11. APTA PR-CS-S-034-99, Rev. 2 Standard for the Design and Construction of Passenger Railroad Rolling Stock

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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.

Key Words: analysis, CEM, collision post, corner post, crash energy, strength, stress, structure test, severe deformation

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This Standard is a consolidation of existing standards and recommended practices for the design and construction of car body structure appearing in the APTA Manual of Standards and Recommended Practices for Rail Passenger Equipment, along with additional topics not previously covered. The American Public Transportation Association again expresses its appreciation for the efforts of the several individuals who drafted the existing standards and recommended practices on which this consolidation is based, and, in addition, to Gordon Campbell and Cliff Woodbury, who served as editor of the consolidation and drafter of the few requirements which appear for the first time in this *Standard for the Design and Construction of Passenger Railroad Rolling Stock.*

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APTA PR-CS-S-034-99 Rev. 2
Standard for the Design and Construction of Passenger Railroad Rolling Stock

1. Overview

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

The standard is based on the obsolete AAR Standard S-034, "Specifications for the Construction of New Passenger Equipment Cars," and on similar requirements of the FRA for "MU locomotives" introduced in April 1956 and currently appearing at 49 CFR 229.141 (a) (2) and (3). The intent of the Construction & Structural Subgroup of the APTA PRESS Task Force in preparing this standard was to document and improve upon current practice. The requirements of this standard in many areas exceed those of the obsolete AAR S-034 and 49 CFR 229.141.

AAR S-034 was the standard for passenger car design for many decades. It was first adopted by the AAR in 1939, 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. See informative Annex A for additional information tracing the history that motivated some of the requirements contained in this standard.

AAR S-034, as is this standard, was an industry consensus standard. AAR S-034 contained emergency load requirements, but also contained normal load requirements and other requirements intended to standardize designs to facilitate interchange of equipment among member railroads. It is expected that over time this APTA standard will be expanded to cover normal load requirements and standardization issues.

APTA is aware that the Federal Railroad Administration Rail Safety Advisory Committee (RSAC), in conjunction with AAR, is currently developing crashworthiness standards for locomotives. The results will be incorporated in a comprehensive update of AAR S-580. In order to not have two industry standards that address identical issues all requirements for non-passenger-carrying power cars and locomotives in this Standard shall sunset at such time that the final rule for the FRA Locomotive Crashworthiness becomes effective. The final rule is inclusive of the latest revision of AAR S-580 – Locomotive Crashworthiness Requirements. APTA will remove all requirements for conventional (non-passenger carrying) locomotive from this Standard at that time.

1.1 Scope

This standard shall apply, unless otherwise indicated, to new railroad passenger equipment of all types, including locomotive-hauled, MU, 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.

1.2 Purpose

The purpose of this document is to provide minimum structural standards to improve the crashworthiness of passenger rail vehicles.

2. 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 229, Body Structure, MU locomotives

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

AAR S-034, Specification for the Construction of New Passenger Equipment Cars (obsolete, available from APTA)

APTA PR-M-RP-003-98, Recommended Practice for Purchase and Acceptance of Type H Tightlock Couplers

APTA PR-M-RP-009-98, Recommended Practice for New Truck Design Process

APTA PR-CS-S-004-98, Standard for Austenitic Stainless Steel for Railroad Passenger Equipment

APTA PR-CS-S-006-98, Standard for Attachment Strength of Interior Fittings to Passenger Railroad Equipment

APTA PR-CS-S-011-99, Standard for Crew Cab Seating Design and Performance

APTA PR-CS-S-015-99, Standard for Aluminum and Aluminum Alloys for Passenger Equipment Car Body Construction

APTA PR-CS-RP-016-99, Standard for Row-to-Row Seating in Commuter Rail Cars

ASTM A 6, Standard Specification for General Requirements for Rolled Structural Steel Bars, Plates, Shapes, and Sheet Piling

ASTM A 563, Standard Specification for Carbon and Alloy Steel Nuts

ASTM A 568, Standard Specification for Steel, Sheet, Carbon and High-Strength, Low- Alloy, Hot Rolled and Cold-Rolled

ASTM A 588, Standard Specification for High-Strength Low-Alloy Structural Steel with 50 ksi [345 Mpa] Minimum Yield Point to 4-in [100 mm] Thick

ASTM A 606, Standard Specification for Steel, Sheet and Strip, High Strength, Low-Alloy, Hot Rolled and Cold Rolled, with Improved Atmospheric Corrosion Resistance

ASTM A 710, Standard Specification for Age-Hardening Low-Carbon Nickel Copper-Chromium-Molybdenum-Columbium Alloy Structural Steel Plates

AWS D 1.1, Structural Welding Code, Steel

AWS D1.2, Structural Welding Code, Aluminum

AWS D1.3, Structural Welding Code, Sheet Steel

AWS D15.1, Railroad Welding Specification – Cars and Locomotives

3. Definitions, abbreviations, and acronyms

3.1 Definitions

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

3.1.2 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.

3.1.3 flat-end MU car or cab car: A flat-end MU car or cab car is 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.

3.1.4 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.

3.1.5 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.

3.1.6 MU car: An MU car is an electric multiple unit (EMU), with or without traction motors, or a diesel multiple unit (DMU).

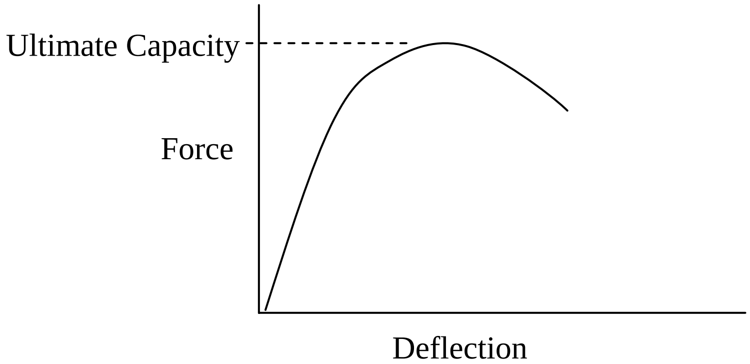
3.1.7 permanent deformation: A member shall be permanently deformed if:

1) The material supplier's guaranteed minimum yield strength, or other minimum yield strength agreed to by Purchaser and Car Builder, 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.

3.1.8 side sill: The outside longitudinal member of the underframe.

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



3.2 Abbreviations and acronyms

AAR	Association of American Railroads
ASTM	ASTM International (formerly the American Society for Testing and Materials)
A-T	anti-telescoping plate
AWS	American Welding Society
CEM	crash energy management
CFR	Code of Federal Regulations
FEA	finite element analysis
HSLA	high-strength low-alloy Steel *Syn:* low alloy high tensile
LAHT	low alloy high tensile *Syn:* high-strength low-alloy steel
MU	multiple unit

4. Materials

4.1 Austenitic stainless steel

Where austenitic stainless steel is required for structural use, it shall be in accordance with APTA SS-C&S-004.

4.2 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 A 588. Plate may alternatively conform to ASTM A 710.

General requirements for delivery of HSLA shapes, plates, and bars shall be as required by ASTM A 6.

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

Cold and hot rolled HSLA sheet and strip shall, as a minimum, conform to the requirements of ASTM A 606. General requirements for delivery of these products shall be as required by ASTM A 568.

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.

4.3 Aluminum

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

4.4 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.

5. Design loads

Unless otherwise stated, empty, ready-to-run condition shall be assumed for the load conditions defined in this part.

5.1 Static end-compression strength (49 CFR 238.203)

5.1.1 Car body structure designs without crash energy management (CEM) system

a) Car body 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 car body. Under this condition, there shall be no permanent deformation in the car body structure.

b) For all equipment except non-passenger-carrying locomotives, car body 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. Under this condition, there shall be no permanent deformation in the car body structure.

5.1.2 For car body structure designs with a CEM system:

a) If no shear-back coupler or drawbar is used, the requirement of Section 5.1.1 shall apply.

b) If a shear-back coupler or drawbar is used, the required strength on the line of draft may be reduced to not less than 125 percent of the maximum load developed by the coupler or drawbar during push back, including the operation of energy absorbing features if present in the coupler or drawbar.

c) Car body structure shall be designed to resist a minimum end-compression load of 800,000 lbs. (3560 kN) for vehicles equipped with shear-back couplers or drawbars with or without energy absorbing feature. The required load shall be applied over an area not exceeding 6 in (152 mm) high and a width not exceeding the distance between outboard webs of the collision posts, centered vertically and horizontally on the underframe end sill or buffer beam construction. Under this condition, there shall be no permanent deformation in the car body structure.

d) The static end-compression strength of unoccupied zones of the car body structure shall be compatible with the CEM design, but in no case less than 50% of the value required for occupied zones.

e) The end-compression strength of occupied zones of the car body structure shall be adequate to resist the loads applied during the operation of the CEM system as intended. Under this condition, there shall be no permanent deformation in occupied zones of the car body structure.

