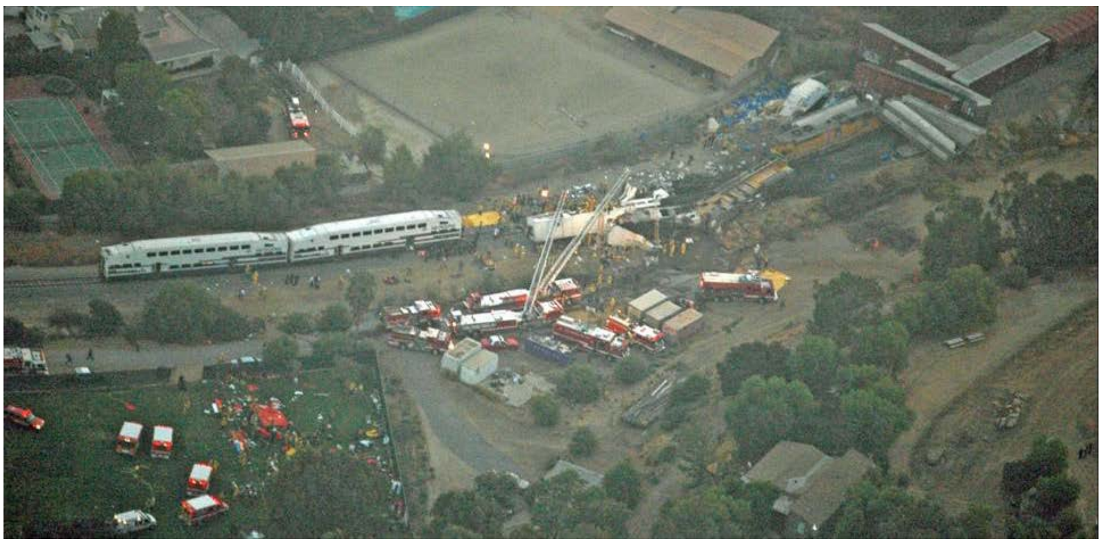
U.S. Department of Transportation

Federal Railroad Administration

Passenger/Freight Train Collision September 12, 2008, Chatsworth, CA: Main Report

Office of Research, Development and Technology
Washington, DC 20590



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On September 12, 2008, a passenger train and freight train collided head-on in the Chatsworth district of Los Angeles, CA. Each train was initially travelling at more than 40 mph. Twenty-five people were killed and approximately 138 were injured, many severely. With assistance from emergency responders, local authorities, and accident survivors, both the U.S. Department of Transportation's Rail Accident Forensic Team and the National Transportation Safety Board investigated the accident. This report on the Chatsworth accident by the Forensic Team presents the estimated sequence of events of the collision, the behavior (dynamics) and specific structures of the trains, passenger injuries, the performance of emergency preparedness and crashworthiness features, and recommendations for enhanced protections to improve passenger safety in the future. The appendices include greater technical detail on the train structures and dynamics, and passenger experiences.

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METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in)	=	2.5 centimeters (cm)
1 foot (ft)	=	30 centimeters (cm)
1 yard (yd)	=	0.9 meter (m)
1 mile (mi)	=	1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz)	=	28 grams (gm)
1 pound (lb)	=	0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp)	=	5 milliliters (ml)
1 tablespoon (tbsp)	=	15 milliliters (ml)
1 fluid ounce (fl oz)	=	30 milliliters (ml)
1 cup (c)	=	0.24 liter (l)
1 pint (pt)	=	0.47 liter (l)
1 quart (qt)	=	0.96 liter (l)
1 gallon (gal)	=	3.8 liters (l)
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm)	=	0.04 inch (in)
1 centimeter (cm)	=	0.4 inch (in)
1 meter (m)	=	3.3 feet (ft)
1 meter (m)	=	1.1 yards (yd)
1 kilometer (km)	=	0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm)	=	0.036 ounce (oz)
1 kilogram (kg)	=	2.2 pounds (lb)
1 tonne (t)	=	1,000 kilograms (kg)
	=	1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 liter (l)	=	2.1 pints (pt)
1 liter (l)	=	1.06 quarts (qt)
1 liter (l)	=	0.26 gallon (gal)
1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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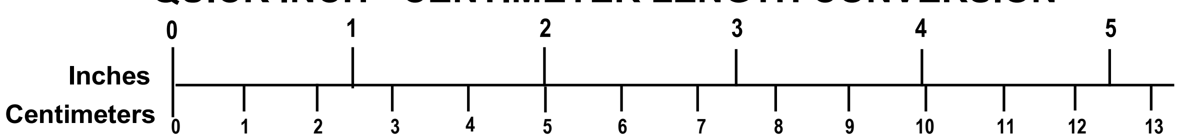
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286 **Updated 6/17/98**

Contents

Illustrations

Tables

Executive Summary

The U.S. Department of Transportation's Rail Accident Forensic Team, in support of the Federal Railroad Administration, investigates rail accidents with the primary objective of estimating the sequence of accident events to identify causal mechanisms of injury. The Rail Accident Forensic Team gathers information at the site of the accident, interviews train crew members, passengers, and emergency responders, as well as organizes, and synthesizes this information to estimate the sequence of events and identify causal mechanisms of injury. The effectiveness of current crashworthiness and emergency preparedness regulations is evaluated and recommendations for improved crashworthiness safety regulations are then developed.

On September 12, 2008, a passenger train and freight train collided head-on in the Chatsworth district of Los Angeles, CA. Each train was initially travelling at more than 40 mph. Twenty-five people were killed and approximately 138 were injured, many severely. With assistance from emergency responders, local authorities, and accident survivors, both the Rail Accident Forensic Team and the National Transportation Safety Board investigated the accident.

This report on the Chatsworth accident by the Rail Accident Forensic Team presents the estimated sequence of events of the collision, the behavior (dynamics) and specific structures of the trains, passenger injuries, the performance of emergency preparedness and crashworthiness features, as well as recommendations for enhanced protections that would improve passenger safety in the future. The appendices include greater technical detail on the train structures and dynamics, and passenger experiences.

1. Introduction

On September 12, 2008, a passenger train and a freight train collided head-on in the Chatsworth district of Los Angeles, CA, with each train initially travelling at more than 40 mph. Twenty-four passengers and one crew member were killed on the passenger train, and approximately 138 train occupants were injured, many severely.

1.1 Background – Accident Overview

Figure 1 shows the relative positions of the trains just prior to impact, as the Union Pacific Railroad (UP) freight train and the Metrolink passenger train were each travelling at just over 40 mph. The passenger train consisted of an Electro-Motive Diesel (EMD) F-59 four-axle locomotive, two Bombardier multi-level trailer cars, and a Bombardier cab car. The freight train consisted of 2 EMD SD-70 6-axle locomotives, with the second locomotive travelling long-hood forward, followed by 7 loaded freight cars and 10 empty freight cars.

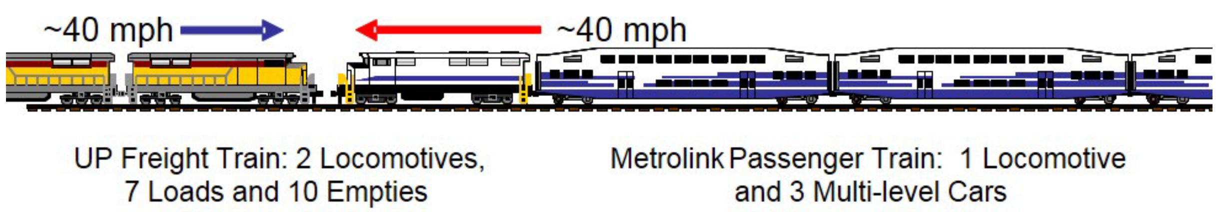


Figure 1. Schematic of Initial Impact Conditions

The accident occurred on a 6-degree curve, with the freight train just exiting the transition spiral[1] and about to enter the body of the curve, and the passenger train conversely just exiting the body of the curve and about to enter the spiral leading to the tangent track.

Figure 2a is an aerial photograph provided by the Southern California Regional Rail Authority (SCRRA), the authority that governs Metrolink. The photo was taken shortly after the accident occurred. On the left side, the photograph shows the trailing two passenger cars, with little visible damage. In the center, the lead passenger car is shown, with substantial damage. The car is nearly on its side and much of the roof is peeled back. The fans and other roof-mounted equipment on the lead passenger locomotive can be seen adjacent to the sidewall of the lead passenger car. The lead freight locomotive is on its side, while the second freight locomotive is upright toward the upper right-hand side of the photograph. Seven trailing freight cars are stacked up sideways against the trailing end of the trailing freight locomotive. Behind the sideways freight equipment, three freight cars (two of which are visible in Figure 2a) are upright and derailed. The trailing seven freight cars, which are not visible in Figure 2a, remained upright and on the track.

[1] A spiral is a section of track that gradually curves to ease the transition as the train travels from straight track into a curved portion.

Figure 2b shows another aerial photograph, this time from a view looking nearly straight down at the accident. The photograph is annotated with survey locations and the equipment markings. The photograph shows a more complete sketch of the trailing freight equipment, the freight locomotive and at least 10 derailed freight cars.

