied transversely anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or supporting structure.

2.3.2.3.3.3 Body corner post

The body corner posts of cab cars meeting the alternate requirements, acting together with supporting carbody structure, and intervening connections shall resist each one of the following horizontal loads individually applied toward the inside of the vehicle (see **Figure 6**).

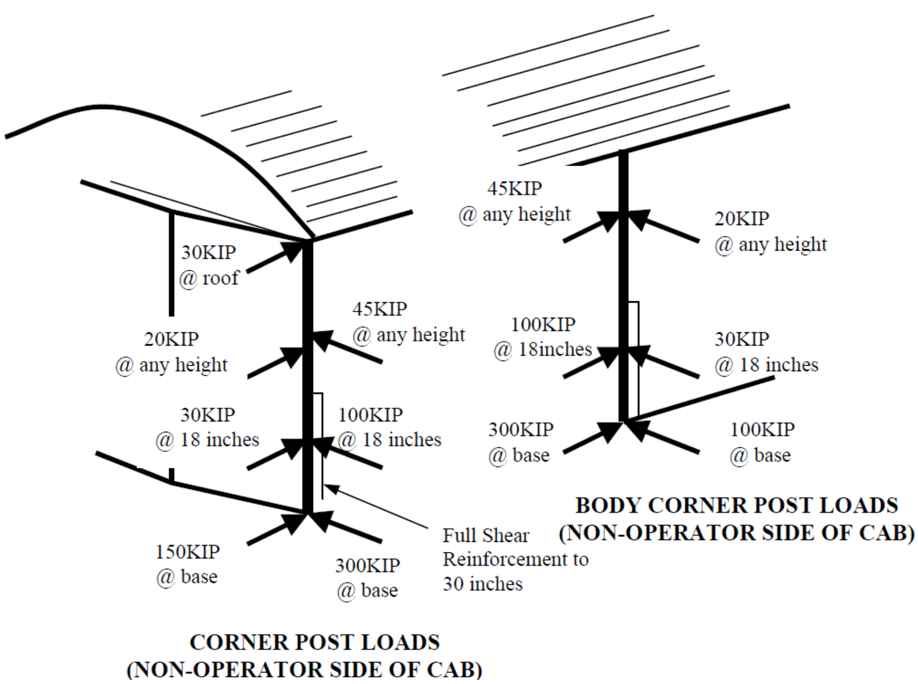
a) Minimum 300,000 lbf (1334 kN) applied longitudinally such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs). The load shall be applied exclusively to the corner post and may not be applied to any part of the underframe structure.
b) Minimum 100,000 lbf (445 kN) applied longitudinally centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.

c) Minimum 45,000 lbf (200 kN) applied longitudinally anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or supporting structure.
d) Minimum 100,000 lbf (445 kN) applied transversely such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is the depth of the post in the direction of loading times the thickness of the webs). The load shall be applied entirely to the corner post and may not be applied in any part to the underframe structure.
e) Minimum 30,000 lbf (134 kN) applied transversely, centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.
f) Minimum 20,000 lbf (90 kN) applied transversely anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or supporting structure.

The area properties of the corner post and body corner post, including any reinforcement required to provide the specified shear strength at the top of the underframe, shall extend from the bottom of the end sill or side sill to at least 30 in. (762 mm) above the top of the underframe.

Each corner post, and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CSA code, or equivalent recognized standard.

FIGURE 6
Schematic of Corner Post and Body Corner Post Loads for MU and Cab Cars
(Cab End, Non-Operator Side Only with Step Well)



2.3.2.3.4 Alternative requirements for cab-end corner posts (49 CFR 238 Appendix F)

As an alternative to the requirements of Section 2.3.2.3.1, cab ends may be designed to meet the Alternative Requirements for Corner Posts provided in Appendix F to 49 CFR 238. The collision scenario shall involve a vehicle at AW0 (empty, ready-to-run weight) and an object with a recommended weight of 9,000 lbs. (4082 kg). The impact speed shall be adjusted to achieve a minimum impact energy of 120,000 ft-lb

(0.16 MJ). The object weight may be adjusted to achieve higher impact speeds with the same impact energy, as agreed by the Purchaser and Manufacturer.

Conformance with the requirements of this section shall be demonstrated through analysis. Where feasible, elastic–plastic testing of the front end structure shall be performed to validate the analysis results.

2.3.2.4 Coach car corner posts (49 CFR 238.213[a])

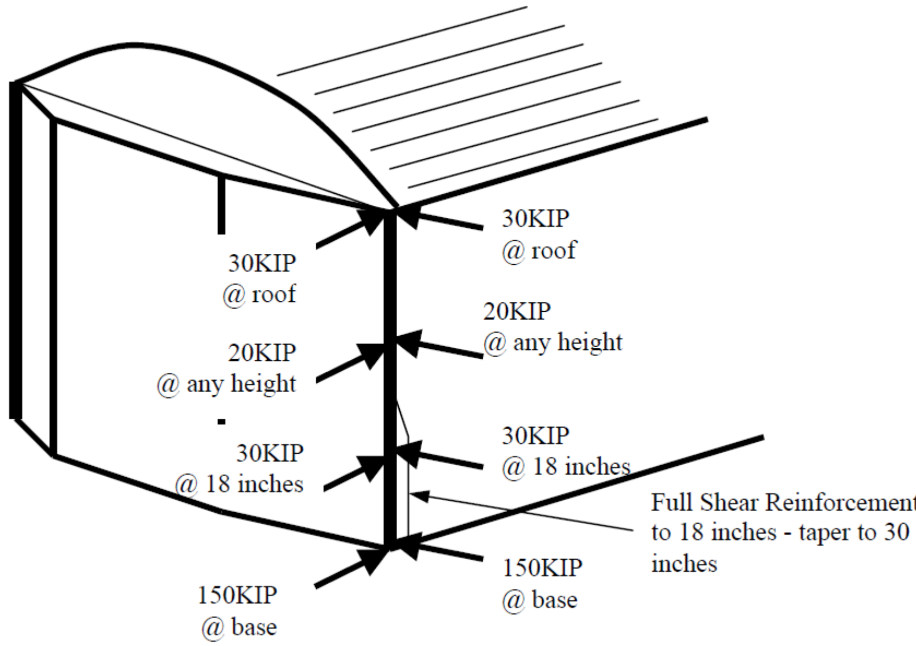
Each corner post, acting together with supporting carbody structure, and intervening connections shall resist each one of the following horizontal loads individually applied toward the inside of the vehicle in any direction from longitudinal to transverse (see **Figure 7**). Analysis shall be performed to demonstrate compliance with all of the following requirements. Testing shall be performed to demonstrate compliance with the elastic portion of the following requirements. A load distribution device may be used between the loading ram and post that is not greater than 10 in. (254 mm) high by 10 in. (254 mm) wide.

a) Minimum 150,000 lbf (667 kN) applied such that the bottom of the load is even with the top of the underframe, without exceeding the ultimate shear strength of the post (based on the shear area of the post, which is depth of the post in the direction of loading times the thickness of the webs). The load shall be applied exclusively to the corner post and may not be applied to any part of the underframe structure.
b) Minimum 30,000 lbf (133 kN) centered at a height of 18 in. (457 mm) above the top of the underframe, without permanent deformation of the post or supporting structure.
c) Minimum 30,000 lbf (133 kN) applied such that the top of the load is even with the point of attachment to the roof structure, without permanent deformation of the post or supporting structure.
d) Minimum 20,000 lbf (89 kN) applied anywhere between the top of the post at its connection to the roof structure and the top of the underframe, without permanent deformation of the post or the supporting structure.
e) The corner posts shall be designed so that if overloaded longitudinally at a point 30 in. (762 mm) above the underframe, the post will fail beginning with bending or buckling in the post and the post will continue in the plastic bending mode until its ultimate capacity has been developed. The connections of the post to the supporting structure shall support the post at its ultimate capacity.

The area properties of the corner posts, including any reinforcement required to provide the specified 150,000 lbf (667 kN) shear strength at the top of the underframe, shall extend from the bottom of the end sill to at least 18 in. (457 mm) above the top of the underframe, and shall then taper to a point at a level not less than 30 in. (762 mm) above the top of the underframe.

Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with welded joints qualified to the applicable AWS or CSA code, or equivalent recognized standard.

FIGURE 7
Schematic of Corner Post Loads for Coach Cars



2.3.3 Horizontal framing members, MU cars, cab cars and other cars

End frame collision and corner posts may be connected by horizontal structural members as necessary to resist the lateral components of the design loads specified in Sections 2.3.1 and 2.3.2. In addition, an A-T plate may be used to connect the tops of the collision and corner posts.

Cab-end framing of cars with full or partial cabs shall include a horizontal structural member between the collision post and corner post on each side at a height equivalent to the bottom of the windshield. The structural shelf shall support a load of not less than 15,000 lbf (67 kN) applied horizontally, perpendicular to the member at any point on its span without permanent deformation of any part of the vehicle structure. Analysis shall be performed to demonstrate compliance with this requirement. Testing may be performed to validate the analysis results.