5.1.3 Acceptance criteria

a) The acceptance criterion for each design load case shall be as specified in Sections 5.1.1 and 5.1.2 above.

b) It is recommended that highly localized yielding or plastic 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 vehicle builder and purchaser.

5.2 Transverse strength requirements

5.2.1 General

The transverse strength requirements of this Section 5.2 shall apply to MU cars, cab cars, other cars, and cabs of non-passenger-carrying locomotives.

5.2.2 Side strength

5.2.2.1 Side structure framing and sheathing

5.2.2.1.1 Framing (49 CFR 238.217 a)

The sum of the section moduli in in^3 (mm^3) 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 in^3 (16.4mm^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 in^3 (mm^3) 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 in^3 (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 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.

5.2.2.1.2 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 1/8-inch (3 mm) nominal thickness. Other metals of a thickness in inverse proportion to their yield strengths may be used.

Outside metal sheathing of lesser thickness may be used if it is reinforced to produce at least an equivalent sectional area at right angles to the reinforcement as the flat sheathing specified above.

5.2.2.2 Side loads

5.2.2.2.1 Rollover (49 CFR 238.215)

Except for switcher-cab locomotives, car body 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 multi-level 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.

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 roll-over 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.

5.2.2.2.2 Side impact

Vehicle body structures shall be designed to resist an inward-directed load of 40,000 lbf (178 kN) applied to the side sill, and, except for non-passenger carrying locomotives, 7,000 lbf (31 kN) applied to the belt rail. These loads shall be applied separately over the full vertical dimension of the specified member for a distance of 8 ft. (2.4 m) in the direction of the length of the vehicle.

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 stress and the critical buckling stress, 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 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.

5.3 End frame

The strength requirements for the collision posts and the supporting structure are defined in Section 5.3.1 and for the corner posts and supporting structure in Section 5.3.2. These strength requirements are intended to assure that the top connection to the carbody 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), the effects of the A-T plate on the roof-post connection may be considered.

5.3.1 Collision posts

5.3.1.1 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.

5.3.1.2 Non-passenger-carrying locomotives

This section shall sunset at such time that the final rule for the FRA Locomotive Crashworthiness becomes effective. The final rule is inclusive of the latest revision of AAR S-580 – Locomotive Crashworthiness Requirements.

5.3.1.2.1 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 below.

There shall be two collision posts extending from the underframe to a height within 6 inches (152 mm) from the bottom of the windshield. They shall be located at the approximate 1/3 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 supporting car body structure, and intervening connections shall resist each one of the following horizontal inward loads individually applied at any angle within 15 degrees 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 inches (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. (445kN) longitudinal shear load
- 30,000 lbf. (133 kN) vertical downward 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 inches (762 mm) above the top of the underframe.

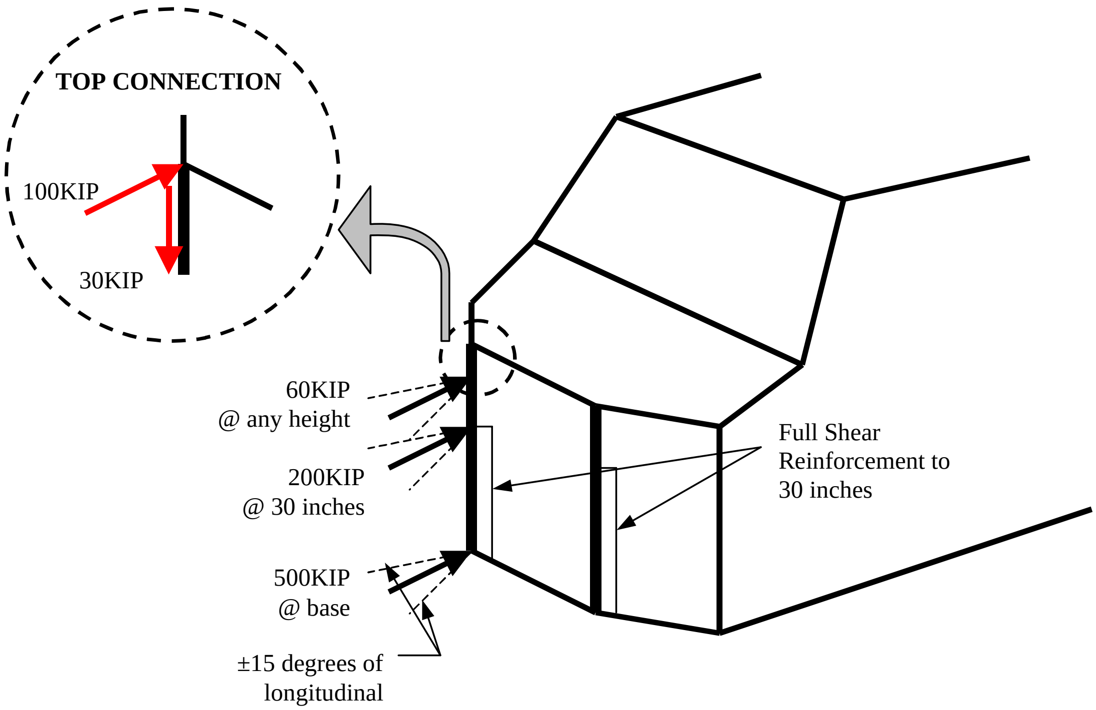


Figure 1 - Schematic of Collision Post Loads for Non-Passenger-Carrying Locomotive

Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

5.3.1.2.2 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.

5.3.1.3 MU cars and cab cars

5.3.1.3.1 Cab-end collision posts (49 CFR 238.211 b)

The cab ends of MU cars and cab cars shall have structural collision posts meeting the requirements outlined below. 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 1/3 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 supporting car body structure, and intervening connections shall resist each one of the following horizontal inward loads individually applied at any angle within

15 degrees of the longitudinal axis (see Figure 2):

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 inches (762 mm) above the top of the underframe, without exceeding the ultimate strength.

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 on a flat-end MU car or cab car shall be capable of absorbing a minimum of 135,000 ft-lb (0.18 MJ) of energy when loaded longitudinally at a height of 30 inches (762 mm) above the top of the underframe. A load distribution device may be used between the loading ram and post that is not greater than 6 inches high and wide enough to distribute the load directly into the post webs. At the moment that the collision post has absorbed this minimum energy:

    - The post shall not permanently deflect more than 10 inches (254 mm) into the operator's cab or passenger seating area and,
    - 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).

    Compliance with this requirement shall be demonstrated through either analysis or quasi-static testing as agreed to by the vehicle builder and purchaser.

e) Cab end collision posts and supporting structure on a non-flat-end MU car or cab car designs or on cars with crash energy management, shall meet the severe deformation requirements defined in d) above. Compliance with this requirement shall be demonstrated either through analysis or testing as agreed to by the vehicle builder and purchaser.

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 inches (762 mm) above the top of the underframe.

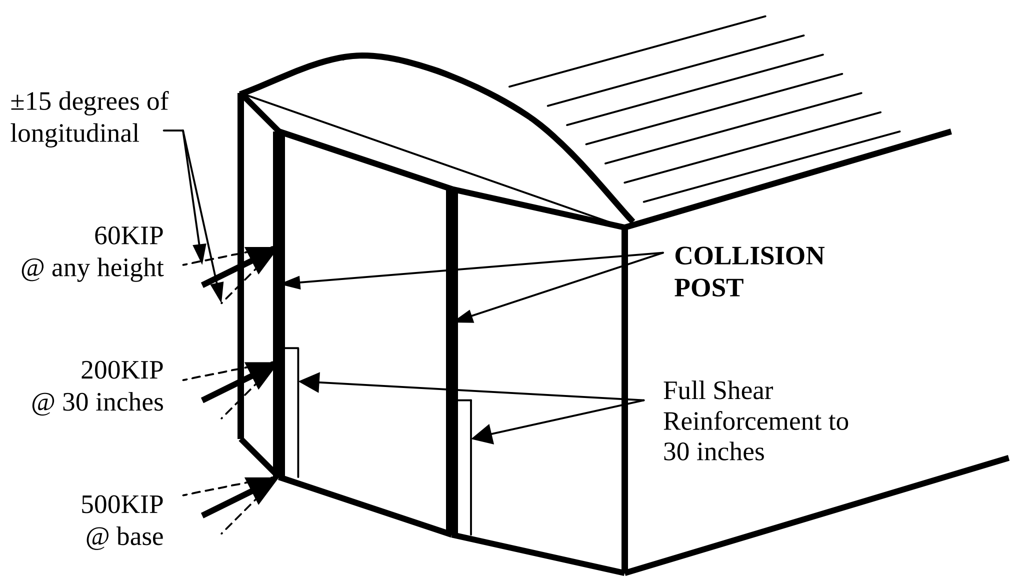


Figure 2 - Schematic of Collision Post Loads for MU and Cab Cars (Cab End Only)

Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

5.3.1.3.2 Non-cab-end collision posts

The non-cab ends of MU cars and cab cars shall have structural collision posts meeting the requirements of Section 5.3.1.4.

