9. APTA PR-CS-S-016-99, Rev. 2 Standard for Passenger Seats in Passenger Rail Cars

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APTA Commuter Rail Executive Committee

Abstract: This standard contains design guidelines, recommendations and requirements for the procurement, design, strength, and testing of passenger seats for use in passenger rail cars.

Key Words: ATD, crashworthiness, injury, seat, seating

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Summary of Revision 2 Changes

The following list describes the principal changes that were made to this standard as part of Revision 2:

- Define and require HIC15.
- Added explicit reference to Walkover seatback attachment requirement in section 4.4.
- Added requirement for positive seat securement indicator for rotating seats in section 4.7.
- Added neck injury criteria for forward-facing ATDs in dynamic sled tests described in section 5.2.
- Added the same test requirements for rear-facing dynamic test as for forward-facing dynamic test in section 5.2, including head, chest, femur, and neck injury criteria.
- Require Hybrid III anthropomorphic test devices for dynamic tests described in section 5.2 in order to measure neck forces and moments.
- Require lateral and vertical attachment strength tests to be conducted dynamically, not statically or analytically, in section 5.3.
- Add reference to SAE AS8049 for acceptable crash pulse tolerance.
- Added a forward-facing seat attachment strength test using un-instrumented 95th percentile ATDs in section 5.3.4, which is intended to satisfy the requirements of Code of Federal Regulations, Title 49, Part 238, Section 233.
- Modified Scope in Section 1.2 to reflect inclusion of all classes of passenger seating, i.e., coach, first, business, etc., and specify dynamic testing of predominant seat variation.
- Modified Limitations of Standard in Section 1.3 to specifically exclude seating in food service cars, lounge cars, and sleeping cars, as well as flip-up seats and longitudinal seats that face the center aisle or window.
- Added selected test results from CEM train-to-train full-scale tests to Annex B.
- Revision 1 allows seats to be mounted to a rigid test fixture *or* to a simulated car structure. Revision 2 specifies that the attachment must use the same fasteners or attachment method used in service. Reaction loads shall be measured with load cells, at the request of the purchaser, if seats are mounted to a rigid test fixture.
- Analysis is not allowed as a substitute for any testing requirements.
- Modified definition and evaluation of ATD compartmentalization.

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APTA PR-CS-S-016-99, Rev. 2
Standard for Passenger Seats in Passenger Rail Cars

1. Overview

This standard provides design guidelines, recommendations and requirements for row-to-row passenger seating equipment installed in passenger rail cars that are part of the general railroad system of transportation.

This standard is intended to be applied to passenger seating equipment in all new passenger rail car procurements, and generally describes the qualifying processes, review and submittal requirements and documentation associated with the procurement process. Seating equipment in compliance with Revision 1 of this standard may be used for refurbishments or retrofits of existing rail cars. This standard becomes effective on the date of authorization stated on the title page.

1.1 Purpose

The purpose of this standard is to:

– Establish minimum requirements for seat attachment strength

– Establish minimum human injury criteria associated with dynamic seat testing

– Specify minimum flame and smoke standards

– Specify minimum reporting requirements to demonstrate compliance with this standard.

– Provide background information and design guidelines

– Provide nomenclature and definitions associated with passenger rail seating

The intent for complying with this standard is to provide and maintain an appropriate level of safety for rail passengers, for that component of safety influenced by the seating. Due diligence to meet the intent of this standard shall be maintained.

1.2 Scope

This standard is intended to provide guidance on the design, manufacture and testing requirements of passenger seating in passenger rail cars. This standard shall apply to transversely mounted row-to-row passenger seats in all classes, i.e., first, business, coach, etc., on passenger rail cars. Portions of this standard are intended to provide details for meeting the requirements of *49 CFR Part 238.233 for Tier I Passenger Seating Equipment.* [1]

It is **not** the intention of this standard to test every possible seat variation, which may include seat capacity, seat height, seat pitch, etc. The intent of this standard is to test the predominant seat variation(s), such that the variation(s) tested represent most of the seating capacity in a car. For the predominant seat variation, the seats should be tested using the largest seat pitch.

[1] For references in Italics, see Section 2.

Typically, only one forward-facing and one rear-facing sled test need to be conducted on the predominant seat variation. However, if a given seat variation consists of more than 10% of a car's seating capacity, it shall also be tested.

1.3 Limitations of this standard

This seating standard does **not** apply to seating in food service cars, lounge cars, or sleeping cars, flip-up seats, or longitudinal seats that face the center aisle or side windows. This seating standard does not address bulkhead seating or other seating arrangements in which there is an impact surface other than a seat back.

1.4 Facing Seat Configuration

The facing seat configuration, in which two rows of seats are positioned such that passengers face one another, is common in passenger cars. This configuration is often preferred by passengers for a variety of reasons. There is mounting evidence, however, from computer analyses[2], dynamic sled tests[3], and accident investigations[4,5], that facing seats, also known as open bay seats, do not provide the same level of occupant protection during an accident as row-to-row seats that face the same direction.

Fixed workstation tables that are designed to absorb the kinetic energy associated with an occupant during a collision have been shown to mitigate hazards associated with open-bay seats[6]. Where practical, it is recommended that fixed workstation tables be positioned between facing seats to compartmentalize passengers and minimize injury severity in the event of a collision. Workstation tables must meet the requirements in the APTA SS-C&S-XXX-09 Standard for Fixed Workstation Tables in Passenger Rail Cars.

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 571, Federal Motor Vehicle Safety Standards

49 CFR Part 572, Anthropomorphic Test Devices

49 CFR Part 238, Federal Railroad Administration Passenger Equipment Safety Standards

APTA RP-I&M-002-98, "Development Model for Rail Car Technical Documentation"

APTA SS-PS-004-99, Rev.1 "Standard for Low-Location Exit Path Marking"

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[2] Tyrell, D.C., Severson, K.J., Marquis, B.J., "Analysis of Occupant Protection Strategies in Train Collisions," American Society of Mechanical Engineers, AMD-Vol. 210, BED-Vol. 30, pp. 539-557, 1995.

[3] VanIngen-Dunn, C., "Commuter Rail Seat Testing and Analysis of Facing Seats," US Department of Transportation, DOT/FRA/ORD-03/06, December 2003.

[4] Accident of Metrolink passenger train #111 on Sept. 12, 2008, in Chatsworth, CA.

[5] Accident of Metrolink passenger trains #100 and #901 on Jan. 25, 2005, in Glendale, CA.

[6] Severson, K. Parent, D., "Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Occupant Experiments," American Society of Mechanical Engineers, Paper No. IMECE2006-14420, November 2006.

SAE AS8049, Performance Standards for Seats in Civil Rotorcraft and Transport Airplanes

SAE J 826, Devices for Use in Defining and Measuring Vehicle Seating Accommodation

SAE J 1454, Dynamic Durability Testing of Seat Cushions for Off-Road Work Machines

SAE J211-1, Surface Vehicle Recommended Practice

Technical Data Sheet, First Technology Safety Systems, 1992 for Models H3-5F-R, H3-50, and H3-95-R

2.1 Procurement specifications

This standard is intended to be supplemented by procurement specifications prepared by the Purchaser and directed to the Seat Manufacturer. These procurement specifications should, as a minimum, include:

- Expected environmental operating conditions and standards against which measurable results should be specified for conditions such as temperature ranges, humidity, salt atmosphere, ultra-violet radiation, static electricity and vibration.
- Normally used cleaning agents.
- Requirements for Aesthetic features such as:
  a) Fabric types and colors
  b) Finishes
- Format for Parts, Service and Maintenance Manual (see APTA RP-I&M-002-98 titled "Development Model for Rail Car Technical Documentation")

The procurement specifications may, at the option of the Purchaser, modify the requirements of this standard where special conditions make such modifications reasonable and do not unduly or unreasonably alter the intent of this standard with respect to the crashworthiness design of the seat and the safety and comfort of the occupant.

3. Definitions, abbreviations and acronyms

For the purpose of this standard the following terms and definitions apply:

3.1 Definitions

3.1.1 anthropomorphic test device (ATD): Also know as a crash test dummy, this device is a biofidelic representation of a human body, which is used to assess the risk of injury under simulated collision conditions.

3.1.2 axial neck load, F_z: Neck injury criterion indicating maximum allowable axial tension/compression force measured at the upper neck load cell.

3.1.3 compartmentalization: Compartmentalization is a seat design strategy that aims to contain occupants between rows of seats during a collision, preventing occupants from traveling over the tops of seat backs and impacting other more hostile objects. During sled testing, ATD compartmentalization is evaluated up until the point of maximum forward progress of the ATD. The ATD's torso must be confined between the seat backs (potentially deformed) of consecutive rows of seats until the ATD begins to rebound and move away from the impacted seat.

3.1.4 facing seats: Seats which are mounted in the car such that occupants face one another, also known as open-bay seating

3.1.5 fixed seat: Seat which cannot be rotated, and not of the walkover type design. These seat types can only face in the direction at which they are mounted.

3.1.6 flip seat: Seats that have bottom cushions that can be flipped up to provide additional space. Flip seats are often used in areas of a car to provide wheelchair parking space.

3.1.7 g, G: An acceleration equal to 32.2 ft/sec^2 (9.8 m/sec^2).

3.1.8 H-Point: Hip Point location on the seated occupant as measured according to SAE J 826.

3.1.9 HIC: Head Injury Criterion – calculated according to the following:

$$HIC = \left[(t_2 - t_1)\left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)dt\right]^{2.5}\right]_{max}$$

where:

t_1, t_2 = any two points in time during the head impact, in seconds,

a(t) = the resultant head acceleration during head impact, in Gs.

HIC15 indicates that t_1 and t_2 are not separated by more than 15 milliseconds.

3.1.10 High Performance Photo-Luminescence: A material that is capable of emitting fluorescent and/or phosphorescent light at a high rate and for an extended period of time after absorption of light radiation from an external source by the process of photon excitation. Reference APTA SS-PS-004-99.

3.1.11 hip to knee space: A horizontal dimension from the back rest of a seat to the back of the next seat. This dimension is measured along the centerline of an occupant placement in a horizontal plane tangent to the top of the bottom cushion. See Figure 1.

3.1.12 impact seat: The forward-most seat in two rows of seats into which ATDs are thrown in the testing described in Sections 5.2.1 and 5.3.4.

3.1.13 ingress/egress space: Space available for passengers to occupy or leave an occupant space. This has importance for both normal passenger seating and also for emergency exit considerations. See Figure 2.

3.1.14 lateral crash pulse: A time based acceleration curve, triangular and symmetrical in shape and having a 250 millisecond base and a 4g peak. A lateral crash pulse is in the horizontal direction and perpendicular to the normal direction of travel of the car.

3.1.15 launch seat: The rear-most seat of two rows of seats, initially containing ATDs in the testing described in Sections 5.2.1 and 5.3.4.

3.1.16 left hand and right hand seats: Seat handedness is most easily defined by sitting in the seat. If the seat is a transverse seat and the window is on the left hand, then it is a left hand seat assembly.

3.1.17 left hand and right hand seat components: Handedness of seat components are also defined by sitting in the seat. If an armrest, for example is on the left side of the seat, then it is a left hand armrest. Seat components that are not symmetrical and only one of which can be supplied with the seat, carry the same handedness name as the seat assembly. See Figure 3 and Figure 4 for illustrations.

3.1.18 longitudinal: Descriptive of a direction parallel to the normal direction of car travel.

3.1.19 longitudinal crash pulse: A time based acceleration curve, triangular and symmetrical in shape and having a 250 millisecond base and an 8g peak. A longitudinal crash pulse is in the direction parallel to the normal direction of travel of the car.

3.1.20 Longitudinal seating: Seats that face the center aisle or side window, perpendicular to the direction of travel.

3.1.21 Low-Location Exit Pathway Marking: Evacuation guidance for passengers and crewmembers when normal and emergency sources of illumination are obscured or inoperative. Reference APTA SS-PS-004-99.

3.1.22 N_{ij}: Neck Injury Criterion, calculated according to the following:

$$N_{ij} = \frac{F_z}{F_{\text{int}}} + \frac{M_{ocy}}{M_{\text{int}}}$$

where:

F_z = upper neck axial load-time history,

F_{int} = critical intercept values used for normalization of axial neck load, +1530 lbf (6086 N), tension; and -1385 lbf (6160 N), compression,

M_{ocy} = flexion (forward)/extension (rearward) neck bending moment-time history at the, occipital condyle

M_{int} = critical intercept value used for normalization of fore/aft neck bending moment, +229 lbf-ft (310 Nm), flexion (forward bending); and -100 lbf-ft (135 Nm), extension (rearward bending),

3.1.23 occupant: A seated passenger occupying a seat placement in a normal manner.

3.1.24 occupant placement: That portion of a seat assembly that is normally occupied by a seated passenger. For example, a two passenger seat assembly has two occupant placements.

3.1.25 passenger: A person who is within the occupied volume of a passenger rail car, whether seated or not.

3.1.26 primary impact: During a car crash, primary impact refers to the impact of the car itself.

3.1.27 purchaser: The agency or organization (transit authority or carbuilder) responsible for the acquisition of seating equipment.

3.1.28 rotating seats: Seats that are transversely mounted, and can be rotated to face the front or back of a passenger rail car.

3.1.29 row-to-row seating: Seating arrangement such that each row of seats face the same direction as illustrated in Figure 1. Also known as theater style seating.

3.1.30 seat manufacturer: The agency or company responsible for the design, specification compliance and warranty of the seat and its design.

3.1.31 seat pitch: The distance between like features on seats facing the same direction, as illustrated in Figure 1.

3.1.32 shall: Practices directed by shall are required or standard practices.

3.1.33 secondary impact: During a car crash, secondary impact refers to the impact of passengers to features on the car or other passengers.

3.1.34 should or may: Practices directed by should or may are recommended practices.

3.1.35 tertiary impact: Passengers who have undergone a secondary impact and have glanced off of that object to impact another object in the car.