2.3.4 End frame sheathing, MU cars, cab cars and other cars; and non-passenger-carrying locomotives (49 CFR 238.209[a])

Cab-end frame sheathing of MU cars, cab cars and other cars with full or partial cabs shall have the following characteristics:

a) Equivalent to a ½ in. (13 mm) thick steel plate with a 25,000 psi (172 MPa) yield strength. Multiple skin/structural elements or materials of higher yield strengths may be used to meet this requirement, provided that the sum of the shear strengths of each element from the leading edge of the vehicle to a vertical plane just forward of the engineer's normal operating position, based on the yield strength of the material, is equivalent to the shear strength of a ½ inch (13 mm) thick plate with a 25,000 psi (172 MPa) yield strength.
b) Designed to inhibit the entry of fluids into the occupied cab area of the equipment. Fluid entry inhibition shall be provided by a continuously welded or continuously sealed metallic plate or sheet. An FRP mask alone is not sufficient to meet this requirement.
c) Connected to underlying framing members sufficient to develop the full strength of the sheathing.

The end frame sheathing does not include doors or forward-facing windows.

2.4 Roof

2.4.1 Roof framing and sheathing, all passenger equipment

a) The projected area on a horizontal plane, in units of square feet (square millimeters), of the portion of the roof supported by carlines divided by the sum of the section moduli in units of cubic inches (cubic millimeters) of the carlines at any longitudinal section shall not be more than 60 sq. ft/cu. in. (340 mm^{-1}).
b) Flat roof sheets of mild steel with 32 ksi (221 MPa) yield strength and without reinforcements, aside from the roof framing, shall be of a minimum thickness of 0.05 in. (1.3 mm). Metals of other strengths may be used of a thickness in inverse proportion to yield strength.
c) Metal roof sheets of a lesser thickness may be used, provided that the sheets are reinforced to produce at least an equivalent sectional area, on any lateral section, as the roof sheets specified in b).

2.4.2 Rollover, all passenger equipment (49 CFR 238.215[b])

Vehicles, except non-passenger-carrying locomotives with non-structural equipment hoods, shall be designed to rest on their roofs so that any structural damage in occupied areas is limited to roof sheathing and framing members. Deformation to the roof sheathing and framing is allowed to the extent necessary to permit the vehicle, including the weight of the trucks, to be uniformly supported directly on the top chords of the side frames and end frames. For this condition, the allowable stress for the structure of the occupied zones of the carbody shall be one-half yield or one-half the critical buckling stress, whichever is less. Structural analysis shall be performed to demonstrate compliance with this requirement.

Non-passenger-carrying locomotives with non-structural equipment hoods shall be designed such that in the event of a rollover, the operator’s cab will maintain a survivable volume. The Manufacturer shall show by layout and calculation (classic or FEA) that the locomotive is capable of resting upside-down at two or more points of contact while simultaneously maintaining a survivable volume within the operator’s cab. The points of contact may be a major piece of equipment (for example, the diesel engine and transformer), one end of the platform or the other (depending on the location of the center of gravity), or structural members added to satisfy this requirement. Deformation of equipment enclosures and operator’s cab roof sheathing is allowed to the extent necessary to permit the vehicle to be supported as described. The allowable stress for structural members added to the structure specifically for this load case shall be one-half yield or one-half the critical buckling stress. The load applied to the structural members shall be determined from a static balance calculation, while the locomotive is upside-down, assuming only the truck adjacent to the operator’s cab is still attached to the structure.

2.4.3 Other roof loads, all passenger equipment

Roof framing members and roof sheathing shall have sufficient strength to withstand, without permanent deformation, three loads of 250 lbf (1112 N) spaced 30 in. (760 mm) apart, each load distributed over an area no larger than 5 in. (127 mm) by 5 in. (127 mm), such as might be applied by maintenance personnel working on the roof. The placement of the loads shall be such as to produce the worst-case condition for the roof structure. Structural analysis shall be performed to demonstrate compliance with this requirement.

2.5 Climb, bypass and overturn resistance

2.5.1 General

At each end of each unit or car there shall be a structural arrangement designed to resist vertical climb loads, lateral bypass loads, and torsional loads resulting from the incipient overturning of one or more units in a consist. The vertical, lateral and torsional loads shall be considered as applied separately. The loads discussed in this section do not apply to couplers, only to the carbody structure that contains the couplers.

2.5.2 Passenger cars

2.5.2.1 Climb resistance (49 CFR 238.205[a])

Both ends of all passenger equipment shall have an anti-climbing system capable of resisting a vertical load (both upward and downward), which shall not be less than 100,000 lbf (445 kN). The acceptance criteria for this load condition shall be no permanent deformation of the anti-climbing system components, supporting carbody structure and intervening connections. Structural analysis shall be performed to demonstrate compliance with this requirement.

If using a coupling device (e.g., Type F interlocking, Type H tightlock, drawbars, semi-permanent couplers, articulation joints) to comply with this requirement, the load shall be applied at the interface points between the carbody structure and coupling device (e.g., buffer beam and coupler carrier). The reaction load at the pivot point of the draft gear shall be considered in the analysis. If the end of the car is equipped with a separate anti-climber (e.g., shelf-type or ribbed anti-climber), then the load shall be applied directly to the anti-climber.

Unless pushback couplers provide equivalent anti-climbing resistance at all points during the stroke, any vehicle end using a pushback coupler shall have a separate anti-climbing mechanism meeting the requirements of this section. If equipped with pushback coupler and separate anti-climber, the anti-climbers shall be engaged within the pushback coupler nonrecoverable stroke. Reference APTA-PR-CS-RP-019-12 for recommended practices for pushback couplers.

2.5.2.2 Bypass resistance

The lateral strength of the structural arrangement in both directions shall not be less than the minimum climb-resistance design strength in accordance with Section 2.5.2.1. Structural analysis shall be performed to demonstrate compliance with this requirement.

2.5.2.3 Overturn resistance

Unless the vehicle is designed and equipped with a pushback coupler, the coupler anchor and supporting carbody structure shall have sufficient strength to develop the ultimate torsional strength of the coupler, without permanent deformation of the coupler anchor and supporting carbody structure. The ultimate torsional strength of the coupler shall not be less than that of an equivalent coupler approved under APTA-PR-M-RP-003-98 using AAR Standard M-201 Grade C Steel. Structural analysis shall be performed to demonstrate compliance with this requirement. If a vehicle is equipped with a pushback coupler, then the coupler anchor and supporting structure shall have sufficient strength to develop the torsional capacity of the pushback coupler, as required by APTA PR-CS-RP-019.

2.5.2.4 Coupler and drawbar carrier and buffer beam (49 CFR 238.207)

The structural arrangement shall include a coupler carrier designed to resist a 100,000 lbf (445 kN) vertical downward thrust applied over an area equivalent to that of the coupler shank at any possible horizontal position of the coupler. The acceptance criteria for this condition shall be no permanent deformation of the coupler carrier, supporting carbody structure and intervening connections.

The structural arrangement shall be designed to resist the 100,000 lbf (445 kN) vertical upward thrust from the coupler for any horizontal position of the coupler. The acceptance criteria for this condition shall be no permanent deformation of the supporting carbody structure and intervening connections.

Structural analysis shall be performed to demonstrate compliance with these requirements.

2.5.3 Non-passenger-carrying locomotives

Bypass and overturn resistance of non-passenger-carrying locomotives shall be as required by Section 2.5.2.

Each non-passenger-carrying locomotive must be equipped with an anti-climber that extends to the approximate one-third points across the width on its cab end. Except for pushback couplers, the center of the anti-climber must extend to within 4 in. of the pulling face of the coupler with the draft gear fully compressed. The center of the anti-climber must extend no less than 10 in. from the locomotive front plate for its required width.

The anti-climber must be able to resist an upward or downward vertical force of 100,000 lb applied over a 12 in. width anywhere along the anti-climber perimeter. The load must be applied without exceeding the ultimate strength of the anti-climber.

Coupled non-passenger-carrying locomotives and passenger cars shall be equipped with a compatible anti-climbing system.

2.6 Truck to carbody attachment strength

2.6.1 General (49 CFR 238.219)

A mechanism for attaching the completely assembled truck, including the bolster, if used, to the carbody shall be provided in accordance with the requirements of this section. The requirements of sections 2.6.2 and 2.6.3 shall be considered as separate load cases. Structural analysis shall be performed to demonstrate compliance with these requirements.

2.6.2 Horizontal

The ultimate strength of the truck, attachment mechanism, and supporting carbody structure shall be sufficient to secure the entire truck to the carbody in a manner that will prevent separation of the truck from the carbody during derailments and collisions in which a horizontal load of minimum 250,000 lbf (1112 kN) is applied to the truck frame in any horizontal direction and oriented through the center of truck rotation at a vertical position defined by a horizontal plane that passes through the center of gravity (CG) of the complete truck assembly. The required resistance to a 250,000 lbf (1112 kN) horizontal load shall be available at any possible position of the truck in its vertical suspension travel, including the condition of the car raised off the track with the truck hanging from the car, and shall not depend upon external vertical loading.

2.6.3 Vertical

The vertical strength of the attachment mechanism shall provide a minimum factor of safety of 2, based on the yield strength of the structural material used in the truck, carbody and the elements of the attachment mechanism, during jacking or lifting of the carbody with the truck hanging from the carbody.

2.6.4 Truck rotation stops

If truck rotation stops are desired by the Purchaser, they should be arranged to limit truck rotation to a value that does not interfere with normal vehicle operation for any possible truck position between suspension stops, or with vehicle maintenance. The strength of the stops should be selected on the basis of the type of service, vehicle speed and weight, and a minimum value equivalent to 20,000 lbf (89 kN) at 4 ft (1.2 m) from the center of rotation of the truck is suggested.

