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Federal Railroad Administration

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

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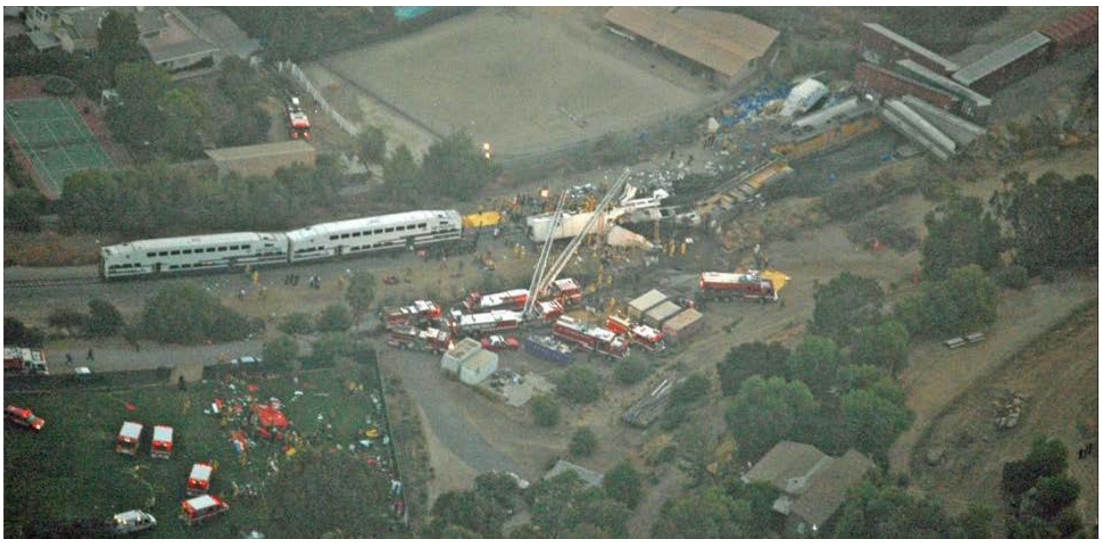
Washington, DC 20590



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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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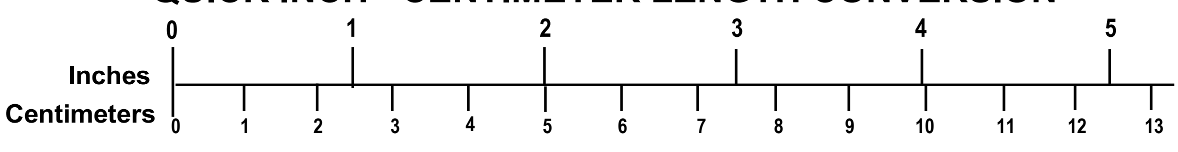

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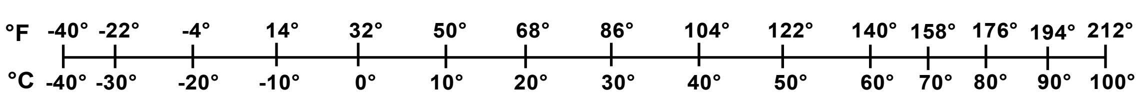

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286 **Updated 6/17/98**

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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.

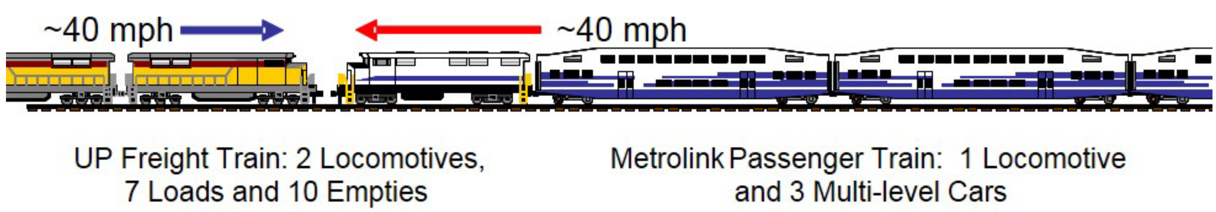


Figure 1. Schematic of Initial Impact Conditions

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)

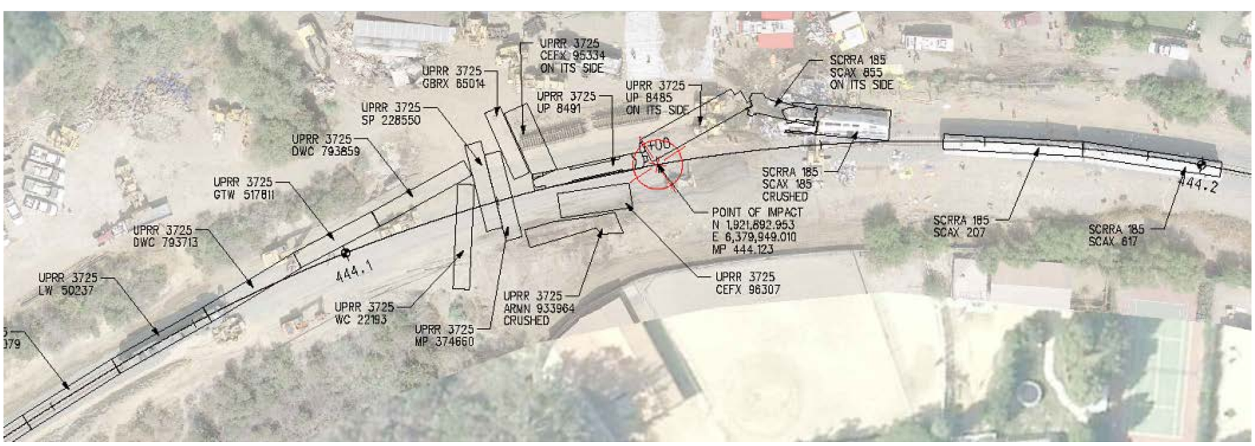


Figure 2b. Aerial Photograph of Accident, with Equipment Locations (From SCRRA)

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.

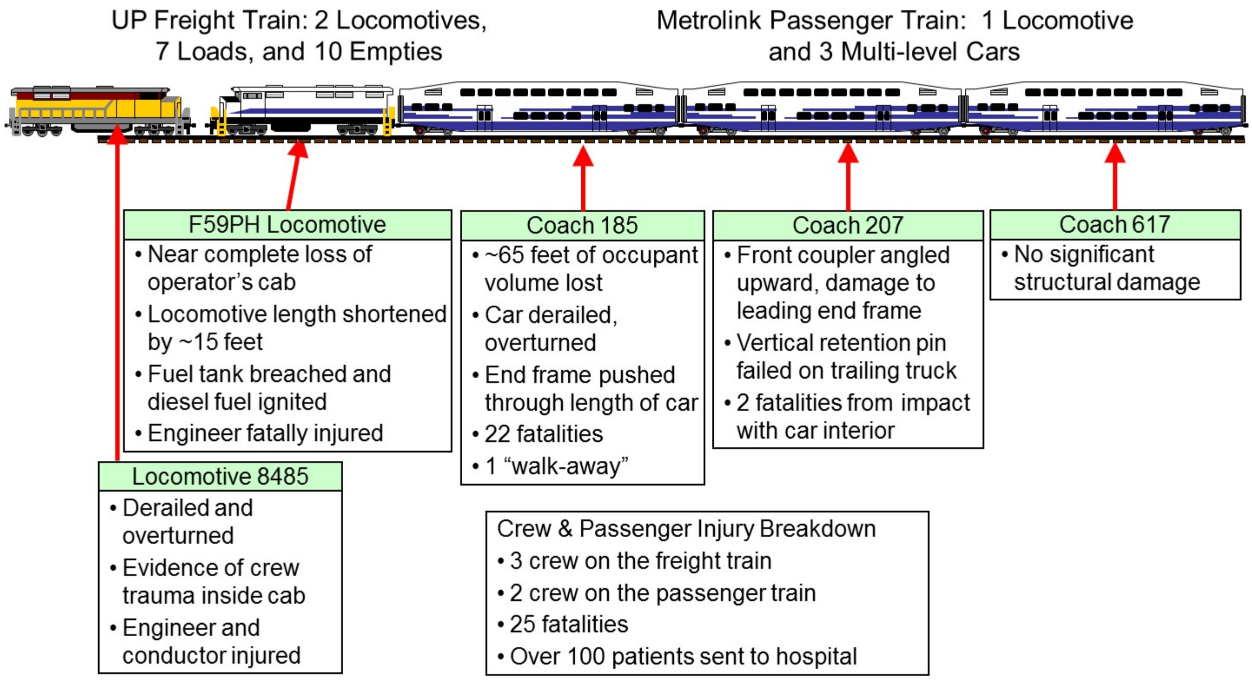


Figure 3. Summary of Equipment Damage and Injury/Fatality Distribution

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

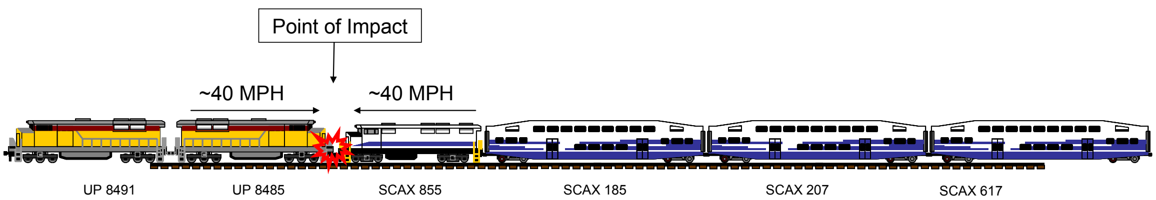
This report consists of a main report, as well as separate Appendices A.1 through B.3, which are available on FRA's eLibrary. The main report describes the sequence of events and causal injury mechanisms, and summarizes the structural and interior car damage. Appendix A provides further detail on the 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.

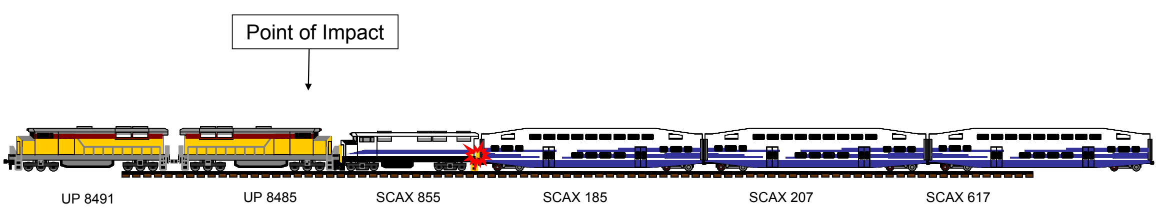
The present tense is used for simplicity in the following description of the sequence of events.

2.1 Initial Contact



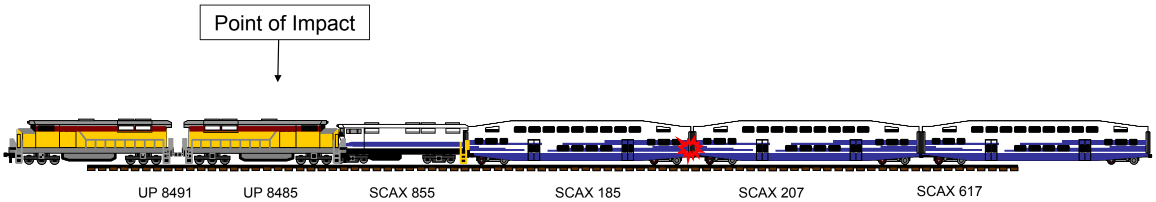
The locomotives come together, initiating contact at the coupler knuckles. The draft gears compress, bottom out, and overload the draft gear pockets on each locomotive. On the freight locomotive, the coupler shank fractures and the draft gear pocket deforms downward. The pilot fractures and tears away. 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



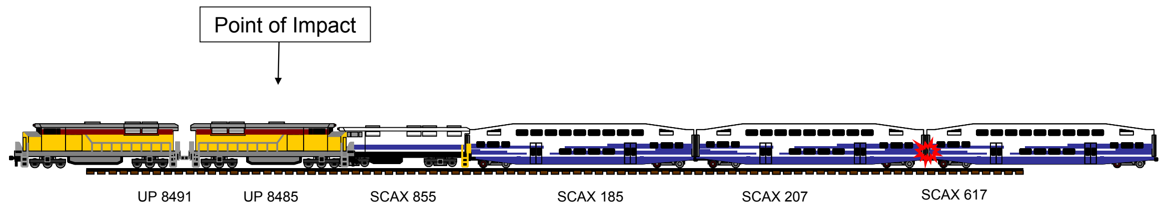
At about 0.03 seconds, the passenger locomotive is crushed by about 2 feet and the main structure cripples. The front portion of the locomotive is vaulted back and up and intrudes into the operator's volume. The first passenger car makes hard contact with the rear of the passenger locomotive. The first 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