5.3.1.4 Coach car collision posts (49 CFR 238.211 a)

Coach cars shall have structural collision posts meeting the requirements outlined below. 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 1/3 points across the width of the vehicle.

Each collision post, acting together with supporting car body structure, and intervening connections shall resist each one of the following horizontal inward loads individually applied at any angle within 15 degrees of the longitudinal axis (see Figure 3):

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 300,000 lbf. (1334 kN) applied at a point 18 inches (457mm) above the top of the underframe, without exceeding the ultimate strength.

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 or supporting structure.

d) The top connection shall resist the resulting loads of the collision post at its ultimate capacity.

As a minimum, the connection of the collision post to either the roof structure or A-T Plate (if used) shall be designed to resist each of the following individually applied ultimate loads:

- 60,000 lbf. (267 kN) longitudinal shear load
- 25,000 lbf. (111 kN) vertical downward load

The roof or A-T plate 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 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 inches (457mm) above the top of the underframe and then taper to 30 inches (762 mm).

The collision posts shall be designed so that if overloaded longitudinally at a point 30 inches (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. Compliance with this requirement shall be demonstrated by analysis[1] or tests.

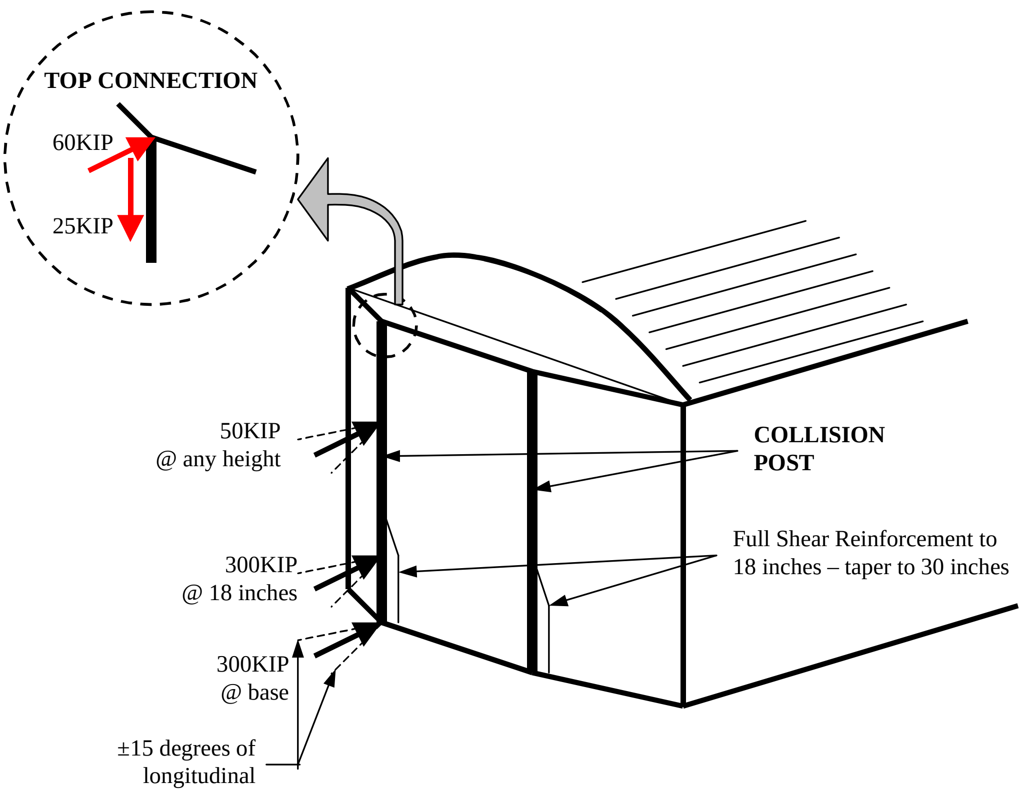


Figure 3 - Schematic of Collision Post Loads for Coach Cars

Each collision post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

[1] As reference, the methodology outlined in AAR Manual of Standards and Recommended Practices, Section C-Part II, Volume 2, Appendix C "Plastic Design Factors" is deemed to be an acceptable means of analysis.

5.3.1.5 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 the intercar coupling meets the climb, bypass and overturn requirements of Section 5.5 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 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 were a non-passenger-carrying locomotive or power car, then the requirements of Section 5.3.1.2.1 would apply. If the end of the assembly of units were at the lead end of the trainset (i.e. similar to a MU car or cab car), then the requirements of Section 5.3.1.3.1 would apply. If the end of the assembly of units were not at the lead end of the trainset, then the requirements of Section 5.3.1.4 would apply.

5.3.2 Corner posts

5.3.2.1 General

Each locomotive and passenger car shall have at each end of the vehicle two structural corner posts, one located at each extreme corner of the car body structure. 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.

5.3.2.2 Non-passenger-carrying locomotives corner posts

This section shall sunset at such time that the final rule for the FRA Locomotive Crashworthiness becomes effective. The final rule is inclusive of the latest revision of AAR S-580 – Locomotive Crashworthiness Requirements.

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 below. Each corner post, acting together with supporting car body 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 inches (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
- 22,500 lbf. (100 kN) vertical downward 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 inches (762 mm) above the top of the underframe.

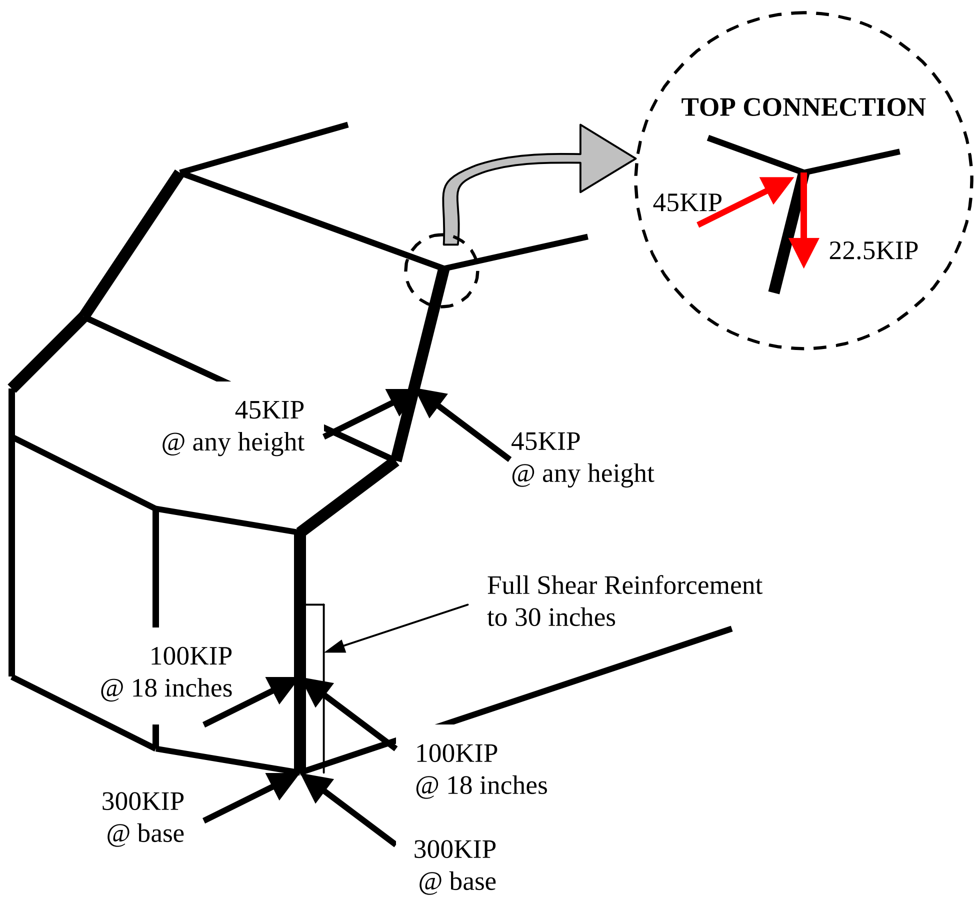


Figure 4 - Schematic of Corner Post Loads for Non-Passenger-Carrying Locomotive

Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

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 part 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.