Figure 2a. Aerial Photograph of Accident (From SCRRA)

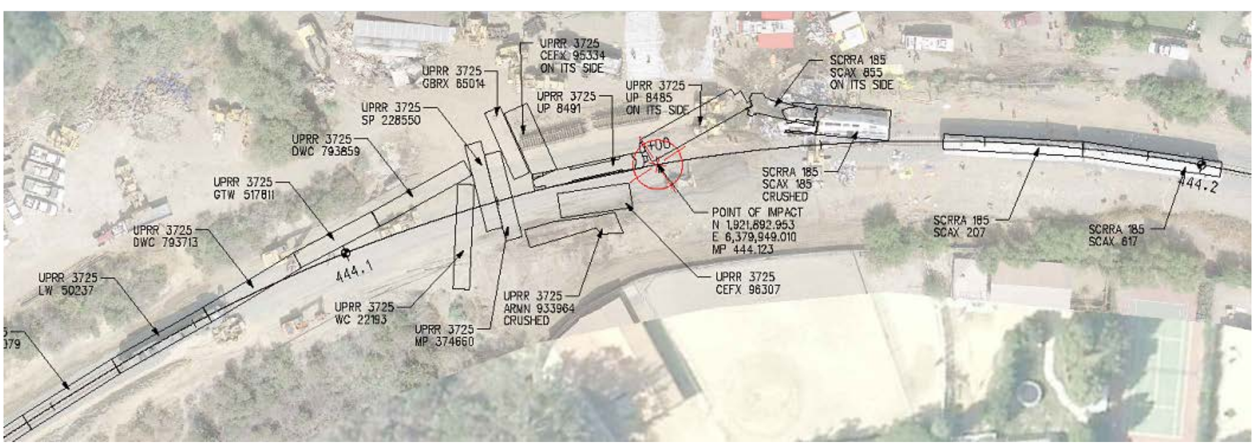


Figure 2b. Aerial Photograph of Accident, with Equipment Locations (From SCRRA)

Figure 3 shows a schematic and a summary of the equipment damage. In the passenger train, the locomotive cab was crushed, eliminating the survival space. The first passenger car, originally 85 feet in length, was crushed approximately 65 feet, back to the trailing boarding doors. The survival spaces in the forward mezzanine level and bi-level section were lost. Survival space was maintained in the trailing mezzanine level. In the two trailing passenger cars, survival space was maintained. Survival space was maintained in the freight locomotives, although a significant portion of the roof of the second freight locomotive was torn off.

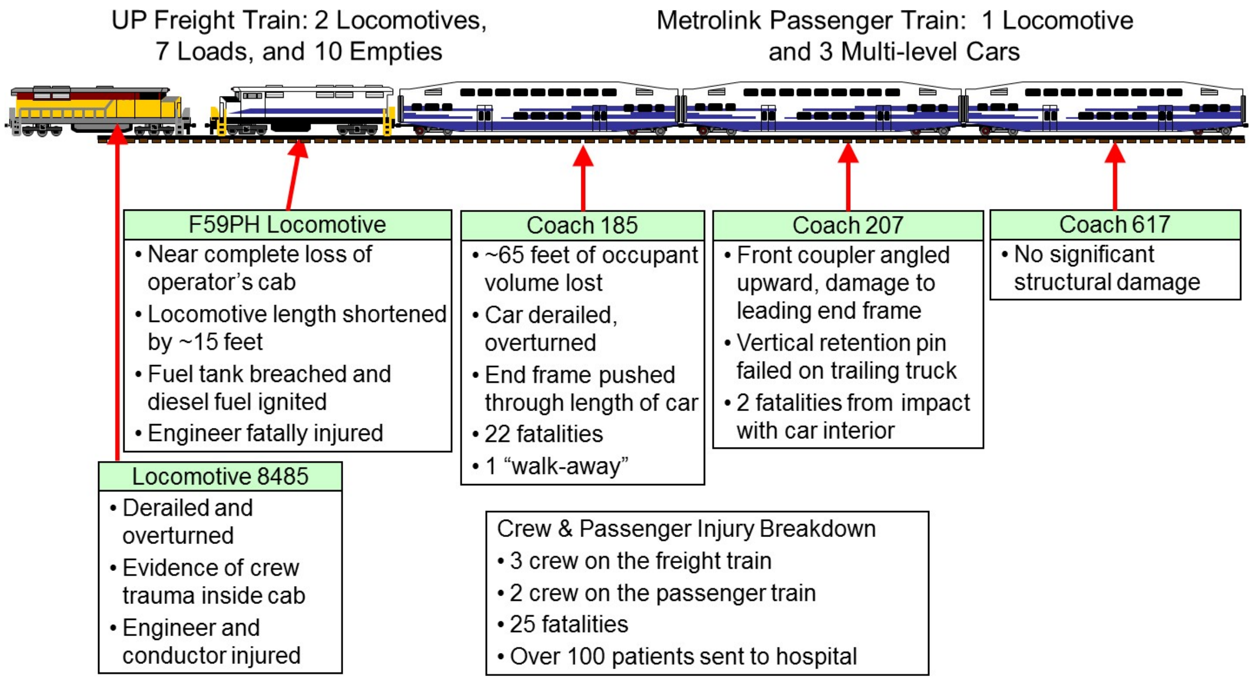


Figure 3. Summary of Equipment Damage and Injury/Fatality Distribution

1.2 Objectives

The objectives of this report are to estimate the sequence of events following the initial impact and to identify causal mechanisms of injury.

1.3 Scope

The following items are included in the scope of this report:

1) The estimated sequence of events, from the moment of initial impact to the resulting injuries and fatalities;
2) A description of the dynamics of the train during the impact, and the performance of the individual car structures;
3) A summary of occupant injuries, based on forensic information from the car and locomotive interiors as well as interviews with victims and emergency responders;
4) The performance of the emergency preparedness features of the equipment;
5) The effectiveness of equipment meeting crashworthiness and emergency preparedness regulations in effect at the time; and
6) Recommendations for research and development for future regulations.

Determining the probable cause of the accident is not included in the scope. The National Transportation Safety Board investigates rail accidents with the objectives of determining probable cause of the accident and issuing safety recommendations aimed at preventing future accidents.

1.4 Organization of the Report

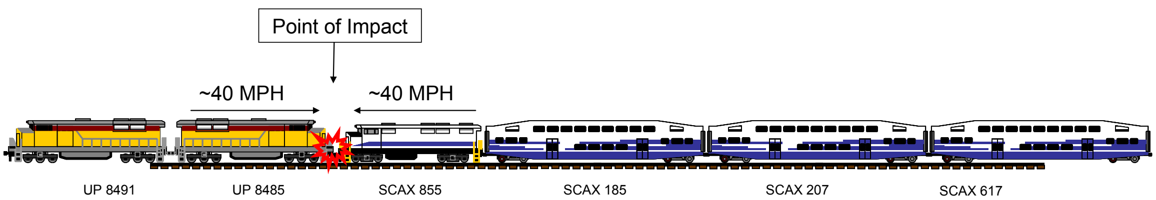
This report consists of a main report, as well as separate Appendices A.1 through B.3, which are available on FRA's eLibrary. The main report describes the sequence of events and causal injury mechanisms, and summarizes the structural and interior car damage. Appendix A provides further detail on the condition of train equipment and features designed to protect passengers. Appendix B discusses passenger experiences drawn from a forensic investigation of the accident site as well as interviews with passengers and emergency responders.

2. Estimated Progression of Accident

This section describes the estimated train-to-train collision dynamics from the time the two trains collide until coming to rest. This sequence of events is based upon the evidence gathered during the investigation and conditions prior to impact, including the characteristics of the equipment, track conditions, and impact speed. The computer simulation used to model the collision is described further in Appendix A.4. The structural damage is described in Section 4.0 of this report, as well as in Appendices A.2.1 and A.2.2. The commuter train consisted of a locomotive leading three multi-level passenger cars. The freight train was led by two locomotives (the second locomotive was rearward facing) followed by 7 loaded and 10 empty freight cars. The lead locomotive of the freight train was just entering the body of a 6-degree curve and the locomotive of the passenger train was just exiting the body of the same curve. At the time of impact, the passenger and freight trains were each travelling at about 40 mph. The lead passenger and freight locomotives collided head-on at a closing speed of over 80 mph.

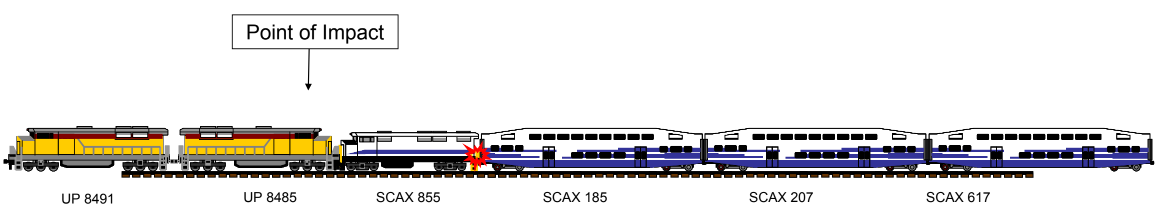
The present tense is used for simplicity in the following description of the sequence of events.

2.1 Initial Contact



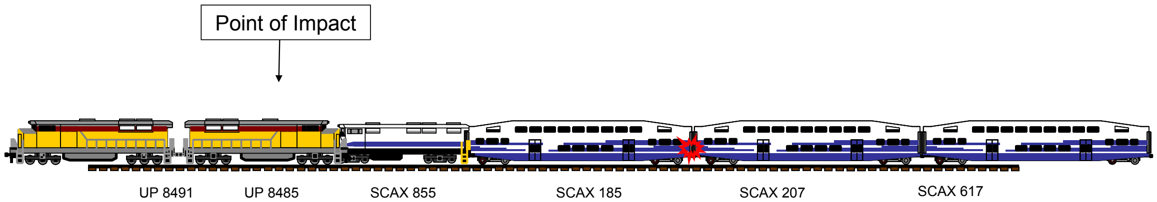
The locomotives come together, initiating contact at the coupler knuckles. The draft gears compress, bottom out, and overload the draft gear pockets on each locomotive. On the freight locomotive, the coupler shank fractures and the draft gear pocket deforms downward. The pilot fractures and tears away. On the passenger locomotive, the coupler and draft gear pocket fracture off completely from the locomotive underframe. Next, the locomotive end structures come together. Though the front faces of the colliding trains are not symmetrical, the anti-climber devices still engage and effectively lock the two locomotives together vertically. There is little evidence of vertical motion at the colliding interface.

2.2 ~0.03 Seconds: Locomotives Begin to Crush and First Passenger Car Begins to Decelerate



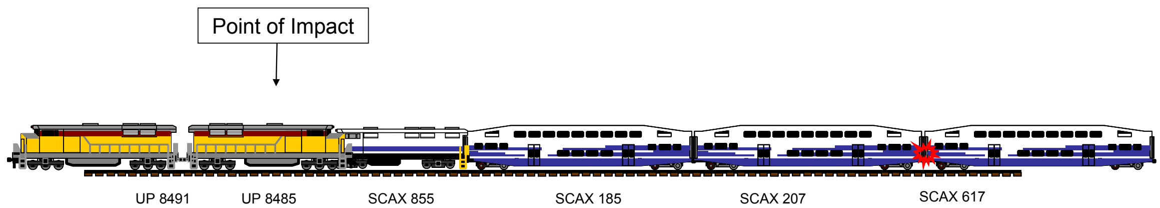
At about 0.03 seconds, the passenger locomotive is crushed by about 2 feet and the main structure cripples. The front portion of the locomotive is vaulted back and up and intrudes into the operator's volume. The first passenger car makes hard contact with the rear of the passenger locomotive. The first passenger car (#185) begins to decelerate. There will be about a 0.05 second delay before the second passenger car (#207) begins to decelerate.