3.1.36 tier I: Rail Equipment operated at speed not exceeding 125 mph (200 k/h) as defined in 49 CFR Part 238.

3.1.37 transverse: Descriptive of a direction perpendicular to the normal direction of car travel.

3.1.38 walkover seat: A particular type of seat design in which the seat back and bottom cushion are articulated such that the direction that occupants face can be reversed by moving the seat back longitudinally.

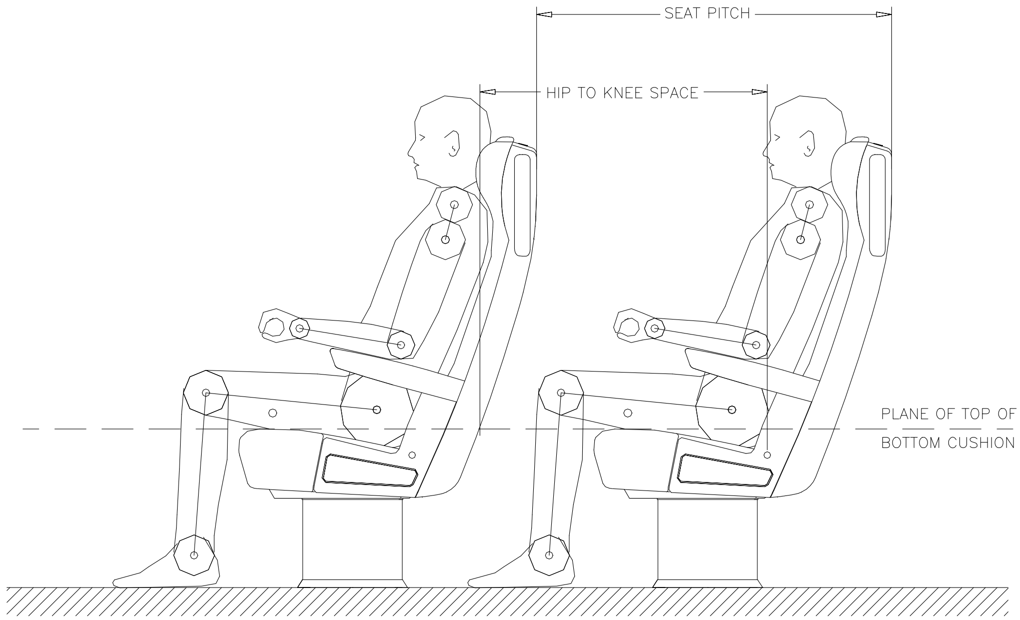


Figure 1 – Hip to Knee Space and Seat Pitch

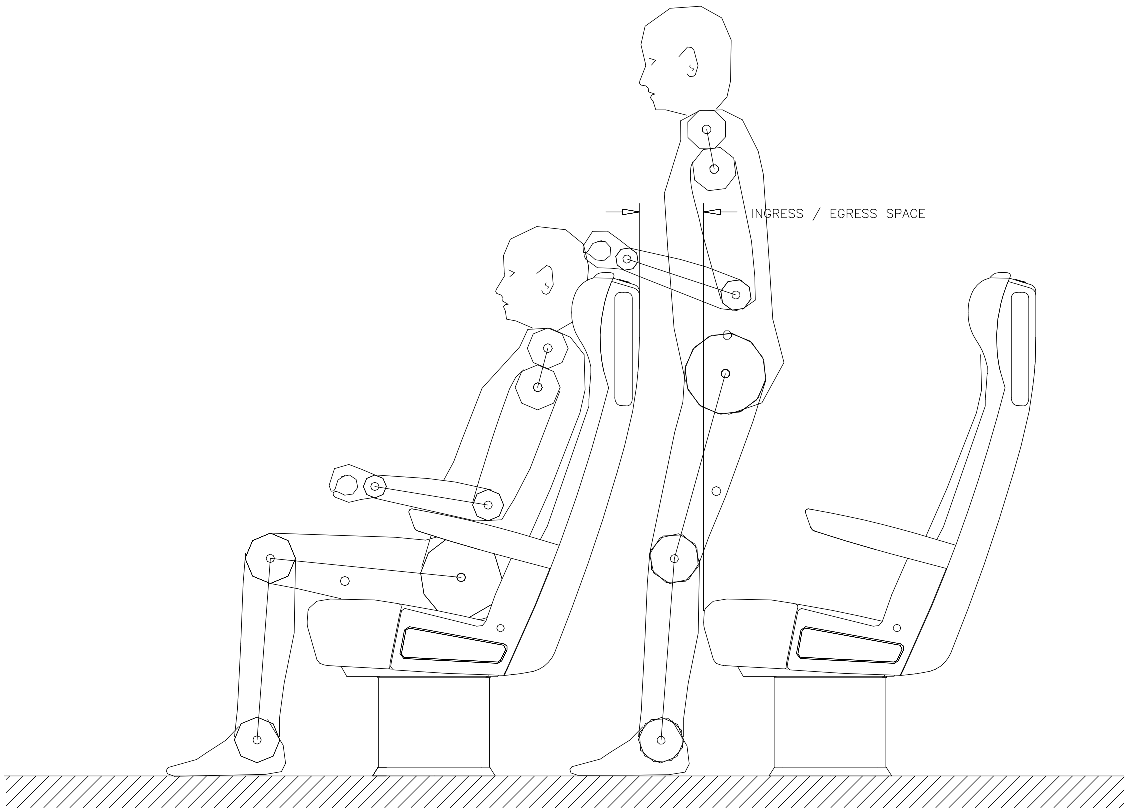


Figure 2 – Ingress/Egress Space

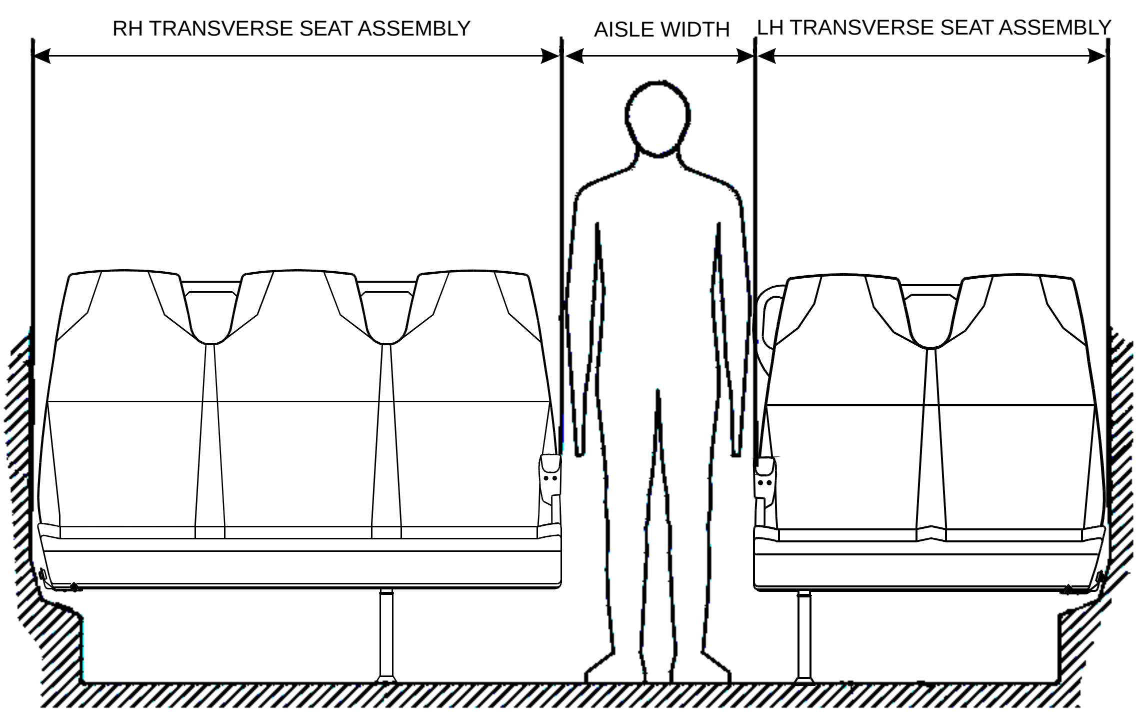


Figure 3 – Cross Section through 3+2 Seating

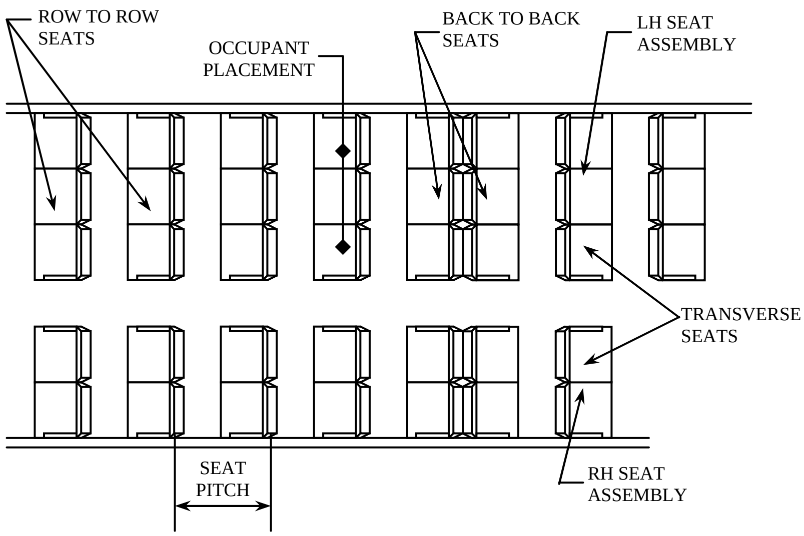


Figure 4 – Seat Arrangement and Nomenclature

3.2 Abbreviations and acronyms

ADA	Americans with Disabilities Act
ASME	American Society of Mechanical Engineers
ATD	Anthropomorphic Test Device (also referred to as crash test dummy - see 49CFR Part 572)
CFR	Code of Federal Regulations
FMVSS	Federal Motor Vehicle Safety Standard
HPPL	High Performance Photo-Luminescence
LLEPM	Low-Location Exit Pathway Marking
MIL-STD	Department of Defense Military Handbook
SAE	Society of Automotive Engineers
SRP	Seat Reference Point as given by SAE AS8049

3.3 Anthropomorphic test devices (ATDs)

Reference is made in this standard to a series of Anthropomorphic Test Devices (ATDs) that are designed to represent the 50th-percentile male occupant, and the 95th-percentile male occupant. The ATDs used to meet the test requirements specified in this standard must be compliant with 49 CFR Part 572.

A table of available ATDs and their typical weights as used in testing to represent these occupant populations is given below for reference in Table 1:

Table 1 – Typical Weights of ATDs

ATD	WEIGHT	
Hybrid III 50th male	172.3 lb	78.2 kg
Hybrid III 95th male	223.4 lb	101.3 kg

Reference: First Technology Safety Systems, Technical data sheet, 1992 for Models H3-5F-R, H3-50, H2-50 and H3-95-R.

4. Seat design features

This section is intended to provide guidelines, recommendations and requirements regarding features commonly found on passenger rail seating equipment.

4.1 Materials and workmanship

Seating should be made of materials suitable for use in the railroad environment. All materials should be new. The seat shall be free of protrusions, sharp edges or corners that could cause injury catch or damage the clothing of passengers or crew members. The seat should be free of rattles or loose joints that could create noise or vibration during normal operation. All parts of the seat should be interchangeable with parts of like seats. No unusual adjustments or procedures such as grinding or bending of materials should be required to replace parts that are designed to be replaced. The use of exposed fasteners should be minimized.

4.2 Industrial design

To provide a pleasing and coordinated environment within the car interior, the seat manufacturer should participate with the purchaser in a comprehensive Industrial Design Program. As part of this program the seat manufacturer should submit decorative samples of materials that form the finished exterior of the seating equipment. Human factors addressing such issues as accessibility, emergency exits, use by the elderly, hearing and sight impaired should be part of the Industrial Design Program.

Seating should be designed to comfortably accommodate the range of passengers anticipated, from the 5th percentile female to the 95th percentile male. Adequate hip to knee space should be provided for the 95th percentile male. To document the ergonomic aspects of the seat design the purchaser should ask that the seat manufacturer prepare an Ergonomic Analysis and Report as part of its work for the supply of seating equipment. Contents of the Ergonomic Analysis should address issues such as seat comfort, hip to knee space, cushion contours, armrest height, lateral passenger space, ingress-egress space, effort required to adjust and operate various seat features, and other issues involving the use of the seating equipment by passengers.

4.3 Cushions and upholstery

Cushions should be contoured to provide optimal occupant retention and comfort during normal use. Cushioning material should be durable and should be capable of passing the cushion life test described herein.

4.4 Walkover seats

Walkover seats, if provided, shall be fitted with a locking mechanism designed to prevent the seat back from moving from one extreme seating position to the other during the crash pulse shown in Figure 13. Adequacy of the lock mechanism shall be demonstrated as part of the Dynamic Sled Test given in Section 5.2. The purchaser may require additional testing of the lock mechanism according to test procedures agreed to by the purchaser and the seat manufacturer. The lock mechanism should not require any maintenance over the life of the seat. The seat back on walkover seats must be adequately fastened to the seat base such that it will not become separated from the seat base during the dynamic tests from Sections 5.2 and 5.3.

4.5 Recline

Recline mechanisms, if provided, should meet the requirements of this section. Seat back should recline according to the dimensions specified in the Procurement Specification. Recline control should provide for infinite adjustment through the range specified. Recline mechanism design should be such that activation of the recline control does not allow a sudden change in back rest position. Reclining seat backs should return to the up position in a controlled, damped manner. Care should be taken so that reclined seats do not present obstructions for emergency egress.

4.6 Armrests

Armrests, if provided should be optimally positioned to support the range of occupants specified. The top of the armrests should be covered with a durable material as provided for in the Procurement Specifications. Armrests shall be capable of passing the Armrest Strength Test given in Section 5.1.4.