5.3.2.3 MU cars and cab cars

5.3.2.3.1 Cab end corner posts

The cab ends of MU cars and cab cars shall have structural corner posts meeting the requirements outlined below. Each corner post, acting together with supporting car body structure, and intervening connections shall resist each of the following horizontal loads individually applied toward the inside of the vehicle in any direction from longitudinal to transverse (see Figure 5):

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 the depth of the post times the thickness of the webs).

b) Minimum 100,000 lbf. (445 kN) applied at a point 18 inches (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 supporting structure.

d) Each corner post on a flat-end MU car or cab car shall be capable of absorbing a minimum of 120,000 ft-lb (0.16 MJ) of energy when loaded longitudinally at a height of 30 inches (762 mm) above the top of the underframe. A load distribution device may be used between the loading ram and post that is not greater than 6 inches high and wide enough to distribute the load directly into the post webs. At the moment that the corner post has absorbed this minimum energy:

    - The post shall not permanently deflect more than 10 inches (254 mm) into the operator’s cab or passenger seating area and,
    - 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).

    Compliance with this requirement can be demonstrated through either analysis or quasi-static testing as agreed to by the vehicle builder and purchaser.

e) Cab end corner posts and supporting structure on non-flat-end MU car or cab car designs or on cars with crash energy management, shall meet the severe deformation requirements defined in d) above. Compliance with this requirement shall be demonstrated either through analysis or testing as agreed to by the vehicle builder and purchaser.

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

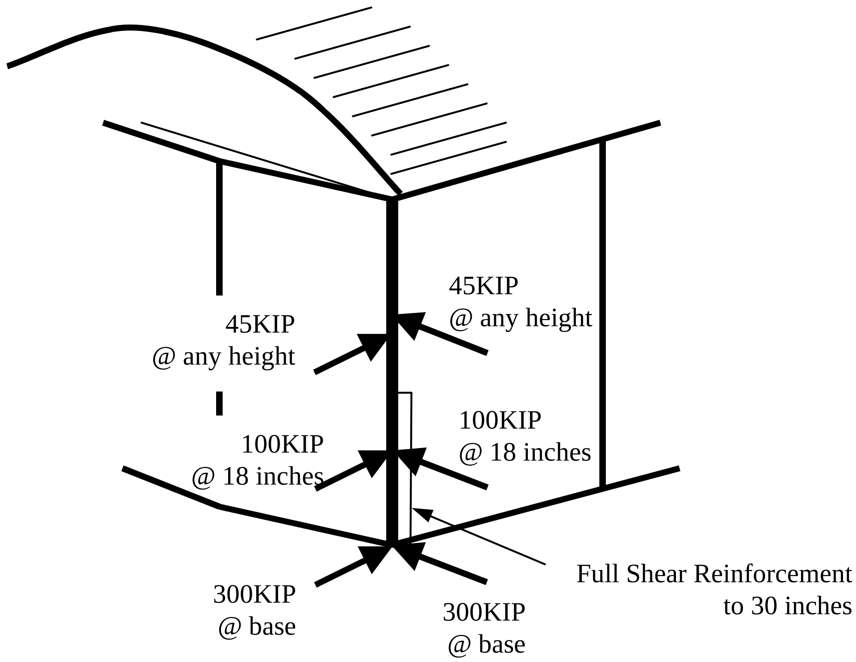


Figure 5 - Schematic of Corner Post Loads for Cab Ends of MU Cars and Cab Cars

Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

5.3.2.3.2 Non-cab end corner posts

The non-cab ends of MU cars and cab cars shall have structural corner posts meeting the requirements outlined in Section 5.3.2.4.

5.3.2.3.3 Cab end-non-operator side of cab-alternate requirements

MU cars and cab cars which utilize low level passenger boarding at the non-operating side of the cab end and are unable to meet the requirements outlined in Section 5.3.2.3.1, 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:

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

$$E_{min} = E_{CP} + E_{BCP}$$

where: E_{min} = minimum total energy absorbed = 120,000 ft-lb (0.16 MJ)

E_{CP} = energy absorbed by the corner post

E_{BCP} = 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 (E_{CP}). The load shall then be applied to the body corner post to absorb the remaining energy (E_{BCP}).

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 inches (254 mm) into the passenger seating area and,
- There shall be no complete separation of the body corner post, its connection to the underframe, or its connection to either the roof structure or A-T Plate (if used).

Compliance with these requirements shall be demonstrated through either analysis or quasi-static testing as agreed to by the vehicle builder and purchaser.

5.3.2.3.3.1 Corner Post

The corner post, acting together with supporting car body structure, and intervening connections shall resist each one of the following horizontal loads individually applied toward the inside of the vehicle:

a) Minimum 150,000 lbf. (667 kN) applied longitudinally 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 30,000 lbf. (133 kN) applied longitudinally at a point 18 inches (457 mm) above the top of the underframe, without permanent deformation.

c) Minimum 30,000 lbf. (133 kN) applied longitudinally at point of attachment to the roof structure, without permanent deformation.

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 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).

f) Minimum 100,000 lbf. (445 kN) applied transversely at a point 18 inches (457 mm) above the top of the underframe, without permanent deformation.

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 deformation of the post or supporting structure.

5.3.2.3.3.2 Body Corner Post

The body corner post, acting together with supporting car body 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 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 longitudinally at a point 18 inches (457 mm) above the top of the underframe, without permanent deformation.

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 roof structure.

d) Minimum 100,000 lbf. (445 kN) applied transversely 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).

e) Minimum 30,000 lbf. (134 kN) applied transversely at a point 18 inches (457 mm) above the top of the underframe, without permanent deformation.

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 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 inches (762 mm) above the top of the underframe.

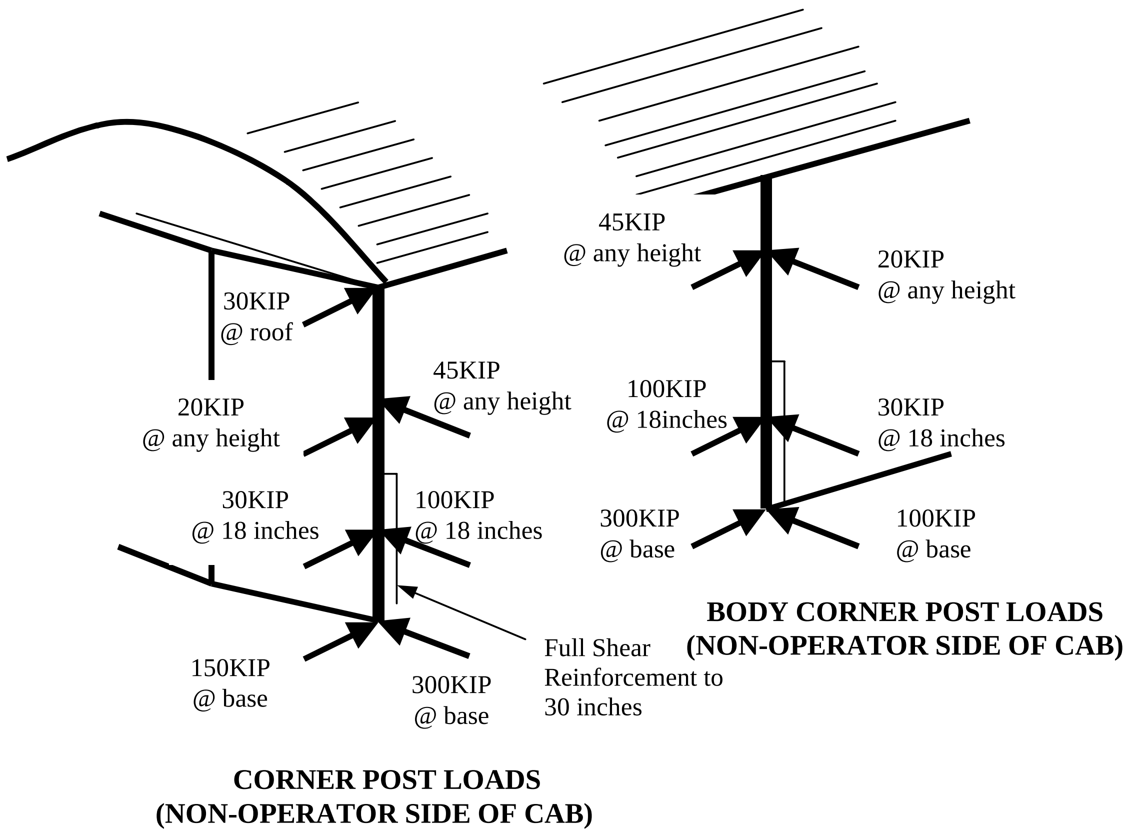


Figure 6 - Schematic of Corner Post & Body Corner Post Loads for MU and Cab Cars (Cab End Only Non-Operator Side with Step Well)