2.7 Equipment attachment

2.7.1 General

This section contains minimum requirements for the static strength of attachment of major equipment to the carbody structure of railroad passenger equipment. The purpose of the requirements is to maximize the strength of attachment of the equipment to the extent possible within the parameters defined by the applicable performance requirements, to minimize the risk of the attachments failing prematurely in case of collision, derailment or other emergency.

Structural supports for passenger locomotives and equipment having a weight greater than 150 lb (667 N) shall conform to the requirements of this standard.

These requirements do not apply to seats and interior fittings in passenger and crew compartments; refer to latest revisions of APTA-PR-CS-S-016-99, "Row-to-Row Seating in Commuter Railcars," APTA-PR-CS-S-011-99, "Cab Crew Seating Design and Performance," and APTA-PR-CS-S-006-98, "Attachment Strength of Interior Fittings for Passenger Railroad Equipment." These requirements do not apply to safety appliances required by 49 CFR 231; refer to APTA-PR-M-S-016-06, "Safety Appliances for Rail Passenger Cars."

2.7.2 MU cars and passenger cars

2.7.2.1 Strength

The design static load factor for all underfloor and roof-mounted equipment, any portion of the equipment, equipment boxes, equipment hangers, standby supports, safety hangers, and the carbody supporting structure shall not be less than ±8g longitudinal, ±4g vertical, and ±4g lateral. The load shall be equal to the weight of the equipment times the appropriate load factor, applied at the center of gravity of the equipment, and each shall be combined with the vertical 1g down-load of the weight of the equipment. The static load factors shall be applied separately so there are a total of six load cases, one corresponding to each sense in each of the three directions combined with the weight of the equipment. The load for each case must be less than the ultimate strength of the component or connection. Structural analysis shall be performed to demonstrate compliance with these requirements.

For equipment mounted on or in roof hatches, the requirements shall apply to the mounting of the equipment to the hatch, and to the installation of the hatch in the carbody.

2.7.2.2 Safety hangers

Safety straps, hangers or other devices shall be used on all equipment weighing more than 150 lb mounted resiliently or rigidly with bolts in the load path.

2.7.2.3 Clearance

With the failure of any one of the attachments, the equipment shall remain within the clearance envelope of the vehicle as defined by the operating railroad.

Safety brackets, hangers and other similar devices shall be designed to carry the equipment within the clearance envelope under normal operating load conditions in case of failure of the primary attachment system.

2.7.2.4 Fasteners

It is recommended that equipment not be supported by bolts in the load path. Designs that incorporate transfer of load by brackets bearing directly on underframe members to the maximum extent possible are preferred.

2.7.2.5 Welding

Welding of equipment attachments shall be in accordance with the requirements of the applicable AWS or CWB code, or equivalent recognized standard.

2.7.3 Non-passenger-carrying locomotive

Non-passenger-carrying locomotives shall comply with Section 2.7.2, except that the design static load factors for equipment weighing more than 7500 lbf (34 kN) shall be not less than ±3g longitudinal, ±2g vertical and ±1.5g lateral, and the allowable stress for each load case as otherwise defined by Section 5.7.2 for equipment weighing more than 7500 lbf (34 kN) shall be yield strength.

2.8 Structural connections

As agreed between the Purchaser and Manufacturer, critical connections between structural members of the carbody shall be designed such that the strength of the connection exceeds the ultimate load-carrying capacity of the weakest member joined. This requirement shall apply to connections between primary carbody and truck structural members under the actions of the following emergency load cases: end-compression loads, end-frame collision post, corner post and structural shelf loads; side loads; rollover loads; climb, bypass and overturn loads; and the horizontal truck connection. The ultimate strength of the weaker member shall be calculated on the basis of overloading the member at the point of application of the emergency load.

3. Design loads and practices

3.1 Carbody vertical load

Except for non-passenger-carrying locomotives, the completely equipped, ready-to-run carbody shall be designed to carry its carbody weight (not including truck weight) supported on the trucks, plus a uniformly distributed maximum passenger load as agreed upon by the Purchaser and Manufacturer. The stresses in the carbody under vertical load shall not exceed the lesser of 50 percent of the guaranteed minimum material yield strength, or 100 percent of the buckling strength.

3.2 Carbody fatigue analysis

Except for non-passenger-carrying locomotives, the fatigue strength of the joints between major structural elements and areas with stress concentrations (such as door and window corners) shall be demonstrated using one of the following methods:

- Cumulative damage approach; the Manufacturer may use this approach if the track-induced load data are known. In this case, the required fatigue life is as agreed between the Purchaser and the Manufacturer.
- Endurance limit approach; the Manufacturer shall use a stress range as agreed between the Purchaser and the Manufacturer, but not less than 0.4 times the stress calculated for the maximum vertical load. If mean stress is accounted for in the fatigue analysis, it shall be equal to the stress calculated for the maximum vertical load. The design fatigue life shall be 10 million cycles. A lesser value may be used, if agreed to by the Purchaser and Manufacturer.

The Manufacturer shall use a codified methodology for evaluating fatigue. These include, but are not limited to, the following:

- AAR M1001-CII
- AWS D1.1, Structural Welding Code – Steel
- Aluminum Design Manual, The Aluminum Association

- DVS 1608, Design and Strength Assessment of Welded Structures from Aluminium Alloys in Railway Applications
- DVS 1612, Design and endurance strength assessment of welded joints with steels in rail vehicle construction
- BS 7608, Guide to fatigue design and assessment of steel products
- EN 1993-1-9, Design of steel structures – Part 1-9: Fatigue
- EN 1999-1-3, Design of aluminum structures – Part 1-3: Fatigue
- IIW-1823, Recommendations for Fatigue Design of Welded Joints and Components

The AISC Design Guide 27 on Structural Stainless Steel advises that guidance on estimating fatigue strength of carbon steels structures is applicable to austenitic and duplex stainless steels.

In cases for which the codes do not provide allowable fatigue stress for a particular material or fabrication detail, the Manufacturer shall conduct tests to determine the allowable fatigue stress. The methodology for establishing fatigue design allowables from the test results (i.e., survival, probability, and confidence interval) shall be as agreed between the Purchaser and Manufacturer.

As of this writing, APTA knows of no codes for the fatigue design of resistance welds. The Manufacturer shall conduct tests to determine the allowable fatigue loads for the materials, thicknesses and welding parameters to be used in the fabrication of the rail vehicle. Fatigue data from prior projects or from the technical literature may also be used, provided that the materials, thicknesses and welding parameters to be used in the fabrication of the subject rail vehicle are the same.

3.3 Carbody torsional loads

Except for non-passenger-carrying locomotives, the finished car at empty condition shall resist a three-point jacking case at most extreme outboard jacking locations, without permanent deformation and without damage to any component. Vertical deflection of the unsupported corner, choice of jacking points, and the presence or not of trucks shall be agreed to between Purchaser and Manufacturer.

The analysis model required to demonstrate compliance shall be validated against a test of the bare shell carbody with particular attention to torsional stiffness, in addition to stress evaluations. The bare carbody shell used for the torsion test may include a floor arrangement with shear stiffness and fastening equivalent to those of the finished floor.

3.4 Roof emergency access

3.4.1 All passenger equipment except non-passenger-carrying locomotives

All passenger equipment except non-passenger-carrying locomotives shall be provided with a minimum of two roof soft spots or a roof access hatch to provide access from the exterior of the vehicle to the occupied areas of the passenger car in the event of complete access blockage of all side doors and end doors after a rollover.

Roof soft spots shall be identified in accordance with the requirements of APTA-PR-PS-S-002-98, Rev. 3.

3.4.2 Non-passenger-carrying locomotives

All non-passenger-carrying locomotives shall be provided with a single roof soft spot or roof access hatch above the cab to provide access from the exterior of the vehicle to the occupied areas of the passenger car in the event of complete access blockage of all side doors and end doors after a rollover.

Roof soft spots and roof access hatches shall be identified in accordance with the requirements of APTA-PR-PS-S-002-98, Rev. 3

3.4.3 Location

3.4.3.1 All passenger equipment except non-passenger-carrying locomotives

One roof soft spot or roof access hatch shall be located wholly on each side of the vertical plane through the longitudinal centerline of the vehicle. The two roof soft spots or roof access hatches shall be located as far apart laterally as practical in order to place one access means as close as possible to the track bed when the vehicle is overturned through 90 deg.

One roof soft spot or roof access hatch shall be located wholly on each side of the vertical plane through the lateral centerline of the vehicle.

3.4.3.2 Non-passenger-carrying locomotives

One roof soft spot or roof access hatch shall be located centrally on the vertical plane through the longitudinal centerline of the vehicle. The roof soft spot or roof access hatch shall be located as practical centrally above the cab.

3.4.4 Opening size

Each roof soft spot or roof access hatch shall have at least the following minimum clear opening:

a) 26 in. (660 mm) in the longitudinal direction. The clear opening shall extend from one roof transverse structural member to the next roof transverse structural member.
b) 24 in. (61 cm) in the lateral direction.