4.7 Rotation

Seat rotation, if provided should be 180 degrees. A lock capable of passing the anti-rotation test described in Section 5.3.1 shall be provided in both extreme positions. A seat securement system is required to prevent the disengagement and undesired rotation of seats. The system shall have a positive seat securement indicator that makes clear to rail operators as well as passengers whether or not the rotating seat is in a locked and secured position. The rotation mechanism should operate smoothly. Lateral offset of the rotation mechanism or seat mounting geometry should be sufficient to allow passenger seats to be placed close to the wall for maximum aisle width.

5. Seat testing

Seating equipment shall be subjected to a series of static, dynamic and durability tests to verify that the requirements given in this section are met. Testing shall be conducted on seat assemblies or components that are representative of seating equipment to be delivered. If a structurally identical seat has met all the requirements in the current version of this standard, then the manufacturer may provide data from the previous tests to satisfy the corresponding portion of this standard, for approval of the subject seat by the purchaser. Due diligence to meet the intent of this standard shall be maintained.

5.1 Static strength testing

The purpose of static seat strength testing is to verify that the seat structure and its components meet the various loading conditions that are expected in passenger rail operation. The testing should be conducted on representative samples of various configurations of the seats supplied. For example, if the supply of seating includes one, two and three passenger seats then each should be tested. Where, however, sufficient similarity between seat types exist, the purchaser and manufacturer may jointly agree to apply the results of testing to various seat types.

In general, static testing can be performed on the structural parts of a seat assembly, usually the seat frame, pedestal and other mounting equipment and hardware. Where concern exists that non-structural components can be damaged by the stresses and flexing of structural components, they may be included in the testing.

Seat frames and components shall be designed and tested to meet the individually applied static load requirements given below with no yielding of structural materials, loss of function or change in appearance of the seat or component. A small amount of yielding due to relieving of trapped manufacturing stresses (welding, forming, etc.) shall be permissible.

5.1.1 Backrest strength test

The purpose of this test is to establish the strength of the seat back for durability, especially against the effect of a passenger sitting behind this seat pushing his/her feet against the seat back. Therefore, a load of 300 lb. (136 kg) per occupant shall be applied to the upper part of the seat back at the lateral midpoint of each seat back and at an elevation of 36 inches (914 mm) above the floor, or 3 inches (76 mm) below the top of the seat back, whichever is lower, and in a direction perpendicular to the seat back (reference Figure 5). This load is to be distributed across the seat back. Reclining seats shall be in the full upright position. A fixture may be used to distribute the load across the seat back members. Load shall be applied for a minimum of 5 seconds. This test shall be repeated in both horizontal directions, from the back of the seat and from the front of the seat.

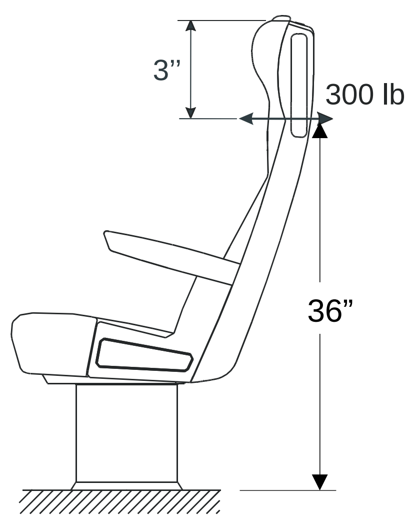


Figure 5 – Backrest Strength Test Loading Conditions

5.1.2 Grab handle strength test

A 300 lb. (136 kg) load shall be applied to the grab handle at a point near the middle of the grab handle in a longitudinal direction (reference Figure 6). Load shall be applied for a minimum of 5 seconds. This test shall be repeated in both longitudinal directions. A fixture may be used to insure that the load is properly applied and distributed onto the grab handle.

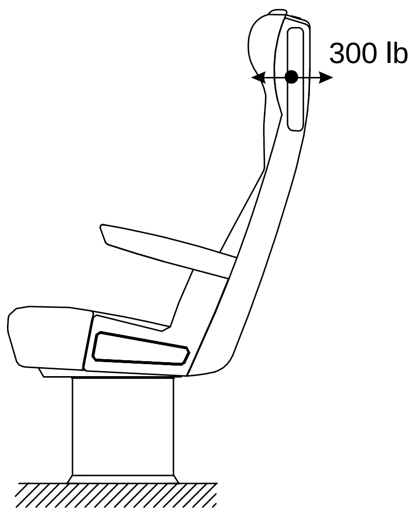


Figure 6 – Grab Handle Strength Test Loading Conditions

5.1.3 Vertical seat strength

A load of 450 lb. (204 kg) per occupant shall be applied on the seat bottom near the front edge of each occupant placement in a vertical downward direction at the midpoint of each occupant position (reference Figure 7). The contact area of the applied load shall not exceed 4 square inches (26 square centimeters). The load shall be applied for a minimum of 5 seconds.

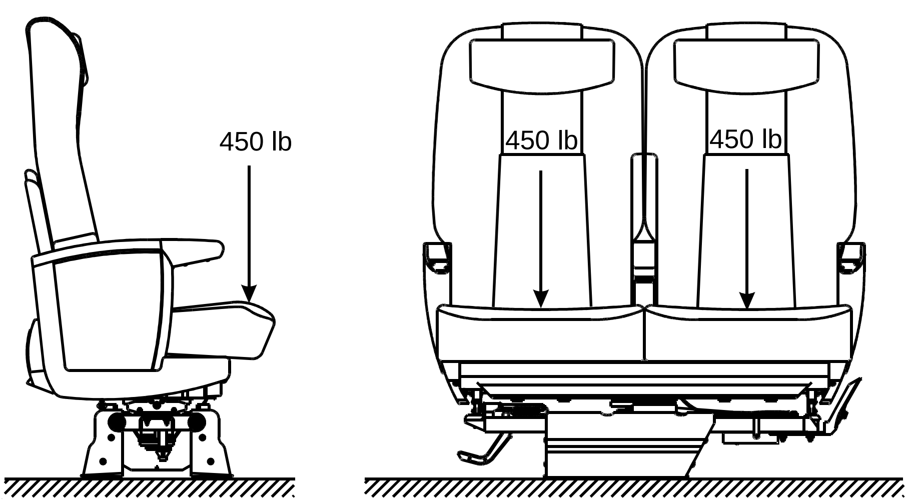


Figure 7 – Vertical Seat Strength Test Loading Conditions

5.1.4 Armrest strength

A load of 250 lb. (113 kg) shall be applied to the horizontal member of the armrest structure at a point that produces maximum stress in the member (reference Figure 8). A fixture may be used to properly apply and distribute the load. The contact area of the applied load shall not exceed 4 square inches (26 square centimeters). The load shall be applied for a minimum of 5 seconds. This test shall be repeated for the two horizontal conditions (toward the aisle and toward the wall side of the seat) and then vertically downward.

For seats with folding center armrests, the folding armrest shall be tested by applying a vertical 150 lb. (68 kg) load as near as practical to the end of the armrest. Separately, a horizontal 150 lb. (68 kg) load shall be applied as near as practical to the end of the armrest. The horizontal load test shall be repeated for both directions. The contact area shall not exceed 4 square inches (26 square centimeters) in all cases.

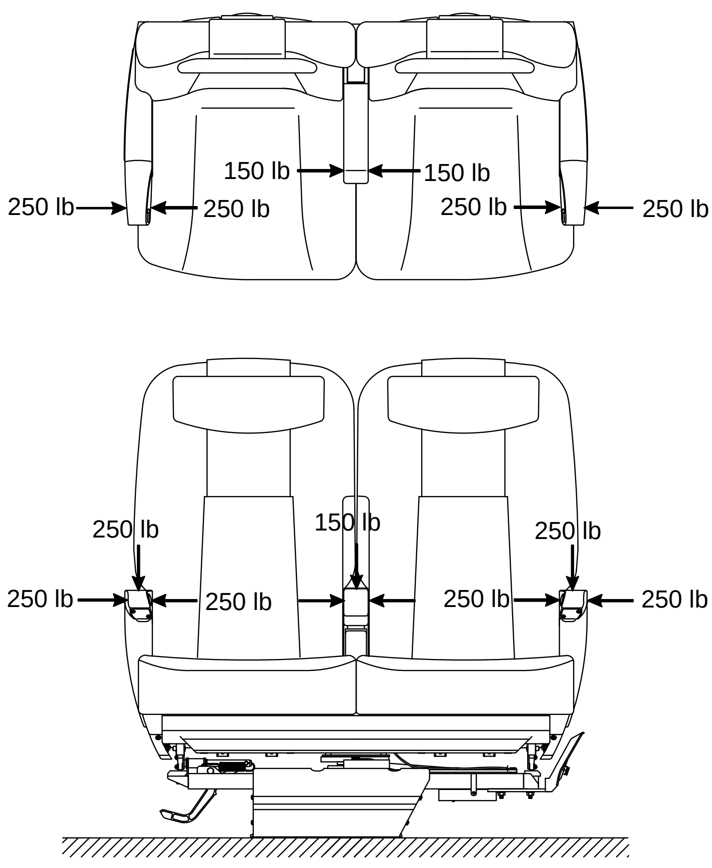


Figure 8 – Armrest Strength Test Loading Conditions

5.1.5 Footrest test

With footrest deployed in the most nearly horizontal position, a 400 lb. (180 kg) load shall be placed on the diagonal center of the footrests surface (reference Figure 9).

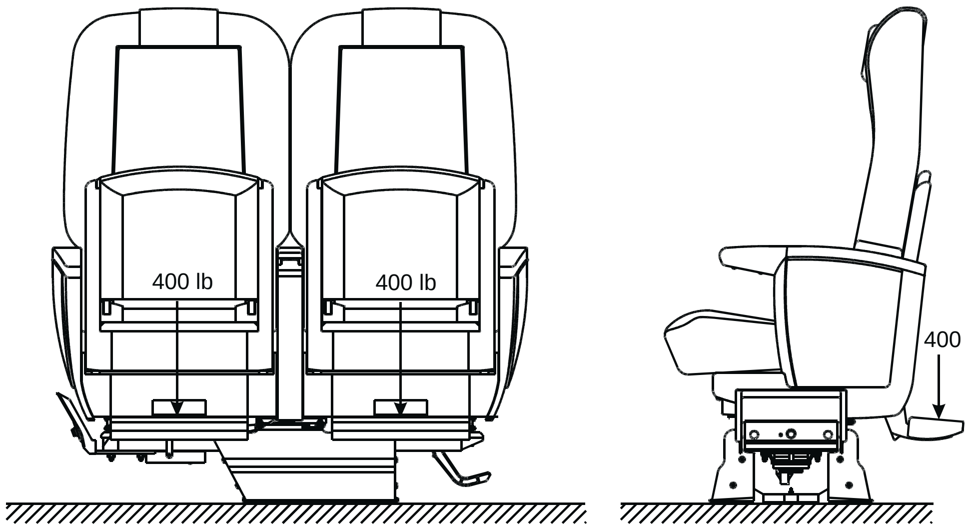


Figure 9 – Footrest Strength Test Loading Conditions

5.1.6 Legrest test

With the legrest assembly in the most nearly horizontal position, place a 65 lb. (30 kg) load distributed over an area of 25 square inches (160 square centimeters) on the diagonal center of the legrest cushion (reference Figure 10). This test is intended for legrests that have a load limiting feature to prevent passengers from using it as a step stool. Overloading of these types of legrests shall not result in structural failure or sudden drop of the load.

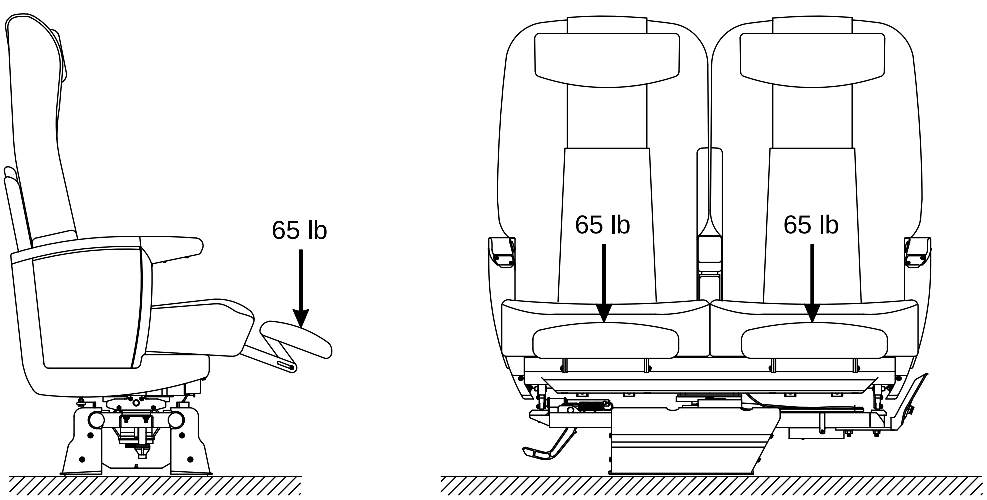


Figure 10 – Legrest Strength Test Loading Conditions

5.1.7 Tray table test

With the tray table mounted to the seat in deployed and extended position, place a 5 lb. (2.2 kg) load distributed over an area of 25 square inches (160 square centimeters) upon the diagonal center of the tray and let it remain for 10 seconds to determine the pre-load height from a reference location (reference Figure 11). Add an additional 17 lb. (7.7 kg) to the 5 lb. pre-load and let it remain for 10 minutes. The maximum temporary deflection from the reference position should not exceed 1 inch (19 mm).