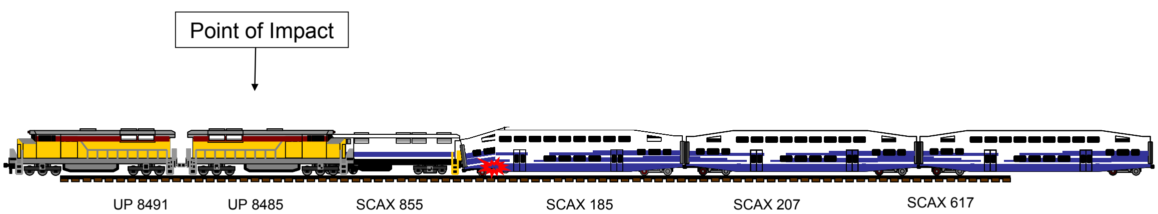
At about 0.1 seconds the passenger locomotive is crushed another 6 feet (at this time, 8 feet in total). The passenger locomotive's lead truck rotates back and the truck attachments, which connect the truck to the car, fail. As the collision pulse moves back through the train, the second passenger car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



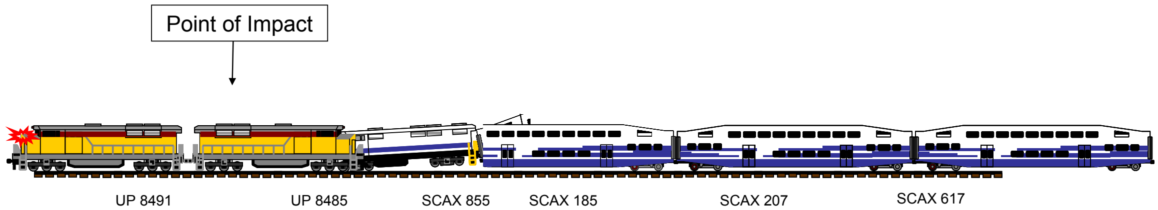
At about 0.15 seconds the passenger locomotive front end is crushed by about 10 feet. The lead truck impacts the adjacent fuel tank. The impact punctures the tank and the fuel tank detaches from the carbody underframe. The first passenger car is crushed by about one foot and the underframe starts to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



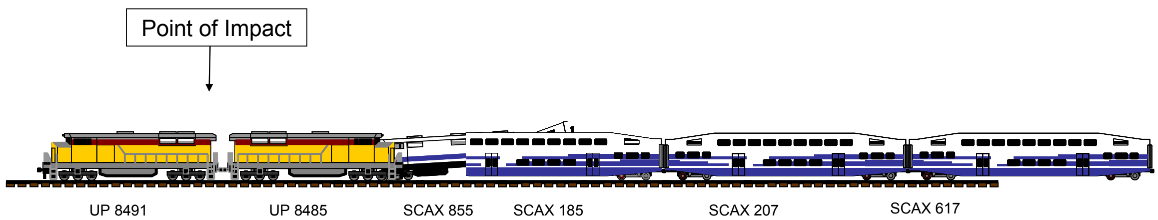
At around 0.25 seconds the passenger locomotive front end has finished crushing, about 15 feet in total. The passenger locomotive has finished decelerating and begins to reverse direction as it is pushed by the momentum of the freight train. The gooseneck of the first passenger car catastrophically fails 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



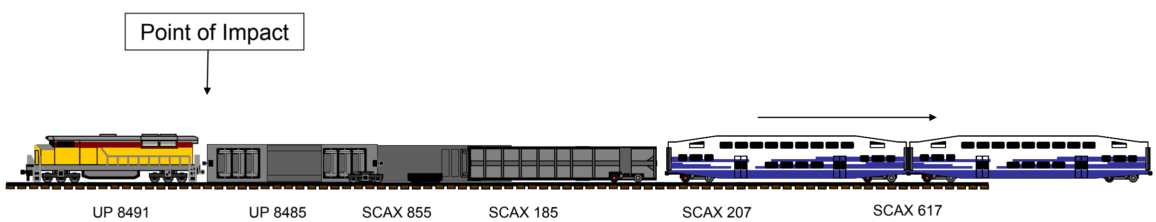
At about 0.4 seconds, the first freight car behind the second rear-facing freight locomotive overrides and crushes the operator's compartment. The freight cars successively pile up in a large scale sawtooth buckle mode. The detached front portion of the first passenger car has plunged about 10 feet deeper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

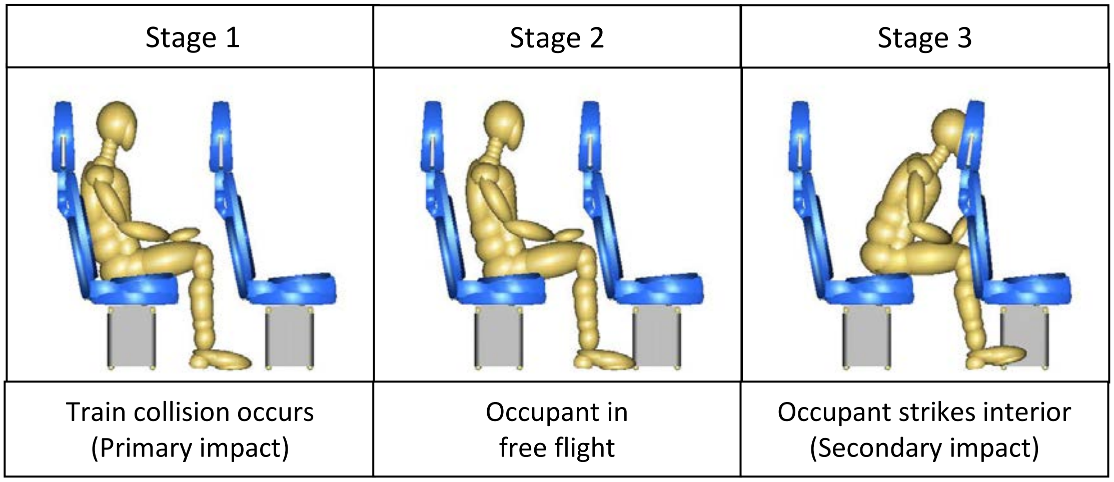


Figure 4. Three Stages of a Secondary Impact Scenario

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.

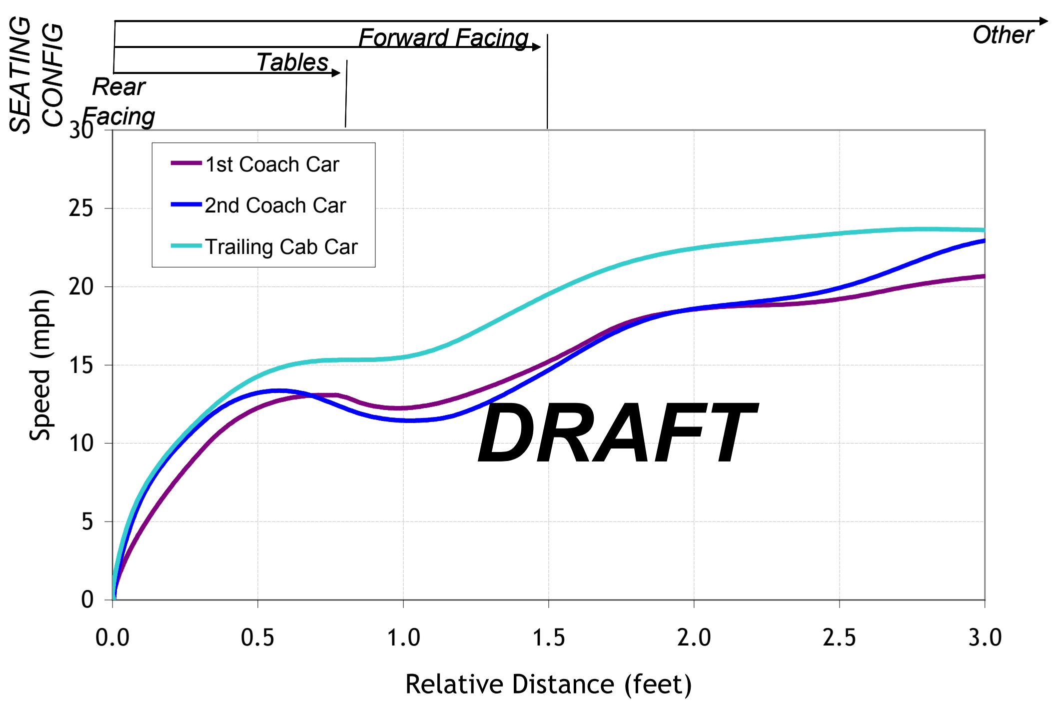


Figure 5. Secondary Impact Velocity

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.

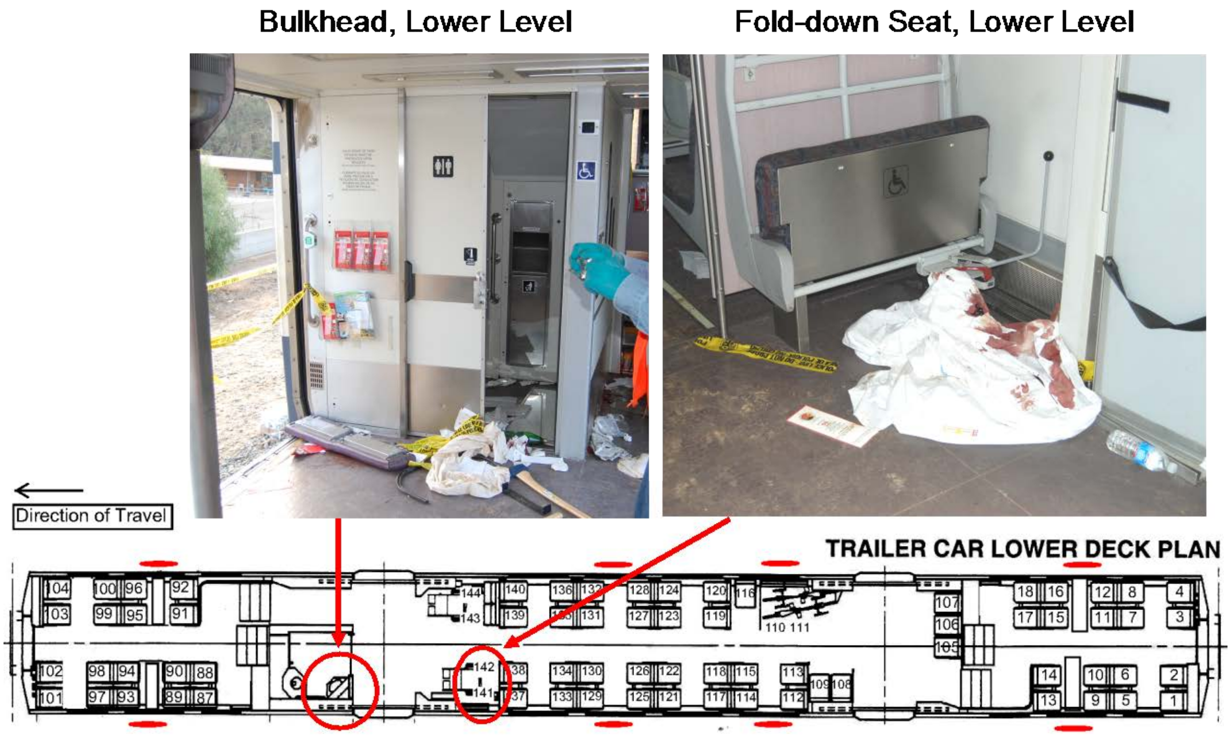


Figure 10. Forward Stepwell, Lower Level to Mezzanine Level, and Lower Level Fold-down Seat, Car #207

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.

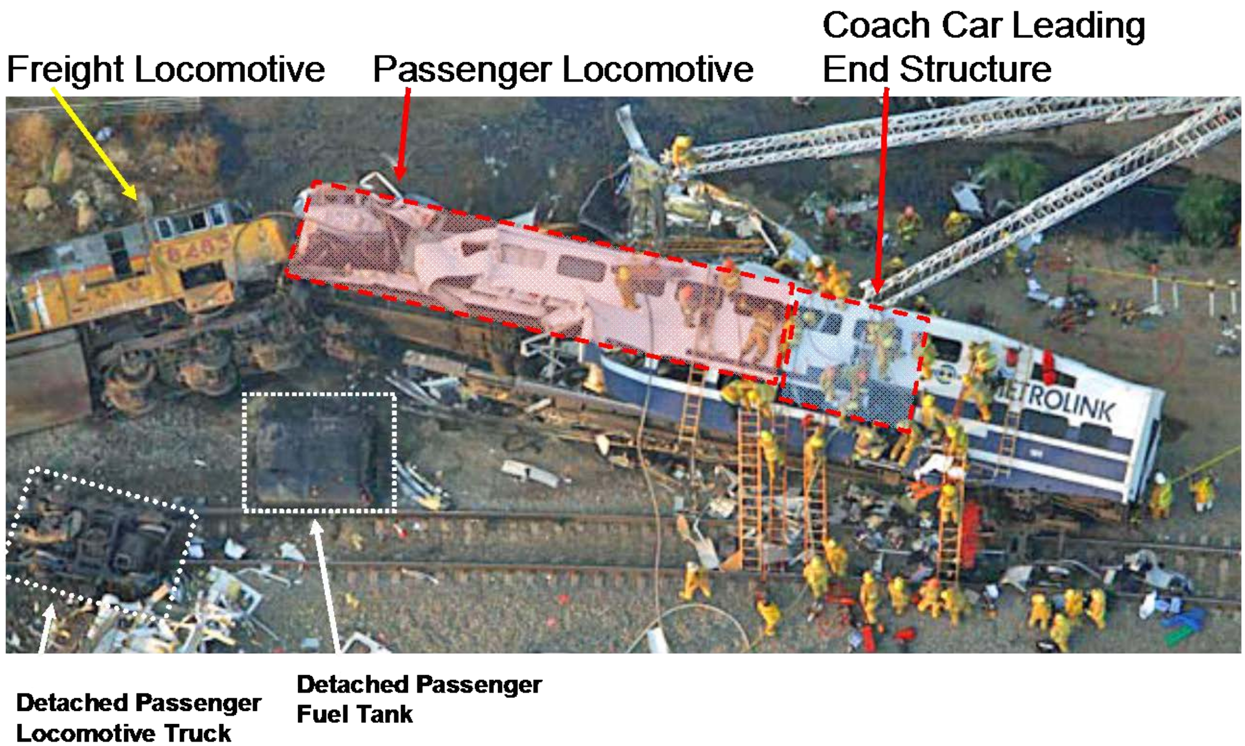


Figure 12. Annotated Photograph of Lead Freight Locomotive, Lead Passenger Locomotive, and First Passenger Car (Photograph from *LA Times* Web site)

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.