3.4.5 Secondary obstruction

The ceiling space below each roof soft spot or roof access hatch shall be free from the following:

a) Wire, cabling, conduit and piping
b) Rigid secondary structure (e.g., duct walls, diffusers, diffuser supports, lighting back fixtures, mounted PA equipment, luggage racks)

Interior panels and liners below each roof soft spot shall be designed such that, after making the cutout through the roof soft spot, it shall be possible to cut an equally sized clear opening through the interior panels and liners using the same tools that were used to cut the soft spot.

4. Analysis

4.1 General

The Manufacturer shall perform structural analysis of the carbody structure and of supports for equipment weighing over 150 lbf (667 N), as defined in Section 2 of this standard. By agreement, the equipment Purchaser may review and approve reports of the structural analysis as a condition for acceptance of the cars. Format and content of the structural analysis reports should be as agreed to by the Purchaser and Manufacturer. The Manufacturer and Purchaser shall agree on an analysis plan prior to performing the analysis.

4.2 Structural representation

In order to define the carbody structure, a structural representation is required. The purpose of the structural representation is to define the primary carbody structure in advance of formal stress analysis and structural drawings.

If presented in 2-D, the structural representation should 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.

The 2-D representation should also include cross-sections of the structural members, showing their shape, dimensions, material and thickness.

A 3-D representation should be issued in a format that will allow review and dimensional extraction with the use of commonly available 3-D viewers. Whether presented in 2-D or 3-D, material identification shall be provided, along with a preliminary description of anticipated connections.

The members shown should include, to the extent used in the particular design, typical side frame and door frame posts; end, side, draft and center sills; belt, top and roof rails; collision and corner posts; bolsters, floor beams and cross-bearers; roof carlines and purlins; roof sheathing or corrugation; side frame sheathing and/or corrugation, jacking pads; and locations of energy-absorbing mechanisms where applicable.

4.3 Elastic and elastic-plastic stress analysis

Linear elastic load cases shall be subject to stress analysis consisting of a linear-elastic finite element analysis (FEA) supplemented as necessary by manual analyses. The FEA shall use a recognized code that is readily available and widely used in North America for railcar structural analysis.

For all linear-elastic load cases, the elastic stability of plates, webs and flanges shall be calculated for members subject to compression and/or shear as agreed upon by the Purchaser and Manufacturer.

Severe deformation load cases shall be carried out using non-linear, large-deformation stress analysis consisting of an FEA. The analysis shall account for nonlinear material behavior above the material’s elastic limit. The FEA shall use a recognized code that is readily available and widely used in North America for railcar structural analysis.

Manual analysis shall be performed to examine details of the carbody structure (i.e., weld connections, welded and/or bolted joints, buckling and fatigue conditions) that are not readily handled in the FEA.

4.4 Stress analysis report

Analysis report(s) shall be created to demonstrate compliance with the analysis requirements of this standard. The format and content of the report(s) shall be as agreed to by the Purchaser and Manufacturer, but shall contain the following at a minimum:

1. General information about the analyzed item(s), including:
    a) description of each item and the item’s intended function;
    b) load case(s) documented in the report;
    c) diagram showing key dimensions, identifying relevant structural member(s), and showing the load application and reaction location(s); and
    d) drawing references.

2. Details about the materials used in the analyzed item(s), including:
    a) diagram showing the locations of each material used; and
    b) mechanical properties and their sources for all materials used, including, at a minimum, tensile modulus, shear modulus, yield strength/proof strength, and ultimate tensile strength.
3. Description of the acceptance criteria for each analysis performed, including:
    a) allowable stresses and/or strains and the means for deriving these values; and
    b) reference to the applicable requirements of this standard.
4. Description of finite element analyses performed, including:
    a) identification of the solver used and type of analysis performed;
    b) diagram showing the applied forces and other boundary conditions for each loading condition;
    c) modeling methods used for load application;
    d) assumptions of how joint behavior is represented (e.g., rivets, bolts, welds)
    e) description of the mesh, including element types, quantity of elements, characteristic element sizes, locations of mesh refinement, and meshing accuracy index; and
    f) important differences between the model and the actual structure.
5. Analysis results using appropriate views and scales, including:
    a) reaction forces and moments;
    b) deflection in three orthogonal axes;
    c) contour plots of von Mises or other approved combination stress;
    d) where agreed to by the Purchaser and Manufacturer, minimum and maximum principal stresses and their directions;
    e) detailed results at locations of highest stress and other critical areas;
    f) identification of structural components with margins of safety less than a threshold agreed to by the Purchaser and Manufacturer, at a minimum 0.2; and
    g) identification of any locations at which allowable stresses are exceeded and an explanation of whether such exceedances are acceptable.
6. Supporting hand calculations or other supplemental analyses, such as buckling, joint strength, or fatigue analysis, with sufficient detail to explain the methodology employed and complete results.
7. Conclusion presenting whether the identified acceptance criteria were met.
8. For large-deformation analyses, the report shall include the nonlinear stress/strain curve and other material properties, such as damping, used in the analysis. Allowable plastic equivalent strain values shall be identified for each material. In addition to identifying the solver and type of analysis, the time step used for the analysis shall be provided. Analysis results shall show, at a minimum, plots of reaction forces and moments over time, deflection in all three axes, energy parameters, and plastic equivalent strain values. The results shall demonstrate that the support structure of the plastically deforming components remains stable under the prescribed conditions.

4.5 Model validation

It is anticipated that compliance with load cases required to achieve compliance with federal regulations, industry standards and the technical specification will not all be demonstrated through physical testing and that modeling results alone will be used to satisfy some of these requirements.

Therefore, it is critical that adequate documentation be provided to establish credibility in the modeling methodology and the ability of the model to produce realistic results.

A model validation report that fulfills this purpose is to be provided. The format and content of the report shall be as agreed to by the Purchaser and Manufacturer, but shall contain the following at a minimum:

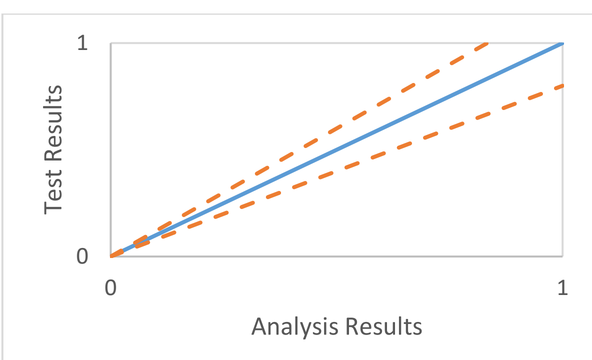
- Identification of which tests will be used for model validation. At a minimum, the static end compression test results (strains and deflections/displacements) shall be included in the model validation activity.
- Identification of which measurement device (strain gauges, displacement sensors, load cells, etc.) output will be used for model validation (if not all). It is recommended that strain gauge measurements that indicate stresses greater than or equal to 25 percent of the allowable be considered in the validation activity. The Manufacturer shall provide an explanation of the rationale for excluding any measurements from the validation activity.
- Identification of the version of the model used to perform the validation activities.
- Appropriate tabulations or other graphical depictions of the comparisons of the model and test results for each of the relevant load cases and for each of the relevant measurement devices and documentation of the relative differences between the two results.
- Explanation of reason(s) for instances in which model results do not correlate with the measured value using the prescribed criteria.

For the purposes of the validation report, the following maximum correlation criteria shall be applied. More restrictive values can be used if agreed to by the Purchaser and Manufacturer:

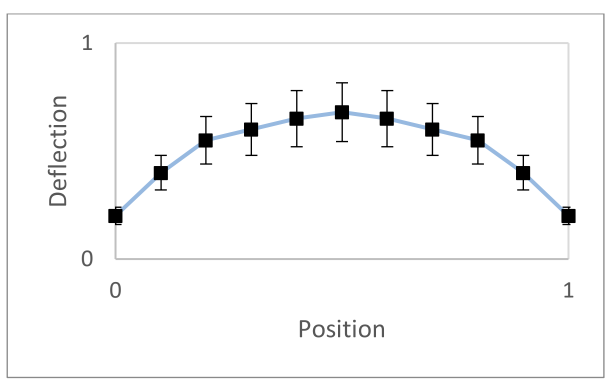
- Model-predicted values of strains/stresses shall be within ±20 percent of the measured values at the relevant locations.
- Model-predicted values of deflections/displacements shall be within ±10 percent of the measured values at the relevant locations.
- Model-predicted load reactions shall be within 5 percent of the measured values at the relevant locations.

Correlation between measured and predicted values shall be presented in a form similar to that shown in **Figure 8**, in which the dashed curves or the error bars represent the correlation tolerance and the solid curves represent the test result. Data for the model-predicted values are added to these plots. Quantities represented by the horizontal and vertical axes are selected based on the relevant load case. Depending on the quantities compared, alternate representations are allowed based on agreement between the Purchaser and the Manufacturer.

FIGURE 8
Format for Correlations Between Measured and Predicted Values



Typical depiction of comparison between test and analysis results for stresses or strains.



Typical depiction of comparison between test and analysis results for deflections/displacements.

In the event that validation cannot be achieved within the correlation tolerances, and model refinement or revision is required for any reason to improve correlation, results for all load cases must be reproduced using the revised model unless the Manufacturer can provide a documented, compelling case describing why this is not necessary.