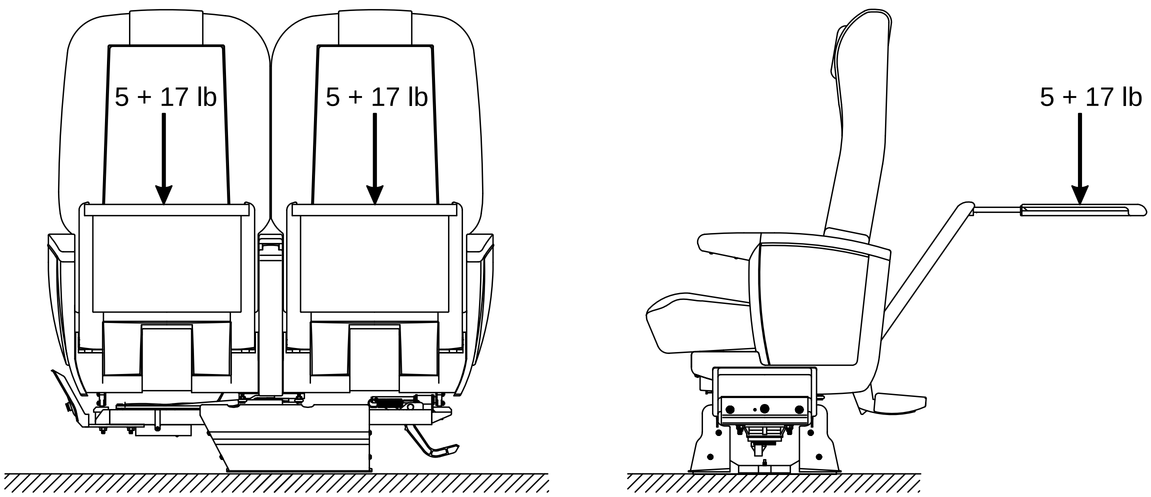


Figure 11 – Tray Table Strength Test Loading Conditions

5.2 Dynamic sled testing

The primary objectives of the dynamic sled tests in this section are to simulate a rail car crash and verify the following:

- That seat assemblies remain attached to the car
- That all seat components, including cushions, remain attached to the seat assembly
- That the seat effectively compartmentalizes the occupants
- That the seat does an effective job of mitigating human injury

There are two dynamic sled tests prescribed to measure these objectives. Each test uses instrumented Hybrid III 50th percentile male ATDs to simultaneously measure the seat's structural strength and human injury potential. In one test the seats and ATDs will be forward-facing. In the other test the seats and ATDs will be rear-facing.

As described in the Scope in Section 1.2, the predominant seat variation should be tested, using the largest seat pitch. Typically, only one forward- and one rear-facing sled test need to be conducted on the predominant seat variation. However, if another seat variation consists of more than 10% of a car's seating capacity, it shall also be dynamically sled tested.

The ATDs shall meet the standards and requirements needed to comply with *49 CFR Part 572, Subpart E*[7]. The adjustment, positioning, and care of all ATDs used in the testing processes shall be in accordance with the standards and requirements needed to comply with SAE AS8049.

Each ATD shall be clothed in a form fitting, cotton stretch garment with short sleeves, and mid-thigh-length bottoms. The ATDs shall also be fitted with shoes. Each ATD shall be seated in the center of the occupant placement, in as nearly symmetrical a position as possible and in a uniform manner so as to obtain reproducible test results. The following ATD components shall be positioned as follows:

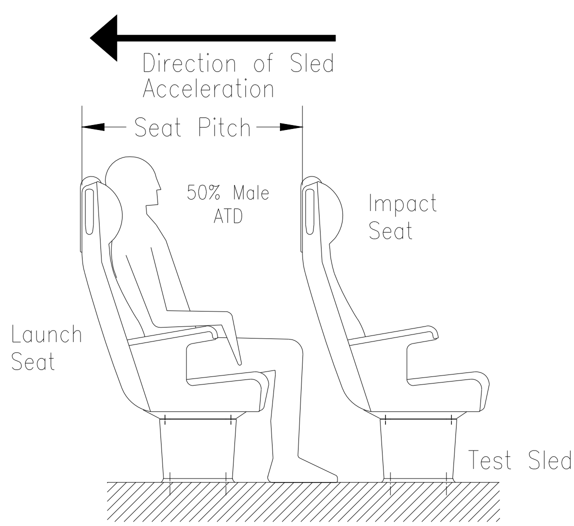
- Back shall be placed against the seat back without clearance.
- Knees shall be separated by four inches.
- Hands shall be placed on the top of the upper legs, just behind the knees.
- Feet shall be placed flat on the floor and so that the centerlines of the lower legs are approximately parallel.
- Lower legs shall be placed as close to vertical as possible.

The ATDs may be tethered to the sled; however tethering shall not restrict ATDs such that evaluation of compartmentalization is impeded.

5.2.1 Forward-facing seat attachment and human injury test

5.2.1.1 Test Conditions

This test shall use two transversely mounted rows of seats so that occupants are facing seat backs of an adjacent row of seats and facing the direction of travel (see Figure 12). If seats contain adjustable features such as recline, tray tables, footrests, these should be placed in the upright and stowed positions.



[7] For references in Italics, see Section 2

Figure 12 – Schematic of Forward-Facing Seat Attachment and Human Injury Test

Seats shall be subject to the following test:

- Two rows of seating shall be tested with the rear row of seats fully occupied by Hybrid III 50th percentile male ATDs, one ATD per seating position. All the ATDs shall be instrumented with head, chest, neck, and femur transducers.

- Seats shall be mounted on a rigid test fixture or simulated car structure using the same fasteners or attachment mechanism used in service, i.e., bolts, screws, seat track, tapping plate, etc., and at the largest seat pitch for the seat's application. It is preferred to mount seats to a simulated car structure. If seats must be fastened directly to a rigid test fixture, the purchaser may request that load cells be placed at the seat mounting locations between the seat and the test fixture to measure the reaction loads that would be applied to structural carbody design.

- The test sled shall be subjected to an 8g, 250 millisecond crash pulse as shown in Figure 13. The crash pulse shall be in a direction such that the occupants in the rear row of seats are thrown into the seat backs of the front row of seats. The crash pulse shall comply with the requirements established in SAE AS8049, Appendix A. Sled braking forces on acceleration-type sleds should be kept as low as possible to minimize the sled deceleration after the 250 ms crash pulse to prevent damage to the launch seat caused by the rebounding ATD.

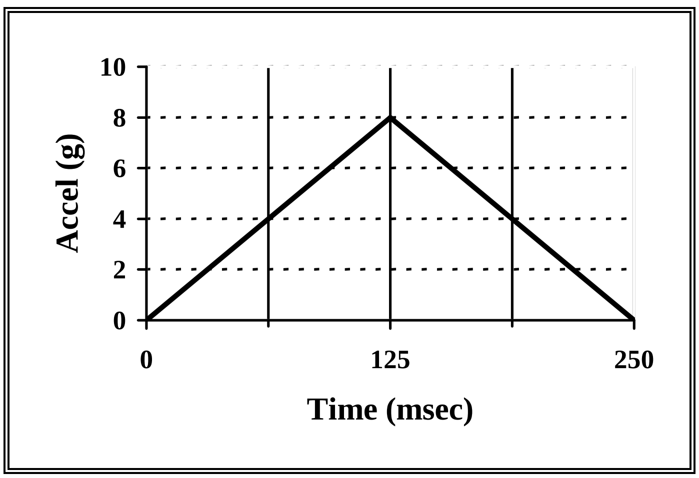


Figure 13 – Longitudinal Crash Pulse

5.2.1.2 Test Measurements and Documentation

The following forces, displacement, and accelerations shall be measured in accordance with SAE J211/1:

- Triaxial head acceleration-time history for each ATD
- Triaxial chest acceleration-time history for each ATD
- Axial left and right femur force-time history for each ATD
- Upper neck extension/flexion bending moment, My, for each ATD

- Upper neck axial force, Fz, for each ATD
- Upper neck shear force, Fx, for each ATD
- Axial Acceleration-time history of the test sled

The following injury criteria shall be computed in accordance with 49 CFR 571.208, where applicable:

- HIC15
- 3ms chest Gs
- Axial femur load
- Peak upper neck axial tension/compression forces
- Nij

Unless otherwise indicated, instrumentation for data acquisition, data channel frequency class, and moment calculations are the same as given for the 49 CFR Part 572, Subpart E Hybrid III test dummy.

The test shall be captured on video to evaluate the occupant kinematics and assess compartmentalization effectiveness.

5.2.1.3 Performance Requirements

For a successful test, the following requirements must be met:

- Seats may deform but shall not tear loose from their mountings.

- Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.

- The ATDs shall be compartmentalized between rows of seats, per the definition in Section 3.1. After testing, the seat backs shall not be collapsed to such an extent that they present an impediment to emergency egress.

- All injury measurements computed in Section 5.2.1.2 must meet the following criteria, which are defined in CFR 49 Part 571, Standard No. 208: Occupant Crash Protection. The injury criteria shall be calculated from test data that has been filtered in accordance with SAE J211-1, Table 1.

  - Head injury criteria, HIC15, must not exceed 700;
  - Neck injury criteria, Nij, must not exceed 1.0;
  - Neck axial tension, Fz, must not exceed 938 lbf (4,170 N);
  - Neck axial compression, Fz, must not exceed 899 lbf (4,000 N);
  - Chest deceleration must not exceed 60g over a 3ms clip;
  - Axial femur load must not exceed 2,250 lb (10,000 N).

5.2.2 Rearward-facing seat attachment and human injury test.

5.2.2.1 Test Conditions

The rearward facing test is similar to the forward facing test described above, except the seat is accelerated in the opposite direction and it is not mandatory to have more than one row of seats for the test. See schematic in Figure 14.

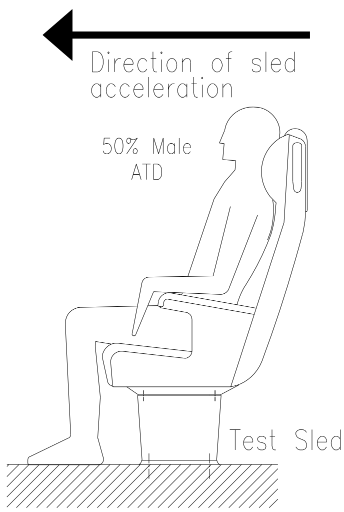


Figure 14 – Schematic of Rearward-Facing Seat Attachment and Human Injury Test

The ATDs shall be positioned in the same manner as described in section 5.2 above and subjected to the following test:

– The seat shall be fully occupied by Hybrid III 50th percentile male ATDs, one ATD per seating position. All the ATDs shall be instrumented with head, chest, and neck transducers.

– The seat shall be mounted on a rigid test fixture or simulated car structure using the same fasteners or attachment mechanism used in service, i.e., bolts, screws, seat track, tapping plate, etc. It is preferred to mount the seat to a simulated car structure. If the seat must be fastened directly to a rigid test fixture, the purchaser may request that load cells be placed at the seat mounting locations between the seat and the test fixture to measure the reaction loads that would be applied to structural carbody design.

– The test sled shall be subjected to an 8g, 250 millisecond crash pulse as shown in Figure 13. The crash pulse shall be in a direction such that the seated occupants are accelerated into the seat backs of the occupied seat. The crash pulse shall comply with the requirements established in SAE AS8049, Appendix A.

5.2.2.2 Test Measurements and Documentation

The following forces, displacement, and accelerations shall be measured in accordance with SAE J211/1:

- Triaxial head acceleration-time history for each ATD
- Triaxial chest acceleration-time history for each ATD

- Upper neck extension/flexion bending moment, My, for each ATD
- Upper neck axial force, Fz, for each ATD
- Upper neck shear force, Fx, for each ATD
- Axial Acceleration-time history of the test sled

The following injury criteria shall be computed in accordance with 49 CFR 571.208, where applicable:

- HIC15
- 3ms chest Gs
- Peak upper neck axial tension/compression forces
- Nij

Unless otherwise indicated, instrumentation for data acquisition, data channel frequency class, and moment calculations are the same as given for the 49 CFR Part 572, Subpart E Hybrid III test dummy.

The test shall be captured on video to evaluate the occupant kinematics.

5.2.2.3 Performance Requirements

For a successful test, the following requirements must be met:

- The seat may deform but shall not tear loose from its mountings.

- Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.

- The ATDs shall be compartmentalized in the aft direction, per the definition in Section 3.1. After testing, the seat backs shall not be collapsed to such an extent that they present an impediment to emergency egress.

- All injury measurements computed in Section 5.2.2.2 must meet the following criteria, which are defined in CFR 49 Part 571, Standard No. 208: Occupant Crash Protection. The injury criteria shall be calculated from test data that has been filtered in accordance with SAE J211-1, Table 1.

    - Head injury criteria, HIC15, must not exceed 700;
    - Neck injury criteria, Nij, must not exceed 1.0;
    - Neck axial tension, Fz, must not exceed 938 lbf (4,170 N);
    - Neck axial compression, Fz, must not exceed 899 lbf (4,000 N);
    - Chest deceleration must not exceed 60g over a 3ms clip.

5.3 Additional dynamic testing

5.3.1 Anti-rotation test

On seats equipped with rotation, an anti-rotation test shall be performed to insure that during a simulated car crash, the seat does not rotate inadvertently. All rotating seats shall pass an "anti-rotation" test composed of the following criteria:

- Use a complete double seat assembly.
- A pendulum shall be swung such that the combined height and weight of the pendulum deliver a total kinetic energy of 1850 foot pounds (2508 joules) of kinetic energy to the seat at impact.
- Contact points shall be the center of each seat back, at a point 1 inch (25 mm) above the bottom plane of the rotating seat frame assembly.

The locking device shall retain the seat in its locked position after attempts have been made to drive the seat in the clockwise, then counterclockwise directions via the test described above. Permanent deformation of the rotating frame and seat back are acceptable. Additionally, the seat pedestal and sidewall mounting system (including fasteners) shall survive without failure in the above test.