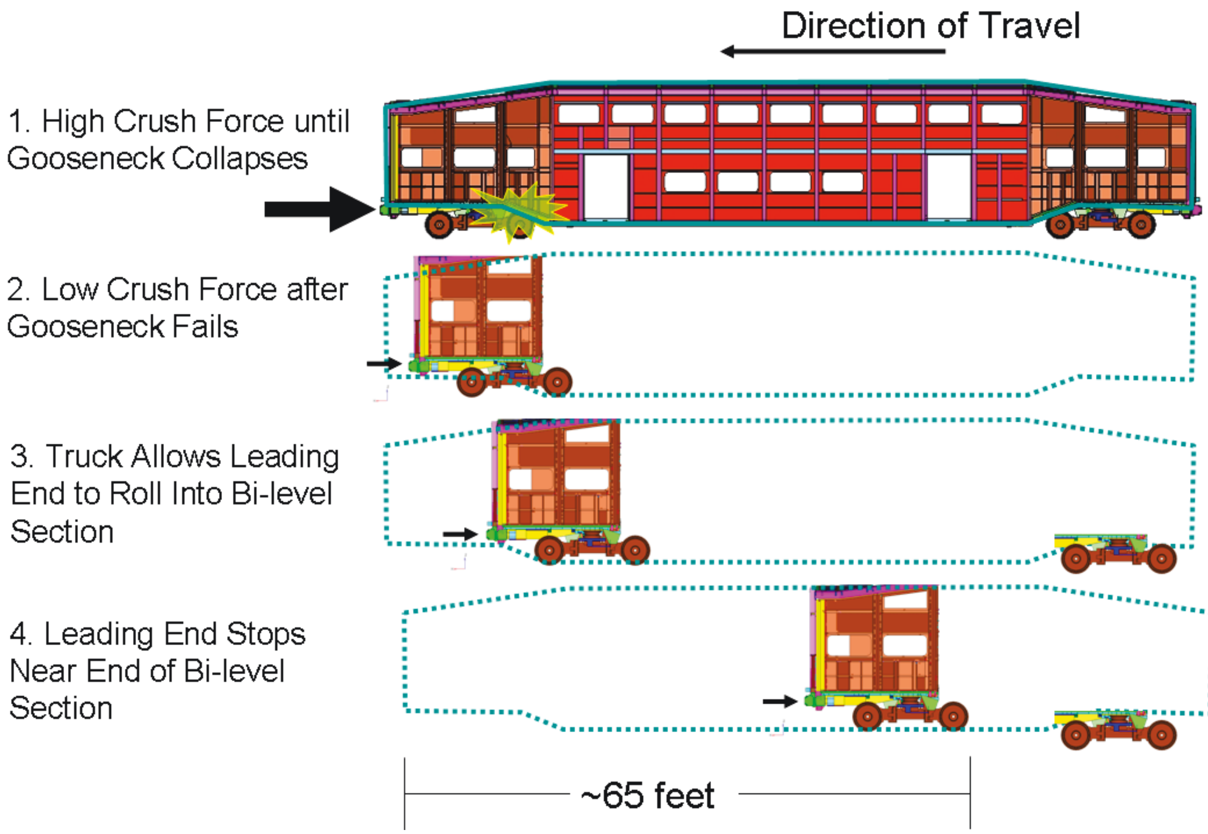


Figure 15. Likely Progression of Gooseneck Collapse and Failure

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.

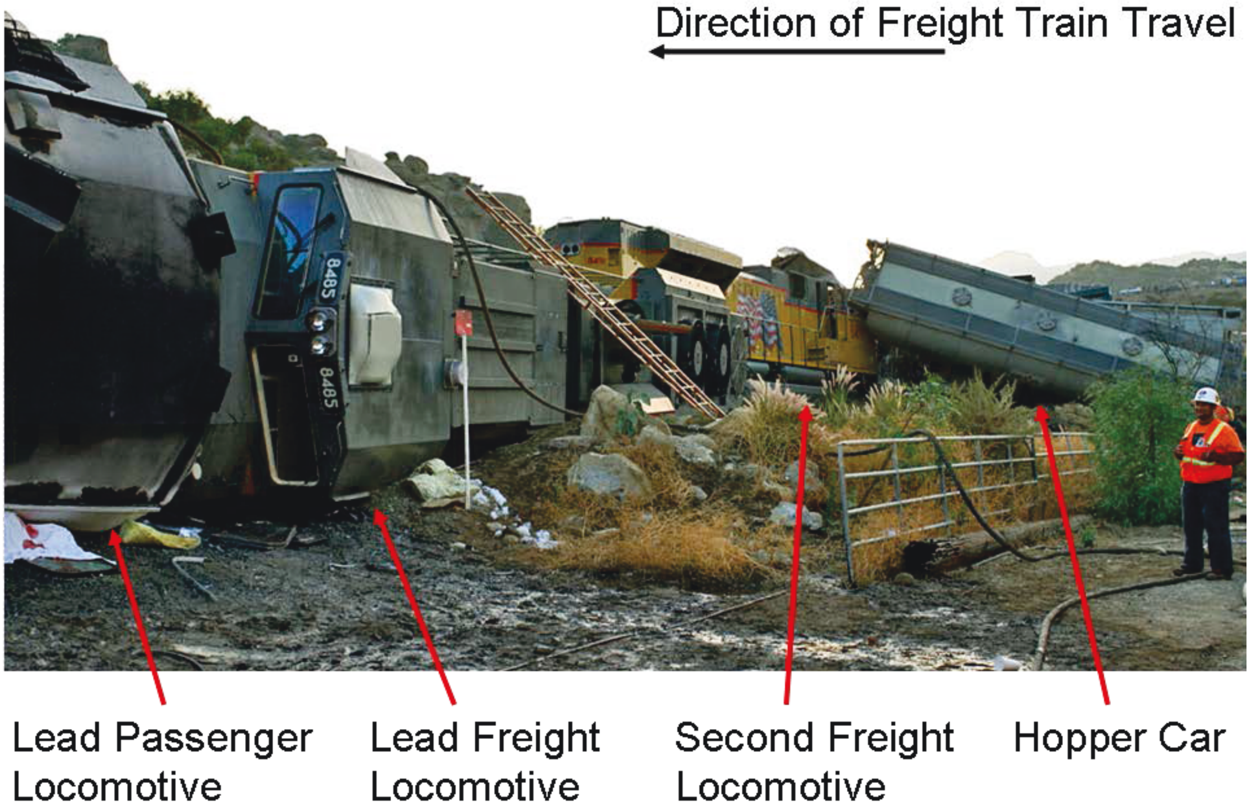


Figure 17. Annotated Photograph: Lead Passenger Locomotive, Lead and Second Freight Locomotives, and Trailing Freight Equipment

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 45^{o} 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.

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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

Contents

Appendix A.1: Equipment Interactions

This appendix describes the interactions of the equipment, starting from the interaction of the colliding locomotives. The interactions of the coupled passenger equipment are described in detail, and an overview is presented of the interactions of the coupled freight equipment.

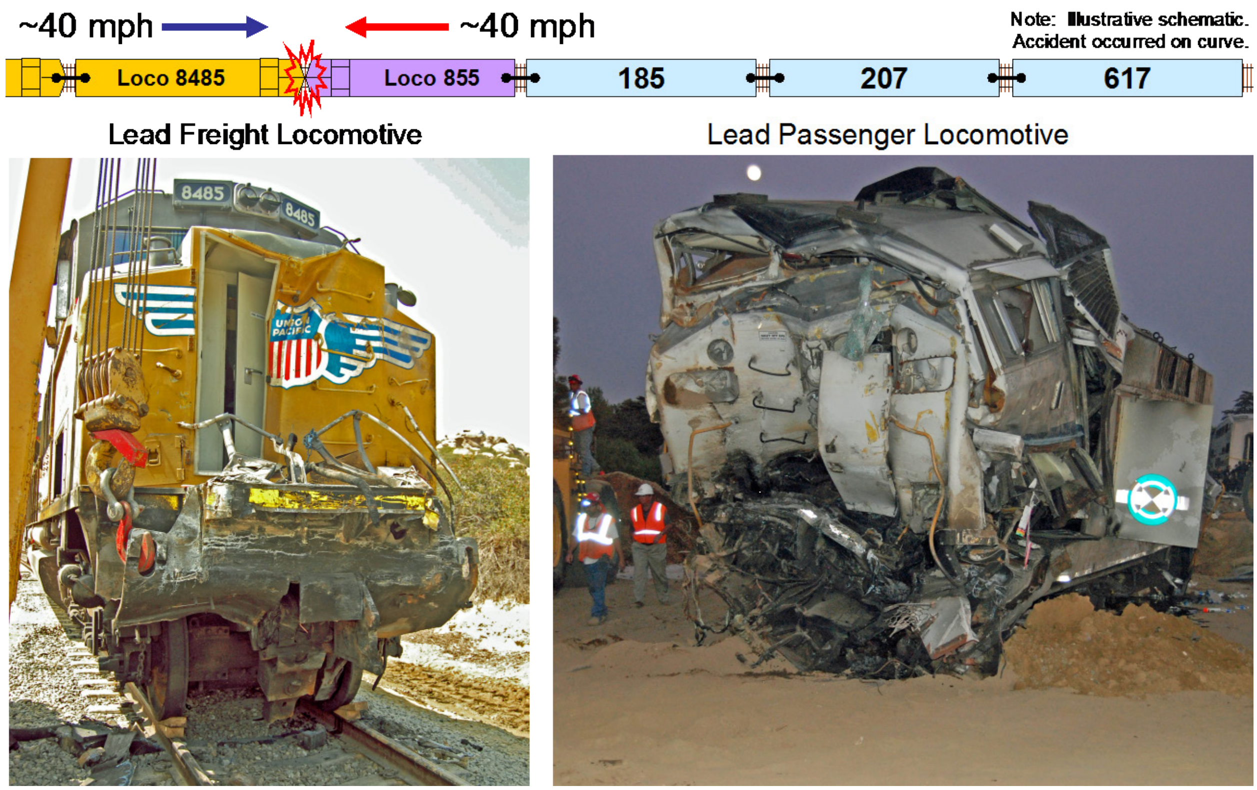


Figure A.1-1. Lead Freight and Passenger Locomotives, Impact Ends

Figure A.1-1 shows the impact ends of the lead passenger and freight locomotives. The freight locomotive sustained substantially less damage than the passenger locomotive. Damage to the freight locomotive includes separation of the plow, the breast plate bent up under the underframe, damage to the short-hood door and sheet metal. The draft gear box is largely destroyed, and the draft gear and broken coupler shank can be seen hanging down in the photograph. The collision posts remain essentially intact, and the truck is attached. The passenger locomotive is shown after it has been up-righted. While the shape of the cab appears recognizable, the cab has been pushed back over the rotating equipment, eliminating the operator’s survival space. The collision posts have been separated from their attachments to the underframe, and the lead truck is not under this locomotive.

Lead Freight Locomotive

Broken coupler shank. Coupler draft pocket deformed and oriented downward.

Pilot fractured and tore away. Sides of draft gear pocket fractured.

Lead Passenger Locomotive

Coupler and draft gear pocket fractured off of locomotive underframe.

Figure A.1-2. Coupler and Draft Gear Damage, Lead Freight and Passenger Locomotives

Figure A.1-2 shows the remains of the coupler pockets and draft gear housings of the lead freight and passenger locomotives. Both are substantially damaged. Most of the draft gear housing has been separated from the passenger locomotive and the draft gear, yoke, and coupler are missing from the photograph. The freight draft gear housing also appears to be largely missing, but the draft gear, yoke, and broken coupler shank are hanging, and appear trapped by the bent breast plate.

Uprighted Passenger Locomotive

Passenger Locomotive Anti-climber Engages Beneath Freight Locomotive Anti-climber.

Uprighted Freight Locomotive: Left Side

Freight Locomotive Anti-climber Engages Above Passenger Locomotive Anti-climber.

Figure A.1-3. Anti-climber Engagement of Lead Freight and Passenger Locomotives

Figure A.1-3 shows the anti-climbers on the lead freight and passenger locomotives. The anti-climbers appear to have functioned as intended, helping to keep one locomotive from climbing the other. The anti-climber of the passenger locomotive appears to have locked under the anti-climber of the freight locomotive. The freight anti-climber appears to have speared through the short hood of the passenger locomotive, near its attachment to the underframe.