2.3 ~0.10 Seconds: Passenger Locomotive Continues to Crush and Second Passenger Car Decelerates



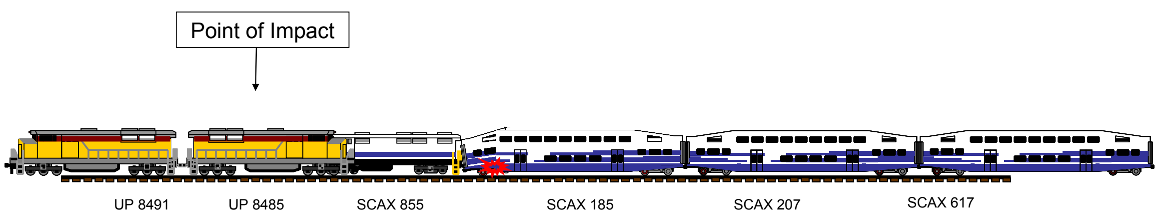
At about 0.1 seconds the passenger locomotive is crushed another 6 feet (at this time, 8 feet in total). The passenger locomotive's lead truck rotates back and the truck attachments, which connect the truck to the car, fail. As the collision pulse moves back through the train, the second passenger car makes hard contact with the first passenger car and begins to decelerate.

2.4 ~0.15 Seconds: Passenger Locomotive Continues to Crush, First Passenger Car Cripples and Third Passenger Car Decelerates



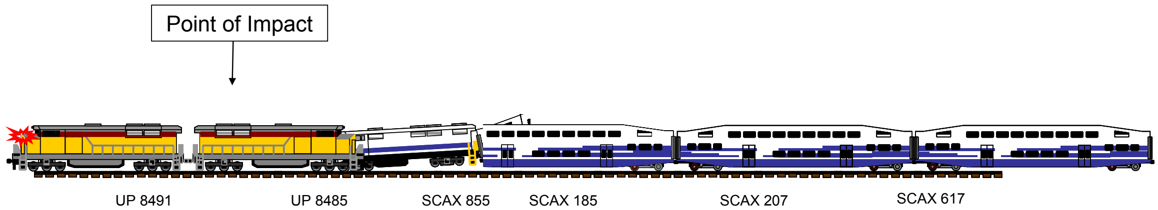
At about 0.15 seconds the passenger locomotive front end is crushed by about 10 feet. The lead truck impacts the adjacent fuel tank. The impact punctures the tank and the fuel tank detaches from the carbody underframe. The first passenger car is crushed by about one foot and the underframe starts to cripple at the front end gooseneck. The trailing cab car begins to decelerate.

2.5 ~0.25 Seconds: First Passenger Car Catastrophically Fails at Gooseneck



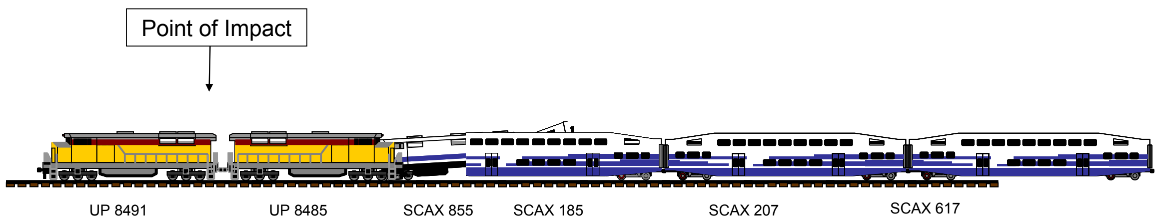
At around 0.25 seconds the passenger locomotive front end has finished crushing, about 15 feet in total. The passenger locomotive has finished decelerating and begins to reverse direction as it is pushed by the momentum of the freight train. The gooseneck of the first passenger car catastrophically fails at ~3.5 feet of crush. The car breaks into two pieces and the front portion pitches upward and begins to plunge back through the middle portion of the multi-level car (the structural damage to the first passenger car is summarized in Section 4 and described in detail in Appendix A.2.1). The trailing cars in the passenger train finish running into each other and from this point on act essentially as a single mass, decelerating at a steady rate of about 0.5 g.

2.6 ~0.4 Seconds: Freight Cars Begin to Pile Up and First Passenger Car Continues to Crush



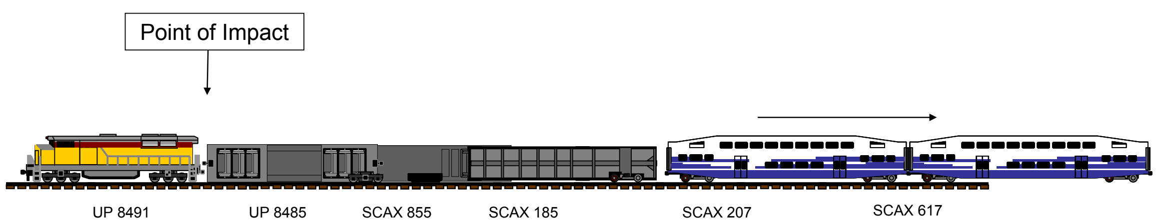
At about 0.4 seconds, the first freight car behind the second rear-facing freight locomotive overrides and crushes the operator's compartment. The freight cars successively pile up in a large scale sawtooth buckle mode. The detached front portion of the first passenger car has plunged about 10 feet deeper into the middle portion and continues to move backward, peeling open the roof and side walls.

2.7 ~0.75 Seconds: Second and Third Passenger Cars Change Direction of Travel



At about 0.75 seconds the passenger train has finished decelerating and begins moving in the opposite direction. The first passenger car has crushed a total of about 30 feet.

2.8 ~1.25 Seconds: First Passenger Car Crush Complete; Lead Locomotives and First Passenger Car Roll; Second and Third Passenger Cars Separate



The front portion of the first passenger car has plunged back into the middle portion of the car by 44 feet, stopping just before the lower level rear doors, as described in Section 4 and in Appendix B.3.1. The lead freight locomotive, the passenger locomotive and first passenger car roll and the coupled connections to adjacent cars fail. The second and third passenger cars reverse direction, rolling back what is roughly estimated to be between 80 and 100 feet.

3. Casualties and Seating Configurations

Injuries and fatalities to train occupants can be attributed to one of two main causes: 1) lack of sufficient survival space, 2) secondary impacts. In this accident, it appears that 23 of the 25 fatalities were due to lack of survival space. Two fatalities were attributed to secondary impact with part of the interior. Approximately 135 injured passengers and train crew were treated at the scene of the accident. Over 100 of these people were taken to local hospitals with injuries ranging from minor to life-threatening. Casualties are discussed below, in accordance with the likely cause of injury, with comments from interviewed passengers. Passengers are referred to by number, corresponding to the numbered list of passengers interviewed, in Appendix B.1.

3.1 Casualties Due to Loss of Survival Space

As stated above, 23 fatalities were caused by a lack of survival space, caused by bulk crushing of the car structure of Car #185 and Locomotive #855. In each of the 23 autopsy reports, the cause of death was attributed to multiple traumatic injuries or multiple blunt force injuries. Locomotive #855 and the accumulated crushed material of Car #185 penetrated nearly 65 feet into the passenger volume of Car #185 in a collapsible telescoping action. The bulk crushing of the interior and exterior car structure resulted in fatal injuries to most of the passengers occupying this space.

The Metrolink engineer was operating the passenger train from Locomotive #855 at the time of impact, seated approximately 11 feet aft of the point of impact. Upon impact, the length of the locomotive was reduced by about 15 feet, crushing the front of the passenger locomotive. The operator’s cab was pushed back over the heavy equipment inside the locomotive, eliminating the survival space for the operator. The autopsy report indicated multiple blunt force injuries as the cause of the engineer’s death.

At least two survivors in Car #185 experienced severe but non-fatal injuries as a result of car crush.

3.2 Casualties and Injuries Due to Secondary Impacts

While most of the fatalities were caused by car crush, the majority of the non-fatal injuries were caused by secondary impacts with interior car surfaces. When a train rapidly decelerates due to the collision forces, an occupant continues to travel at the speed of the train prior to impact. The occupant’s subsequent impact with the interior (i.e., secondary impact) occurs when the occupant strikes some part of the car interior. The severity of the resulting injury varies based on the speed the occupant is traveling relative to the speed of the car and the stiffness of the object that is impacted. See Figure 4 for a schematic representation of the three stages that lead to a secondary impact.

The speed or velocity at which an occupant strikes the interior is termed the secondary impact velocity (SIV). The SIV is a function of the carbody deceleration-time history and the seating configuration. In general, as the distance an occupant travels before striking the interior increases, so does the SIV. The plot in Figure 5 depicts the relationship between seating configuration and travel distance for passengers in each car in the train consist. The horizontal axis represents the distance travelled by an occupant in free flight with respect to the carbody (which varies with seating configuration). The vertical axis represents the velocity of an occupant in free flight, also with respect to the carbody.