Each corner post, and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

5.3.2.4 Coach Car corner posts (49 CFR 238.213)

Each corner post, acting together with supporting car body 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):

a) Minimum 150,000 lbf. (667 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 30,000 lbf. (133 kN) applied at a point 18 inches (457 mm) above the top of the underframe, without permanent deformation.

c) Minimum 30,000 lbf. (133 kN) applied at point of attachment to the roof structure, without permanent deformation of the post or the roof 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 top connection shall resist the resulting loads of the corner post at its ultimate capacity. As a minimum, the connection of the corner post to either the roof structure or A-T Plate (if used) shall be designed to resist each of the following individually applied ultimate loads:

- 30,000 lbf. (133 kN) longitudinal shear load
- 15,000 lbf. (67 kN) vertical downward load

The roof or A-T plate connection loads specified in e) above are to be used to design the strength of the connections and not the supporting structure.

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

The corner posts shall be designed so that if overloaded longitudinally at a point 30 inches (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. Compliance with this requirement shall be demonstrated by analysis[2] or tests.

[2] As reference, the methodology outlined in AAR Manual of Standards and Recommended Practices, Section C-Part II, Volume 2, Appendix C “Plastic Design Factors” is deemed to be an acceptable means of analysis.

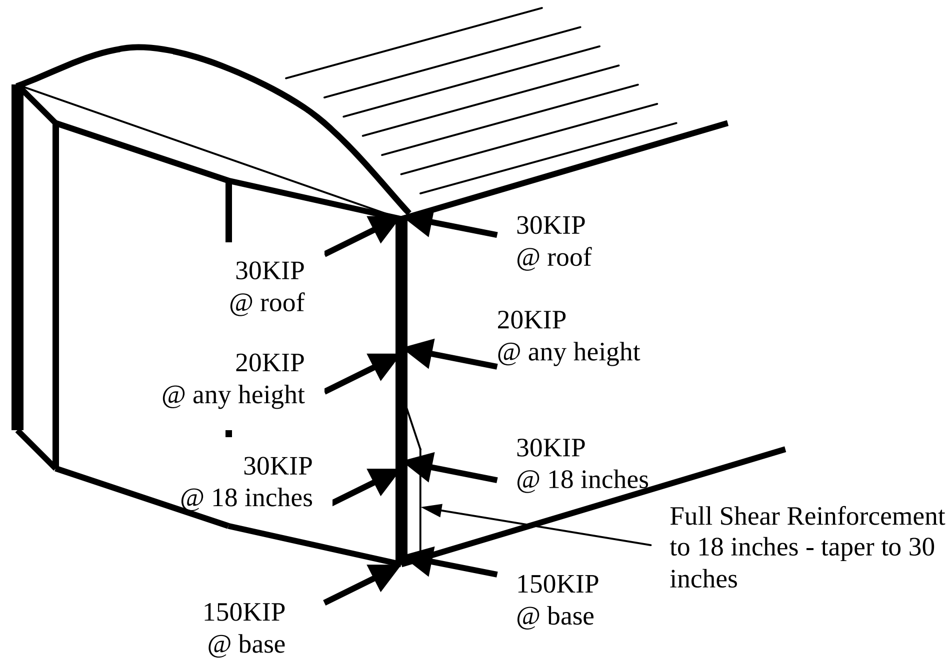


Figure 7 - Schematic of Corner Post Loads for Coach Cars

Each corner post and any shear reinforcement, if used, shall be welded to the top and bottom plates of the end sill with the equivalent of AWS pre-qualified welded joints.

5.3.3 Horizontal Framing Members, MU Cars, Cab Cars, and Other Cars

End frame collision and corner posts may be connected by horizontal intercostals as necessary to resist the lateral components of the design loads specified in Sections 5.3.1 and 5.3.2, respectively. In addition, a structural header may be used to connect the tops of the collision and corner posts.

Cab-end framing 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 transverse to the member at any point on its span without permanent deformation of any part of the vehicle structure.

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

Cab end frame sheathing shall be:

a) Equivalent to a 1/2-inch (13-mm) steel plate with a 25,000-psi (172-MPa) yield strength. Material of a higher yield strength may be used to decrease the required thickness of the material provided an equivalent level of strength is maintained;

b) Designed to inhibit the entry of fluids into the occupied cab area of the equipment; and

c) Connected to underlying framing members sufficient to develop the full strength of the sheathing.

5.4 Roof

5.4.1 Roof framing and sheathing

a) The projected area in units of ft^2 (mm^2) of the portion of the roof supported by carlines divided by the sum of the section moduli in units of in^3 (mm^3) of the carlines at any longitudinal section shall not be more than 60 ft^2/in^3 (340 mm^{-1}).

b) Flat roof sheets of mild steel with 32 ksi (221 MPa) yield strength and without reinforcements shall be of a minimum thickness of 0.05 inches (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 the sheets are reinforced to produce at least an equivalent sectional area at right angle to roof sheets specified in Section 5.4.1.2.(b)

5.4.2 Rollover (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 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 car body shall be one-half yield or one-half the critical buckling stress, whichever is less.

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 above. 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.

5.4.3 Other roof loads

Roof framing members and sheathing shall have sufficient strength to withstand, without permanent deformation, three (3) concentrated loads of 250 lbf. (1112 N) spaced 30 inches (760 mm) apart, 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.

5.5 Climb, bypass, and overturn resistance

5.5.1 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, but each in combination with high compression load as agreed to by the purchaser and manufacturer. The loads discussed in this section do not apply to couplers, only to the car body structure that contains the couplers.

5.5.2 Cab cars, MU cars, and other cars

5.5.2.1 Climb resistance (49 CFR 238.205)

The structural arrangement shall resist a vertical load (both upward and downward), which shall not be less than 100,000 lbf (448 kN). The acceptance criteria for this load condition shall be no permanent deformation of the structural arrangement, supporting car body structure, and intervening connections.

5.5.2.2 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 5.5.2.1.

5.5.2.3 Overturn resistance

The coupler anchor and supporting car body structure shall have sufficient strength to develop the ultimate torsional strength of the coupler, without permanent deformation of the coupler anchor and supporting car body 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.

5.5.2.4 Couplers and drawbars

If used, drawbars, semi-permanent couplers, standard AAR Type F interlocking couplers, and APTA RP-M-003 Type H tightlock couplers may be considered as providing the required climb, bypass, and overturn resistance if the requirements of Section 5.5.2.3 and if the following additional requirements are met:

a) The structural arrangement shall include a coupler carrier designed to resist the 100,000 lbf. vertical downward thrust from 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 car body structure, and intervening connections.

b) The structural arrangement shall include a buffer beam above the coupler, which shall be designed to resist the 100,000 lbf. 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 buffer beam, supporting car body structure, and intervening connections.

5.5.3 Non-passenger-carrying locomotives

This section shall sunset at such time that the final rule for the FRA Locomotive Crashworthiness becomes effective. The final rule is inclusive of the latest revision of AAR S-580 – Locomotive Crashworthiness Requirements.

Climb, bypass, and overturn resistance of non-passenger-carrying locomotives shall be as required by Section 5.5.2, except that the climb resistance design strength shall not be less than 200,000 lbf (890 kN), and the allowable stress shall be ultimate.

5.6 Truck to car body attachment strength

5.6.1 General (49CFR 238.219)

A mechanism for attaching the completely-assembled truck, including the bolster, if used, to the car body shall be provided in accordance with the requirements of this section. The requirements of Sections 5.6.2 and 5.6.3 below shall be considered as separate load cases.