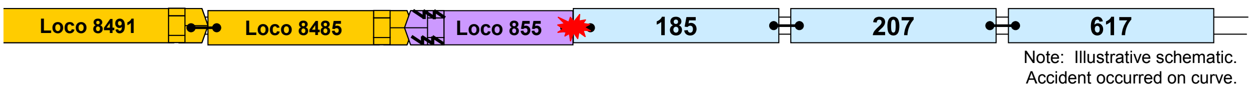


Figure A.1-4. Interaction of Passenger Locomotive and First Passenger Car

(Photograph from the *LA Times* Web site)

Figure A.1-4 shows the interaction of the passenger locomotive and the first passenger car. There was extensive structural damage to the passenger car, while there appears to be little damage to the trailing end of the locomotive. The photograph shows the locomotive telescoped into the passenger car. The locomotive is on its side, while the passenger car is not quite fully on its side. (Note: the photograph shows the cars in reverse position from the schematic above that illustrates the relative position of cars in the collision).

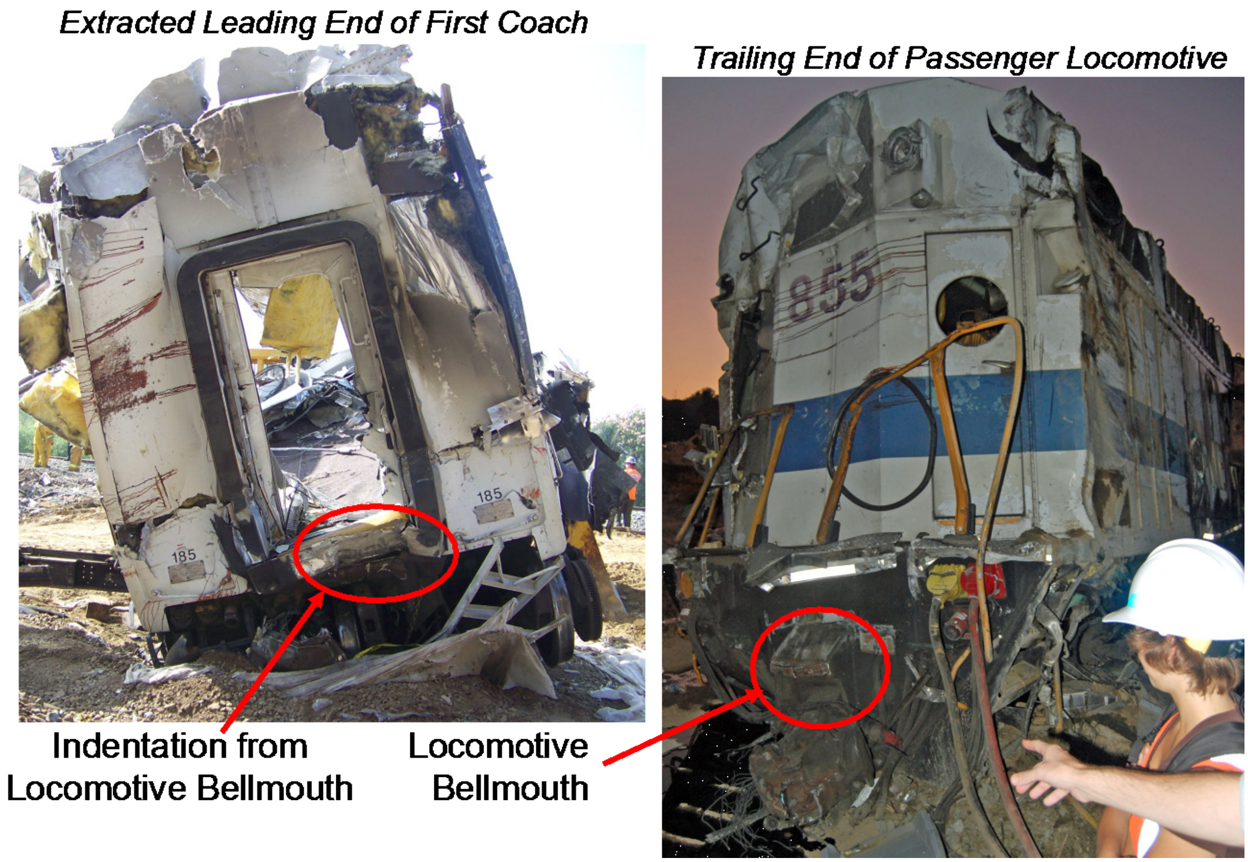
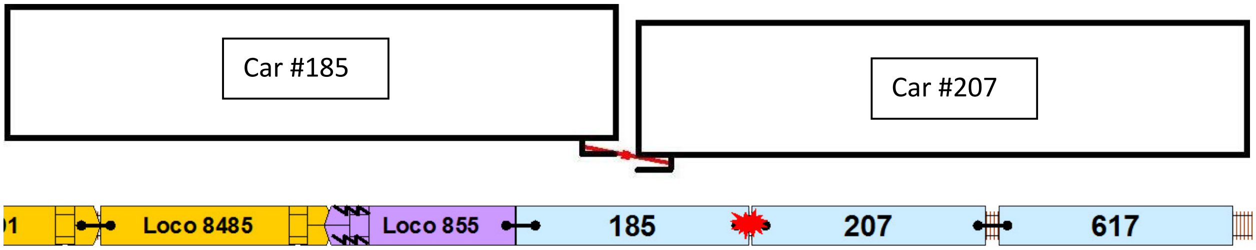


Figure A.1-5. First Passenger Car Lead End Frame Interaction with Locomotive Trailing End Bellmouth

Figure A.1-5 shows the lead end structure of the first passenger car, after it has been extracted from the body of the car. The collision and corner posts are essentially intact. There is a large dent in the underside of the end beam, circled in red. The shape of this dent corresponds to the shape of the bellmouth on the trailing end of the locomotive, which is also circled. This dent suggests that the rear of the passenger locomotive applied an upward vertical force to the front of the passenger car, as the front of the passenger car was also pitching downward.

The trailing end of Car #185 lifts upward relative to Car #207. The leading end of Car #207 pitches downward.



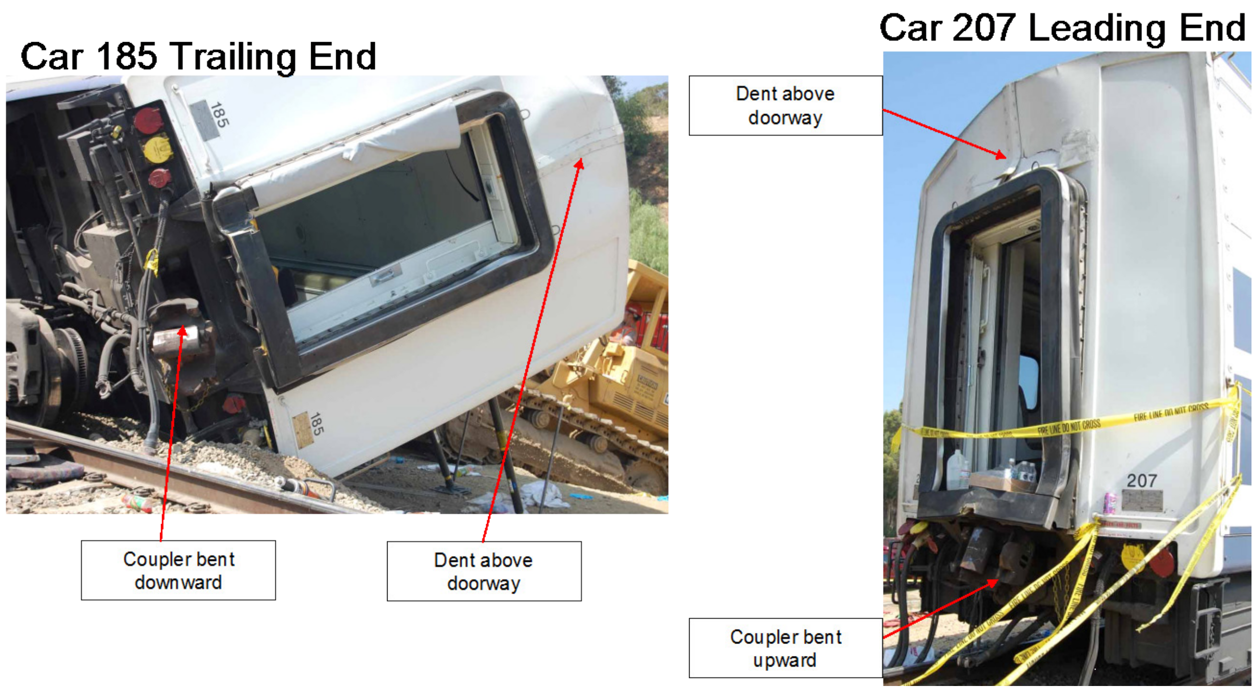


Figure A.1-6. Trailing End of First Passenger Car and Leading End of Second Passenger Car

Figure A.1-6 shows the interaction between the trailing end of the first passenger car and the leading end of the second passenger car. The first passenger car coupler head is bent downward. There is a dent in the lower corner of the door bellows, on the left side, and there is a dent above the doorway. At the leading end of the second passenger car, the coupler is bent upward. The left side collision post appears bent, near its attachment to the floor-level structure, and the right side post appears bent in a similar location but to a lesser degree. The damage suggests that both cars pitched forward, i.e., the front ends of both cars went down and the back ends went up.

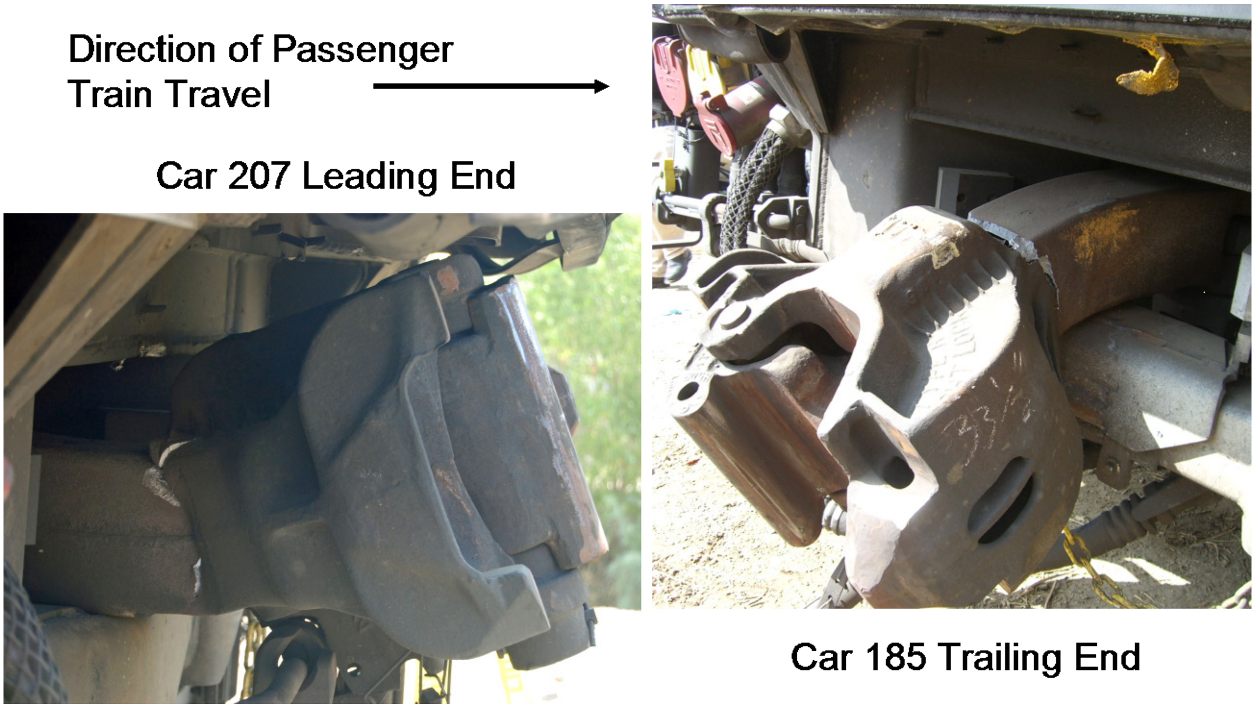


Figure A.1-7. Trailing Coupler of Lead Passenger Car and Leading Coupler of Second Passenger Car

Figure A.1-7 shows the trailing coupler of the lead passenger car and the leading coupler of the second passenger car. At some point during the accident, the cars became uncoupled, but the extent of damage suggests that the cars remained coupled for most of the impact, including the pitching forward discussed in relation to Figure A.1-5. There is significant material failure near where the head blends into the shank in both couplers. This damage suggests that the lead car tried to override the second car.

Figure A.1-8. Interaction of Second Passenger Car and Trailing Cab Car

Figure A.1-8 shows the coupled connection between the second passenger car and the trailing cab car. There is little damage at this interface. Both cars remained on the track, and rolled backward after the impact, for a distance of what is estimated to be between 80 and 100 feet.

Appendix A.2.1: Additional Detail on Structural Damage to Passenger Locomotive and Cars

Most of the damage to the passenger equipment was focused on the locomotive and first passenger car. The second and third passenger cars sustained little structural damage. Table A.2.1-1 summarizes the structural damage to the passenger locomotive and cars.