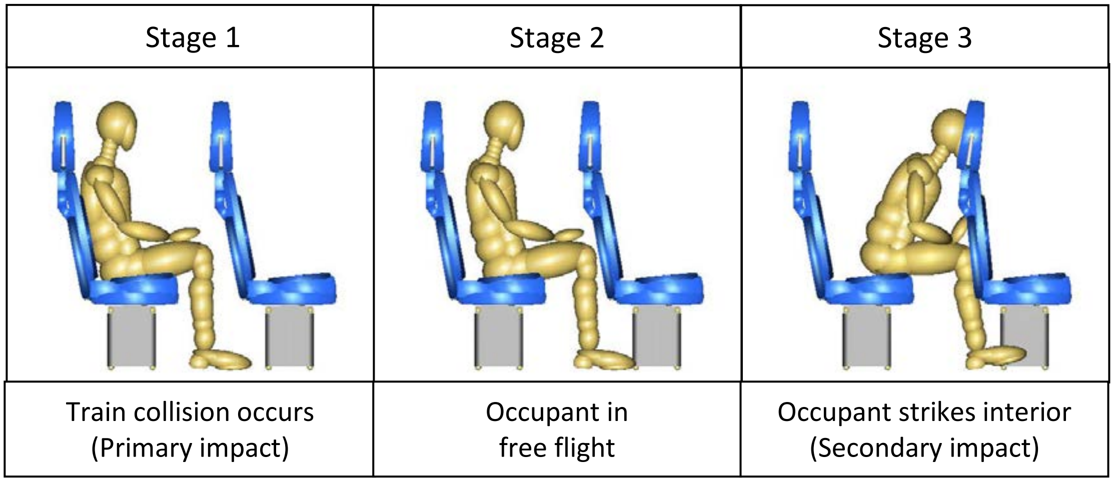


Figure 4. Three Stages of a Secondary Impact Scenario

As an example, an occupant in a forward-facing seat, seated behind another row of forward-facing seats would travel about 1.5 feet before making contact with the back of the seat ahead. In the trailing cab car in this accident, the SIV for a passenger in this situation was almost 20 mph. In general, the SIVs are lowest for occupants in rear-facing seats because those individuals travel virtually no distance before coming in contact with the back of their seats; and highest for occupants in open bay seats or seats facing the forward stairwell on the lower level because with only open space in front of them, they travel the greatest distance before striking a part of the interior.

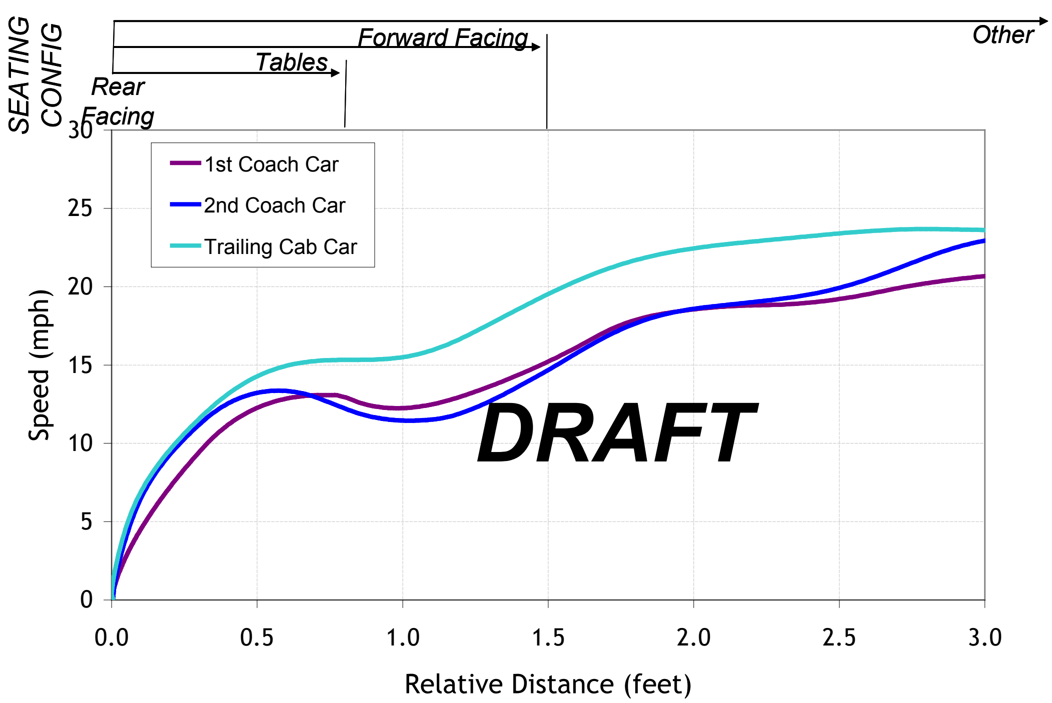


Figure 5. Secondary Impact Velocity

Figure 5 first shows with arrows that the passengers in a rear-facing seating configuration traveled the least distance following the collision (essentially no distance); followed by passengers seated at tables (they traveled closer to 1 foot); passengers in forward-facing seats (they traveled 1.5 feet); and passengers in other scenarios, with nothing to obstruct them, traveled through the car until striking a fixed object.

In the bottom section, the graph indicates that generally, the SIV of the Metrolink passengers increased with the relative distance they traveled before striking part of the interior. The graph also shows that SIVs were highest in the trailing passenger car, and about equivalent in the first and second passenger cars.

Once a secondary impact has occurred, the stiffness of an impacted object influences the occupant's rate of deceleration and injury severity. A flexible structure will deform, absorbing the kinetic energy associated with the moving occupant and decelerating the occupant gradually. A rigid structure will not absorb a significant amount of kinetic energy. Rather, the occupant's kinetic energy will be absorbed by the occupant's body, often causing significant injury.

Information from passenger and emergency responder interviews was combined with evidence gathered during the forensic investigation of the cars to estimate causal mechanisms of injury and fatality. Casualty and injury type and severity are strongly influenced by seating configuration, and the results discussed in this section are categorized accordingly: first all rear-facing seats; then forward-facing seats set up row-to-row, with table, and without table (open bay); and finally other arrangements.

3.3 Rear-Facing Seats

Collision forces cause a rear-facing occupant to be pressed into the back of the occupied seat, in the direction of travel prior to the collision. The SIV is minimal because the occupant does not have appreciable travel distance in which to develop a significant velocity with respect to the seat. The fiberglass seat backs are not very flexible, so little energy is absorbed through deformation. Provided that the head rest is tall enough to support the occupant's head, all body parts are reasonably supported. This uniform support minimizes excessive forces on the head, neck and thorax. When the center of gravity of the occupant's head is higher than the top of the head rest, significant neck forces and moments can occur, as well as head acceleration.

Based on interior evidence and passenger interviews, the passengers seated in rear-facing seats suffered the least severe injuries as a result of secondary impacts. There was minimal structural damage to seats in consecutive rows of rear-facing seats. In cases where rear-facing seats were damaged in an open bay configuration, the cause was likely due to impacts from occupants seated in the opposite facing seat. As an example of injuries to a rear-facing occupant, Passenger #9, who was seated in a rear-facing seat, spoke of having a headache and aches and pains consistent with a game of football following the accident, but no moderate or severe injuries. This outcome is consistent with dynamic seat analyses and tests that have been conducted previously [3, 4]. The right-hand seat shown in the photograph in Figure 6 is believed to be the initial location of Passenger #9.

Figure 6. Rear-Facing Seat

3.4 Forward-Facing Row-to-Row Seats

Forward-facing row-to-row seats in the Metrolink cars provide a relatively high level of safety. The seats are reasonably close together, with a seat pitch of about 32 inches, which places the front of the occupant about 1.5 feet away from the rear of the adjacent seat back. This seating configuration compartmentalizes the occupants between rows of seats, with minimal distance to travel in free-flight during a collision, which minimizes the secondary impact velocity. The fiberglass seat back is fairly rigid, but injuries experienced by passengers in this configuration are usually not extremely severe because the SIV is moderate. Compartmentalization is an occupant protection strategy that aims to contain occupants in a prescribed space with relatively compliant impact surfaces, such as between rows of seats or between a seat and a workstation table, preventing occupants from traveling large distances, developing significant velocity with respect to the rail car, and impacting other more hostile objects.

Passenger #12, who was seated in a forward-facing row-to-row seat on the upper level of Car # 617, experienced only facial injuries due to contact with the forward seatback. Passenger #12 is believed to have been initially located in the seat closest to the window, on the left side of the photograph shown in Figure 7. This passenger is believed to have impacted the back of the window-side seat on the right in the photograph.

Figure 7. Example Forward-Facing Row-to-Row Seats

3.5 Forward-Facing Bay Seats with Tables

In a collision, forward-facing bay seats with tables result in less severe injuries than open bay seats without tables. The tables act to compartmentalize occupants, which can limit secondary impact velocity and prevent tertiary impacts with other objects or passengers. A table that remains attached also prevents secondary impacts between two passengers seated in facing seats.

The tables in the Metrolink cars were made of 1-inch thick plywood with a melamine cover on the top and bottom surfaces. A thin strip of neoprene covered the table edge around the perimeter. The table structure is rigid and does not absorb kinetic energy through deformation, and the thin tabletop can result in concentrated loads being imparted to an occupant's abdomen. Though the occupant absorbs a great deal of force via the abdomen, the table limits what otherwise may be a larger SIV leading to a greater number of significant injuries to additional parts of the occupant's body.

Figure 8 shows a table that has broken off its mounts, on the upper deck of Car #207. A number of people seated forward-facing at a table suffered serious abdominal injuries due to impact with the table. Injuries included fractured ribs, lacerated liver, mesenteric tear, and damage to the spleen.

Figure 8. Example of Forward-Facing Bay Seats with Table

3.6 Forward-Facing Seats without Tables (Open Bay Seats)

A forward-facing open bay seating configuration leaves a considerable space, relative to other seating configurations, between occupants and the object that may potentially stop their forward momentum following a collision. Because of the larger travel distance, the consequent SIV will be higher, resulting in more severe injuries.

Forward-facing seats without intervening tables was one of the more hazardous seating configurations in this accident. In some cases, the hazard was exacerbated by an apparent vertical pitching motion of the cars caused by their inertia and the restraining coupling forces. Based on coupler deformation, it appears that each car pitched down in front and lifted up in the back. The pitching motion may have been more severe in the trailing cab car because there was no force at the rear coupler to constrain the vertical motion on the rear end.

The combination of low seat height and vertical carbody motion caused some passengers to be launched over the facing seat back and come to rest some 20 feet or more forward of the initial seat position. For example, Passenger #9 was originally seated in the rear-facing seat of an open bay seat pair near the middle of the upper level of Car #617. Seated in the forward-facing seat catty-corner across the open bay seat pair from Passenger #9 was a friend, Passenger #8. Passenger #9, who only had minor injuries, explained that after the impact, Passenger #8 seemed to have disappeared. Passenger #9 found Passenger #8 at the bottom of the stairs in the front mezzanine, some 20-25 feet away. There were five to six other passengers lying unconscious in the same area. It is likely that some or all of these passengers were initially seated in the upper level. There was a major crack in the seat pan of seat 94 in the front mezzanine that was likely caused by the impact of a passenger from the upper level. There were also significant pools of blood in this area, indicating significant blood loss from one or more immobilized passengers. Forensic evidence was also found in Car #207 indicating that the same conditions may have caused occupants from the upper level of that car to be launched forward to the front mezzanine. Evidence of this effect of vertical pitching motion was not observed in the lower levels of the cars.