5. Tests

5.1 General

Testing of the carbody structure, as required by Section 2, shall be performed in accordance with the requirements of this section. When a complete carbody structure is used for testing, the carbody shall be structurally complete, but excluding 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 car from view. Flooring shall be included in the tests if it is part of the load-carrying structure. All components included in the tests shall be included in the analysis of the test load cases. Underfloor apparatus may be installed, or equivalent weights distributed at their respective locations.

When a separate end frame section is used for testing, the test element shall simulate to the maximum extent possible the location, the degree of fixity, and the magnitude and direction of reactions of the supporting carbody structure.

The test carbody shall be completely inspected and any nonconformances corrected and documented prior to testing. The carbody shall be weighed, and the weight recorded prior to installation of any test equipment.

All gauges and instruments used as part of the test shall be in current calibration and remain so for the duration of the test. The methods of calibration and time periods for recalibration shall be in accordance with a certified standard.

For any design for a carbody that is based on a qualified vehicle, the Manufacturer may provide data from previous tests to satisfy the corresponding portion of these requirements, as approved by the Purchaser. The differences between the qualified vehicle and the new design and the effect of those changes on the carbody structure shall be defined by the Manufacturer.

5.1.1 Test procedure

A test procedure shall be developed prior to conducting any test. The test procedure should include, but should not necessarily be limited to, drawings, sketches, tables, and other descriptions that provide the following:

a) The purpose of the test.
b) A description of the load application equipment and test fixture.
c) The location and type of each load applicator and point of fixation (boundary conditions).
d) A table showing the load applied at each load applicator for each test increment.
e) A table showing the parameters that should be recorded for each test increment.
f) A table showing the pass/fail criteria for each test.
g) The location of each load, strain and deflection-measuring device.
h) Requirements for monitoring stress (or strain) output during the test.
i) A list of conditions under which the test will be terminated, including maximum allowable strains or displacements.

The following items shall be agreed upon by the Purchaser and Manufacturer and listed in the test procedure:

a) Loading the carbody prior to the witness test.

5.1.2 Test report

The Manufacturer shall develop a test report that describes test results and presents supporting data as agreed to by the Purchaser and Manufacturer. Test report shall contain the following, as a minimum:

a) Tables showing stresses and deflections.
b) Description and explanation of any value that exceeded the test criteria.
c) Appendixes containing all data, i.e., output from each gauge for each load step. These data shall be clearly identified and include the date that they were recorded.
d) Stress (or strain) vs. load curves for any gauges that reach more than 80 percent of the allowable stress (or strain) at the maximum load. If no gauges reach this value, then the 10 greatest tension stress locations and the 10 greatest compressive stress locations shall be provided for each test series.
e) A table showing each applied load and reaction load.
f) If the carbody is loaded prior to the witness test, it shall be noted in the test report.

5.2 Compression load tests

5.2.1 Test description

The ability of the carbody structure to resist the compression loads specified in Section 2.1 shall be tested. During the compression test, the carbody shall be supported on trucks, or a simulation thereof, to allow longitudinal movement. For multi-section articulated units, each unique carbody section shall be tested separately. Reactions shall simulate the attachment of the articulation joints. If both ends of the tested section have articulation joints, then both the applied load and reaction configuration shall simulate the attachment of the articulation joints.

The carbody shall be loaded with sufficient dead weight to bring the total body weight up to that of an empty, ready-to-run vehicle. This loading shall be distributed in proportion to the distribution of weight in the finished vehicle.

The coupler compression load shall be applied to the rear buff stop for equipment with conventional couplers or to the coupler support for equipment with pushback couplers, centered along the line of draft. The end sill compression load shall be applied to the end beam or anti-climber using cushioning means to ensure uniform bearing. The test loads shall be applied horizontally along the car's longitudinal centerline; no allowance shall be made for the camber of the carbody. The test loads shall be applied by means of a controlled hydraulic ram and the force measured by a means independent of those producing the force. The ram may be supported at the car end but shall remain free to rotate at its contact with the car end.

The test load shall be applied in increments of 25, 50, 75, 87.5 and 100 percent of full load. After each load increment is applied, the load shall be reduced to not more than 2 percent of full load. Strain, deflection and load readings shall be taken at each load increment and at each relaxation of load.

5.2.2 Test criteria

The carbody shall comply with the compression test requirements if all of the following criteria are met:

a) There shall be no visual permanent deformation, fractures, cracks or separations in the vehicle structure. Broken welds shall be inspected to determine if the failure is the result of inadequate weld quality or overstress.

b) The maximum stresses calculated from the strain reading in any structural element do not exceed the corresponding allowable stresses as specified in Section 2.1.
c) Indicated residual strains at strain gauges on principal structural elements following removal of the maximum load do not exceed 5 percent 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).
d) Test results agree with the structural analysis results within the acceptance criteria specified in Section 4.5. If the structural analysis results do not agree with the test results within the acceptance criteria, then the analysis shall be revised until agreement of the results is within the acceptance criteria.

It is recommended that highly localized yielding or elastic buckling that does not otherwise compromise the ability of the affected structure to meet the requirements of this standard and of the corresponding contract technical requirements be permitted on a case-by-case basis as agreed by the Manufacturer and Purchaser.

5.3 Collision post and corner post tests

5.3.1 Elastic test description

The ability of the collision post, corner post and associated supporting structures to resist the elastic portion of the design loads as listed in **Table 1** shall be tested.

TABLE 1
Elastic Design Loads

Test Article	Section Reference	Load Direction and Sense
Cab-end collision posts	2.3.1.3.1	Longitudinal inward[1]
Alternative requirements for cab-end collision posts	2.3.1.3.2	Longitudinal inward[1] (where feasible)
Non-cab-end collision posts; collision posts, coach cars	2.3.1.4	Longitudinal inward[1]
Collision posts, permanently and semi-permanently coupled articulated cars	2.3.1.5	Longitudinal inward[1] (depending on vehicle configuration)
Cab-end corner posts	2.3.2.3.1	Worse case of longitudinal and lateral inward
Cab-end, non-operator side corner posts, alternate requirements	2.3.2.3.3	Worse case of longitudinal and lateral inward for each post
Non-cab-end corner posts; corner posts, coach cars	2.3.2.3.4	Worse case of longitudinal and lateral inward
Coach car corner posts	2.3.2.4	Longitudinal inward[1]

1. Test load 15 deg. from longitudinal is permitted as an alternate if agreed to between Purchaser and Manufacturer.

The test loads shall be applied to a structurally complete carbody, or as an alternative, a separate end frame section may be constructed and tested.

The force of the testing machine shall be measured by a load cell or equivalent device independent of the equipment producing the applied force. Cushioning means shall be provided to ensure uniform bearing. The means of cushioning should not be attached to the post. For testing collision posts, the load application area should not exceed a height of 6 in. (152 mm) by the width of the post, up to a maximum of 36 in. (914 mm). For testing corner posts, the load application area should not exceed 10 in. (254 mm) by 10 in. (254 mm).

The test load shall be applied in increments of 50, 75 and 100 percent of full load. The load shall be reduced to not more than 2 percent of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. The ram shall be supported at the car end but shall remain free to move longitudinally with respect to the car end.

5.3.2 Elastic test criteria

The collision and corner posts shall comply with the elastic test requirements if all of the following criteria are met:

a) There shall be no visual permanent deformation, fractures, cracks or separations in the vehicle structure. Broken welds shall be inspected to determine if the failure is the result of inadequate weld quality or overstress.
b) The maximum stresses calculated from the strain reading in any structural element do not exceed the corresponding allowable stresses as specified in Section 2.3.
c) Indicated residual strains at strain gauges on principal structural elements following removal of the maximum load do not exceed 5 percent 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).
d) Test results agree with the structural analysis results within the acceptance criteria specified in Section 4.5. If the structural analysis results do not agree with the test results within the acceptance criteria, then the analysis shall be revised until agreement of the results is within the acceptance criteria.

It is recommended that highly localized yielding or elastic buckling that does not otherwise compromise the ability of the affected structure to meet the requirements of this standard and of the corresponding contract technical requirements be permitted on a case-by-case basis as agreed by the Manufacturer and Purchaser.

5.3.3 Elastic–plastic test description

The ability of the collision post and associated supporting structures to resist the elastic/plastic design loads specified in Section 2.3 shall be tested.

The placement of the applied load shall be 30 in. in height from top of the underframe in longitudinal direction of the carbody.

It is recommended that the test loads be applied to a special test article consisting of an end frame and sufficient carbody structure to provide a representative support condition. The test article shall be supported in such a fashion as to allow the load path to be fully developed, as would occur in a complete car with the load reacted at the opposite end of the car.

The force of the testing machine shall be measured by a load cell or equivalent device independent of the equipment producing the applied force. Cushioning means shall be provided to ensure uniform bearing. The means of cushioning should not be attached to the post. For testing collision posts, the load application area should not exceed a height of 6 in. (152 mm) by the width of the post, up to a maximum of 36 in. (914 mm). For testing corner posts, the load application area should not exceed 10 in. (254 mm) by 10 in. (254 mm).

The initial load, within the elastic limit of the post, shall be applied in increments of the same magnitude as described in Section 5.3.1 for elastic tests. The load shall be reduced to not more than 2 percent of full load after each step. Strain gauge and deflection readings shall be taken at each load increment and at each relaxation of load. This portion of the elastic–plastic test may be used to satisfy the requirements of Section 5.3.1. After the full elastic limit load has been attained, additional load shall be applied until the energy absorption requirement is met. All load cells, strain gauges and deflection gauges shall be recorded continuously.