Table A.2.1-1. 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 from impact - 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

Figure A.2.1-1. Typical Metrolink Train

Figure A.2.1-1 shows a typical Metrolink train in running condition. The train is led by four-axle Passenger Locomotive #856 which was built in the same production run as Passenger Locomotive #855, the locomotive involved in this accident. Passenger Locomotive #856 as shown here is followed by four passenger cars, while Locomotive #855 was followed by three trailing cars in the accident, two passenger cars and a cab car.

A.2.1-1. Passenger Locomotive Damage

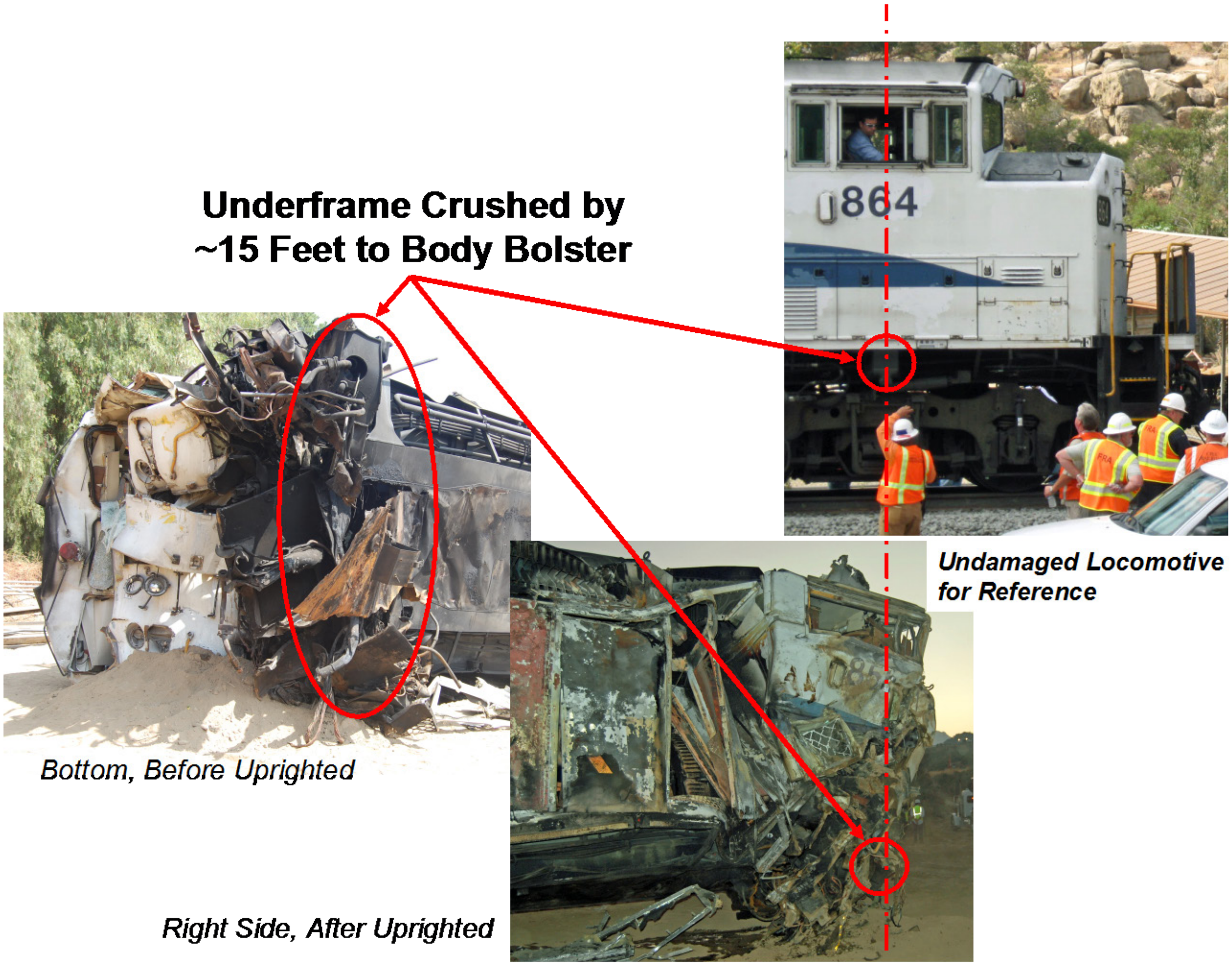


Figure A.2.1-2. Passenger Locomotive Lead End Crush

Figure A.2.1-2 shows the structural damage to the lead end of the passenger locomotive. A photograph of an undamaged locomotive is included for reference. While the side window frame is visible in the lower right photo, there is no interior cab space, as the cab has been pushed back over rotating equipment. The locomotive has been crushed approximately 15 feet, from the coupler back to the body bolster. The truck normally mounts to the frame at the body bolster; however, the attachments were destroyed in the collision. The lead truck separated from the equipment it supported, both the locomotive car and the fuel tank.

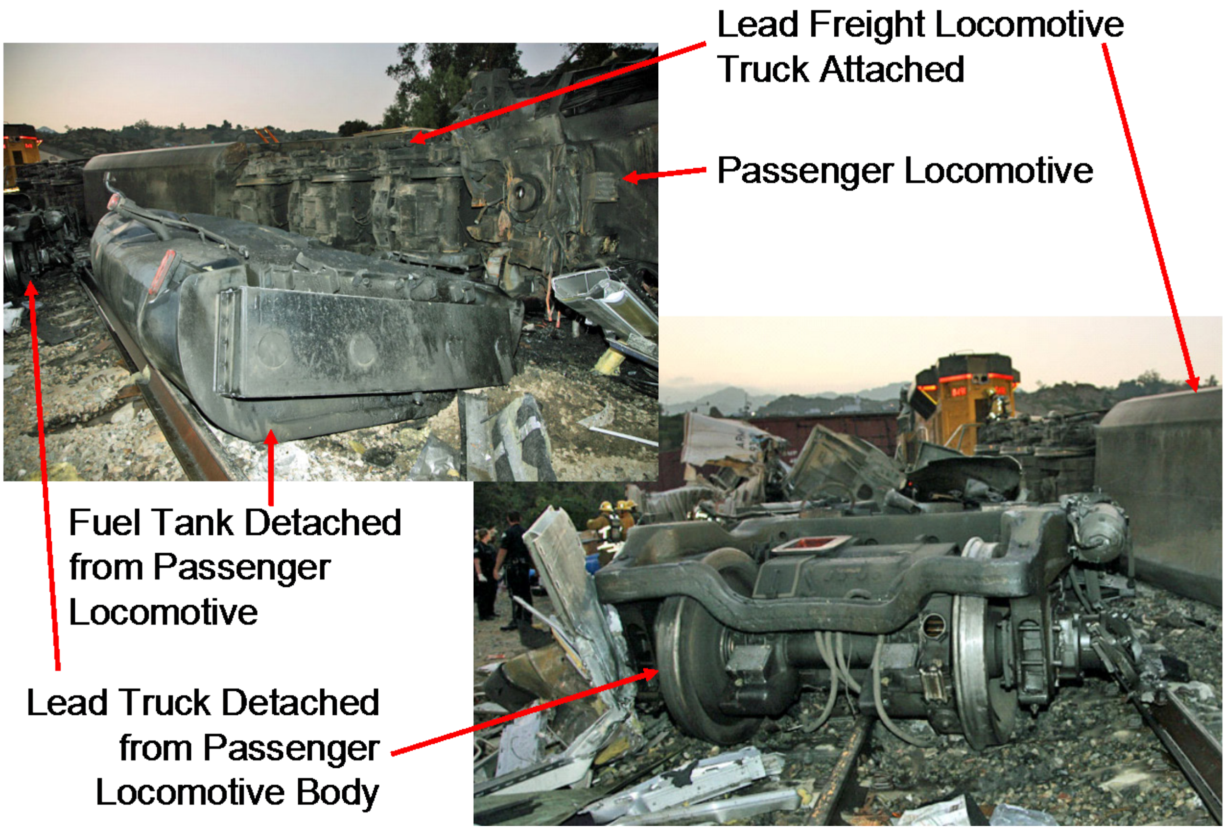


Figure A.2.1-3. Passenger Locomotive Fuel Tank and Lead Truck Separated from Locomotive

Figure A.2.1-3 shows the passenger locomotive fuel tank and lead truck. Both the fuel tank and truck were separated from the locomotive, and found proximate to the lead freight locomotive. It appears that the 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 fed by the spilled fuel. More detail on the fuel tank damage is provided in Appendix A.3.

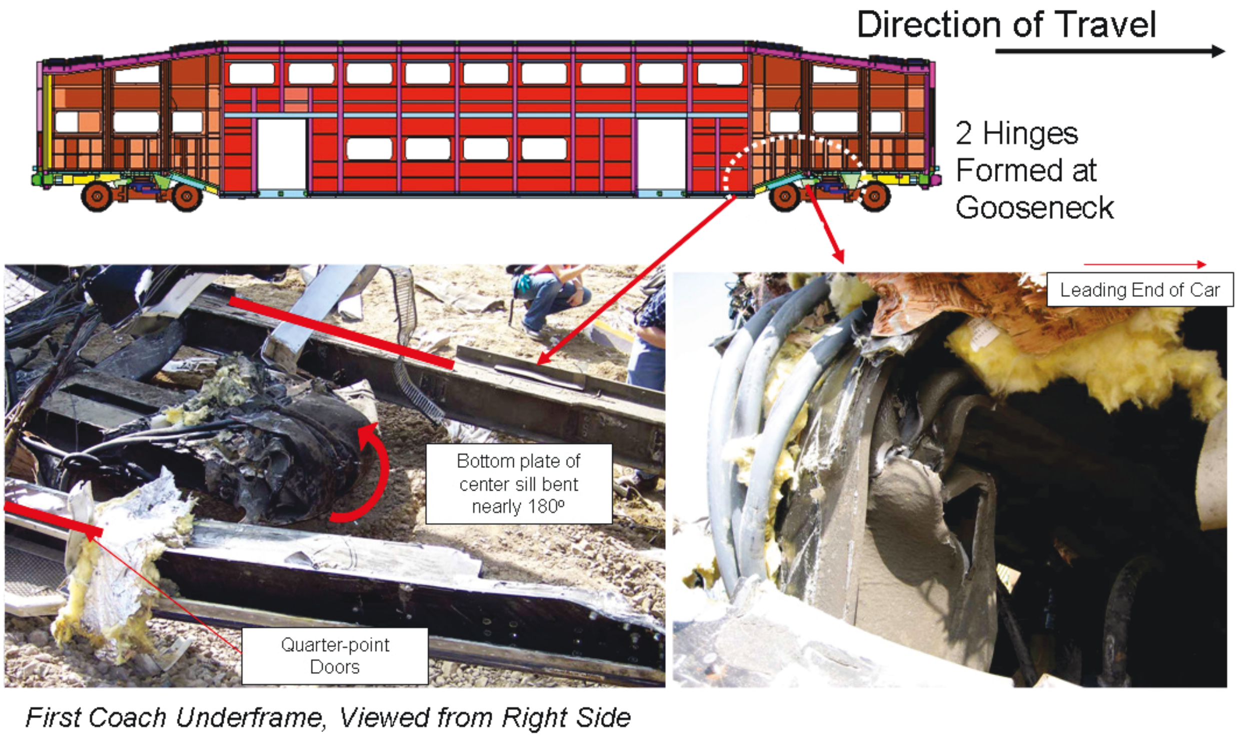


Figure A.2.1-4. Gooseneck Damage

Figure A.2.1-4 includes a schematic of the first passenger car, with the primary area of structural collapse circled. The primary area of structural collapse is termed the gooseneck. In this part of the structure, the underframe transitions from being above the truck, approximately 34 inches above top-of-rail (TOR), down to 18.5 inches above TOR. This transition is made to accommodate the two-level center section of the car. The diagonal section of the gooseneck was apparently destroyed in the accident; as no evidence of it was found. The photograph in the lower left of the figure shows the remains of the end of the lower center sill. It can be seen that the end has been pounded and bent nearly 180^o into a 'U' shape. The lower side sills extend to essentially their initial length. Holes for the rivet connections to the diagonal portion of the gooseneck can be seen in the right side sill. The photograph on the right shows the remains of the end of the single-level portion of the center sill. This end has been bent down about 90 degrees into a 'L' shape. This end of the center sill does not appear to have been pounded repeatedly, as the lower end of the side sill in the left side photograph appears to have been.