The likely initial location of Passenger #8 is in the aisle-side seat shown in Figure 9. Injuries incurred by Passenger #8 include a fractured tibia, fibula, humerus, and rib, dislocated shoulder, head laceration and concussion. Interviewed forward-facing passengers that remained compartmentalized, or contained in the space between open bay seats, experienced fractures of the femur and patella, concussion, and facial lacerations.

Figure 9. Example of Forward-Facing Open Bay Seats

3.7 Other Interior Arrangements in Passenger Cars

Other seating arrangements include seats facing bulkheads, open seats (those with no forward structure for several feet, such as the seats aft of both sets of doors on the lower level), side-facing seats, and handicapped seating. There are hazards associated with these configurations that are related to increased SIV and stiffness of the impacted structure. The configuration that caused the most severe secondary impact injuries in this accident was the open seats.

In both of the trailing cars it appears that passengers who were initially seated in the flip-down seats just aft of the leading side doors travelled 10 to 15 feet prior to impacting either the stairs leading to the front mezzanine on the right side or the bulkhead on the left side. One passenger was found to be fatally injured on these stairs in Car #207. This passenger was likely seated at the flip-down seat on the right side of the car. Trauma included extensive fractures to the skull, brain contusions and lacerations, multiple bilateral rib fractures, lung contusions, and right femur shaft fracture.

Interviewed Passenger #7 was seated on the flip-down seat on the left side of Car #207 and impacted the bulkhead about 10 feet away (see Figure 10). This passenger suffered serious injuries, including four fractured ribs, four fractured vertebrae, fractured tibia, fractured forearm, and a fractured finger. This increased severity of the injuries to these passengers was likely caused by an extremely high SIV and very rigid impact surfaces, i.e., the stairs and the bulkhead wall.

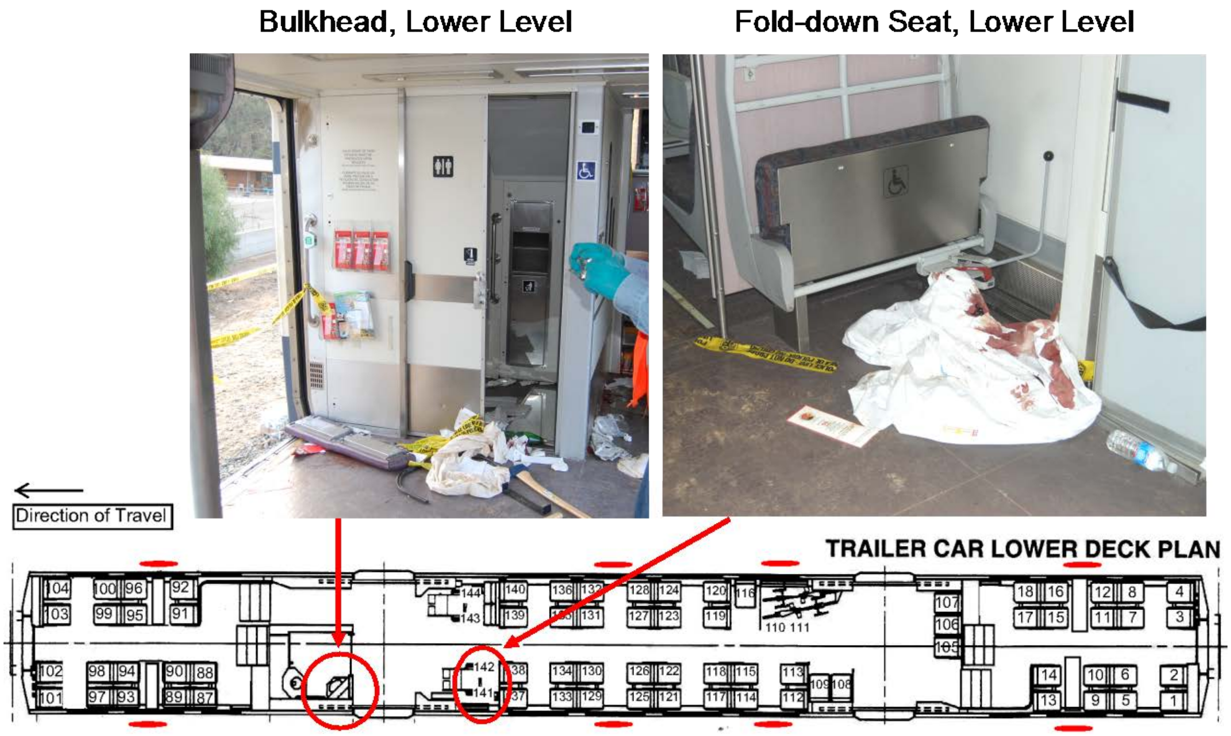


Figure 10. Forward Stepwell, Lower Level to Mezzanine Level, and Lower Level Fold-down Seat, Car #207

Figure 10 shows the bulkhead wall, which is next to the bathroom door, and the fold-down seat where Passenger #7 was likely initially located.

A passenger in a wheelchair was reported by interviewed passengers and first responders to have been found on the stairs leading from the lower level of Car #617 to the front mezzanine. There was no obvious damage to the wheelchair retention mechanism. It is unclear if the wheelchair was restrained in any way prior to the collision. Based on interviews with Passenger #8 and first responders, and damage observed in the stairwell, it appears that the passenger in the wheelchair was originally seated in the wheelchair at the designated handicapped seating area on the right side of the car, and following the collision came to rest on the stairs to the front mezzanine 15 feet away.

Passenger #6 was seated in a side-facing flip-down seat near a forward bulkhead on the lower level of Car #617. The passenger's right side reportedly impacted the bulkhead, resulting in several injuries, including a fractured right clavicle, scapula, and multiple ribs, punctured lung, and lacerated liver. Given the severity of the injuries, the passenger was likely seated some distance away from the bulkhead, such that the SIV was moderate to severe.

4. Locomotive Cab

There are, in general, two types of operator control layouts used in locomotives: the vertical console-stand style controls and the horizontal console style controls.

The vertical console-stand is a tall control placed to the left of the engineer near the center of the cab so that forward vision through a windshield and right-side vision through a window is clear. The engineer sits facing forward on the right side of the locomotive cab in close proximity to the controls, wall and window. Egress (leaving) from the seat requires standing or rotating the seat and moving to the left past the vertical console-stand. The only significant change in this design, which has existed since the 1940s, was the adoption of the clean cab design in the 1970s. The clean cab concept removed many secondary impact hazards such as protruding parts and sharp edges that can cause injuries to the occupants during a collision as well as everyday operation.

Interiors with the horizontal console style have a desk-like control display console in front of the engineer's seat. The engineer still has forward vision through a windshield and right vision through a window, but the area to the left of the engineer in the cab is unobstructed. The horizontal console restricts local movement and position change more than the vertical console-stand, but exiting from the seat only requires rotating the seat.

Many of the regulations and recommended practices focus on mitigating the effects of occupant secondary impact injury "to the extent possible" through equipment design features such as padded surfaces and rounded corners. In spite of these regulations, standards, and recommended practices, there are a number of features in both interior styles that are potentially injurious to occupants during a collision.

The vertical console-stand in the UP freight train was operated by an engineer, with two additional crewmen on board. The engineer and conductor were seated in the cab of the leading locomotive #8485, which is shown in Figure 11. The brakeman was located in the second freight locomotive #8491, which was positioned rear-facing at the time of the accident. The first locomotive derailed and rolled onto its left side. The second locomotive derailed but remained upright.

Figure 11. Cab in Union Pacific Locomotive #8485

Initially, all possible modes of egress were blocked for the crew of the first freight locomotive. As the car had tipped onto its side, the main door and right side window were out of reach above and the left side window offered no exit because it was against the ground. Another door in the nose of the locomotive was inaccessible because of the collision. The front windshield was blocked by an external fire that burned for 22 minutes. Rescuing firefighters extinguished the blaze, saw the crew trapped inside, and pried open the front windshield to allow the crew to escape the cab.

5. Summary of Structural Damage

Most of the structural damage to the passenger equipment was focused on the passenger locomotive and first passenger car. The second and third passenger cars sustained little structural damage. Table 1 summarizes the structural damage to the passenger locomotive and cars.

Table 1. Summary of Structural Damage to Passenger Equipment

Equipment	Summary of Structural Damage
Lead Passenger Locomotive	- Reduced in length by ~15 feet - Complete loss of operator's compartment due to crushing - Lead truck detached - Fuel tank detached
First Passenger Car	- Reduced in length by 65 feet, from 85 to 20 feet - Trailing coupler damaged - Trailing truck detached
Second Passenger Car	- Gooseneck slightly deformed - Lead coupler damaged - Some truck attachments failed
Trailing Passenger Car	- No significant carbody damage - Some truck attachments failed

The photograph in Figure 12 shows the lead freight locomotive, lead passenger locomotive, and first passenger car. The photograph is annotated to highlight the damage. Little of the passenger locomotive is visible, since it is telescoped into the passenger car. The illustration shows that the leading end structure (mezzanine level) has penetrated the bi-level section to the stairs of the trailing mezzanine level. The location of the detached passenger locomotive lead truck and fuel tank, both of which have been separated from the locomotive, are illustrated.