5.6.2 Horizontal

The ultimate horizontal strength of the attachment mechanism shall be sufficient to secure the entire truck to the car body in a manner which will prevent separation of the truck from the car body during derailments and collisions in which a horizontal load of minimum 250,000 lbf (1112 kN) is applied in any direction at any point on the truck frame through the center of truck rotation. 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. The strength of the truck and supporting car body structure shall be sufficient to develop the ultimate horizontal strength of the attachment mechanism as specified.

5.6.3 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, car body, and the elements of the attachment mechanism, during jacking or lifting of the car body with the truck hanging from the car body.

5.6.4 Recommended Practice - Truck Rotation Stops

If truck rotation stops are desired, 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 vehicle maintenance. The strength of the stops should be selected on the basis of the type of service, and 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.

5.7 Equipment Attachment

5.7.1 General

This section contains minimum requirements for the static strength of attachment of major equipment to the car body 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 locomotive and car equipment having a weight greater than 150 lbs (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 APTA PR-CS-S-016-99, Standard for Row-to-Row Seating in Commuter Rail Cars, APTA PR-CS-011-99, Standard for Crew Cab Seating Design and Performance, and APTA PR-CS-S-006-98, Standard for Attachment Strength of Interior Fittings to Passenger Railroad Equipment.

5.7.2 MU cars and passenger cars

5.7.2.1 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 car body 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, and each shall be combined with the vertical 1g down load of the weight of the equipment. These loadings shall be applied separately so that 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 allowable stress for each such load case is ultimate material strength.

Equipment within an equipment box need not comply provided it can be shown that the internal equipment will not penetrate the walls of the equipment box when exposed to the specified load levels. In this case, the equipment box shall conform to the specified load criteria with the rearranged equipment (*i.e.*, with an appropriately-modified c.g.) in addition to its normal arrangement.

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 car body.

Fastening shall be designed so that the strength of a fastener or the shearing of the fastener through the base material shall not limit the load carried by a structural member, except that the addition of a bracket or member to act as a failure mechanism solely for the purpose of meeting this requirement is not intended.

5.7.2.2 Safety hangers:

Backup safety straps, hangers or other devices shall be used on all equipment mounted resiliently or rigidly with bolts in tension.

5.7.2.3 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.

5.7.2.4 Fasteners:

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

Attachment bolts shall be minimum Society of Automotive Engineers (SAE) Grade 5 strength, and nuts minimum ASTM A-563 Grade D strength, of not less than 3/8-inch (10 mm) diameter.

5.7.2.5 Welding:

Welding of equipment and structure subject to this Standard shall be in accordance with the requirements of the AWS documents referenced in Section 2.

The strength of equipment attachments that combine the use of bolts and welds shall be based on the strength of the weld joints alone.

5.7.3 Non-Passenger-Carrying Locomotive

Non-passenger-carrying locomotives shall comply with Section 5.7.2 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.

5.8 Structural Connections

As agreed between the Purchaser and Manufacturer, critical connections between structural members of the car body 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 car body and truck structural members under the actions of the specified emergency load cases. The emergency load cases include the end-compression loads; end-frame collision post, corner post and structural shelf loads; side loads; rollover loads; and the horizontal truck connection design requirement. 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.

6. Crash Energy Management (CEM) - Recommended Practice

6.1 General

For effective crashworthiness, car body structures should be designed to maximize energy-absorbing capability within the required static strength parameters. Car body structures, when loaded from the ends in compression, should be designed for controlled energy absorption.

6.2 CEM and Collision Survivability Plan

The rolling stock manufacturer should prepare a CEM and Collision Survivability Plan that demonstrates compliance with the requirements of the purchase contract for CEM and survivability. The Plan should define the specific features of the vehicle structures that will provide the required zones of energy absorption. Submission and approval of the Plan should be required before submission of the vehicle structural drawings and static stress analyses.

6.3 Crash Energy Management

Car bodies should be designed to crush and absorb energy in a controlled manner when subjected to collision-induced end loads that exceed the static load capability of the structure. The design should be based on specific CEM zones as follows, listed in order of highest to lowest survivability:

Zone A: High-density passenger and crew space, such as cabs and passenger seating space;

Zone B: Low-density passenger and crew space, such as entryways and toilets; and

Zone C: Unoccupied space.

Space occupied by large, solid-mass, relatively uncrushable equipment may be used to the extent possible for structural energy absorption, and should be designed so that the equipment, under the conditions of the selected evaluation scenario, does not penetrate adjacent zones of the structure.

The rolling stock should be designed for energy absorption by controlled crush of Zone types B and C structure. The amount of energy absorption should be as agreed to between the Purchaser and the manufacturer, and should be appropriate for the intended service and evaluation scenario.

6.3.1 Evaluation Scenario

Acceptance of CEM design should be on the basis of performance in accordance with the approved CEM and Collision Survivability Plan, based on an approximate amount of energy to be absorbed, and an evaluation collision scenario. The evaluation scenario should be appropriate for the intended service, and should include at least the following:

a) A closing speed at impact;

b) The arrangement and orientation of the colliding equipment at impact. It is suggested that the following be considered:

c) Two identical consists of the rolling stock to be purchased (“trainset”), colliding head on in all possible orientations (e.g., cab car to locomotive, cab car to cab car, locomotive to locomotive), including the most unfavorable, on level, tangent track;

d) Collision of a trainset with a freight train representing the most severe risk for the intended operation, with both in the most unfavorable arrangement and orientation; and

e) Grade crossing collision of a trainset in the most unfavorable arrangement and orientation with a highway vehicle representing the most severe risk for the intended operation;

f) The state of braking on consist(s) involved in the collision;

g) The state of the equipment during the collision. It is suggested that it be assumed that all cars remain upright, in-line, with all wheels on the track throughout the collision; and

h) Force vs. distance characteristics for the crush of the car bodies, including the CEM zones, developed by analysis and/or test of the specific designs involved.

Analysis for the purpose of determining force vs. distance characteristics should be of the time-dependent, large deflection type. Tests for the purpose of validating analytically-determined force vs. distance characteristics may be performed on test articles that are reduced-scale replicas of the crush-zone elements. It is suggested that, as a minimum, each crush-zone element be analyzed and tested. Then, the validated results for each crush-zone element should be incorporated in an analytical model of each crush zone or the entire structure for the purpose of confirming global crush behavior of each unique car body structure type considered separately. A result of key importance is the acceleration history of the occupied portions of each unit in the consist(s) for sufficient time (approximately 500 ms following impact) to include the initial application of the impact acceleration pulse to each unit in the consist.

Validation of the global crush behavior by test should be performed only as specifically agreed to between Purchaser and manufacturer.

6.4 Acceptance Criteria

Compliance should be demonstrated by analysis in accordance with Section 7.0 and test in accordance with Section 8.0.

Acceptance criteria should include the following:

a) A limit on acceleration[3] of the non-lead vehicles applicable at all times after impact;

b) A requirement that the crush of vehicle structure be confined to Zones B, C, and, to the extent possible, zones containing large, massive, relatively uncrushable equipment; and

c) A limit on the velocity at contact with the back of the seat ahead for a 95th-percentile male in row seating anywhere in the consist subjected to the validated acceleration history.

7. Analysis

7.1 General

It is expected that the Manufacturer will perform structural analysis of the car body structure and of supports for equipment weighing over 150 lbf (667 N). 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.

[3] Analytical and test acceleration data may be filtered using a filter per Appendix C of Society of Automotive Engineers E J-211/1, with CFC 60 or higher, depending on the duration of the event being analyzed.

For truck stress analysis, refer to APTA RP-M-009, Recommended Practice for New Truck Design Process.

For any portion of the proposed design which is based on a service-proven vehicle, the Contractor may provide data from previous tests, historical data from operations, or structural analyses as required to satisfy the corresponding portion of these requirements.

7.2 Structural Sketch - Recommended Practice

In order to define the car body structure, a structural sketch is recommended. The purpose of the structural sketch is to define the primary car body structure in advance of formal stress analysis and structural drawings.

The structural sketch should include a side view; a top view showing one longitudinal half of the roof and one longitudinal half of the underframe; and typical car body cross-sections.

Cross-sections of the structural members, showing the shape, dimensions, material, and thickness of each member, should be included. 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.

7.3 Linear Elastic Stress Analysis

Linear elastic load cases shall be subjected to stress analysis consisting of a manual stress analysis supplemented by a linear-elastic Finite Element Analysis (FEA) using a recognized computer FEA code which is readily available and widely used in North America for rail car structural analysis. Stress analysis requirements for other load cases shall be as agreed by Purchaser and Manufacturer.