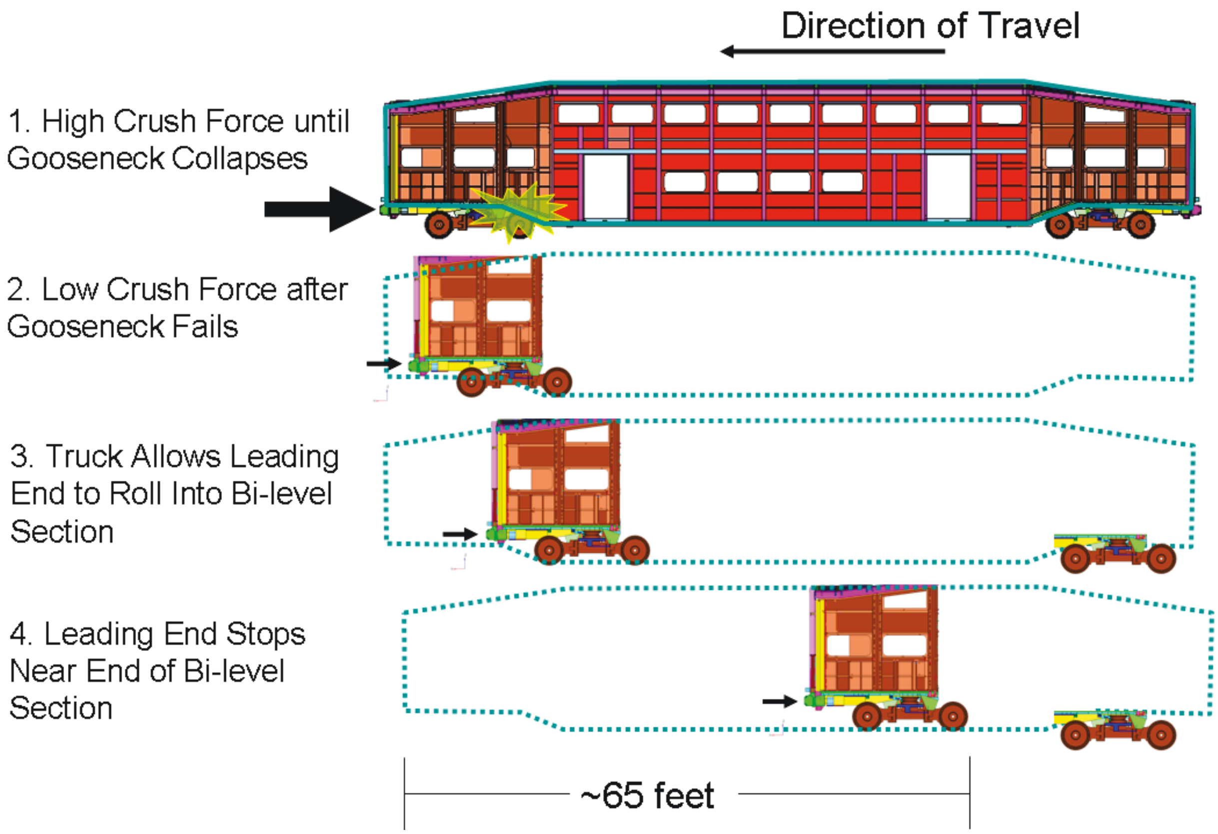


Figure A.2.1-5. Progression of Gooseneck Collapse and Failure

Figure A.2.1-5 shows schematics illustrating how the structural damage shown in Figure A.2.1-4 occurred. Shortly after the initial contact between the lead freight and passenger locomotives, a high force was generated between the leading passenger locomotive and leading passenger car. This force was sufficient to cripple and fail the gooseneck area of the passenger car 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 raised the wheels of the lead truck to the height of the lower floor of the bi-level section of the car, and the center sill was no longer carrying a longitudinal force. A relatively low longitudinal load was provided by the remaining sidewall and roof structures. The end section of the car, including the truck that had lifted up, penetrated and moved backward through the bi-level section of the car with relatively little force.

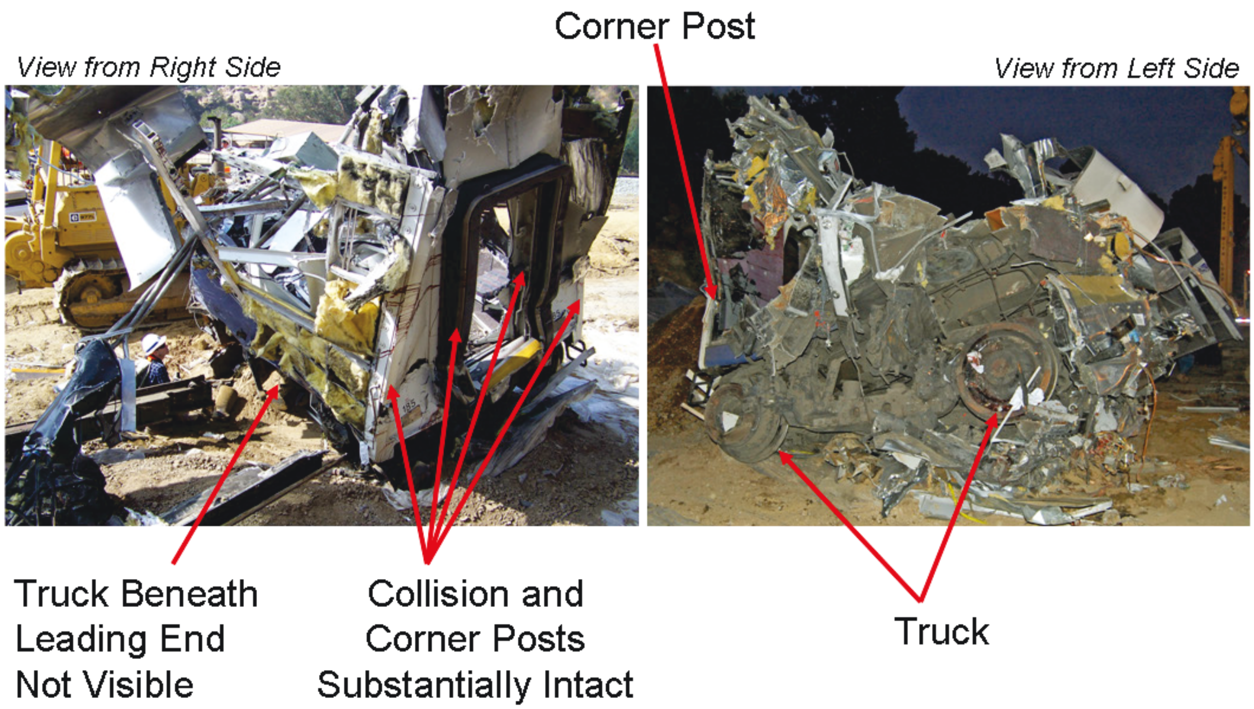


Figure A.2.1-6. Remains of First Passenger Car Lead End Mezzanine Level

Figure A.2.1-6 shows the remains of the lead end structure of the first passenger car, including the lead truck. The end frame, including both corner posts and both collision posts, is essentially intact. There is a significant amount of debris compacted onto the remains. The center and side sills of this single-level portion appear to be largely intact. The relatively light roof and sidewall structures have been stripped off, and likely contributed to the compacted debris.

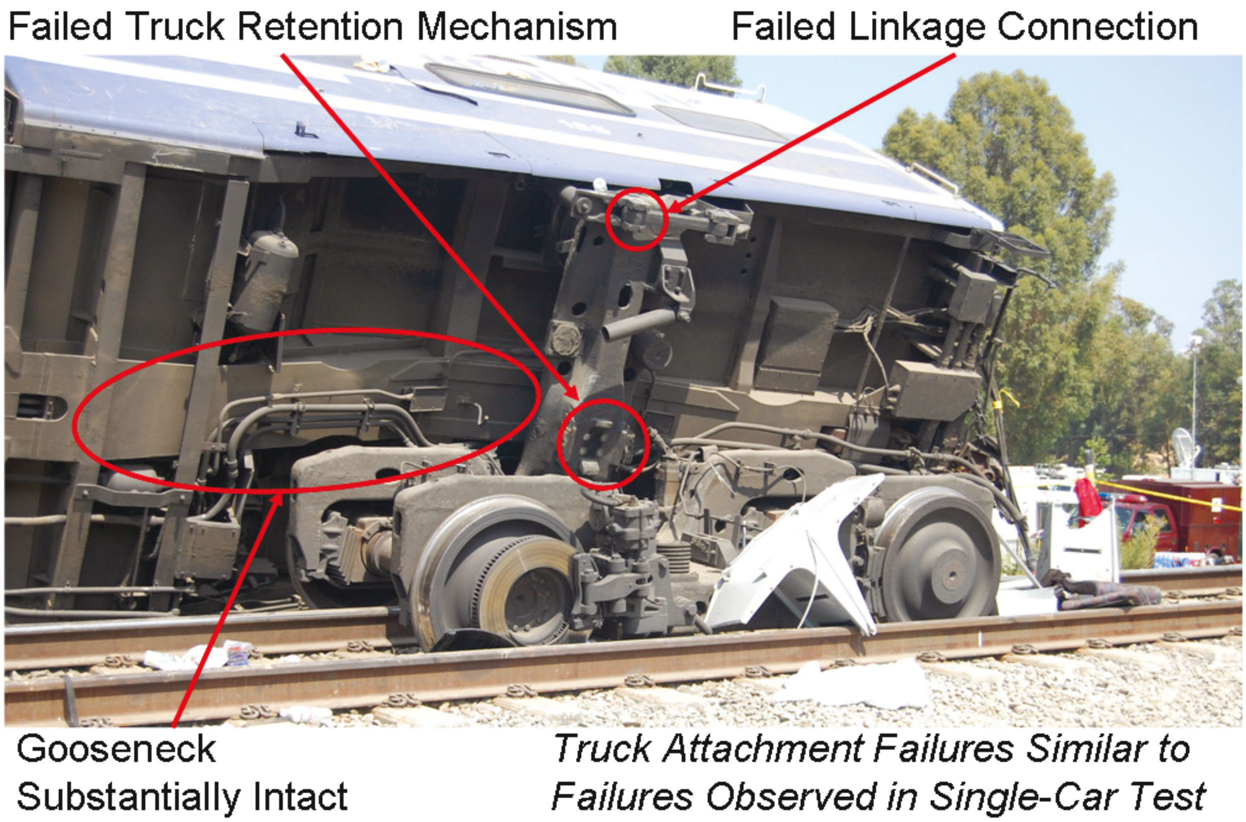


Figure A.2.1-7. Separation of Trailing Truck from Lead Passenger Car

Figure A.2.1-7 shows trailing end of the lead car. In the left side of the photograph, the transition structure of the underframe, including the gooseneck, can be seen to be nearly undamaged. The trailing truck, resting on the ground, is separated from the overturned carbody. The damaged truck-to-carbody connection elements are annotated. The damage to these elements is similar to damage observed in a single-car impact test of similar equipment [1].

Figure A.2.1-8. Right Side of Lead Passenger Car

Figure A.2.1-8 shows the right exterior wall of the lead passenger car, which is being supported by a piece of earth-moving equipment. There is little visible damage to the sidewall, indicating that the car side did not slide along the ground. On the left side of the photograph, damage to the end wall can be seen, and may have been caused by contact with the roof of the trailing car.

A.2.1-2. Second Passenger Car Damage

Figure A.2.1-9. Leading End of Second Passenger Car

Figure A.2.1-9 shows the leading end of the second passenger car. The bellows shows damage from contact with the car ahead. There are dents on the bellows frame, just above the spring loaded buffer beam. There is also damage to the fiberglass end cap above, just above the bellows. This damage is consistent with the leading car attempting to override this car.

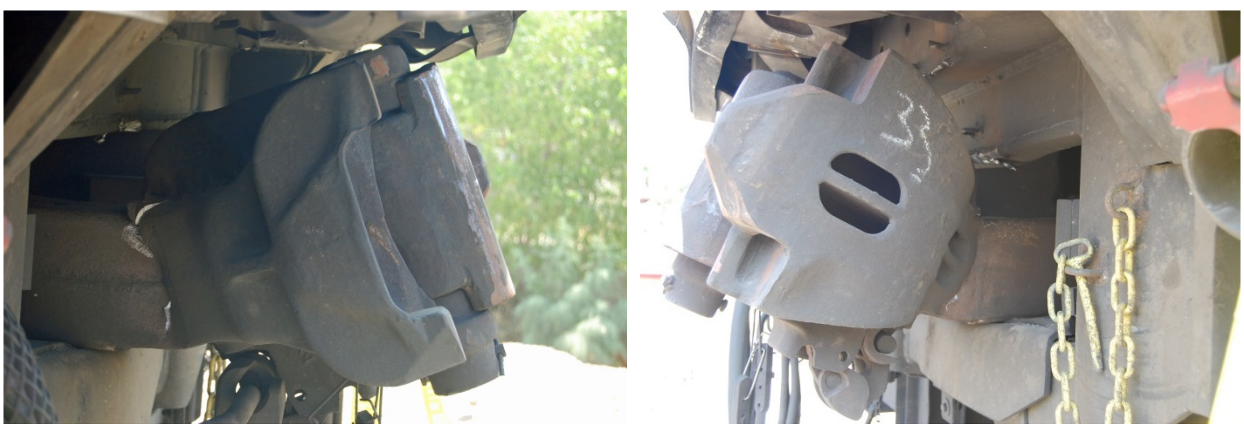


Figure A.2.1-10. Leading (B) End Coupler of Second Passenger Car

Figure A.2.1-10 shows left-side and right-side view of the leading end coupler of Car #207. The coupler is bent at the connection area between the head and the shank. The head is bent upward at an angle of roughly 30 degrees. There are indications of material failure near the corners of the shank where it meets the head. The material of the sidewalls of the shank remained together. The damage suggests that separation of the head and the shank is imminent. This damage is also consistent with the lead car attempting to override Car #207.

Figure A.2.1-11. Scar on Carbody Above B End Outboard Axle Bearing Housing

Figure A.2.1-11 shows a scar on the underframe. This scar appears to be due to the bearing housing of the truck axle contacting the underframe. Such contact could occur if the truck pitched significantly during the impact.