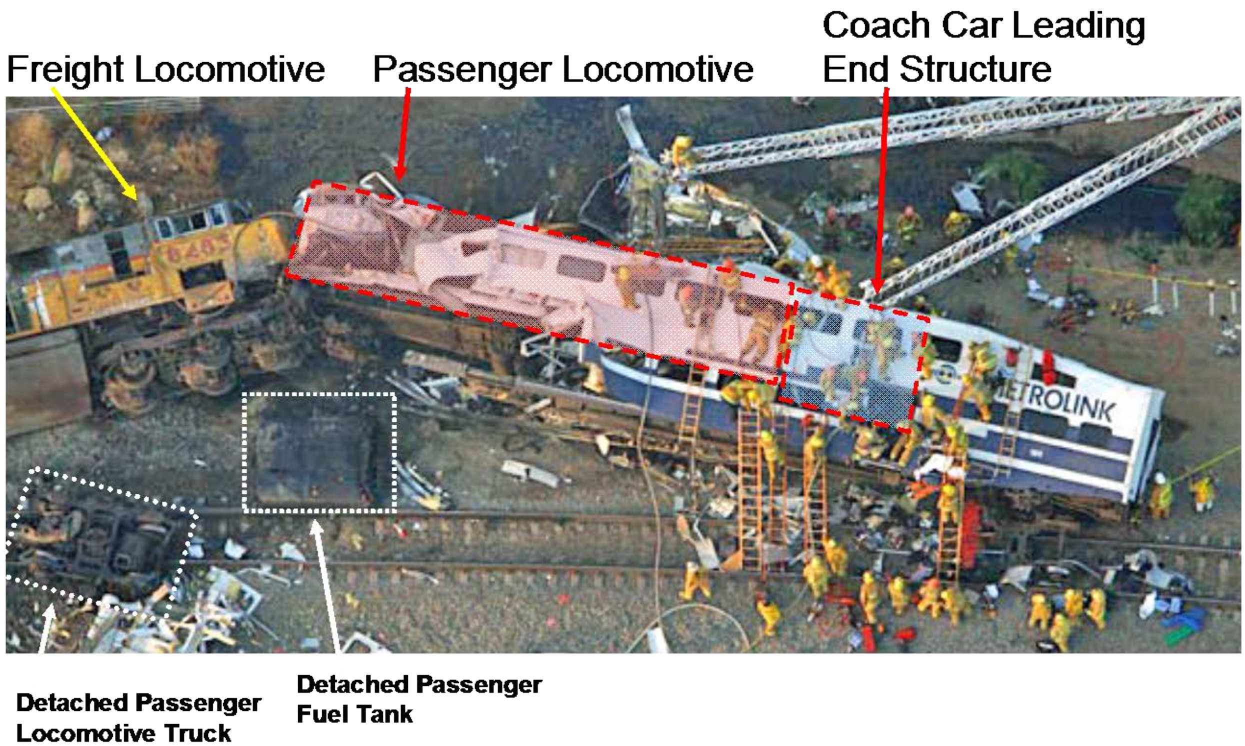


Figure 12. Annotated Photograph of Lead Freight Locomotive, Lead Passenger Locomotive, and First Passenger Car (Photograph from *LA Times* Web site)

Figure 13 shows a perspective view of the front and right side of the lead passenger locomotive, after the rear truck had been removed and the locomotive restored to an upright position. The operator's cab can be seen to be pushed back and upward, over the compartment for the rotating equipment. There is no survival space remaining inside the operator's cab. The locomotive has been crushed approximately 15 feet, from the coupler back to the lead body bolster. The front truck normally mounts to the frame at the lead body bolster, however the attachments were destroyed in the collision. Both the fuel tank and front truck were separated from the locomotive, and found proximate to the lead freight locomotive after the accident. It appears that the front truck separated owing to crush of the attachments on the locomotive body bolster, and that the fuel tank separated due to impact with the lead truck. There were significant breaches of the fuel tank, and a fire was fed by the spilled fuel. More detail on the fuel tank damage is provided in Appendix A.3. The trailing truck of the locomotive was found still attached after the accident, and was separated from the locomotive during clean-up of the accident site.

Figure 13. Lead Passenger Locomotive

Figure 14. First Passenger Car Structural Damage

The top photograph in Figure 14 shows the lead passenger car after the passenger locomotive was cleared away. The bellows and end frame from the front of the car are visible, pushed into rear portion of the car, with the left side wall ahead of it held up by the backhoe. The side sill can be seen, pointing to the right. Close inspection shows the threshold for the left side door on the side sill. The lower photograph shows the end frame being pulled from the interior of the car. Though not visible in this figure, the underframe of the separated leading end of the car is essentially intact, with the lead truck still attached.

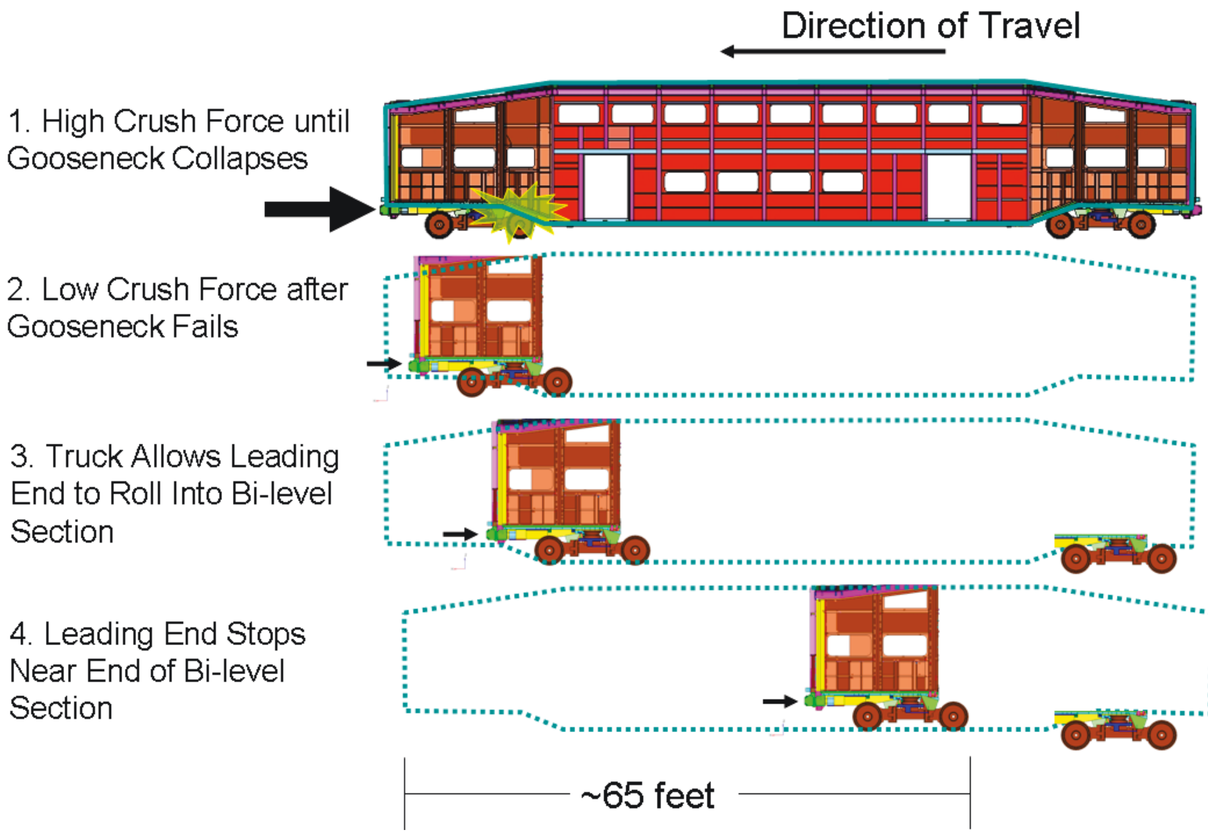


Figure 15. Likely Progression of Gooseneck Collapse and Failure

Figure 15 shows schematics illustrating how the structural damage shown in Figure 12 likely occurred. Shortly after the initial contact between the lead freight and passenger locomotives, a high force was generated between the rear of the lead passenger locomotive and front of the lead passenger car. This force was sufficient to cripple and fail the gooseneck area of the underframe. Simultaneously, due to the geometry of the gooseneck and its mode of collapse, the end underframe and truck were vaulted upward. This upward movement was sufficient to raise the wheels of the lead truck to the height of the lower floor of the bi-level section of the car. When the gooseneck failed, the primary longitudinal structure of the railcar was no longer loaded longitudinally. A relatively low longitudinal force was provided by the remaining sidewall and roof structures to resist intrusion into the car. The end section of the car, including the truck, penetrated the bi-level section of the car with relatively little force.

Figure 16. Second and Trailing Passenger Cars, (#207 and #617)

Figure 16 shows the second passenger car, Metrolink Trailing Passenger Car #207. Damage to this car was relatively minor. There was some damage to the leading end, which was coupled to the first passenger car. There was also some wrinkling of sidewall panels and damage to the lead truck attachment. There appeared to potentially be some distortion to the leading end draft sill, however, it was difficult to tell conclusively with only a visual inspection. Measurements were not possible with the truck in place. The leading bellows showed damage from contact with the car ahead. There were dents on the bellows frame, just above the spring loaded buffer beam. There was also damage to the fiberglass end cap above, just above the bellows. This damage was consistent with the leading car attempting to override this car.

Figure 16 also shows the third passenger car, Metrolink Trailing Passenger Car #617. There was very little structural damage to this car. The truck retention mechanism did fail, but the running gear remained intact and the truck remained in place beneath the car. Similar failures have been observed in an impact test of like equipment [1].

The passenger locomotive and the first passenger car were damaged much more severely than any of the freight equipment. The underframes of the freight equipment all remained essentially intact. Principal damage to the lead locomotive was to the ancillary structures on the front end – the draft gear housing, the plow, the breast plate, and the short hood. The second locomotive had a portion of the roof peeled back, likely caused by an impact with an empty covered hopper car. Seven trailing freight cars stacked up sideways against the trailing end of the trailing freight locomotive, and consequently received damage to their superstructures. Behind the sideways freight equipment, three freight cars derailed but stayed upright. These cars received fairly minor damage. The trailing seven freight cars remained upright and on the track, and did not appear to be damaged. Table 2 summarizes the structural damage to the freight locomotives and cars.