As an option to pendulum testing, the purchaser and seat manufacturer may jointly agree to conduct sled tests to meet this requirement. The sled tests shall be conducted using the procedure given in Section 5.2.1, except the seat shall be occupied by one 95^{th} male ATD placed in the seating position that maximizes the load on the locking mechanism. A minimum of two sled tests shall be conducted: one tending to drive the seat in the clockwise direction and the other tending to drive the seat in the counter clockwise direction.

5.3.2 Lateral seat attachment test

The objective of this test is to insure that seat assemblies remain attached to the car structure when subjected to lateral forces resulting from a simulated rail car crash. The intent of this test is to insure that the seat remains attached to the car structure when subjected to accelerations of 4g in the lateral direction acting on the mass of the seat. This test must be performed dynamically as described below.

- The seat shall be mounted on a rigid test fixture or simulated car mounting using the same fasteners or attachment mechanism used in service, i.e., bolts, screws, seat track, tapping plate, etc., as shown in Figure 15.
- The seat shall be subjected to a 4g, 250 millisecond triangular crash pulse as shown in Figure 16 in a direction tending to drive the seat into the aisle. The crash pulse shall comply with the requirements established in SAE AS8049, Appendix A.
- The test shall be captured on video.

Seats may deform but shall not tear loose from their mountings. Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.

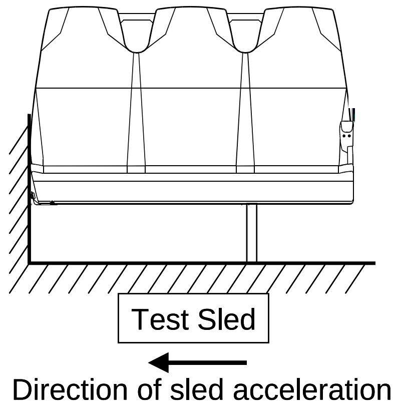


Figure 15 – Seat Orientation for Lateral Seat Attachment Test

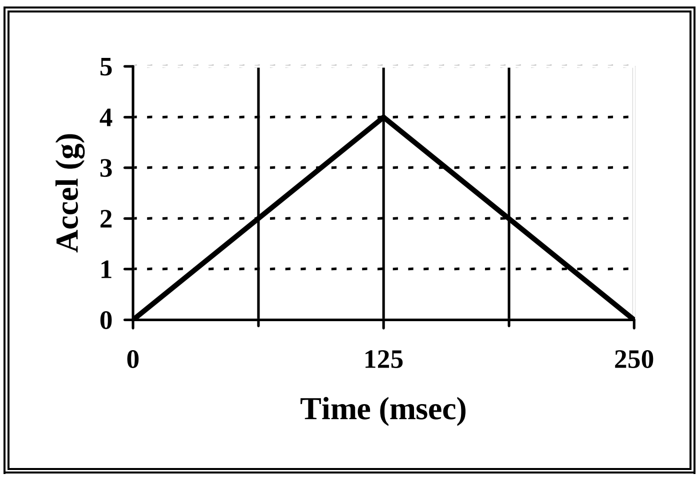


Figure 16 – Lateral and Vertical Crash Pulse

5.3.3 Vertical seat attachment test

The objective of this test is to insure that seat assemblies remain attached to the car structure when subjected to vertical upward forces resulting from a simulated rail car crash. The intent of this test is to insure that the seat and seat components remain attached to the car structure when subjected to accelerations of 4g in the vertical upward direction acting on the mass of the seat. This test must be performed dynamically as described below.

- The seat shall be mounted on a rigid test fixture or simulated car mounting using the same fasteners or attachment mechanism used in service, i.e., bolts, screws, seat track, tapping plate, etc., as shown in Figure 17.

- The seat shall be subjected to a 4g, 250 millisecond triangular crash pulse as shown in Figure 16 above, in a direction to drive the seat away from the floor. The crash pulse shall comply with the requirements established in SAE AS8049, Appendix A.

- The test shall be captured on video.

Seats may deform but shall not tear loose from their mountings. Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.

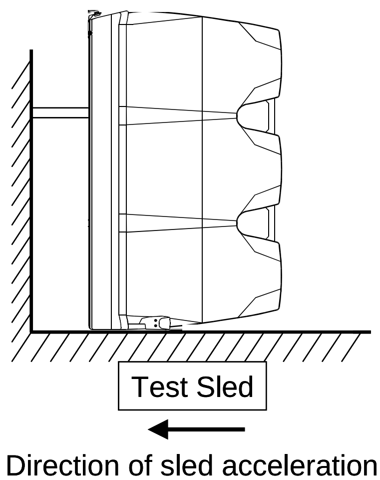


Figure 17 – Seat Orientation for Vertical Seat Attachment Test

5.3.4 Forward-facing seat attachment test

The objective of this test is to insure that the seat and seat components remain attached to the car structure under the following test conditions. See schematic of test set-up in Figure 18. The intent of this test is to satisfy the requirements described in the Code of Federal Regulations, Title 49, Part 238, Section 233. This test must be performed dynamically as described below.

- Two rows of seats shall be tested with the rear row of seats fully occupied by Hybrid III 95th percentile male ATDs, one ATD per seating position. The ATDs shall be forward-facing. The ATDs do not need to be instrumented.

- The seats shall be mounted on a rigid test fixture or simulated car mounting using the same fasteners or attachment mechanism used in service, i.e., bolts, screws, seat track, tapping plate, etc., and at the predominant seating pitch for the seat's application. Where a rigid test fixture is used, the purchaser may request the seat manufacturer to place load cells at seat mounting locations between the seat and the test fixture to measure reaction loads applicable to structural car design.

- Seats shall be subjected to an 8g, 250 millisecond crash pulse as shown above in Figure 13. The crash pulse shall comply with the requirements established in SAE AS8049, Appendix A.

- The test shall be captured on video.

Seats may deform but shall not tear loose from their mountings. Seat components shall not tear loose and become separated from the seat assembly such that the components become projectiles.

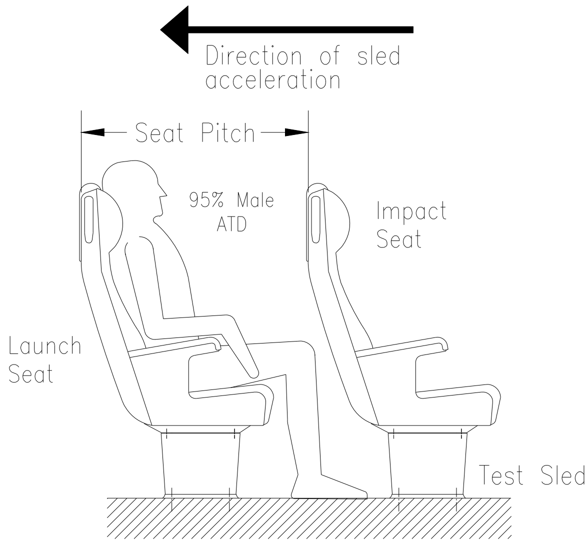


Figure 18 – Schematic of Forward-Facing Seat Attachment Test

6. Seat durability testing

Seating and seating components should be designed to provide an optimal life as specified by the purchaser and used in the environment defined by the purchaser.

6.1 Mechanisms

Moving components and adjustment mechanisms should be tested to verify their durability. These components and mechanisms include:

– Recline

– Rotation and rotation locks

– Walkover

– Flip up Seats

– Tray Tables

– Fore/Aft Adjustment

– Other moving parts

The purchaser and seat manufacturer should jointly determine a test plan for life cycle testing of these components and mechanisms.

6.2 Cushions and upholstery

This accelerated life test is intended to simulate the wear and tear on seating upholstery. A cushion durability test should be performed using SAE J 1454 as a guide. Tests should be performed on both bottom and back cushion. Test should consist of an automotive “jounce and squirm” test using a “jounce and squirm” machine similar to that shown in Figure 19. Each cushion should be subjected to the following:

- 200,000 jounce cycles @ 100 cycles per minute
- 4,000 squirm cycles @ 4 cycles per minute
- 180 lb. (82 kg.) load on bottom cushion
- 110 lb. (50 kg.) on back cushion

Jounce and squirm cycles should be applied simultaneously, although motions should be independent. Thigh and torso forms should be employed to transmit the motions to the cushions. Forms should be located as would a seated passenger, using the procedure given in SAE J 826.

As a result of testing, cushions should not show undue wear or signs of failure. Cushion upholstery should show no signs of tearing or ripping and should remain attached to the cushion pans or structure. Upholstery stitching should show no signs of unraveling or breakage. Cushion foam should show no signs of tearing, shearing or significant loss of height.

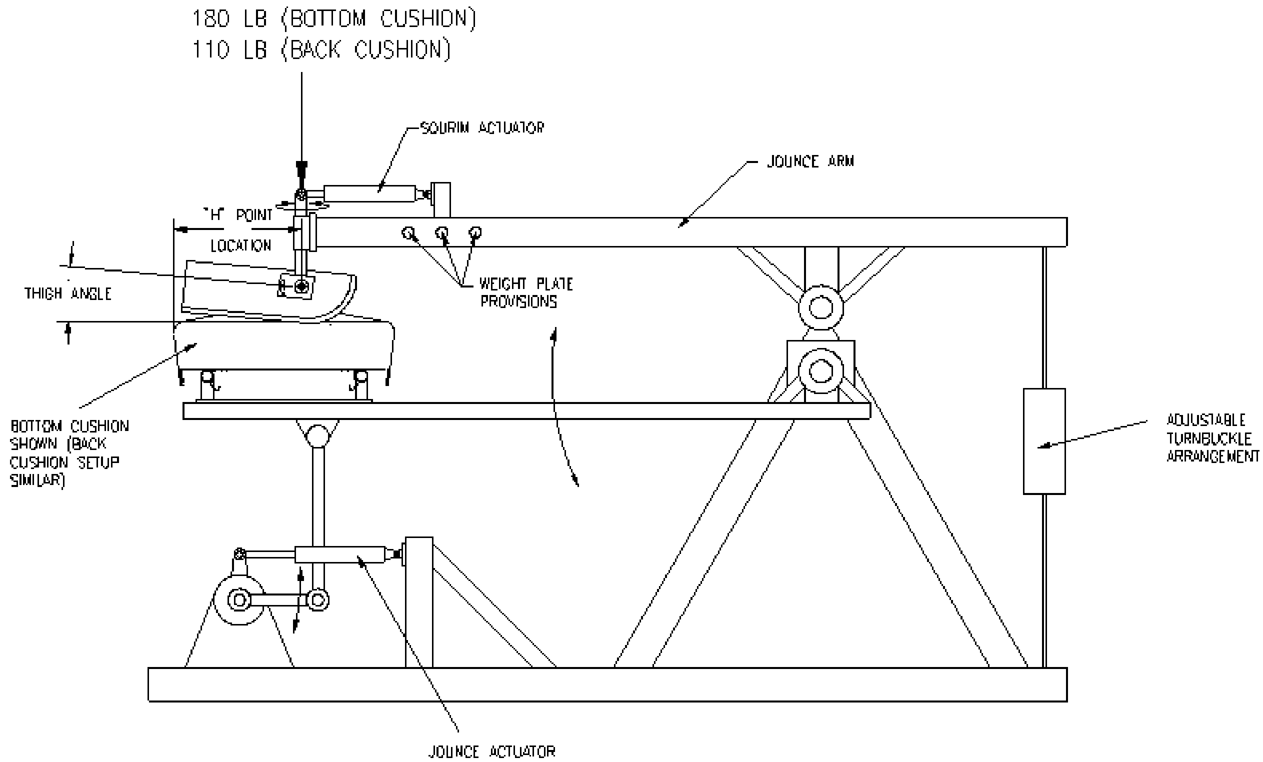


Figure 19 – Jounce and Squirm Test Machine

7. Maintainability

The seat should be easy to maintain and clean and should require no unscheduled adjustments or lubrication for the specified life of the seat. Design of the seat should be such that parts can be replaced with the use of standard hand tools. Components of like seats should be interchangeable. Pockets where dirt and debris can collect should be minimized.

8. Test plan, procedures and reports

All seat testing performed by the seat manufacturer shall be documented with a test plan, test procedures, and test reports. This shall include the procedures and reports for Static Load Tests, Seat Attachment Tests, Cushion Durability Tests and Service Life Cycle Tests.

Test plan and procedures should be submitted and approved by the purchaser prior to actual testing. Tests should be scheduled to allow the purchaser to, at his or her option, witness the testing. The purchaser may elect to accept existing test reports and procedures provided the seat to be purchased is demonstrated to be structurally identical to that tested and the test reports and procedures meet the requirements listed below.

8.1 Test plan

Prior to seat testing, a test plan should be submitted by the seat manufacturer to the purchaser.

The final test plan shall be reviewed and approved by the purchaser. The test plan shall identify the seating to be tested and the tests to be performed in order to qualify the seat design and attachment requirements.

8.2 Test procedures

Test procedures for those tests not defined by recognized standards shall be prepared by the seat manufacturer and submitted for approval to the purchaser. The test procedures shall as a minimum include:

- Test Objective
- Complete Description of Item to be tested
- Pass / Fail criteria
- List of Test Equipment
- Descriptions and/or drawings of Test Setup
- Description of Test Personnel Required
- Scheduled Time and Location of Tests
- Sequential, Step by Step Test Procedure
- Test Data Sheets (for recording data during testing)

8.3 Test reports

Test Reports shall as a minimum include:

- A copy of the test procedure meeting the requirements listed above
- Text or cover letter which gives a summary of the test results, the date and location of the test, and includes the signature of the person or person(s) responsible for conducting the test and writing the report.
- Calibration data for all test measuring equipment
- Pre and post test measurements (dimensions, adjustment activation force, etc.)
- Filled-in Test Data Sheet
- Photos of test set-up and results

9. Flammability and smoke emission

Materials used in seat construction shall meet the requirements given in *CFR Part 238, Appendix*

B[8], including notes. A test report for each combustible material tested shall be submitted by the Seat Manufacturer to the Purchaser. Testing shall be performed by an independent qualified testing facility. Test reports shall be prepared by the test facility.