The results of the linear stress analysis shall include calculated stresses, allowable stresses, and margins of safety for all structural elements for all design loading conditions required by this Standard, and others as agreed to by the Purchaser and Manufacturer.

For all linear-elastic load cases, the elastic stability of plates, webs, and flanges shall be calculated for members subject to compression and shear.

The purpose of the manual analysis shall be to examine details of the car body structure (weld connections, welded and/or bolted joints, fatigue conditions, column and plate stability) that are not readily handled in the FEA. The format and content of manual analyses shall be as agreed to by the Purchaser and Manufacturer, and the following is suggested as a minimum:

a) Title,

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

c) Drawing references,

d) Material properties,

e) Allowable stress,

f) Detailed stress analyses, and

g) Conclusions.

7.4 Crash Energy Management Analysis

For equipment where structural CEM is incorporated in the design, time dependent, large deflection analysis shall be performed using a recognized computer program that has a proven record of use for rail car crashworthiness analysis. The following shall be analyzed:

a) Individual energy absorbing structural elements,

b) Individual frangible structural elements (elements in the crush zone which must be designed to quickly fail when overloaded by the forces causing the crushing in order to not destabilize the crushing action),

c) Each crush zone, consisting of the validated energy absorbing and frangible structural elements, and

d) The global car body, including representative portions of the remainder of the car body structure.

If, by agreement, a report of the crashworthiness analysis is required to be prepared by the manufacturer and submitted to the purchaser, it shall include computer animations of the results of the time-dependent, large deflection analysis in a self-contained format which can be displayed on a PC, or on a commonly available digital or analog video media, such as CD, DVD, or VHS. The computer animations shall contain sufficient detail, view directions, and magnifications, and shall be of sufficiently high resolution to allow review of the behavior and stability of individual energy absorbing elements, and frangible elements, and, for the global analysis, the crushable zone, the non-crushable structure inboard the crush zones, and the car body as a whole. The report shall demonstrate that the crushing of energy absorbing zones of the car body structure is stable, and that structure inboard the energy absorbing zones is not permanently deformed during crushing up to the full capacity of the crushable structure.

The report shall include a description of the model in sufficient detail to show that it is appropriate for the application. This shall include, as a minimum, description of the structural elements and restraints, and the conditions of the simulation. It shall also include the output of the simulation to show that the relevant requirements of this Standard and of the purchase specification have been met, including force displacement plots, and an itemization of energy absorbed.

8. Tests

8.1 General

One of the first car body structures shall be tested to verify compliance of the structure with this APTA Standard. The car body shall be structurally complete including plymetal flooring if used as part of the primary car body structure, but shall exclude such items as exterior and interior trim, windows, doors, seats, lights, insulation, interior lining, or any other materials that will obscure any structural member of the car from view. Underfloor apparatus may be installed or equivalent weights distributed at their respective locations.

For any portion of the design that is based on a service-proven vehicle, the manufacturer may provide data from previous tests to satisfy the corresponding portion of these requirements, as approved by the purchaser.

A test procedure shall be submitted prior to conducting a test. The test procedure should include, but should not necessarily be limited to, drawings, sketches, tables and other descriptions, which provide:

a) A description of the test load equipment;

b) The location of each point that a load or reaction is applied to the specimen;

c) A table showing the load applied at each load point for each test increment; and

d) The location of each load, strain, and deflection-measuring device.

The Manufacturer may conduct preliminary tests prior to the official tests.

8.2 Compression Load Test

8.2.1 Test Description

The ability of the car body structure to resist the compression loads specified in Section 5.1 shall be tested. During the compression test, the car body shall be supported on trucks, or a simulation thereof, to allow longitudinal movement.

The car body 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 force of the testing machine shall be measured by a load cell or equivalent device that is independent of the equipment producing the applied force. The compression test load shall be applied to the rear draft stop in the draft gear housing at the centerline of draft by means of a controlled ram. If a "shear-back" coupler or drawbar is used, the specified buff load shall be applied to the end beam or anticlimber. Cushioning means, such as lead sheets, shall be provided to assure uniform bearing. The test loads shall be applied horizontally on the car shell longitudinal centerline. No allowance shall be made for the camber of the car body.

The test load shall be applied with incremental increases, and shall include at least one return to a load not greater than 2000 lbf. (9 kN) after attaining not less than 80% of the required maximum load.

8.2.2 Test Criteria

The car body 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 jointly inspected by the Purchaser and Manufacturer 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 5.1;

c) Indicated residual strains at strain gauges on principal structural elements following removal of the maximum load do not exceed the maximum strain agreed to by the Purchaser and Manufacturer; and

d) It is recommended that highly-localized yielding or plastic 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 vehicle builder and Purchaser.

8.3 Collision post and corner post test

8.3.1 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 the following table shall be tested.

Test Article	**CS-S-034 Section Reference**	**Load Direction and Sense**
Collision Posts, Cab Ends, and Non-Cab Ends with Hostler Panel, Non-Passenger-Carrying Locomotives	5.3.1.2.1 b)	Longitudinal Inward[4]
Cab End Collision Posts, MU Cars and Cab Cars	5.3.1.3.1 b)	Longitudinal Inward[4]
Collision Posts, Non-Cab Ends, MU Cars and Cab Cars; Collision Posts, Coach Cars	5.3.1.4 b)	Longitudinal Inward[4]
Collision Posts, Permanently and Semi permanently Coupled Articulated Cars	5.3.1.5	As Specified
Corner Posts, Cab Ends, and Non-Cab Ends with Hostler Panel, Non-Passenger-Carrying Locomotives	5.3.2.2 b)	Worse Case of Longitudinal and Lateral Inward
Corner Posts, Cab Ends, MU Cars and Cab Cars	5.3.2.3.1 b)	Worse Case of Longitudinal and Lateral Inward
Corner Posts, Cab Ends, Non-Operator Side, MU Cars and Cab Cars, Alternate Requirements	5.3.2.3.3.1 b) and f) 5.3.2.3.3.2 b) and e)	As Specified
Corner Posts, Non-Cab Ends, MU Cars and Cab Cars; Corner Posts, Coach Cars	5.3.2.4 b)	Worse Case of Longitudinal and Lateral Inward

The test loads may be applied to a structurally complete car body or, as an alternate, a separate end

[4] Test load 15^{o} from longitudinal permitted as an alternate if agreed between Purchaser and Car Builder.

frame section may be constructed and tested. If the alternate method is chosen, the test element shall simulate to the maximum extent possible the location, the degree of fixity, and magnitude and direction of reactions of the supporting car body structure.

The force of the testing machine shall be measured by a load cell or equivalent device that is independent of the equipment producing the applied force. Cushioning means, such as lead sheets, shall be provided to assure uniform bearing.

8.3.2 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 jointly inspected by the Purchaser and Manufacturer 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 5.3;

c) Indicated residual strains at strain gauges on principal structural elements following removal of the maximum load do not exceed the maximum strain agreed to between the Purchaser and Manufacturer; and

It is recommended that highly-localized yielding or plastic 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 vehicle builder and Purchaser.

8.3.3 Elastic/plastic test description

The ability of the collision post, corner post and associated supporting structures to resist the elastic/plastic design loads specified in Section 5.3 may be tested, if specified by the purchaser.

The placement of the applied load shall be for the worst-case condition, or as agreed to by the purchaser and manufacturer.

It is recommended that the test loads be applied to a special test article consisting of an end frame and sufficient car body structure to provide a representative support condition.

The force of the testing machine shall be measured by a load cell or equivalent device that is independent of the equipment producing the applied force. Cushioning means, such as lead sheets, shall be provided to assure uniform bearing.

8.3.4 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 ultimate strength of the structure is not exceeded.

8.4 Crash energy management tests

8.4.1 Test description

If a vehicle is designed with crash energy management, a series of tests should be conducted to validate the design. This may include a series of tests of the individual elements, testing of sub-assemblies, or testing the global structure.

While it is recommended, as a minimum, to test each crush element, the actual validation of the global crush behavior may also require intermediate steps. The process by which this testing is carried out will be as specifically agreed to between the purchaser and manufacturer.

When required by the Purchaser, element energy tests shall be performed on each element type to validate its design. While it is recommended that full-size elements be used during the testing, reduced-scaled replicas may be used if specifically agreed to between the Purchaser and Manufacturer.

Validation of the global crush behavior of the vehicle should be performed only as specifically agreed to between the Purchaser and Manufacturer.