Figure A.2.1-12. Second Passenger Car Sidewall and Truck Attachment Damage

Figure A.2.1-12 shows sidewall deformation near the gooseneck region of the underframe. Both ends of the car showed similar damage, on opposite sides. On the leading end, the sidewall damage appeared to be associated with a bubble-shaped deformation in the bottom plate of the draft sill, however, the bubble appeared to be shallow. It was not possible to measure the flatness of this plate with the truck in place to confirm the presence of a bubble. On the left side of the leading end, the bolts to the drag link attachment to the carbody were also broken. The failure of these bolts was similar to the failure seen on the trailing truck of the first car. Similar failures have also been observed in an impact test of similar equipment [1].

Figure A.2.1-13. Trailing Cab Car and Failed Truck Retention Mechanism

Figure A.2.1-13 shows the third passenger car, Metrolink Passenger Car #617. There was virtually no structural damage to this car, however the truck retention mechanism did fail (not visible in the photo). Despite this equipment failure, the running gear remained intact and the truck remained in place beneath the car.

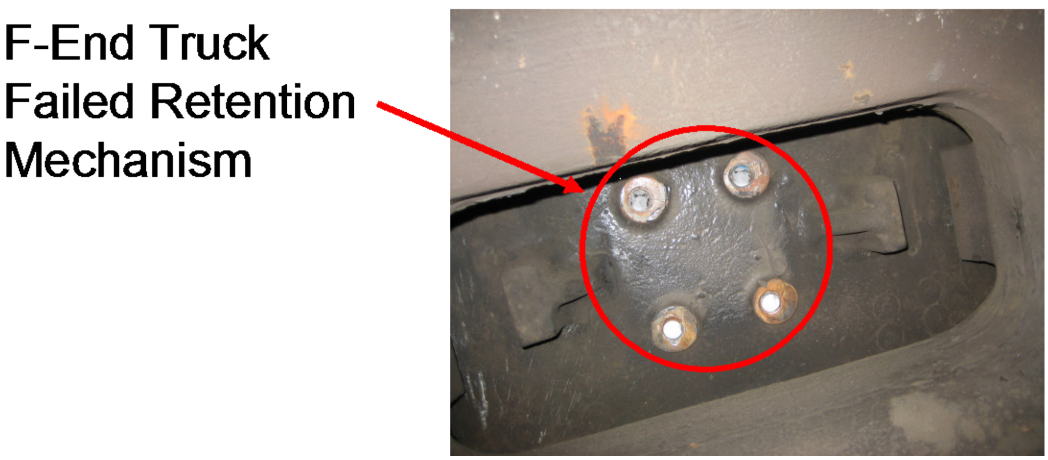


Figure A.2.1-14. Failed Truck Retention Mechanism on Trailing (F) End of Trailing Passenger Car

Figure A.2.1-14 shows the mounting boss for the truck retention mechanism, with the broken bolts visible. The truck retention mechanism is a tulip-shaped casting that protrudes through the rectangular hole in the truck frame. The base of the tulip normally mounts to the casting boss with four bolts. There is normally clearance between the rectangular hole and the tulip-shaped casting, which allows the truck to rotate, so the car can negotiate a curve. The failure of these bolts in the trailing cab car was similar to the failure of these bolts seen on the trailing truck of the first car. Similar failures have also been observed in an impact test of similar equipment [1].

Figure A.2.1-15. Intact Truck Retention Mechanism

For perspective, Figure A.2.1-15 provides visual comparisons showing on the left, the intact truck retention mechanism, and on the right, the bolts after an impact in which the truck retention mechanism failed.

Appendix A.2.2: Additional Detail on Structural Damage to Freight Locomotives and Cars

Following the accident, the Union Pacific Railroad (UP) freight train consisted of one forward-facing locomotive and one rear-facing locomotive in succession; freight cars that have folded perpendicular to the rails; and freight cars that have remained in-line.

Figure A.2.2-1. Aerial View of Freight and Passenger Equipment

The underframes of the freight equipment all remained essentially intact. The principal damage to the lead locomotive affected the ancillary structures on the front end—the draft gear housing, the plow, the breast plate, and the short hood. In the second locomotive, 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 remained 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 A.2.2-1 summarizes the structural damage to the freight locomotives and cars.

Table A.2.2-1. 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 - Paint scraped from left side of fuel tank
Second Locomotive	- No significant underframe damage - Damage to cab roof
Trailing Freight Equipment	- Five cars laterally buckled - Twelve cars with minimal or no damage

A.2.2-1 Lead Freight Locomotive

Figure A.2.2-3. Left Side of Lead Freight Locomotive

Figure A.2.2-3 shows that the right side of the locomotive has little damage. The underframe is essentially intact, and both trucks and the fuel tank remained attached.

A.2.2-2. Second Freight Locomotive

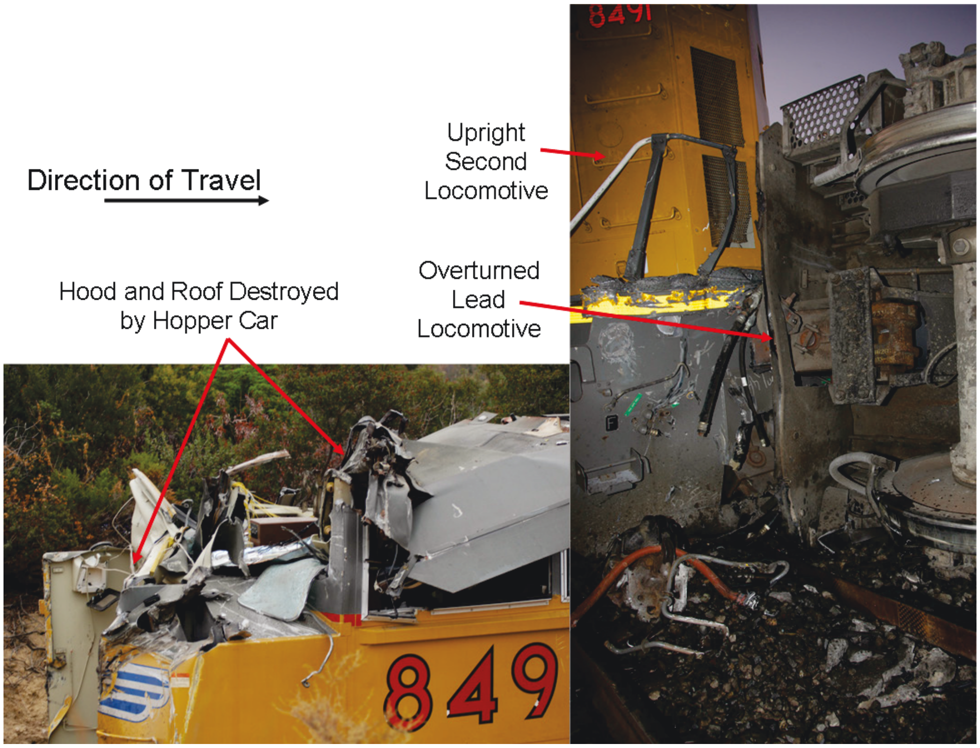


Figure A.2.2-5. Second Freight Locomotive Structural Damage

The photos in Figure A.2.2-5 depict the damage to the second freight locomotive inflicted by the hopper car and the damage caused by the interaction between the first and second freight locomotives.

A.2.2-3. Trailing Freight Equipment Damage

Figure A.2.2-6. Trailing Freight Equipment

Figures A.2.2-6 through A.2.2-8 show the trailing freight equipment. The second freight locomotive and its damaged roof can be seen in the upper-right portion of the photograph above. 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 perpendicular 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 the remaining four trailing freight cars, which are not visible in the photograph.

Figure A.2.2-7. Derailed Freight Cars

Figure A.2.2-8. Displaced Rail and Derailed Freight Cars

UP Metrolink Chatsworth CA Collision
UP Train ID: LOF65-12 Consist Information

Listed From Head End of Train

	Car Initial	Car Number	Tare tons	Load/ Empty	Lading tons	Total Tonnage tons	Total Length ft
Locomotives	UP	8485	204.0			204.0	72.3
	UP	8491	204.0			204.0	72.3
Cars							
1	CEFX	95334	28.2	E	na	28.2	45.8
2	CEFX	96307	27.9	E	na	27.9	45.8
3	ARMN	933964	46.6	L	76.3	122.9	64.9
4	GBRX	65014	27.9	E	na	27.9	45.8
5	MP	374660	38.4	E	na	38.4	58.1
6	SP	228550	39.0	E	na	39.0	58.0
7	WC	22193	39.4	E	na	39.4	67.9
8	DWC	793859	39.2	E	na	39.2	68.4
9	GTW	517811	34.7	E	na	34.7	55.6
10	DWC	793713	39.3	E	na	39.3	68.4
11	LW	50237	38.8	E	na	38.8	67.1
12	ARMN	768079	41.4	L	45.8	87.1	63.8
13	ARMN	761840	43.2	L	67.0	110.2	58.3
14	ARMN	768036	45.2	L	60.9	106.1	63.8
15	ARMN	923979	46.4	L	76.3	122.7	64.9
16	ARMN	769010	42.4	L	61.4	103.8	63.8
17	FBOX	504734	36.4	L	72.2	108.6	58.9

Train Tonnage	1522 tons	*Includes locomotives
Car Tonnage	1114 tons	*Does not include locomotives
Train Length	1164 feet	*Includes locomotives
Car Length	1019 feet	*Does not include locomotives

Loads	7
Empties	10
Total Cars	17

Lines 1 through 10 derailed.
Both locomotives derailed; UP 8485 was on side.
A total of 10 cars and 2 locomotives were derailed.

This information was developed using the UP consist list (list of cars) and UMLER (car tare weights and length) and Waybills (lading weight).

Figure A.2.2-9. UP Freight Train Composition

Figure A.2.2-9 provides additional detail about the cars in the freight train.

Appendix A.3: Fuel Tank Damage

This appendix discusses the forensic evidence and interpretation related to the fuel tank of the passenger locomotive.

Figure A.3-1. Exemplar Passenger Locomotive Fuel Tank

An exemplar fuel tank, on an undamaged locomotive of the type involved in the accident, is shown in Figure A.3-1. The lead end of this fuel tank is located inboard of the lead truck, which is indicated in the figure.

Figure A.3-2. Fuel Tank Attachment to Underframe

The fuel tank on this type of locomotive is suspended from the underframe of the locomotive, attached to the locomotive by bolts and clips, as shown in Figure A.3-2. This arrangement is found at the four corners of the fuel tank. The particular location shown in Figure A.3-2 is at the rear of the fuel tank, on the locomotive's left-hand side.

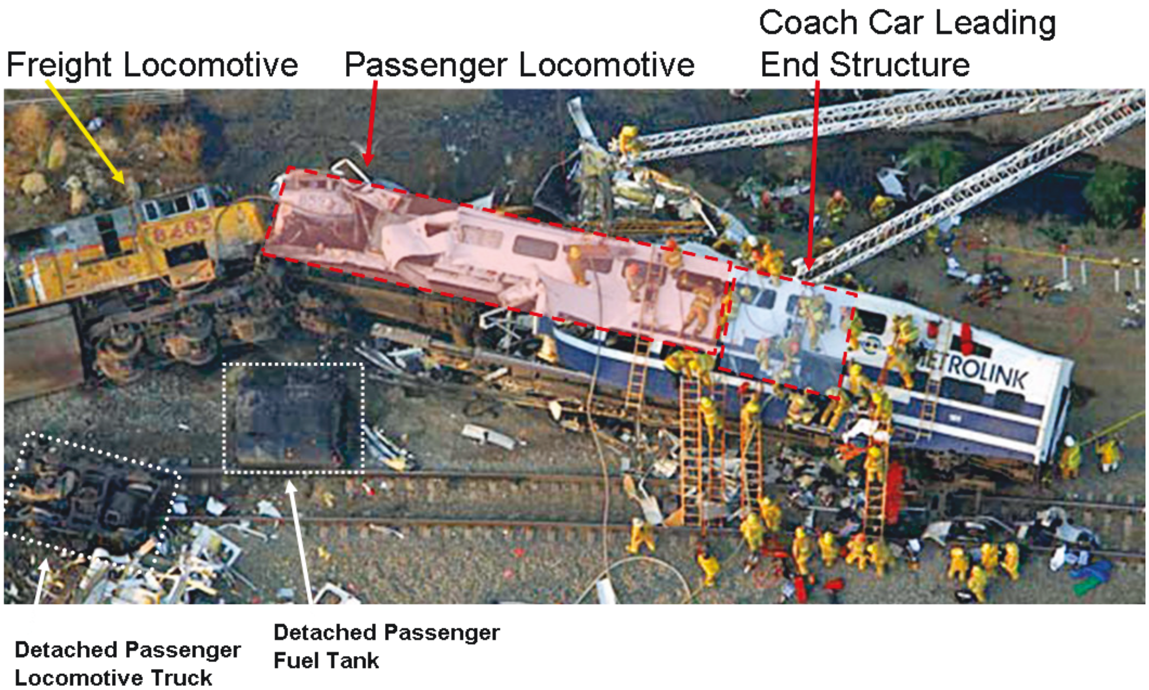


Figure A.3-3. Post-accident View of Locomotives and First Passenger Car (Photo from the *LA Times* Web site)

Post-accident, the fuel tank was found detached from the passenger locomotive, positioned on the ballast adjacent to the overturned freight locomotive. The lead truck of the passenger locomotive was also detached, and was found resting on the ballast adjacent to the running rails. An overhead view of the impacting locomotives and first passenger car are shown above in Figure A.3-3, with annotations showing the locations of the fuel tank and lead truck that detached from the passenger locomotive.