Table 2. Summary of Structural Damage to Freight Equipment

Equipment	Summary of Structural Damage
Lead Locomotive	- No significant underframe damage - Damage to the front plow, breast plate, and draft gear housing - Minor damage to rear breast plate - Left side of fuel tank paint removed
Second Locomotive	- No significant underframe damage - Damage to cab roof
Trailing Freight Equipment	- Five cars laterally buckled - Twelve cars with no or minimal damage

Figure 17 shows the damage to the freight train, which consisted of 1 forward-facing locomotive, 1 rear-facing locomotive, and 17 trailing freight cars. The leading end of the lead passenger locomotive is shown on the left side of the photograph. This locomotive is on its side. The leading freight locomotive is also on its side. As they collided, the lead passenger and freight locomotives apparently rolled outward, away from the center of the curve. The second, rear-facing freight locomotive is shown upright, with a freight car resting on its roof. Damage to the roof is evident. On the right side of the photograph, two of the stacked-up freight cars can be seen.

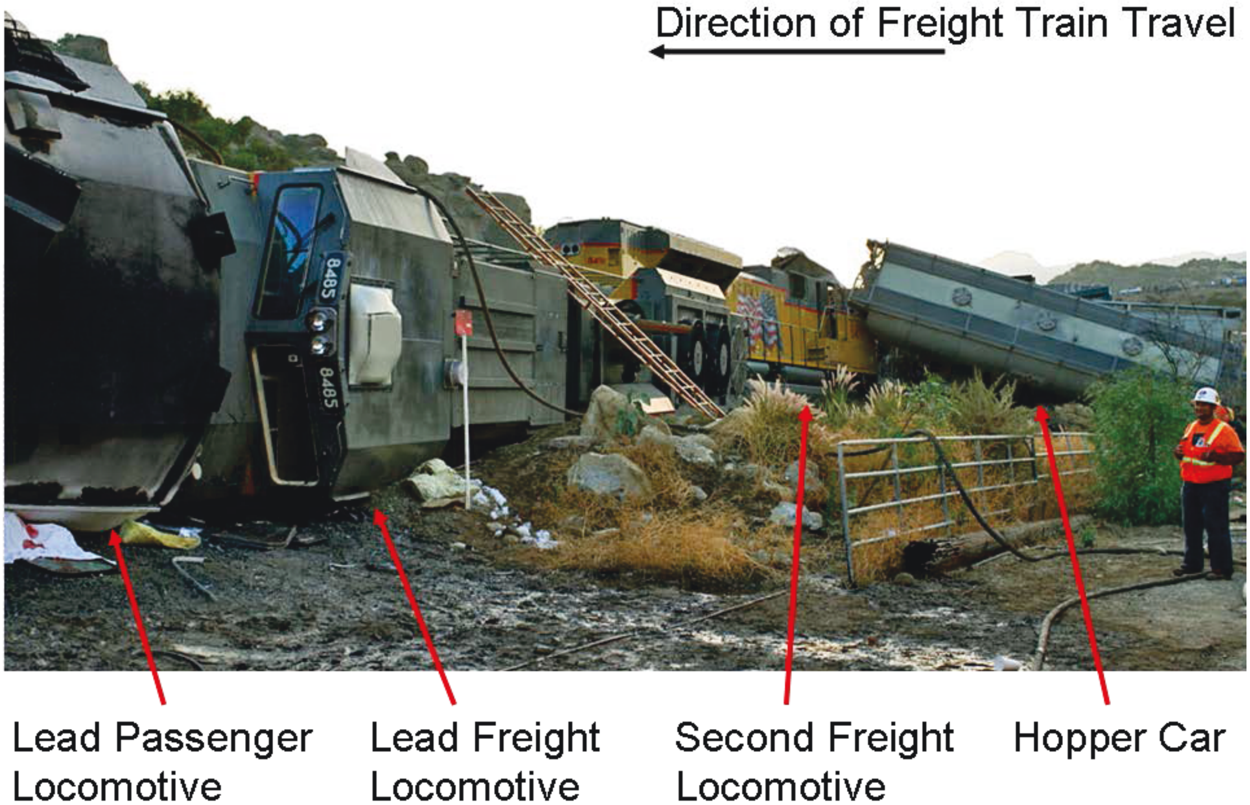


Figure 17. Annotated Photograph: Lead Passenger Locomotive, Lead and Second Freight Locomotives, and Trailing Freight Equipment

Figure 18 includes photographs of the front and the rear of the lead freight locomotive after the locomotive was made upright. Damage to the front of the locomotive, shown in the left-side photograph, includes substantial damage to the draft gear housing, which hangs beneath the underframe and supports the draft gear and coupler. The lower part of the normally vertical breast plate, which surrounds the draft gear housing, is bent back at about a 45º angle. This plate normally supports the plow; however, the plow apparently was ripped off during the accident. The paint on the left side of the fuel tank has been scraped off. The side of the locomotive also shows some scraping damage. This suggests that there was continued motion once the car overturned.

The right-hand photograph shows the rear of the locomotive. The coupler shank is broken, and the bellmouth surrounding the shank has some damage. The left side of the rear breast plate can also be seen to have some damage. The right side of the locomotive has little damage. The underframe is essentially intact, and both trucks and the fuel tank remained attached.

Figure 18. Lead Freight Locomotive Structural Damage

The photographs in Figures 19a and 19b show the second freight locomotive and a hopper car that collided with it. This locomotive was travelling long-hood forward. On the left side of Figure 19a, the lead locomotive can be seen to be on its side. On the right side of this photograph, the roof of an empty covered hopper car can be seen. The end of the covered hopper car is resting on the short hood of the locomotive. The roof of the locomotive was apparently significantly damaged owing to the impact from the covered hopper car.

Figure 19a. Second Freight Locomotive Structural Damage

Figure 19b. Second Freight Locomotive Structural Damage

Figure 20 shows the trailing freight equipment. The second freight locomotive and its damaged roof can be seen in the upper-right portion of the photograph. The end of the covered hopper car resting on the short hood can also be seen. The end of a second covered hopper car can be seen on the left side of the photograph. Three box cars are then stacked up sideways to the track. The next three box cars are upright and derailed. A rail can be seen near the two-people walking up to the middle upright and derailed freight car. The three freight cars near the bottom of the photograph are upright and on the track, as well as remaining four trailing freight cars, which are not visible in the photograph.

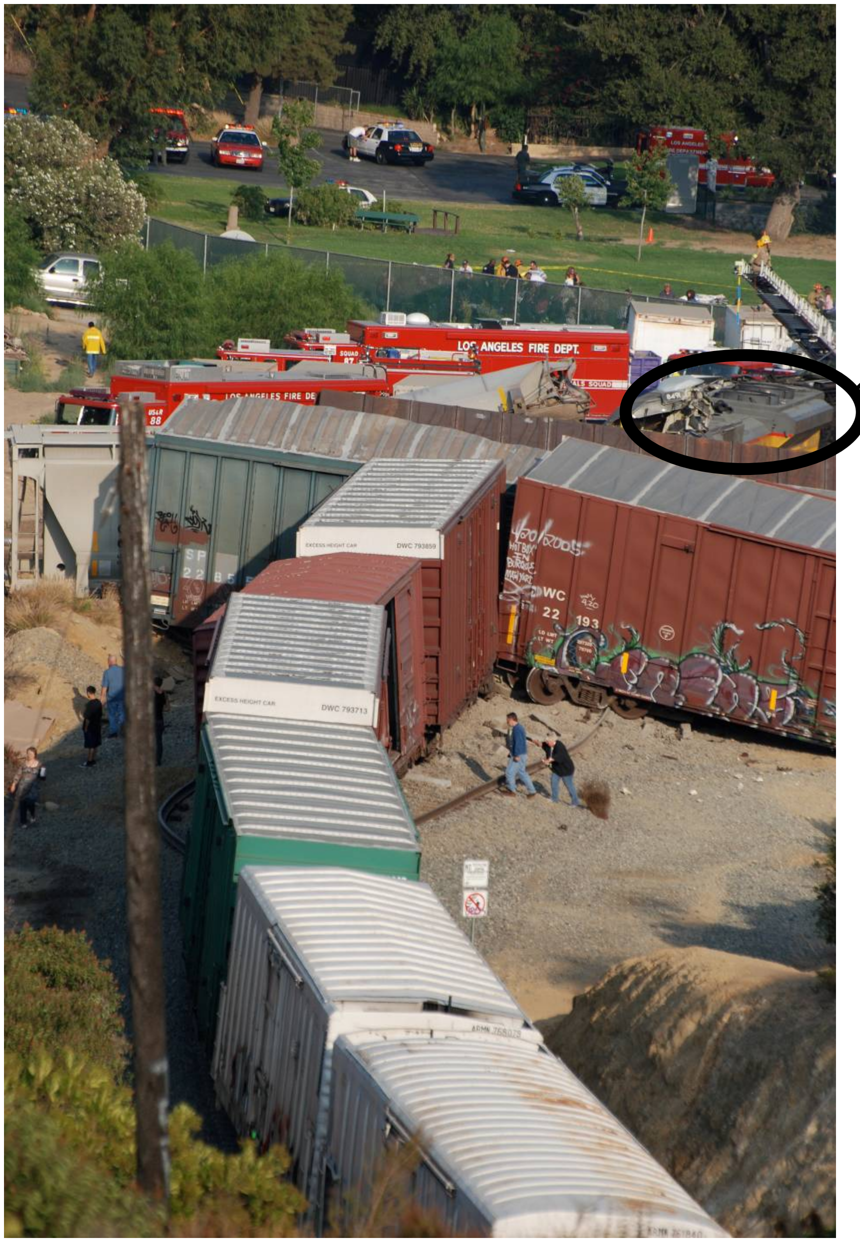


Figure 20. Freight Equipment Structural Damage

6. Summary of Interior Damage

This section of the report summarizes the forensic evidence in the passenger car interiors related to secondary occupant impacts. A summary of the interior damage to each passenger car is given in Table 3. A more detailed account of the interior damage is provided on annotated seating diagrams of each car in Appendix B.3.