Testing of the individual elements or the global structure may be tested either dynamically or statically, as specifically agreed to between the Purchaser and Manufacturer.

8.4.2 Test criteria

The requirements for demonstrating compliance with respect to the Crash Energy Management Tests will be as specifically agreed to by the Purchaser and Manufacturer.

Annex 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

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 (RMS) 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 car body (see discussion in Section A.2.5).

A.2.1 Anticlimbing

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 (actually it was 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 in to 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 “anticlimbing 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.

Anticlimbing as applied to non-passenger carrying locomotives differs in some important respects. The concept of anticlimbing for locomotives was perhaps first codified by AAR S-580 in 1989. The typical design solution has been a shelf or “horns” on the end of the unit above the coupler, intended to resist the tendency of objects struck at, for example, grade crossings, to rise up and impact the cab. Although this differs from the concept applied to cars, it has been observed over the years that the traditional anticlimbing arrangement, a relatively massive tightlock coupler ruggedly built into the end of the car below a buffer beam design to resist the 100,000 lbf (445 kN) vertical up force without yield, is effective to some extent as a locomotive-style anticlimber, even though on cars the primary intent of the anticlimbing arrangement was to reduce the likelihood of climbing between coupled units during collisions.

When first issued, FRA based anticlimbing requirements for MU and cab cars at 49 CFR 238.205 (b) 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 kNat ultimate instead of 100,000 lbf (445 kN) at yield. The FRA persisted in requiring a locomotive style anticlimber. However, the industry was not able to develop a design solution for that style of anticlimber for a MU or cab car that was compatible with a cab design with 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 November 27, 2001, excepting cab and MU cars from the anticlimbing requirements of 49 CFR 238.205 (b). This means that the FRA anticlimbing requirement for cab and MU cars reverts to 49 CFR 238.205 (a) that essentially describes the “traditional” car anticlimbing arrangement. Improved anticlimbing requirements may eventually be drawn from ongoing FRA research into collision dynamics and specifically the mechanism of override.

This APTA Standard applies to all passenger equipment, including cars and locomotives, and 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 car body end frame anti-telescoping structure, this Standard is 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.

A.2.3 Corner Posts

This APTA Standard, unlike AAR S-034 and 49 CFR 229.141, contains specific requirements for corner posts. Passenger cars have for many decades included substantial structural posts at the body corners, or 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). Also, prior to the initial release of this Standard, there had never been a regulation or traditional industry practice that mandated or specified use of corner posts for non-passenger-carrying locomotives.

The corner post requirements in this APTA Standard are, therefore, 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 C/S 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 this Standard.

It should be noted that the corner post design requirements outlined in Section 5.3.2.3 (cab ends with low level boarding) may have significant effect on current car designs with end vestibules with side entrance door which has an additional lower door that covers the step well.[5] From the preliminary review of these new requirements and their effect on car designs, it is anticipated that the current design of the lower Dutch door is not possible with the new design requirements for the body corner post. This is because the ability of the side sill to support the bottom reactions of the body corner post is compromised by the need to provide for a slideway for the door that bifurcates the side sill. Therefore, it should be noted that enclosing and isolating the step well area with the lower Dutch side door configuration might no longer be possible.

In Section 5.3.2.3.1 of this Standard, new requirements for corner posts that are applicable for the cab end of MU cars and cab cars are outlined. These new requirements are significantly higher than had been applied to car design prior to the initial release of this Standard. At that time, given the then-current state of the design of railcars with low-level boarding, it was thought that it might not be possible to achieve the higher strength requirements with the low boarding step well, and such a design has still not been successfully developed. Additional research and development of these cab car designs is necessary to confirm that the higher strength requirements can be achieved with low level boarding.

In case the new, more stringent requirements of Section 5.3.2.3.1 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 requirement, are outlined in Section 5.3.2.3.3.

It is recommended that cab-end, non-cab-side corner posts be designed to meet the requirements of Section 5.3.2.3.1.. Implementation of the alternative requirements of Section 5.3.2.3.3 shall be subject to an evaluation performed by the Manufacturer and approved by the Purchaser that demonstrates that the requirements of Section 5.3.2.1 are not practical, given the other requirements for the design.

[5]This is a door that extends the full height from the lowest step in the stepwell to the top of the door opening in the side of the body, and that is constructed using two door panels. The upper door panel extends from the threshold at the floor to the top of the door opening. The lower door panel extends downward from the threshold to the lowest step of the stepwell. The lower panel can operate independently from the upper panel, and, when closed, isolates the stepwell from the outside environment. This type of door has been called a Dutch door or snow door.

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 which has since been conducted by FRA/Volpe and the industry has lead to Revision 2 of this Standard that requires cab-end collision and corner posts be designed to absorb a significant 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.

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 Transport 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 of the research and testing of cab-end collision posts and corner posts were done for "flat-end" cab cars, the Standard does provide an equivalent alternative approach for car designs that are not flat-ended.

For reference, research conducted by FRA and the Volpe Center has concluded that a dynamic performance requirement could provide an equivalent means of verifying the severe deformation capability of cab-end collision posts and corner posts. The following dynamic requirements were under consideration as an equivalent alternate approach at the time this Standard was being updated:

Cab Car Collision Post

> The cab-end collision post shall resist the impact with a 10,000 pound cylindrical shaped proxy object (outside diameter of 48 inches and width of 36 inches) at a vehicle speed of 21 miles per hour. The proxy object shall impact the collision post 30 inches above the top of the underframe. The proxy object shall not intrude more than 10 inches into the operator's cab or passenger seating area and without complete separation of the post, its connection to the underframe, or its connection to either the roof structure or A-T plate (if used).

Cab Car Corner Post

> The cab-end corner post shall resist the impact with a 10,000 pound cylindrical shaped proxy object (outside diameter of 48 inches and width of 36 inches) at a vehicle speed of 20 miles per hour. The proxy object shall impact the corner post 30 inches above the top of the underframe. The proxy object shall not intrude more than 10 inches into the operator's cab or passenger seating area and without complete separation of the post, its connection to the underframe, or its connection to either the roof structure or A-T plate (if used).

A.2.5 End-Compression Strength

This Standard follows the North American precedent for car body 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 shear back coupler, compatible with the intended use of the equipment, is selected for use. Also, designs using crash energy management are considered (see Section 6.0).

A.2.6 Truck attachment

Truck attachment strength requirements in this Standard were also based on corresponding requirements in AAR S-034 and FRA at 49 CFR 229.141 (a) (5). This APTA Standard is more comprehensive, however, because it applies to all passenger equipment, including cars and locomotives, and because it more definitely establishes the vertical and horizontal strength requirements to obtain the benefit of the weight of the truck and the horizontal strength of the truck attachment to the car body in derailments and collisions.

The truck attachment requirements in this APTA Standard can be traced back to the same 1938 train wreck in Tortuga, California that spawned the anticlimbing requirements discussed in Section A.2.1. Regarding the telescoping discussed in Section A.2.1, 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 car body. This means that 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 car body. 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 car body 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. 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-car body attachment to have a strength in the horizontal plane (a “shear value”) of 250,000 lb (metric) was featured as a specific improvement of the AAR Standard when issued compared to 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 (metric) 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 their being a semi-permanent appendage of the car body 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 car body, so that 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, which must be accounted for by the design of the car body, truck, and attaching structural elements.

A.2.7 Side Impact

Robert Ebenbach, a rail car structural engineer who started with the Budd Company in the early 1930s, was, later in his career, involved in the repair of rail cars 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. Mr. Ebenbach devised a static design load to be applied to the side sill to force the designer to stabilize the gussets, so that 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 that the underframe would be at least partially effective in resisting transverse loads applied to the side sill as a plate girder structure.

Mr. 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 Mr. 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.

Annex B Bibliography

[B1] AAR M-206, Purchase and Acceptance of A.A.R. Approved Tightlock Couplers and Coupler Parts, Radial Connections, Yokes, and Attachments for Passenger Equipment Cars.

[B2] AAR S-028, Specifications for Flexible Coupler Carriers For Use With AAR Standard H Tightlock Couplers (obsolete, available from APTA)

[B3] AAR S-166, H Tightlock Coupler, Rotary Operating, for Locomotives (1980 version, which also covered Passenger Cars, is obsolete, but is available from APTA)

[B4] AAR S-514, Couplers for New Locomotives Other Than Steam

[B5] AAR S-580, Locomotive Crashworthiness (Adopted 1989, Revised 1994, currently being revised by the AAR in conjunction with the RSAC)