In certain instances, materials used in seat construction can not be configured in the sizes required for test samples. For such materials, Seat Manufacturer shall submit a waiver request from testing of this material. The waiver request shall be submitted in writing and shall include the total weight of the material to be used, the location and distribution of the material in the seat and any previous test reports available.

As part of its work for the supply of seating equipment, the Seat Manufacturer should prepare and submit to the Purchaser a Combustible Content Matrix. The matrix should include total weight of each combustible material, where used, supplier's name, flammability and smoke emission, test identity, test facility, test requirements, test results, nature and quantity of the products of combustion, and heating value in BTU/lb. (joule/kg.) and BTU/hr. (joule/hr.) should be submitted by the Seat Manufacturer.

10. Parts, service and maintenance manuals

When not superseded by the requirements of the purchaser's own specifications, as part of its work the seat manufacturer shall provide a set of manuals. The manual(s) shall:

- Provide seat specifications and application data (such as weight, envelope dimensions, ranges of motion, mounting dimensions, mounting bolt sizes, grade and torque requirements, etc.)
- Provide installation and removal information
- Provide assembly and disassembly instructions and data
- Provide a list of replacement parts with part numbers and ordering information
- Provide exploded views of the seat assembly and its components
- Provide scheduled and unscheduled maintenance instructions and data, such as the periodic checking of fasteners (including torque values), lubrication instructions and cleaning instructions

Format and size of manual(s) shall be as agreed to by purchaser and seat manufacturer.

11. Engineering drawings

As part of its work and prior to the supply of seats, the seat manufacturer shall submit engineering drawings for approval. The drawings shall, as a minimum, include the following:

- Overall dimensions and tolerance of the seat assembly

[8] For references in Italics, see Section 2.

- Weight and location of the center of gravity of the seat assembly
- Depictions of the range of motions of all adjustments and tolerances in the range of motions
- Mounting requirements including hole sizes, recommended bolt sizes and torque requirements and recommended grade of bolts to be used for mounting
- Location and operation of all seat controls and adjustments
- Forces required to operate the seat controls during normal use
- Description of materials including cushion and fabric as well as colors and model number.

12. Submittals for approval

Prior to acceptance of the seat by the purchaser, the seat manufacturer shall submit documentation listed below in Table 2.

Table 2 - Submittals

Submittal	**Reference Standard Section**
Decorative Samples	4.2
Ergonomic Analysis and Report	4.2
Static Seat Strength Test Reports	5.1
Horizontal Seat Attachment Tests	5.2.1, 5.2.2 & 5.3.4
Human Injury Test Report	5.2.1 & 5.2.2
Anti Rotation Test (if applicable)	5.3.1
Lateral and Vertical Seat Attachment Tests	5.3.2 & 5.3.3
Mechanism Life Test Report(s)	6.1
Cushion and Upholstery Life Tests	6.2
Test Plan	8.1
Test Procedures	8.2
Test Reports	8.3
Flammability and Smoke Emission Report(s)	9
Combustible Content Matrix	9
Engineering Drawings	11

As an option, submittals from previous seating supply can be submitted to satisfy this requirement as negotiated by the purchaser and seat manufacturer. Timing of submittals of Manuals (Section 10) shall be as negotiated between the purchaser and seat manufacturer, but should be in a timely enough manner so as to serve as a reference and guide during installation of seating equipment into cars.

Annex A Bibliography

Document	Title
SAE ARP750	Passenger Seat Design Commercial Transport Aircraft
SAE J 899	Operator's Seat Dimensions for Off Road Self-Propelled Work Machines
Mil-Std 1472E	Human Engineering Design Criteria for Military Systems, Equipment and Facilities
49CFR Part 216 et al.	Passenger equipment Safety Standards, Proposed Rule September 23, 1997
49CFR Parts 37	Transportation Services for Individuals with Disabilities (ADA)
49 CFR Part 38	Americans with Disabilities Act (ADA) Accessibility Specifications for Transportation Vehicles
Volpe Contract DAAD01-98-C-0010	Commuter Rail Seat Testing and Analysis, Final Report, Document Number TR99008, Simula Technologies, Inc.
National Academy Press, Transportation Research Record No. 1989, July 1995	''Evaluation of Selected Crashworthiness Strategies for Passenger Trains.'' D. Tyrell, K. Severson-Green, & B. Marquis
American Society of Mechanical Engineers, AMD–Vol. 210/BED–Vol. 30, pp. 539–557, 1995	''Analysis of Occupant Protection Strategies in Train Collisions.'' D. Tyrell, K. Severson, & B. Marquis
DOT/FRA/ORD–96/08—DOT–VNTSC–FRA–96–11, October 1996	''Crashworthiness Testing of Amtrak's Traditional Coach Seat.'' D. Tyrell K. Severson
DOT–VNTSC–FRA–96–5, September 1996	"Crashworthiness of Passenger Trains.''
FMVSS 208	Final Rule for Federal Motor Vehicle Safety Standard (FMVSS) 208 – Occupant Crash Protection

Annex B Informative

(The information in this Annex is for informational purposes only and is not required for compliance with this standard.)

B.1 Background on seat safety and crashworthiness

Passenger seating in rail cars can either improve the safety environment within the car interior or can be a hazard, depending on the details of seating design, its arrangement in the car and the strength of its attachment to the car structure.

Seating can become a hazard when:

- Seats and parts of seats tear loose from the seat or its mounting during an accident and become projectiles, cause injuries and become impediments to timely evacuation of a car after an accident.
- Seat backs that are too flimsy or too short and fail to contain the occupant and thus fail to prevent the occupant from impacting with another, possibly less friendly object in the interior.
- Seats that have hard surfaces in the wrong places, or have sharp corners and edges can contribute to injury, even in moderate accidents.

Seating can help improve the interior safety of a passenger rail car when:

- Seats and parts of seats are designed to stay attached during an accident or collision and reduce the hazard associated with loose objects during an accident.
- Seat backs are designed to mitigate injuries by containing a passenger within a defined space during a collision, such that an occupant is compartmentalized between rows of seats, and absorb some of the energy that would otherwise contribute to injury.
- Seats are designed to mitigate injuries and contribute to the timeliness and efficiency of emergency evacuation efforts by increasing the likelihood that passengers can exit with little or no aid from emergency personnel.
- Seats are designed with appropriate padding and rounded corners.

During most train collisions, passenger cars are decelerated to reduce their forward speed. In such train collisions (primary impact), passengers in forward-facing seats and longitudinally mounted seats, in the absence of any restraining devices, gain a velocity relative to the car and its interior features. The magnitude of this relative velocity depends on the distance through which passengers travel before colliding with another feature or passenger within the car interior (secondary impact) and is given by:

$v = \sqrt{2as}$; where v is the relative passenger velocity, a is the deceleration of the car, if constant, and s is the distance through which the passenger travels.

The severity of the secondary impact for passengers in forward-facing and longitudinally mounted seats depends, among other things, on the relative velocity of the passenger at impact. An important fact stemming from the physics is that the kinetic energy reduction that is required to decrease the passengers' speed to that of the car increases as the relative velocity increases. It is the dissipation of this kinetic energy during impacts that is the source of injury for passengers in forward-facing seats. In general, this kinetic energy is dissipated by passengers colliding with features in the interior of the car.

Another consideration is the possibility of passengers colliding with an object close by, such as a seat back, glancing off that object, and then proceeding to impact with another object farther away. This is known as tertiary impact, and can be a primary contributor to serious injuries.

One strategy for reducing the likelihood and severity of tertiary impacts is called "compartmentalization". According to D. Tyrell et al., (AMD-Vol.210/BED-Vol.30, "Crashworthiness and Occupant Protection in Transportation Systems", ASME 1995), "The principle objectives of this strategy are to limit the occupant's range of motion and to ensure that the interior surfaces are designed to limit injury during occupant impact."

Passengers in rear-facing seats remain compartmentalized if the seat remains attached while the car decelerates. Because there is no time delay between the primary impact and occupant-seat contact, the initial deceleration peak is higher for rear-facing occupants than it is for forward-facing occupants. The chance of injury to rear-facing occupants increases if the seat fails at its floor attachment and compartmentalization is no longer provided.

There are also issues associated with human tolerance to impact. In any discussion of overall survivability of accidents, one must take into account a passenger's ability to respond to emergency personnel, find and open emergency exit and evacuate the car and surrounding area. Often, the time associated with post-accident activities is critical. Thus, it is obvious that the fewer debilitating injuries suffered by a passenger, the higher the chances of surviving any post-accident hazards. And it follows that any overall plan to improve emergency preparedness would be more effective if passengers themselves were more capable of participating in post accident activities.

Although there is some disagreement with exact levels of human tolerance to impacts, many other transportation industries place limits on certain measurements related to criteria that have been associated with human injuries or fatalities. Anthropomorphic dummies have been refined to a remarkable level of physical resemblance to human bodies and are available in a range of sizes and with high levels of instrumentation to record forces and accelerations on the human form. Test sleds and highly sophisticated facilities are readily available to simulate certain crashes and record anticipated human responses. In addition, computer programs such as MADYMO are available to aid in the design process and have been validated against simulated crashes (see USDOT/FRA "Crashworthiness Testing of Amtrak's Traditional Coach Seat" by D. Tyrell and K. Severson, Volpe Center, for validation of MADYMO as a predictive tool). In short, there are many tools available to the designer of seating for passenger rail cars to help mitigate the effects of occupant impacts with seating.

All of the discussion above leads to some guidelines for passenger rail seating. These are given below and apply (1) to transverse seats arranged so that passengers face the back of another seat and (2) to transverse, aft-facing seats. They are presented in order of importance:

1. Seats, seat components and the attachment of the seat to the car structure are to be strong enough to prevent the seat and its parts from tearing loose during a crash.

2. The seat back is to be strong enough to prevent occupants who strike the seat back from behind or are pressed against the seat back in a backward-facing seat, from completely collapsing the seat back.

3. The seat back is to be appropriately compliant, energy-absorbing and/or padded in such a way as to mitigate human injury.

B.2 Effects of seating arrangement

Another issue affecting the crashworthiness of seating is that of arrangement in the car. Most passenger rail cars generally have the seats arranged transversely such that occupants are facing the back of another seat. In some places, however, occupants face one another or face a bulkhead wall. There are also situations where occupants face the center of the car in longitudinally mounted seats. Figure 20 illustrates many of these different seating arrangements.

In the event of a collision, the rail car decelerates rapidly while the occupants continue to travel at the speed prior to impact, until the occupants strike some part of the interior. The later impact is termed the secondary impact. The severity of the secondary impact is a function of the secondary impact velocity (SIV) and the stiffness of the impacted object. The SIV generally increases with travel distance, i.e., the longer the travel distance, the higher the SIV. Therefore, secondary impact severity can be minimized by reducing travel distance and providing compliant impact surfaces, such as seats and tables that deform plastically under impact loading conditions.

Although seating arrangement issues often involve considerations for quality of service and optimizing the seating capacity in cars, the designer should be aware of the effects of arrangement on crashworthiness.

In general, the most crashworthy arrangement is when seats are arranged transversely such that occupants face another seat back. When it is necessary to arrange seats differently, there are certain things that can be done to improve the crashworthiness of the arrangement.

It is recommended that facing seats should have an energy-absorbing table positioned between the seats. The table attachment to the car structure should be strong enough to withstand the impact of passengers during a crash. The table should be compliant such that it deforms under the occupant's inertial load and absorbs energy. New tables have been shown to enhance the compartmentalization of occupants seated facing each other, and mitigate occupant injury[9,10]. An APTA standard for workstation tables is currently being developed to address table crashworthiness requirements.

[9] Parent, D., Tyrell, D., Rancatore, R., Perlman, A.B., "Design of a Workstation Table with Improved Crashworthiness Performance," American Society of Mechanical Engineers, Paper No. IMECE2005-82779, November 2005.
[10] Severson, K., Parent, D., "Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Occupant Experiments," American Society of Mechanical Engineers, Paper No. IMECE2006-14420, November 2006.

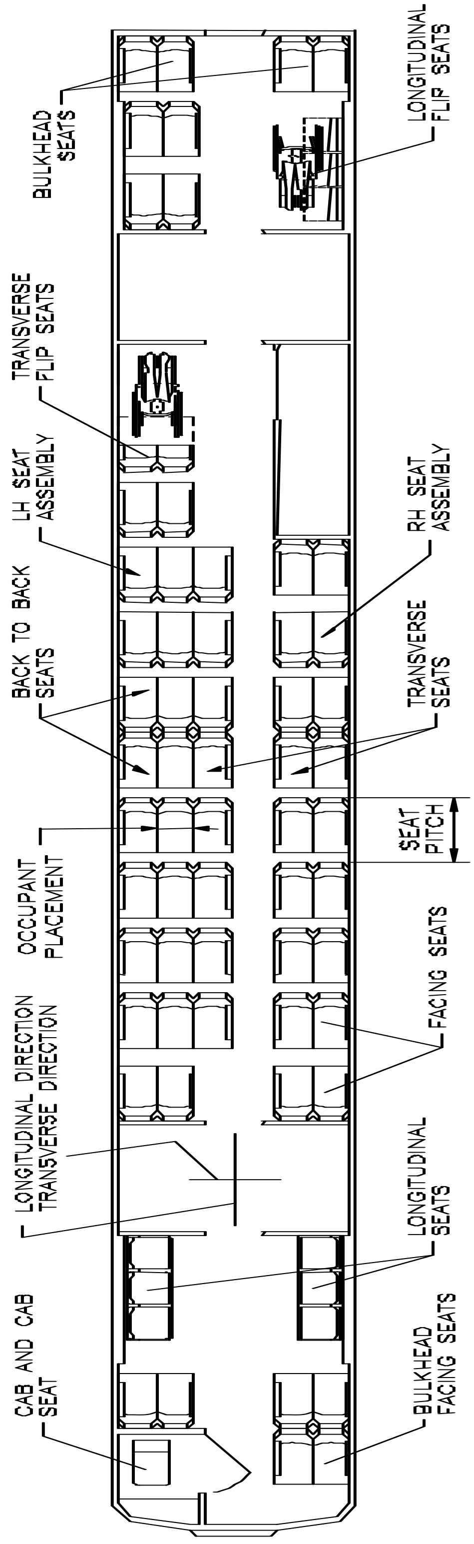


Figure 20 – Seat Arrangement and Nomenclature

In certain types of seating (such as walkover and rotating seats) the seats can be adjusted so that they face one another. When this is the situation, some Transit Authorities may want to consider having the mechanism providing the adjustment (rotation or walkover mechanism) be designed such that control of the adjustment is done by the Transit Authority, rather than the passenger depending on the type of service they wish to provide.