Table 3. Summary of Interior Damage

Passenger Cars	Summary of Interior Damage
Coach 185	**• 144 seat capacity • ~ 65 feet of occupant volume crushed •~ 90% of seats missing or damaged • 75% of tables missing, damaged or detached • Stanchions bent/detached from car**
Coach 207	**• 144 seat capacity • ~ 15% of seats damaged • ~40% of tables damaged or detached • Stanchions bent/detached from car**
Cab 617	**•142 seat capacity • ~ 25% of seats damaged • ~40% of tables damaged or detached • Bulkheads cracked or detached from car • Stanchions bent/detached from car**

6.1 First Passenger Car #185

As described above, virtually no survivable space remained in the leading 65 feet of the first passenger car. However, there was no significant structural damage to the rear mezzanine. There was minimal interior damage in this area that could be used to positively identify secondary impacts between the passengers and interior fixtures. There were cracks to the head rest handle on one seat, indicating likely impact from a passenger. Both tables in the rear mezzanine appeared intact, though information gathered in an interview placed an occupant at the left-side table. There was dirt, debris, and blood on the right-side wall as a result of the car rollover that occurred post-impact. Although the interior damage caused by secondary impacts was minimal, information gathered from passenger interviews indicated that there were at least four survivors from Car 185, including three passengers seated in the rear mezzanine. Appendix B.1 provides passenger interviews.

6.2 Second Passenger Car #207

There was no loss of survivable space due to car crush in the second passenger car. Of the eight tables in the car, two were minimally displaced and one was completely detached from the car at both the floor and wall attachments. The table attachment failure was likely caused by the impact of a single person of large mass, or by the combined loading of two people. Cracked handles, headrests, and/or seat backs were found on fourteen seats. Damage to the fiberglass seat base was observed on two seats. Numerous seat cushions were missing or displaced. A stanchion was completely separated from the floor and wall on the lower level, near the aft doors (see Figure 21).

Figure 21. Detached Stanchion Near Aft Doors, Lower Level, Car #207

6.3 Trailing Passenger Car #617

There was no loss of survival space in the trailing cab car. More interior damage due to secondary impacts was observed in this car than the other cars. Results from train collision dynamics modeling (Appendix A.4) indicate that the increased damage in this car may be the result of an increase in the secondary impact velocity. Of the eight tables in this car, one was dislodged, one was detached from the wall mount (Figure 21), and one was completely detached from the wall and floor mounts. Over 20 seats had cracked handles, cracked or broken headrests (Figure 22), or fractured seat backs. Four seats experienced damage to the fiberglass seat pan. There was damage to three separate bulkheads on the lower level. There were major cracks to two seat pans (Figure 23). One seat pedestal was also cracked. A stanchion was completely detached on the lower level near the aft doors. There were also deformed stanchions and fractures to the walls of the luggage rack on the lower level.

Figure 22. Detached Table, Upper Lever, Car #617

Figure 23. Broken Head Rests in Lower Level, Car #617

Figure 24. Fractured Seat Pan, Front Mezzanine, Car #617

7. Conclusion

On September 12, 2008, a passenger train and freight train collided head-on in the Chatsworth region of Los Angeles, CA, with each train initially travelling at more than 40 mph. Twenty-five people were killed and approximately 138 were injured, many severely. This report estimates the sequence of events from the initial impact to the resulting injuries and fatalities, based on an investigation by the U.S. Department of Transportation's Rail Accident Forensic Team. The Forensic Team has also gathered and organized the information needed to evaluate effectiveness of current crashworthiness and emergency preparedness regulations to develop future regulations.

The operator of the locomotive and 22 passengers were fatally injured due to loss of survival space. During the accident, the front of the passenger locomotive was crushed such that the operator's cab was pushed back over the heavy equipment inside the locomotive, eliminating the survival space for the operator. Nearly simultaneously, the first passenger car broke into two pieces at the lead end gooseneck, and the leading portion telescoped into the trailing portion, eliminating the survival space for 22 passengers. Two passengers in the telescoped portion are known to have survived. Two passengers inside the trailing passenger cars suffered fatal injuries by being thrown into the lower stepwells and sustaining severe head trauma.

Many of the most severe injuries occurred due to passengers being thrown large distances inside the cars, reaching significant speeds relative to the interior, and then impacting a hard and hostile-shaped interior surface. One forward-facing occupant, initially seated on the upper level near the center of the car, was thrown into the aisle, and landed at the bottom of the forward stairwell from the mezzanine level. The passenger sustained head injuries, multiple rib fractures, and a broken leg. Several passengers on the lower level were thrown forward from seats into the forward lower stairwells leading to the mezzanine level. These passengers travelled past the side entry doors for about 8 feet before impacting the stairs. These passengers all received severe injuries.

The Rail Safety Improvement Act of 2008 (RSIA) was implemented on October 16, 2008, in part owing to the Chatsworth accident. RSIA requires implementation of Positive Train Control (PTC) on commuter and intercity passenger rail routes. Features of PTC are intended to prevent train-to-train collisions, such as occurred in Chatsworth. While PTC is expected to significantly reduce the number of passenger train accidents and incidents, it is not expected to eliminate all of them. Grade-crossing incidents may still occur with PTC, such as the one in Glendale, CA, on January 26, 2005. Eleven people were killed and over 100 were injured when a southbound commuter train collided with an SUV placed across the tracks, 150 feet south of the Chevy Chase Boulevard grade crossing. This collision caused the train to derail and impact a freight train standing on a siding track. Subsequently, the southbound commuter train buckled laterally outwards and raked the side of a northbound commuter train. Crashworthiness remains a concern to the Federal Railroad Administration (FRA), even with the widespread introduction of PTC.

Crashworthiness is the ability of a vehicle structure to provide sufficient space to the occupants to ride out the collision and of the vehicle interior to limit, to survivable levels, the forces and decelerations imparted to the occupants. Currently, FRA and industry set standards for structural crashworthiness and interior occupant protection. Despite FRA regulations setting minimum standards, the consequences of this accident suggest areas to investigate for enhanced crashworthiness performance.

The first passenger car broke into two pieces, with the end portion telescoping into the trailing main portion. The structure failed in a manner in which relatively little force was required to eliminate a significant amount of survival space. A more graceful response of the car structure to being overloaded may have been more effective in protecting the survival space. Strategies such as those used with earthquake-tolerant buildings and bridges, which allow the structure to collapse gracefully and remain in one piece, may be worth investigating. Given the severity of the accident conditions, it is unlikely that the survival space could have been preserved in entirety even with an alternate design. However, a carbody structure that requires a relatively high force to propagate collapse could potentially preserve significantly more of the survival space under such conditions.

The large, open space in the vicinity of the side doors allowed passengers to be thrown relatively large distances within the cars. This caused the passengers to develop significant speed relative to the interior. Severe injuries resulted in cases where the passengers subsequently impacted a hostile interior surface, such as stairs, and in two cases these injuries were fatal. In other cases, the injuries were non-fatal but are likely to be life-altering. Reducing the distance passengers can travel inside a car during an accident could significantly reduce the number and severity of injuries. Careful placement of bulkheads and seats facing away from stepwells are strategies that can be effective at compartmentalizing occupants, i.e., to minimize the travel distance and secondary impact velocity, which can limit the forces and decelerations passengers experience.

8. Subsequent Research

FRA is conducting research on structural crashworthiness and occupant protection. Some of this research is guided by the results of investigations of previous incidents with similar equipment. These include the accidents in Glendale, CA, on January 26, 2005, and in Placentia, CA, on April 23, 2002.

As part of the response to the Placentia accident, workstation tables were investigated and a prototype of an improved design was developed [5, 6]. FRA worked with Metrolink to develop a production version of this prototype. These tables were first introduced into service in late 2010 in new equipment.

As part of the response to the Glendale incident, and based on the results of FRA research [7], Metrolink required the incorporation of Crash Energy Management (CEM) into the structures of its latest cars [8]. CEM builds on traditional rail crashworthiness practice and adds crush zones at the unoccupied ends of the equipment. CEM features can significantly increase the collision speed at which all train occupants would be expected to survive. Metrolink equipment with CEM features went into service in December 2010.

However, CEM does not necessarily influence the main structure of the car and how it collapses. While equipment incorporating CEM may do better at preserving the occupant volume than conventional equipment under conditions like the Chatsworth accident, changes to the main structure and how it collapses are potentially needed to preserve most of the occupant volume for such severe conditions. FRA has modeled and tested the equipment involved in these three accidents [1] to better understand its collapse behavior. With this understanding and the results of the Chatsworth investigation, FRA is considering plans to investigate the potential of alternative structural arrangements to more gracefully deform when overloaded and consequently better preserve the occupant volume under severe conditions, such as those of the Chatsworth accident.

9. References

1. Priante, M. "Review of a Single Car Test of Multi-Level Passenger Equipment," American Society of Mechanical Engineers, Paper No. JRC2008-63053, April 2008.
2. Severson, K., Perlman, B.A., Stringfellow, R. "Quasi-Static and Dynamic Sled Testing of Prototype Commuter Rail Passenger Seats," American Society of Mechanical Engineers, Paper No. JRC2008-63051, April 2008.
3. Severson, K., Tyrell, D., Rancatore, R., "Crashworthiness Requirements for Commuter Rail Passenger Seats," American Society of Mechanical Engineers, Paper No. IMECE2005-82643, November 2005.
4. Tyrell, D., Severson, K.J., "Crashworthiness Testing of Amtrak's Traditional Coach Seat," U.S. Department of Transportation, DOT/FRA/ORD-96/08, October 1996.
5. Stringfellow, R., Nutting, J., "Workstation Table Engineering Model Design, Development, Fabrication, and Testing," U.S. Department of Transportation, DOT/FRA/ORD-12/06, May 2012.
6. Stringfellow, R., Nutting, J., "Workstation Table Crashworthiness Tests, "U.S. Department of Transportation, DOT/FRA/ORD-13/48, December 2013.
7. Tyrell, D., Jacobsen, K., Martinez, E., "A Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Structural Results," American Society of Mechanical Engineers, Paper No. IMECE2006-13597, November 2006.
8. Tyrell, D., Martinez, E., Jacobsen, K., Parent, D., Severson, K., Priante, M., Perlman, A.B., "Overview of a Crash Energy Management Specification for Passenger Rail Equipment," American Society of Mechanical Engineers, Paper No. JRC2006-94044, April 2006.

Appendix

Appendices A.1 through B.3 – (A detailed account of the Chatsworth, CA, passenger/freight train collision). Available at https://www.fra.dot.gov/eLib/Details/L19037.

Abbreviations and Acronyms

CEM	Crash Energy Management
EMD	Electro-Motive Diesel
FRA	Federal Railroad Administration
PTC	Positive Train Control
RSIA	Rail Safety Improvement Act of 2008
SCRRA	Southern California Regional Rail Authority
SIV	Secondary Impact Velocity
UP	Union Pacific Railroad