The ultimate load carrying capacity of the post shall be defined as the condition where the post cannot support an increased load or the center of the post has deflected more than its full depth. This deflection shall be measured at the point of greatest deflection experienced on the post with reference to a nonmoving datum on the test article.

5.3.4 Elastic–plastic test criteria

The collision and corner posts shall comply with the elastic–plastic test requirements if the connections between the posts and the supporting structural members are not completely separated and the post deflection into the cab or passenger compartment is not in excess of 10 in. (254 mm) prior to meeting the minimum energy absorption requirements of Section 2.3.

5.4 Other structural testing

Other structural tests to be carried out shall be agreed upon between the Purchaser and Manufacturer. These could include the following:

a) Vertical load test in accordance with Section 3.1.
b) Torsion (diagonal jacking) test in accordance with Section 3.3.
c) Fatigue test of connection components including spot welds.
d) Testing of non-service-proven arrangements and connections.

Related APTA standards

APTA-PR-CS-S-004-98, "Austenitic Stainless Steel for Railroad Passenger Equipment"
APTA-PR-CS-S-006-98, "Attachment Strength of Interior Fittings for Passenger Railroad Equipment"
APTA-PR-CS-S-011-99, "Cab Crew Seating Design and Performance"
APTA-PR-CS-S-015-99, "Aluminum and Aluminum Alloys for Passenger Equipment Carbody Construction"
APTA-PR-CS-S-016-99 Rev. 2, "Row-to-Row Seating in Commuter Railcars"
APTA-PR-CS-RP-019-12, "Pushback Couplers in Passenger Rail Equipment"
APTA-PR-M-RP-003-98, "Purchase and Acceptance of Type H Tightlock Couplers"
APTA-PR-M-S-016-06, "Safety Appliances for Rail Passenger Cars"
APTA-PR-PS-S-002-98, Rev. 3, "Emergency Signage for Egress/Access of Passenger Rail Equipment"

References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision the revision shall apply.

49 CFR, Part 238, Passenger Equipment Safety Standards, Subpart C, Specific Requirement for Tier I Passenger Equipment

Association of American Railroads standards:
- AAR S-034, Specification for the Construction of New Passenger Equipment Cars (obsolete, available from APTA)
- AAR S-580, Locomotive Crashworthiness Requirements

ASTM International standards:
- ASTM A6, Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling
- ASTM A568, Standard Specification for Steel, Sheet, Carbon and High-Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, General Requirements for
- ASTM A572, Standard Specification for High-Strength Low-Alloy Columbium-Vanadium Structural Steel
- ASTM A588, Standard Specification for High-Strength Low-Alloy Structural Steel, up to 50 ksi [345 MPa] Minimum Yield Point, with Atmospheric Corrosion Resistance
- ASTM A606, Standard Specification for Steel, Sheet and Strip, High Strength, Low-Alloy, Hot-Rolled and Cold-Rolled, with Improved Atmospheric Corrosion Resistance
- ASTM A710, Standard Specification for Precipitation–Strengthened Low-Carbon Nickel-Copper-Chromium-Molybdenum-Columbium Alloy Structural Steel Plates
- ASTM A749, Standard Specification for Steel, Strip, Carbon and High-Strength, Low-Alloy, Hot-Rolled, General Requirements for
- ASTM A1011, Standard Specification for Steel, Sheet and Strip, Hot-Rolled, Carbon, Structural, High-Strength Low-Alloy, High-Strength Low-Alloy with Improved Formability, and Ultra-High Strength
- ASTM A1066, Standard Specification for High-Strength Low-Alloy Structural Steel Plate Produced by Thermo-Mechanical Controlled Process (TMCP)

American Welding Society standards:
- AWS D1.1, Structural Welding Code, Steel
- AWS D1.2, Structural Welding Code, Aluminum
- AWS D1.3, Structural Welding Code, Sheet Steel
- AWS D1.6, Structural Welding Code, Stainless Steel
- AWS D15.1, Railroad Welding Specification – Cars and Locomotives

SAE International standards:

SAE J429, Mechanical and Material Requirements for Externally Threaded Fasteners
SAE J995, Mechanical and Material Requirements for Steel Nuts

Definitions

articulated: An arrangement of rail rolling stock where adjacent units share a common truck at their interface.

belt rail: A continuous or effectively continuous longitudinal framing member or longeron in the side frame at approximately mid-height. In side frames with normal passenger side window openings, the belt rail is typically immediately below the windows, where it also serves as part of the framing for the window openings.

body corner posts: Cab cars and MU locomotives using low-level passenger boarding on the non-operating side of the cab may have two full-height corner posts on that side, one post located ahead of the stepwell (the "corner post") and one located behind it (the "body corner post").

carline: Transverse, structural, roof framing member used to support the roof sheets.

flat-end MU car/cab car: A vehicle with an end similar to that of a typical coach, such that the corner and collision posts are essentially vertical for their full height and in the same transverse plane, except as required for curving clearance.

load factor: Load factor is defined as a number by which the actual or specified load is multiplied in computing the design load. The load factor shall include all applicable safety factors.

margin of safety: The margin of safety (MS) is defined as follows:

$$MS = [(Allowable\ Stress)/(Applied\ Stress)] - 1$$

The calculated stress shall include the applicable load factors. The allowable stress may be the ultimate stress, yield stress, critical stability stress, or fatigue stress.

MU car: An electric multiple unit (EMU), with or without traction motors, or a diesel multiple unit (DMU). See also definition for MU Locomotive in 49 CFR 238.5.

passenger car: Refer to definition provided in 49 CFR 238.5.

passenger equipment: Refer to definition provided in 49 CFR 238.5.

non-passenger-carrying locomotive: A locomotive not intended to provide transportation for a member of the general public but used to power a passenger train.

permanent deformation: A member shall be permanently deformed if:

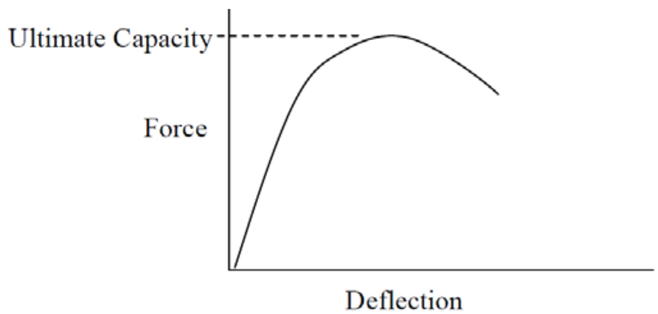
1. the material supplier's guaranteed minimum yield strength, or other minimum yield strength agreed to by the Purchaser and Manufacturer, has been reached or exceeded (for material for which the supplier only publishes a yield strength, the supplier's guaranteed minimum shall be used); or
2. the material has deformed and will not return to its original shape after the load is released.

roof access hatch: Built-in access opening of suitable size, covered by a hatch, which is mechanically locked or latched into place in a watertight manner.

roof soft spot: Designed and identified area of the roof where heavy structure does not impede the cutting-out of access holes of suitable size with tools that are routinely carried on fire department emergency response vehicles.

side sill: The outside longitudinal member of the underframe.

ultimate capacity: maximum peak force resisted by the structural member as illustrated in the figure below.



Abbreviations and acronyms

AAR	Association of American Railroads
AISC	American Institute of Steel Construction
ASTM	ASTM International (formerly the American Society for Testing and Materials)
A-T	anti-telescoping (plate)
AWS	American Welding Society
AW0	empty car, ready to run weight
CEM	crash energy management
CFR	Code of Federal Regulations
CG	center of gravity
CGHAZ	coarse grain heat-affected zone
CWB	Canadian Welding Bureau
DMU	diesel multiple unit
EMU	electric multiple unit
FEA	finite element analysis
FRA	Federal Railroad Administration
FRP	fiber reinforced polymer
ft-lb	foot pound-force
HSLA	high-strength low-alloy steel (low alloy high tensile)
J	joules
kN	kilonewton
ksi	kilopound force per square inch
LAHT	low alloy high tensile (high-strength low-alloy steel)
lbf	pound-force
MJ	megajoule
MS	margin of safety
MU	multiple unit
MPa	megapascal
NATSA	North American Transportation Services Association

PA public address
psi pound-force per square inch
RMS Railway Mail Service specification