If seats face a bulkhead, the bulkhead should be padded or otherwise provide protection for the occupant(s) during a crash. If longitudinal seating is used, the range of motion of an occupant during a crash should be limited by placing features along the length of the seat. These features should be padded or otherwise provide protection for the occupant during a crash.

Wheelchair parking areas should be oriented so that occupants are facing in the direction (or opposite direction) of car travel. The range of motion of a wheelchair and its occupant should be limited by another feature in the car, such as a windscreen, bulkhead wall or seat. In all cases, seating arrangement should meet the requirements of the *49CFR Parts 37 and 38 (Americans with Disabilities Act).*[11]

B.3 Derivation of crash pulse

Figure 21 is taken from The FRA's Notice of Rulemaking 49 CFR Part 216 et al., published in the Federal Register on September 23, 1997. According to the notice, the peak deceleration of passenger rail coach equipment was 8g's for a head on collision during a train-to-train collision at 70 mph. For the purposes of testing, this crash pulse was idealized to the one shown in this standard. Results from recently-conducted research, particularly involving full scale crash tests, as discussed below, have shown that the measured occupant deceleration environment during a collision is different then the originally approximated. The crash pulse used in the standard and the measured occupant deceleration environments from three different full scale tests are shown in Figure 22. The computed secondary impact velocities of a forward facing unrestrained occupant for each crash pulse from Figure 22 are shown Figure 23. An ongoing study of these results is considering if the current crash pulse should be modified.

[11] For references in Italics, see Section 2.

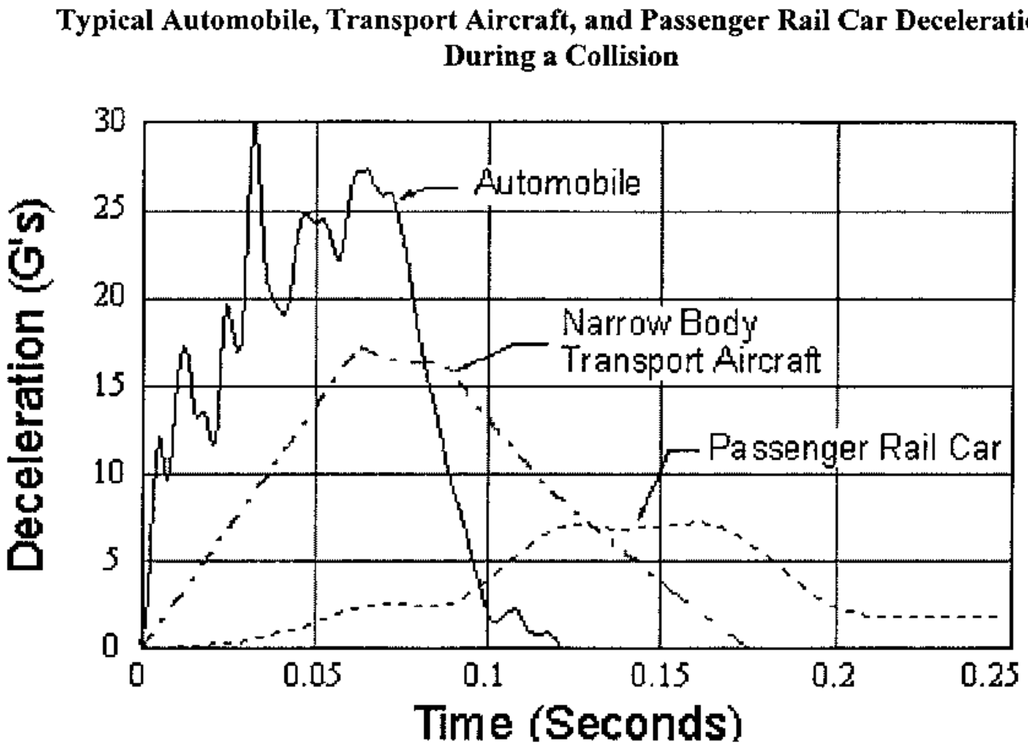


Figure 21 – Typical Decelerations during a Collision

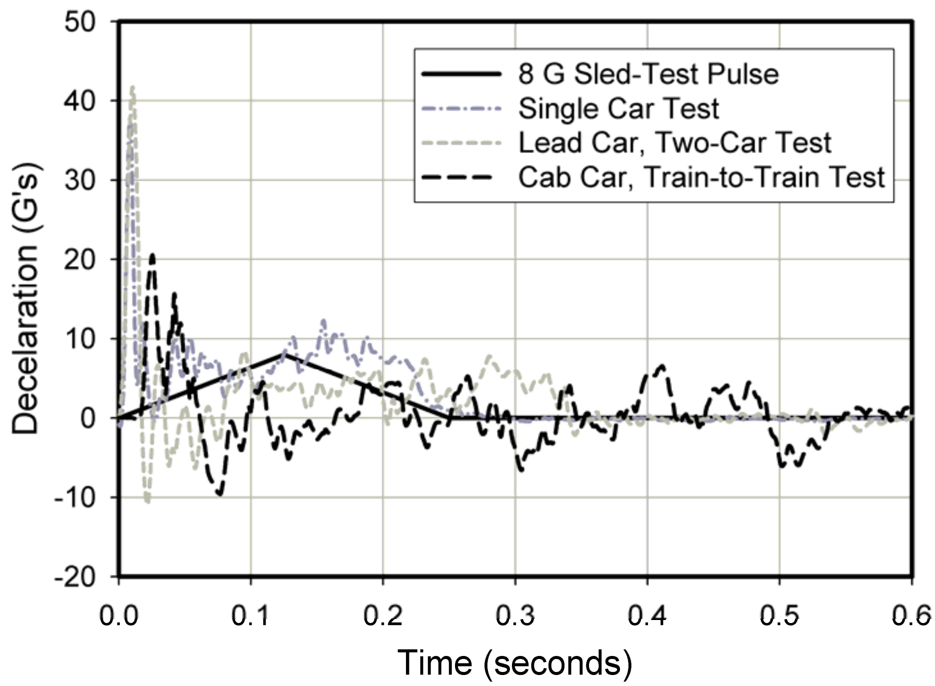


Figure 22 – Actual Decelerations Measured During Conventional Full Scale Tests

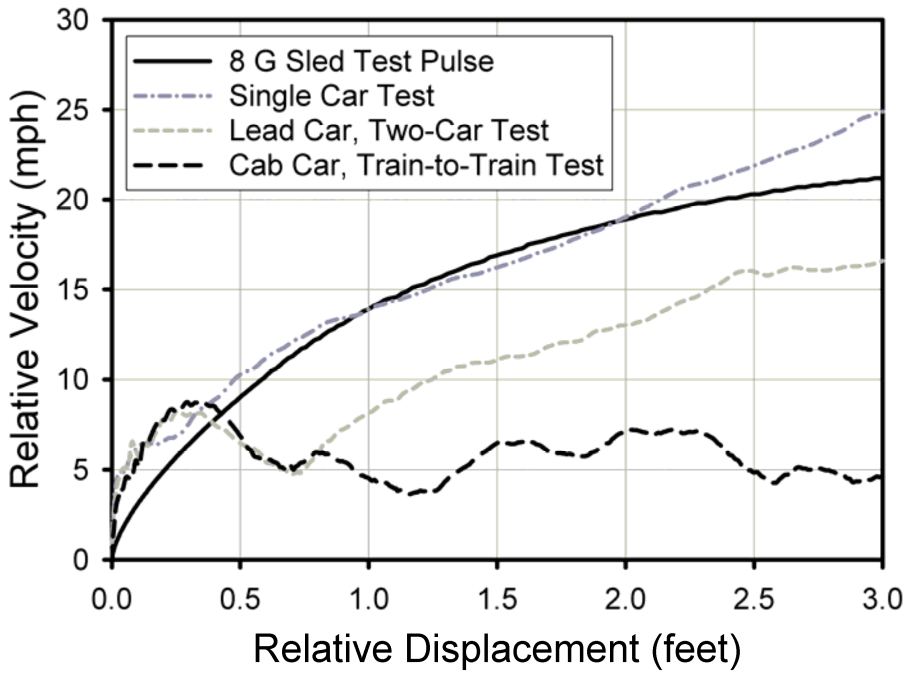


Figure 23 – Secondary Impact Velocity during Conventional Full Scale Tests

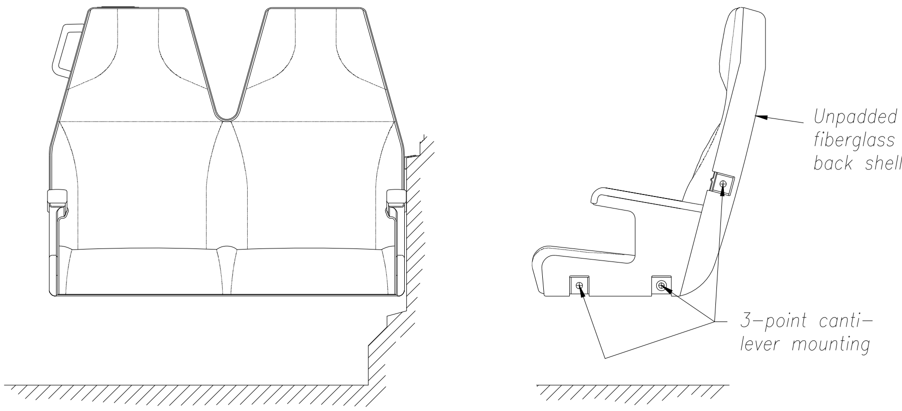
B.4 Research programs

Simultaneous to the development of this standard, the FRA embarked on a comprehensive Rail Crashworthiness Research Program which included a series of dynamic sled tests and full-scale collision testing. At the onset, and particularly as part of the development of this standard, APTA, together with the Volpe Center (FRA) conducted analyses and a series of sled tests on representative commuter seating at Simula, Inc. in Phoenix, AZ.

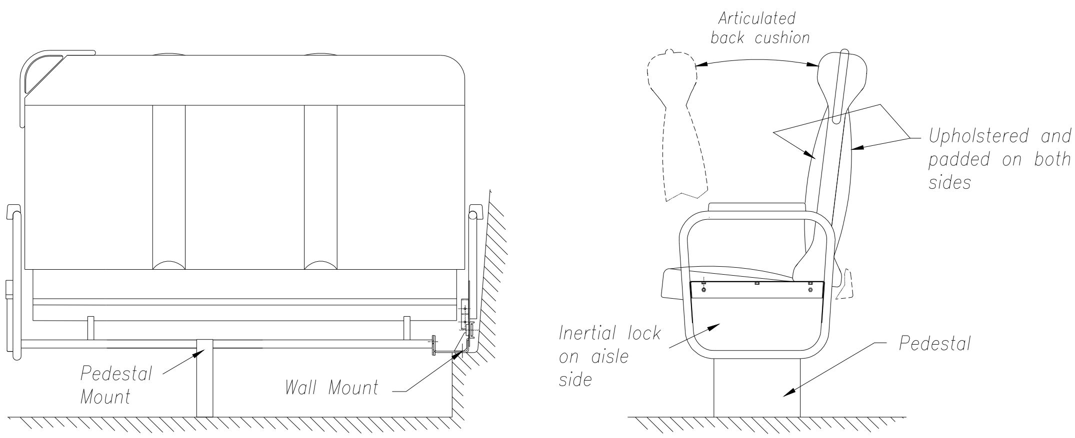
B.4.1 Dynamic sled testing program

The intent of the dynamic sled testing was to provide a better understanding of how traditional commuter seating behaves in a crash environment in terms of both the seat and dummy response.

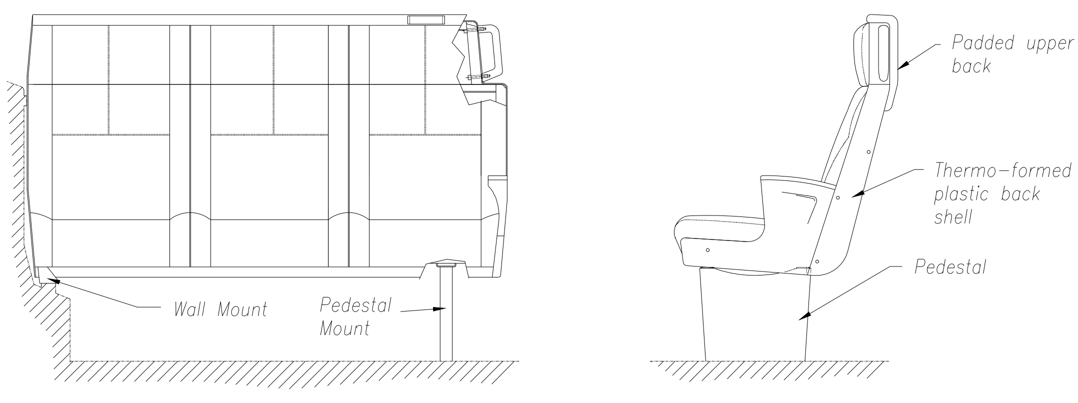
Two test programs have been conducted. One program tested three types of row-to-row commuter seats as shown in Figure 24, and the other program tested a typical facing seat system. Table 3 below is information about the application of these seats:



2 Passenger LIRR C-3 Seat



3 Passenger Walkover Seat



3 Passenger M-Style Seat

Figure 24 – Seats Tested

Table 3 – Description of Seats Used in Test Program

Seat Tested	Comments
2 Passenger LIRR C-3 Seat	This seat was selected because it represents the only cantilever mount commuter seat configuration in current use. Pedestal mount versions of this seat are also to be placed in service during 1999 at PCJPB and NVTC.
3 Passenger Walkover Seat	Used by NJT. Two passenger versions used by METRA and PCJPB.
3 Passenger M-Style Seat	Used in various configurations by Metro-North, LIRR, SEPTA, MBTA, NICTD, MARC and others.
2 Passenger Facing Seat	Manufactured by Bombardier for their bi-level commuter train. Other properties are preparing to install the facing seat configuration in their cars: San Diego, Vancouver, Florida, SCRRA, Dallas, and Seattle.