Summary of document changes

- Document formatted to the new APTA standard format.
- Sections have been moved and renumbered to accommodate the new format.
- Scope and summary moved to the front page.
- Definitions, abbreviations and acronyms moved to the rear of the document.
- Two new sections added: “Summary of document changes” and “Document history.”
- Some global changes to section headings and numberings resulted when sections dealing with references and acronyms were moved to the end of the document, along with other cosmetic changes, such as capitalization, punctuation, spelling, grammar and general flow of text.
- Scope and purpose section was revised to address removal of CEM related requirements from this standard.
- CEM related requirements have been removed from this standard and it will be published in the in-progress APTA PR-CS-S-035. Requirements for passenger equipment with pushback couplers have been retained in this standard.
- Non-passenger carrying locomotive requirements were retained throughout the document based on working group recommendations.
- Several sections were added to clarify and elaborate on alternative requirements per 49 CFR 238 Appendix F.
- Section 1.2 was revised to add additional materials that are frequently used in the manufacture of passenger equipment.
- Section 2.1.2 requirements for passenger equipment with pushback couplers were modified to harmonize changes to APTA PR-CS-RP-019 and also remove inconsistency with 49 CFR 238.203.
- Section 2.1.3 was modified to provide clarity in terms of types of analysis required as well as potential allowance for highly localized yielding or elastic buckling.
- Section 2.2.2.2.1 Clarified that analysis is sufficient to demonstrate rollover strength.
- Section 2.2.2.2.2 Updated requirements to apply to a wider range of carbody constructions, including multi-level vehicles.
- Section 2.3 Clarified that all connections of collision posts and corner posts to the carbody supporting structure must be designed to resist failure during plastic bending of the post.
- Section 2.3.1.2.1 Removed vertical downward loading requirement for non-passenger carrying locomotive collision post connections because the working group does not believe that this requirement leads to improved connection strength for the collision posts.
- Section 2.3.1.3.1 Made several clarifications in terms of load application points as well as added specificity towards energy absorption portions.
- Section 2.3.1.3.2 Added alternative requirements per 49 CFR 238 Appendix F. The quasi-static elastic-plastic testing of the front-end structure is mandatory.
- Section 2.3.1.5 Added reference to applicable CFR requirement.
- Section 2.3.2.3.1 Made several clarifications to load application points, distribution of load, and the use of AWS and CWB as appropriate welding codes.
- Section 2.3.2.3.3 Made elastic testing mandatory for the requirements at 18 inches only which is consistent with section 2.3.2.3.1.
- Section 2.3.3 Clarified that analysis is sufficient to demonstrate the strength requirements for the structural shelf. Testing is optional.
- Section 2.3.4 Updated text for clarification. Added prohibition against using an FRP mask alone to meet the fluid entry inhibition requirement.
- Section 2.4.2 Clarified that the weight of the trucks is included in the rollover load case.

- Section 2.4.3 Changed the concentrated loads to distributed loads over a 5”x5” area.
- Section 2.5.1 Removed requirement to apply climb, bypass, and overturn loads in combination with “high compression” loads.
- Section 2.5.2.1 Added articulation joints as an acceptable means of climb resistance. Added anti-climbing requirements for vehicles with push-back couplers.
- Section 2.6.1 Clarified that structural analysis is sufficient to demonstrate compliance with the truck-to-carbody attachment requirements. Clarified that 250,000 lbf. force is applied at the height of the truck’s center of gravity.
- Section 2.8 Added climb, bypass, and overturn loads to the list of emergency load cases.
- Section 3.0 New section added for design loads and practices. Requirements include: Carbody Vertical Load, Carbody Fatigue Analysis, Carbody Torsional Loads, and Roof Emergency Access.
- Section 4.5 Added requirements for validating finite element models using test results.
- Section 5.1.1 Added test procedure section.
- Section 5.1.2 Added test report section.
- Section 5.2.1 Added requirements for end compression testing of articulated units. Updated load application and measurement requirements for compression tests.
- Section 5.2.2 Added requirements for correlation between test and analysis results.
- Section 5.3.1 Updated load distribution (cushioning) device requirements. Added test load increment requirements.
- Section 5.3.3. Clarified load application location and direction. Added requirements for using end frame assemblies for testing.

Document history

Document Version	Working Group Vote	Public Comment/ Technical Oversight	Rail CEO Approval	Policy & Planning Approval	Publish Date
First published	—	—	—	Oct, 14, 1999	Jan, 11, 2000
First revision	—	—	—	May 22, 2003	Sept, 28, 2003
Second revision	—	—	—	April 10, 2006	June 15, 2006
Third revision	August 15, 2019	Dec. 3, 2019	May 18, 2020	June 12, 2020	June 18, 2020

Appendix A (informative)

A.1 Purpose

This annex traces the history behind some of the structural design requirements contained in the body of APTA PR-CS-S-034-99.

A.2 APTA structural design and construction requirements

APTA PR-CS-S-034-99 is largely based on AAR Standard S-034. A calamitous train wreck in Tortuga, California, in 1938 was the specific reason for the preparation and issuance of AAR S-034 in 1939, based on the Railway Mail Service Specification then in effect. One of the horrific results of the wreck was the telescoping of a car of lightweight design by the heavyweight car to which it was coupled, resulting in heavy casualties in the lightweight car. From descriptions of the analysis of the wreck, it is clear that it was thought that the telescoping was much the worse because of inadequate resistance to climbing forces at the coupled interface between the lightweight and heavyweight cars (inadequate anticlimbing provisions), and because of inadequate provisions for attachment of the trucks to the carbody (see discussion in Section A.2.6).

AAR S-034 was the standard for passenger car design for many decades and, although discontinued by the AAR in 1989, still serves as a reference source for passenger car design now and probably well into the future. APTA PR-CS-S-034-99, when initially published in January 2000, was based upon the then-obsolete AAR S-034 and on similar FRA requirements introduced in April 1959 in 49 CFR 229.141. The intent of the Construction and Structural Subgroup of the APTA PRESS Task Force in initially preparing this standard was to document and improve upon the then-current practice. The requirements of this standard in many areas exceeded those of AAR S-034 and 49 CFR 229.

AAR S-034 was an industry consensus standard and contained emergency load requirements, as well as normal load requirements and other requirements intended to standardize designs to facilitate interchange of equipment among member railroads. Although the initial release of APTA PR-CS-S-034-99 contained primarily emergency load requirements, it was expected that over time the standard would be expanded to fill a similar role as AAR S-034, covering normal load requirements and standardization issues in addition to crashworthiness requirements.

Subsequent revisions of APTA-PR-CS-S-034-99 included requirements for carbody designs using crash energy management (CEM) and structural requirements for non-passenger-carrying locomotives. The CEM requirements were removed from the latest revision of this standard because they will be included in the future standard APTA PR-CS-S-035, currently under development by the Construction and Structural committee. Requirements for passenger equipment with pushback couplers have been retained in this standard.

The following sections provide historical details regarding the specific design loads in this standard.

A.2.1 Anti-climbing

To respond to the inadequacies in climbing resistance observed in the 1938 Tortuga wreck, requirements for an “anticlimbing arrangement” were included in AAR S-034. The AAR standard (a recommended practice when first issued) permitted the use of standard tightlock couplers to meet the requirement. Other requirements imparted a yield strength of 100,000 lbf (445 kN) under the action of vertical forces transmitted between coupled units. The typical design solution has been tightlock couplers that remain locked together even when subjected to vertical forces or displacements, built into the end of the car in a manner that permits vertical forces (up and down) as high as 100,000 lbf (445 kN) to be transmitted from car to car via the coupler without yield of any structure. The AAR requirement was stated in general terms—it was a performance requirement—and other design solutions are certainly possible in response to a requirement for an “anti-climbing arrangement." But the use of a tightlock coupler built in to the end of the car to transmit the required vertical forces has been the nearly universal solution for cars, including MU and cab cars.

Because of the genesis of the AAR anticlimbing requirement for cars, the telescoping in the 1938 Tortuga wreck, it is clear that for cars, the intent and meaning of anticlimbing has been resistance to override (and then telescoping) between coupled units. For car designers, manufacturers and operators, that understanding continues to this day and is the basis for the requirement in this APTA standard.

When first issued, FRA anticlimbing requirements at 49 CFR 238.205(b) were based on the locomotive concept of a separate shelf-like device on the end of the unit above the coupler. The industry responded with designs that employed the traditional solution for cars of a tightlock coupler built into the end of the car with a buffer beam above and coupler carrier below with strength increased to 200,000 lbf (890 kN) at ultimate instead of 100,000 lbf (445 kN) at yield. The FRA persisted in requiring a locomotive style anti-climber. However, the industry was not able to develop a design solution for that style of anti-climber for a MU or cab car that was compatible with a cab design having a trainline door, threshold, and walkover plate, to preserve the option of operating the cab car in consist. FRA solved the problem for the industry by its letter of Nov. 27, 2001, excepting cab and MU cars from the anti-climbing requirements of 49 CFR 238.205(b), and allowing the traditional solution of using tightlock couplers to provide climb resistance. This change was later incorporated into 49 CFR 238.205(a) and (b) in January 2010 and is reflected in this standard.

This APTA standard considers not only vertical (override) forces, but also lateral (bypassing) and torsional (overturning) loads that might be developed between units in collisions and derailments. This standard clarifies that the strength of the coupler carrier and buffer beam constructions are an integral part of the anticlimbing arrangement in cases where a drawbar or a standard APTA (AAR) tightlock coupler or equivalent is used.

A.2.2 End-frame anti-telescoping structure

Regarding carbody end frame anti-telescoping structure, this standard was originally based on the requirements in AAR S-034 and 49 CFR 229.141 for "main vertical members" in the end frame, updated to include the higher strength levels of design practice at the time this standard was originally issued, requirements for compatible strength of the post supporting structure and intervening connections, and other aspects of that earlier design practice. These requirements have been updated in the latest revision of this standard to ensure conformance with the current minimum requirements from FRA in 49 CFR 238. The requirements provided by FRA are in some cases exceeded by this standard.

A.2.3 Corner posts

This APTA standard contains specific requirements for corner posts that were not originally included in AAR S-034 or in 49 CFR 229. Passenger cars have for many decades included substantial structural posts at the body corners, the extreme corners if an end-vestibule design, or both. Designs often met the minimum section modulus requirements of AAR S-034 for end-frame "main vertical members" by distributing some of the required section properties to corner posts ("traditional" design practice).

The initial release of this standard included corner post requirements for non-passenger-carrying locomotives because there had never been a regulation or traditional industry practice that mandated or specified the use of corner posts for non-passenger-carrying locomotives. However, similar requirements for corner posts on non-passenger-carrying locomotives have since been incorporated into AAR S-580 and 49 CFR 229, so they have been removed from the latest revision of this standard.

The corner post requirements in this APTA standard are based on traditional design practice, updated to include the best of design practice at the time of initial release of this standard, and input from the

Construction and Structural Subgroup and APTA PRESS Task Force members in response to the FRA request for higher-strength corner posts. Although most purchase specifications for commuter cars during the period just prior to the initial release of this standard included requirements for corner posts that greatly surpassed earlier design practice, higher corner post strength requirements for non-passenger-carrying locomotives and cab ends of MU cars and cab cars were priority items for the FRA during the preparation of the initial release of this standard, and so they have been addressed in considerable detail. In Section 2.3.2.3.1 of this standard, requirements for corner posts that are applicable for the cab end of MU cars and cab cars are outlined. These requirements are significantly higher than had been applied to car design prior to the initial release of this standard.

In cases where the new, more stringent requirements of Section 2.3.2.3.1 cannot be achieved on cars that use low-level boarding, optional requirements that are compatible with a low-platform stepwell but that still represent a significant increase in corner post design load requirements are outlined in Section 2.3.2.3.3.

It is recommended that cab-end, non-cab-side corner posts be designed to meet the requirements of Section 2.3.2.3.1 when possible. Implementation of the alternative requirements of Section 2.3.2.3.3 shall be subject to an evaluation performed by the Manufacturer and approved by the Purchaser that demonstrates that the requirements of Section 2.3.2.3.1 are not practical, given the other requirements for the design. This approach is consistent with the latest requirements from FRA in 49 CFR 238.213(c).

A.2.4 Cab-end collision posts and corner posts

Revision 1 of this standard included a recommended practice for severe deformation of posts that required cab-end posts to be designed such that the post would reach its ultimate capacity before the top and bottom connections would fail. Further analysis and testing was required to quantify severe deformation requirements that could be included in an APTA standard. Analysis and testing that has since been conducted by FRA/Volpe and the industry has led to Revision 2 of this standard, which required cab-end collision and corner posts to be designed to absorb a specified amount of energy and to limit the amount of permanent deformation of the posts into the operator’s cab or passenger seating area. The standard also defines appropriate pass/fail criteria in an attempt to avoid potential conflicts when trying to demonstrate compliance. These requirements have been carried over to the latest revision of this standard.

Before specifying in the standard an amount of energy that the posts would have to absorb, the industry determined that testing of actual APTA-compliant cab car end frames was needed. The results of these actual quasi-static tests would be used as the basis for the requirements of the standard rather than relying only on the results of finite element modeling. Bombardier Transportation agreed to conduct quasi-static testing of the LIRR M7 cab-end collision post and corner post. The results of these tests indicated that posts could be designed to resist the static loading conditions in this standard and still absorb a significant amount of energy when overloaded. The requirements for the severe deformation of cab-end collision posts and corner posts specified in the standard are based on the results of the M7 tests.

While it was recognized that all the research and testing of cab-end collision posts and corner posts were done for “flat-end” cab cars, this standard also allows the use of the dynamic performance requirements presented in Appendix F to 49 CFR 238 for car designs that are not flat-ended.

A.2.5 End-compression strength

This standard follows the North American precedent for carbody structure to have a minimum of 800,000 lbf (3559 kN) of end-compression strength on the line of draft. However, this standard reinstates a previous practice of permitting a sharing of end-compression strength between the line of draft and the underframe in cases where a pushback coupler, compatible with the intended use of the equipment, is selected for use.

A.2.6 Truck attachment

Truck attachment strength requirements in this standard were also initially based on corresponding requirements in AAR S-034 and 49 CFR 229, but applied these requirements to all passenger equipment. FRA has since added truck-to-carbody attachment requirements to 49 CFR 238.219, but this APTA standard continues to include requirements exceeding those of FRA.

The truck attachment requirements in this APTA standard can be traced back to the same 1938 train wreck in Tortuga, California, that spawned the anti-climbing requirements discussed in Section A.2. Regarding the telescoping discussed in Section A.2, from descriptions of the analysis of the wreck, it is clear that it was thought that the telescoping was much the worse because the truck (or trucks) on the heavyweight car were left behind on the ground due to inadequate attachment to the carbody. This means the additional weight of the trucks was not available to counter a tendency for the car to rise up. Therefore, AAR S-034, when issued, required the trucks to be “locked” to the carbody. This APTA standard includes this requirement, defining “locked” to mean attached with a factor of safety of 2 based on yield of the attaching elements and the weight of the complete truck. In the vertical direction, then, the requirement is related to the weight of the truck, and also addresses safety during maintenance and rerailing operations where the trucks are raised with the car.

There is another potential benefit of the trucks remaining attached to the carbody in an incident like the 1938 Tortuga wreck. Assuming that overriding in such incidents is probably inevitable and that, for whatever reason, the heavyweight overrides the lightweight car (which is what happened in the example wreck), the superstructure of the lightweight car would offer little resistance to telescoping by the battering-ram underframe and superstructure of the heavyweight car. Regardless, then, telescoping to some extent was probably also inevitable during the Tortuga wreck, but if the truck had remained attached with high horizontal strength, once the heavyweight truck struck the end of the underframe of the lightweight car, further telescoping would have been possible only after the attachment strength in the horizontal plane had been overcome. Therefore, a requirement for the truck-to-carbody attachment to have a strength in the horizontal plane (a “shear value”) of 250,000 lbf (1112 kN) was featured as a specific improvement of the AAR standard when issued compared with the RMS on which it was based. This APTA standard includes this requirement along with additional details regarding the conditions under which the requirement must be met. Unlike some international standards that relate truck attachment strength to truck weight, this standard follows the North American concept of setting the horizontal strength of the attachment at the relatively high value of 250,000 lbf (1112 kN) for the purpose of making the truck available as a battering ram for a last-ditch defense against telescoping.

This standard incorporates the practice at the time of its initial release of permitting the vertical and horizontal strength requirements to be considered as separate load cases. This is consistent with the North American concept of retaining the trucks with the car under all conditions except intentional removal, and then taking advantage of there being a semi-permanent appendage of the carbody by also imparting high horizontal strength to the means of retention. The vertical load case is for the purpose of “locking” (as in AAR S-034) the trucks to the carbody, so the benefits of the truck weight and the attachment horizontal shear value are available in collisions and derailments, and for safety while lifting the equipment with the trucks attached for maintenance and rerailing operations. As required by this APTA standard, however, the horizontal load case will have internal forces and moments, including vertical forces, that must be accounted for by the design of the carbody, truck and attaching structural elements.

A.2.7 Side impact

Robert Ebenbach, a railcar structural engineer who started with the Budd Company in the early 1930s, was, later in his career, involved in the repair of railcars damaged by collision, fire, derailment and other accidental damage. There were several cases of sideswiping of stainless steel MU cars in the New York region where the damage to the body structure seemed to him to be extraordinarily severe, even for relatively minor incidents.

He noticed that gussets connecting floor beams and cross-bearers to the side sill buckled in the area of the side sill damaged by the sideswiping. The gussets were, of course, intended to transfer the vertical load from the floor to the side sill and the side frame, and therefore were simple flat plates that were perfectly adequate for that purpose. However, without flanges on their edges, or other stabilizing features, they quickly buckled in a sideswiping incident. Ebenbach devised a static design load to be applied to the side sill to force the designer to stabilize the gussets, so they would not only be effective in transferring vertical load, but also in supporting the side sill in the transverse direction. Then, in a side swiping incident, the gussets would be able to transfer axial load into the floor transverse framing members, so the underframe would be at least partially effective in resisting transverse loads applied to the side sill as a plate-girder structure.

Ebenbach devised a similar design load for the belt rail (the major longitudinal member just below the passenger side windows) to address his observation of unnecessarily severe damage also at that location. In the designs prevalent in the New York region at that time, this was the widest point of the body, and so was almost always subject to damage in side-swiping incidents. The belt rail is intercostal to the side frame posts, and the design load was intended to force the designer to connect the intercostal belt rail sections across the posts so that the rail would act as a continuous member. This greatly increased the resistance of the body structure to side loads at the height of the belt rail.

At the earliest stages of its safety initiative, FRA asked the industry to consider designing rail vehicle structures to resist side impact loads. FRA suggested a scenario that was essentially a loaded highway semi-tractor-trailer driven at relatively high speed into the side of a train. In its deliberations on this subject, the APTA Construction and Structural Subgroup was not able to come to consensus on design requirements that would represent the FRA side-impact scenario. The transverse side sill and belt rail design load concepts devised by Ebenbach were proposed as an alternate, and consensus was achieved.

For the future, the APTA Construction and Structural Subgroup has committed to a more thorough investigation of the feasibility of designing rail vehicles for the FRA side-impact scenario.