Prior to testing, a series of analyses was conducted using MADYMO models of each seat. To help develop the models of the seats, each seat was subjected to static loads across the seat backs to determine the stiffness of the seat backs. Evaluations were made by placing different size occupants in different locations in the seats. As expected, this resulted in different dummy responses depending on the mix of dummies in the seat and the location of the dummies. The analysis on the facing seats included variations with and without a table between the seats.

After seat testing, comparisons were made between test data and the values predicted by the modeling. In general, seat/occupant computer models correlate well with the test results and showed that using a tool like MADYMO can reasonably predict the response of seating and occupants during sled testing.

All of the seat frame structures remained attached to the test fixtures. Cushion detachment during dynamic testing proved to be the primary source of flying objects in the row-to-row series of seat tests and was especially noted on the M-Style seat. In the facing seat testing, the upper part of the seatback (the headrest) typically fractured due to the impacting dummy. This seat failure did not occur when the table was installed between the seats.

The stiffer LIRR C-3 rail seat showed improved passenger compartmentalization and cushion attachment, but, because of the increased stiffness, showed an increased likelihood of neck injuries caused by the dummies impacting the seat in front.

The more compliant seat(s), the M-Style and Walkover seats, increased the risk of passengers ejecting from the seats, but reduced the risk of injuries caused by the dummies impacting the seats in front. Thus the testing showed that to optimize passenger safety, seat backs need to be designed to be stiff enough to provide effective compartmentalization, but not so stiff as to increase the likelihood of injury. The results for the facing seats are similar. Placement of a table between the seats also proved to be an effective method of compartmentalizing occupants if the table remains attached.

The seats and table were all rigidly attached to the test fixture in an effort to eliminate an unpredictable variable during testing, i.e., the rail car floor or wall strength. The consequence of rigid seat attachment was a more repeatable test, however, the tests could not account for any energy that may be absorbed by the rail car floor or wall structure.

All row-to-row seat tests were conducted under conservative spacing conditions; specifically a 32-in. seat pitch. However, commuter seats in the field are typically attached with a 33-in. to 34-in. seat pitch. The computer seat models were all run with a 32-in and a 33-in. seat pitch to compare the difference in occupant injury data. The results suggest that the difference is very slight. Computer results did show that as seat pitch increased to 48 in. the predicted injury loads increased. Therefore, injury outcomes identified from these tests will likely become worse as the seat pitch increases. The facing seat tests were conducted with a 65-in spacing between the seats. Test dummies were not seated in the aft-facing seat during testing. Computer modeling and/or additional testing should be conducted to determine the ramifications of occupants facing each other.

B.4.2 Full-scale rail collision testing

In addition to the commuter seat sled testing and analysis programs, a series of full-scale commuter rail collision test programs has been in progress. To date, five tests have been conducted with occupant experiments:

1. A single conventional car traveling at 35 mph into a rigid barrier in November, 1999.
2. Two coupled conventional cars traveling at 26 mph into a rigid barrier in April, 2000.
3. A conventional train-to-train test involving a cab-car led, 4-car consist trailed by a locomotive colliding at 30 mph into a stationary locomotive coupled with two ballasted freight cars in January, 2002.
4. Two coupled crash energy management (CEM) cars traveling at 29 mph into a rigid barrier in February, 2004.
5. A CEM train-to-train test involving a cab car, 4 coach cars and a locomotive in push mode colliding at 31 mph into a stationary locomotive coupled with two ballasted freight cars in March, 2005.

In all five of these tests, a series of seat/occupant experiments were installed inside the railcars to evaluate the crashworthiness of commuter seats and inter-city seats under realistic collision conditions. The first three tests involved existing, conventionally designed passenger cars. The last two tests involved existing passenger cars that had been modified to incorporate CEM end structures that were designed to absorb collision energy, while preserving the integrity of the occupant volume.

In the first two full-scale tests, five out of nine ATDs instrumented to measure neck load(s) exceeded at least one neck injury criteria. Two out of nine ATDs instrumented to measure femur loads exceeded the femur load criteria. None of the five ATDs instrumented to measure head and chest acceleration exceed the respective criteria. These results suggest that it would be reasonable to add the neck injury criteria as a requirement in this standard.

In the conventional train-to-train test, all ATDs met all injury criteria.

The last two tests that utilized CEM equipment resulted in a more severe acceleration environment for the ATDs. In two experiments the commuter seats collapsed or separated from the car structure, resulting in a loss of occupant compartmentalization. In the two commuter seat experiments in which the seats remained attached, the injury criteria were met.

In addition to providing data for the seat/occupant response to the impact forces of a train collision, these full-scale tests provide realistic crash pulse data that may be used to update the current crash pulse described in this standard.

The crash pulse defined in this standard and used in the seat testing described above (triangular pulse with 8G peak and 250 millisecond duration) was originally derived from computer analyses by the Volpe center. While this pulse appears to produce reasonable seat/occupant responses, it will eventually be validated with the crash pulse data produced through full-scale passenger rail car crash testing. Some features of the crash pulses produced to date from full-scale crash testing, and not currently described by the derived crash pulse, include an initial high peak longitudinal acceleration approximately 25 G followed by an average constant acceleration of approximately 5 G. (See Figure 22 and Figure 25 for the crash pulses obtained from the recent conventional and CEM full scale tests, respectively.) The plots of secondary impact velocity that correspond to these crash pulses are shown respectively in Figure 23 and 26.

The plots of crash pulses and secondary impact velocity indicate a wide range of collision environments. The leading car in both of the CEM equipment tests experienced an acceleration environment that was comparable to a 12 G, 250 millisecond crash pulse, as shown by the SIV plots in Figure 26. Trailing cars in the CEM train-to-train test experienced a collision environment that is approximated by the 8G, 250 millisecond crash pulse.

There has been some discussion about the crash pulse to be used in sled testing specified in this standard. Based on the full-scale test data, the 8G crash pulse appears to be a reasonable representation of a moderately severe rail vehicle collision. Some equipment tested has experienced a more benign crash pulse, and other equipment tested experienced a more severe crash pulse. At this point, there is no clear reason to deviate from the existing 8G crash pulse. Unless further research provides new evidence to justify a change in the crash pulse, the existing 8G pulse will continue to be used in sled testing of commuter rail passenger seats.

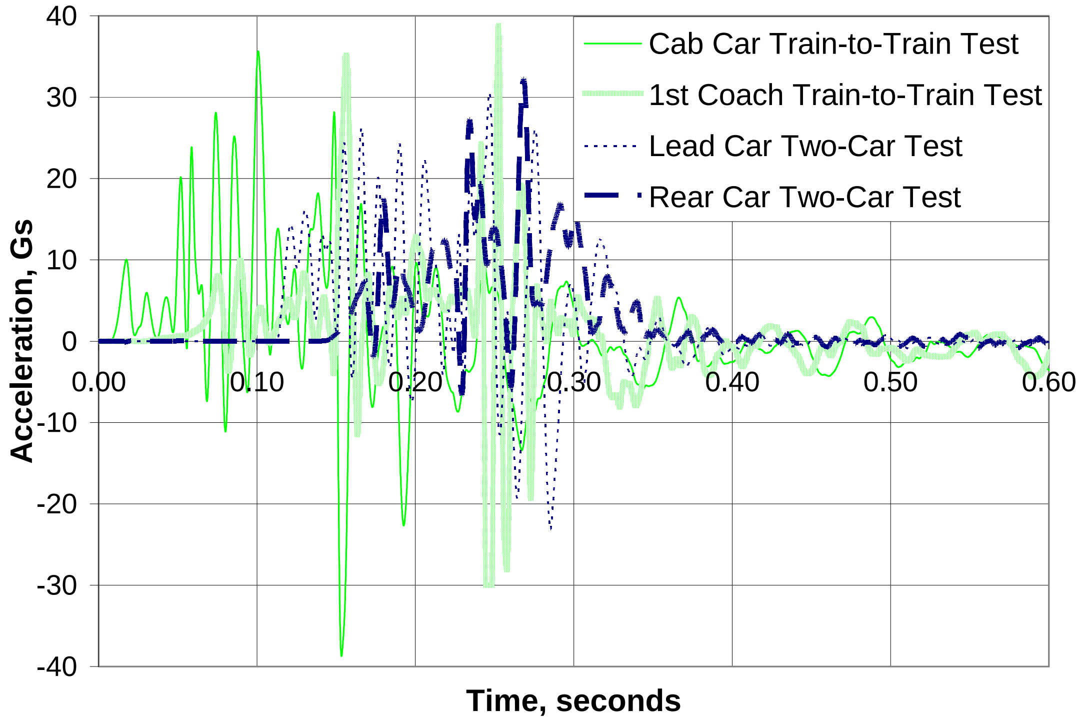


Figure 25 – Actual Decelerations Measured During CEM Full Scale Tests

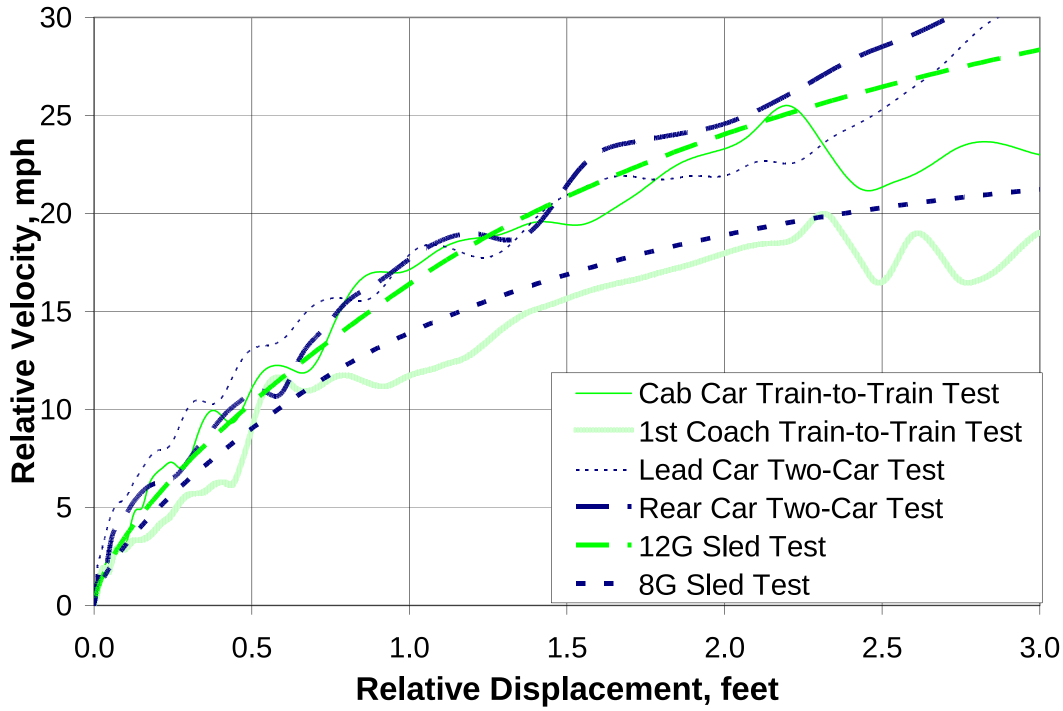


Figure 26 – Secondary Impact Velocity during CEM Full Scale Tests

B.4.3 Neck Injury Criteria

During all these research programs, the ATD neck loads have been recorded along with head, chest and femur loads. It is quite noteworthy that neck loads are the predominant measurements recorded that exceed the given injury criteria. Based on research results from the FRA Rail Crashworthiness Research Program, discussion within the C&S Subgroup, and changes adopted by the automotive industry, neck injury criteria established by NHTSA in FMVSS 208 (10-1-04 edition) have been added to this standard in Revision 2, as shown in Table 4.

Nij is a criterion to access neck injury, where "ij" represents indices for the four injury mechanisms; namely N_{TE}, N_{TF}, N_{CE}, and N_{CF}. The first index, i, represents the axial load (tension or compression) and the second index, j, represents the sagittal plane bending moment (flexion or extension). The criterion can be written as the sum of the normalized loads and moments, where F_z is the axial neck load, F_{int} is the corresponding critical intercept value of axial load used for normalization, M_{ocy} is the flexion/extension bending moment computed at the occipital condyle, and M_{int} is the corresponding critical intercept value for bending moment used for normalization. M_{ocy} is computed using the measured neck bending moment, M_y, and the measured upper neck shear load, F_x.

Table 4 – Neck Injury Limits for Hybrid III 50th-percentile Male ATD

Criterion	**Maximum Value**
Axial Neck Load, Fz	+937/-899 lbf (+4170 N/-4000 N)
Nij, where: F_{int} (critical intercept values) are: +1530/-1385 lbf (-6806/-6160 N) M_{int} (critical intercept values) are: +229/-100 ft-lbf (+310/-135 Nm)	1.0

B.5 References

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