The fuel tank had been breached at its lead end, where the front end sheet and the top sheet come together, behind the mounting bracket. Figure A.3-4 shows this breach at the leading end of the fuel tank, viewed from the side. The front vertical sheet of the fuel tank has been bent backward, toward the trailing end of the leading locomotive. The mounting brackets at the lead end of the fuel tank have also been bent backward and downward.

Figure A.3-4. Damage to Fuel Tank Leading End

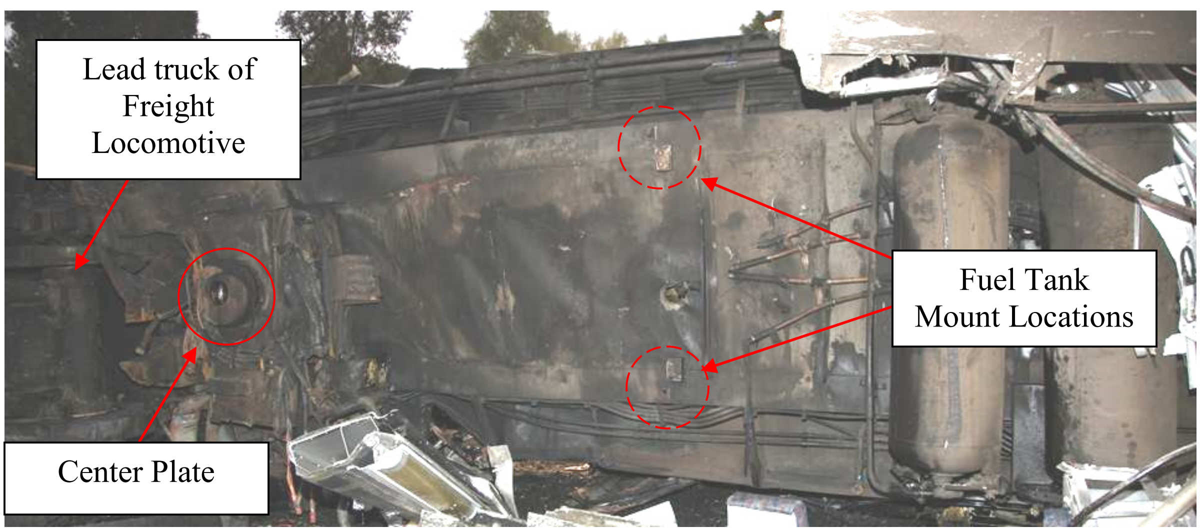


Figure A.3-5. Passenger Locomotive Underframe, Before Locomotive Moved by Rescue and Recovery Crew

The underside of the passenger locomotive is shown in Figure A.3-5. The passenger locomotive is resting on its right side. The wheels of the leading freight locomotive's lead truck are visible in the left of the photograph, indicating that the two locomotives have not yet been separated. This photograph was taken by on-scene personnel prior to the arrival of the crashworthiness team.

This photograph shows the passenger locomotive's center plate, the area where the lead truck is normally attached. The underframe of the locomotive has been deformed backward, resulting in the center plate moving toward the trailing end of the locomotive. Visible toward the center of the photograph are the locations of the trailing-end fuel tank mounts. The top location (left hand side of the upright locomotive) still contains a mounting bolt that has been fractured.

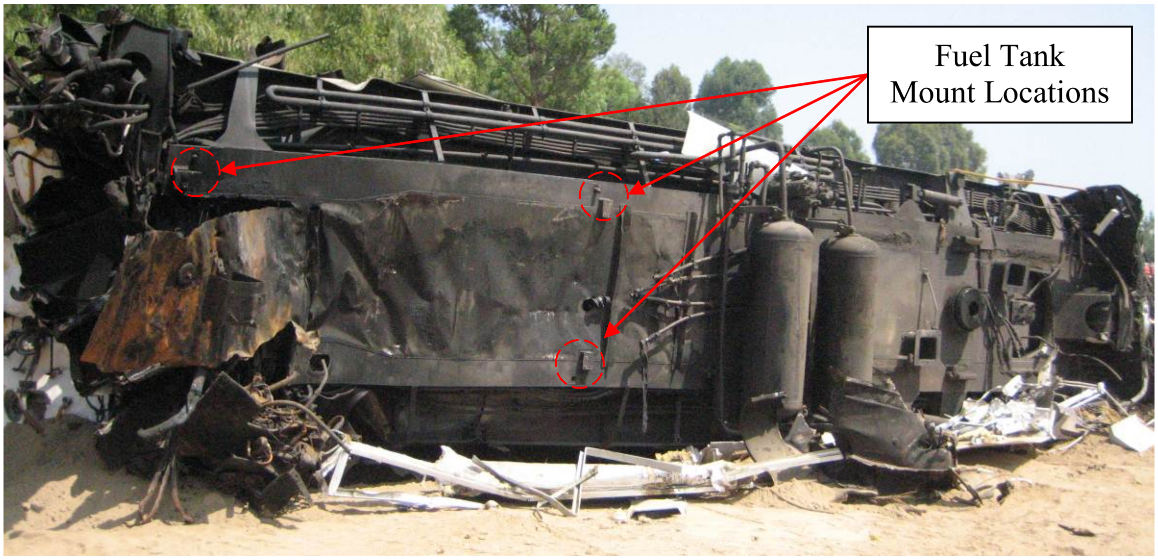


Figure A.3-6. Passenger Locomotive Underframe, After Locomotive Moved by Rescue and Recovery Crew

Prior to the crashworthiness team's arrival on scene, the freight locomotive and the passenger locomotive were moved as part of the rescue and recovery operations. As a result of this move, portions of the damaged passenger locomotive underframe were disturbed, including the center plate from the lead truck. Figure A.3-6 is a photograph of the underframe of the locomotive after it was moved from its post-accident location. Three fuel tank attachment locations are highlighted in this photograph. Two of these three locations include fractured mounting bolts still in their holes.

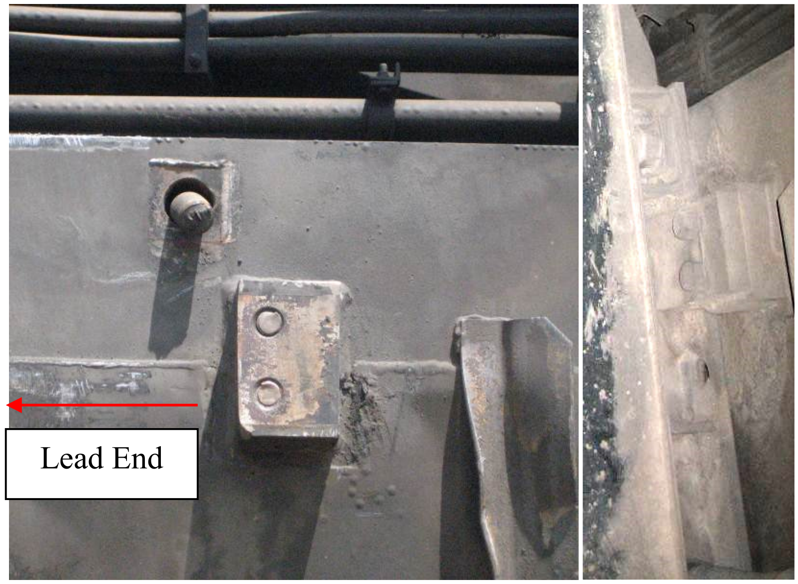


Figure A.3-7. Fractured Fuel Tank Mounting Arrangement (left), undamaged Exemplar Mounting Arrangement (right)

The left side of Figure A.3-7 shows one of the fractured bolts and damaged clips used to mount the fuel tank. This particular bolt was located on the left-hand side of the locomotive, at the trailing end of the fuel tank. The bolt is visibly bent toward the rear of the locomotive. It is unknown whether the orientation of the bolt was a result of the accident or a result of movement during rescue and recovery operations. Additionally, the clip has sustained damage, including shearing of the bolt heads and an apparent fracture to the clip itself. For reference, the right side of Figure A.3-7 shows an undamaged fuel tank mounting arrangement on an exemplar locomotive of a similar type to that involved in the accident. Note that the reference photograph has been rotated to provide a similar view to that of the overturned locomotive.

Figure A.3-8. Trailing End of Fuel Tank

Figure A.3-8 shows the accident fuel tank in its post-accident position. The end shown was toward the trailing end of the passenger locomotive. At the top of the fuel tank there is fracture in the area where the clip would have contacted the fuel tank, indicated above by the box. There does not appear to be a breach of the fuel tank at this end. This area of fractured fuel tank would have been mounted at the location depicted in Figure A.3-7.

Figure A.3-9. Passenger Locomotive Lead Truck: Leading End (left) and Trailing End (right)

Figure A.3-9 shows the lead truck of the passenger locomotive. Note that these photographs were taken at two different times. The left side photograph was taken after the truck had been moved, and the right side photograph was taken when the truck was still in its post-accident position, prior to the arrival of the crashworthiness team. The leading end of the truck, shown on the left, featured extensive structural damage to its frame. The lateral member has been bent backward and has fractured. The trailing end of the truck, shown on the right, also shows some structural damage. The trailing lateral member has been bent toward the lead end of the locomotive. It is probable that the trailing end of the lead truck was able to contact the leading end of the fuel tank during the collision, contributing to the breach of the tank and its eventual attachment failure.

Appendix A.4: Train Collision Dynamics

A key objective of any accident investigation is determining the causes of severe injuries and fatalities. This appendix proposes a possible reconstruction of the train collision dynamics of the Chatsworth accident to understand the physical forces that passengers likely endured. Specifically, determining the dynamics of the incident is key to estimating the secondary impact velocities[1] of passengers in each vehicle. Secondary impact velocity data is correlated to the injuries presented in Appendix B.

The forensic team developed a collision dynamics model to aid in determining the cause of severe injuries and fatalities. The model helps to estimate the gross motions of the two trains and identify how the collision events progressed. Results from the collision dynamics model help reconstruct the sequence of events leading to intrusion of the occupant volume and estimate the gross motions of the colliding trains. Evidence collected from the on-scene investigation, such as the event recorder[2] data, provides supporting evidence of each train's motions.

A one-dimensional collision dynamics model was developed to estimate the longitudinal motions of the train and those experienced by the occupants. The model was developed using ADAMS, a commercial software package. The lumped-mass model of the accident scenario includes a spring-mass representation of each vehicle and is shown below in Figure A.4-1. The model construction accounts for the structural mode of deformation of the first bi-level car as it crippled and its subsequent motion as two separate sections. As described in the main report, the first coach car crippled at the gooseneck and the front portion of the first coach car plunged backward, crushing the middle passenger compartment of the car.

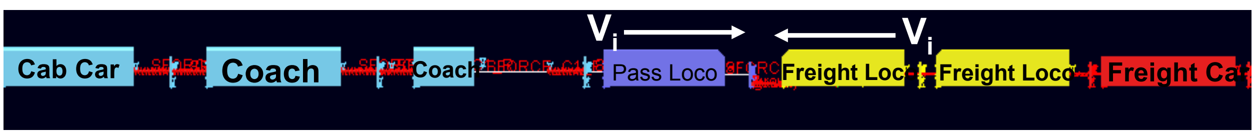


Figure A.4-1. Schematic of One-Dimensional Lumped-Mass Collision Dynamics Model of Chatsworth Accident

The key parameters for the model include the train make-up, vehicle weights, initial speeds of the colliding vehicles, level of braking, and the force-crush behavior of the equipment. The parameters known from the accident investigation are listed in Table A.4-1.

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[1] 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 an interior feature increases, so does the SIV.

[2] An event recorder is a device, designed to resist tampering, that records data such as train speed and direction of motion. In accident investigations, a train event recorder plays a similar to the "black box" from an airplane.

Table A.4-1. Model Input Parameters: Train Make-up

Vehicle	Mass (lb)	Quantity	Initial Speed (mph)
SD70AC EMD Freight Locomotive	409,000	2	40 mph Brakes Applied
Other Freight Cars	Variable	17	
Complete Freight Consist	**3,046,000**	**----**	
F59PH EMD Locomotive	268,100	1	40 mph No Braking
Bombardier Multi-level Car	118,000	3	
Complete Passenger Consist	**616,100**	**----**	

The structural behavior of each vehicle is estimated based on the damage measured during the accident investigation and data from full-scale test results [1]. Both linear and non-linear springs were used in modeling the force-crush behavior of each vehicle end.

Table A.4-2. Summary of Measured Crush Per Vehicle

Vehicle End	Measured Crush
Locomotive Front	~15 feet
Locomotive Rear	~2 feet
First Multi-level Passenger Car Front	65 feet
First Multi-level Passenger Car Rear	None
Second Multi-level Passenger Car	None
Third Multi-level Passenger Car	None

An idealized force-crush behavior is defined at each car end. Key parameters of the estimated force-crush behavior are listed in Table A.4-3.

Table A.4-3. Summary of Key Parameters of Force-Crush Characteristics

Vehicle End	Peak Crush Load (million lb)	Average Crush Force (million lb)	Energy Dissipated (million ft-lb)
Passenger Locomotive	3.5	2.75	48
Multi-level Car	2.5	0.3	42

The passenger locomotive dissipated approximately 48 million ft-lb while it crushed about 15 feet. The adjacent multi-level passenger car dissipated approximately 42 million ft-lb as it crushed about 65 feet.

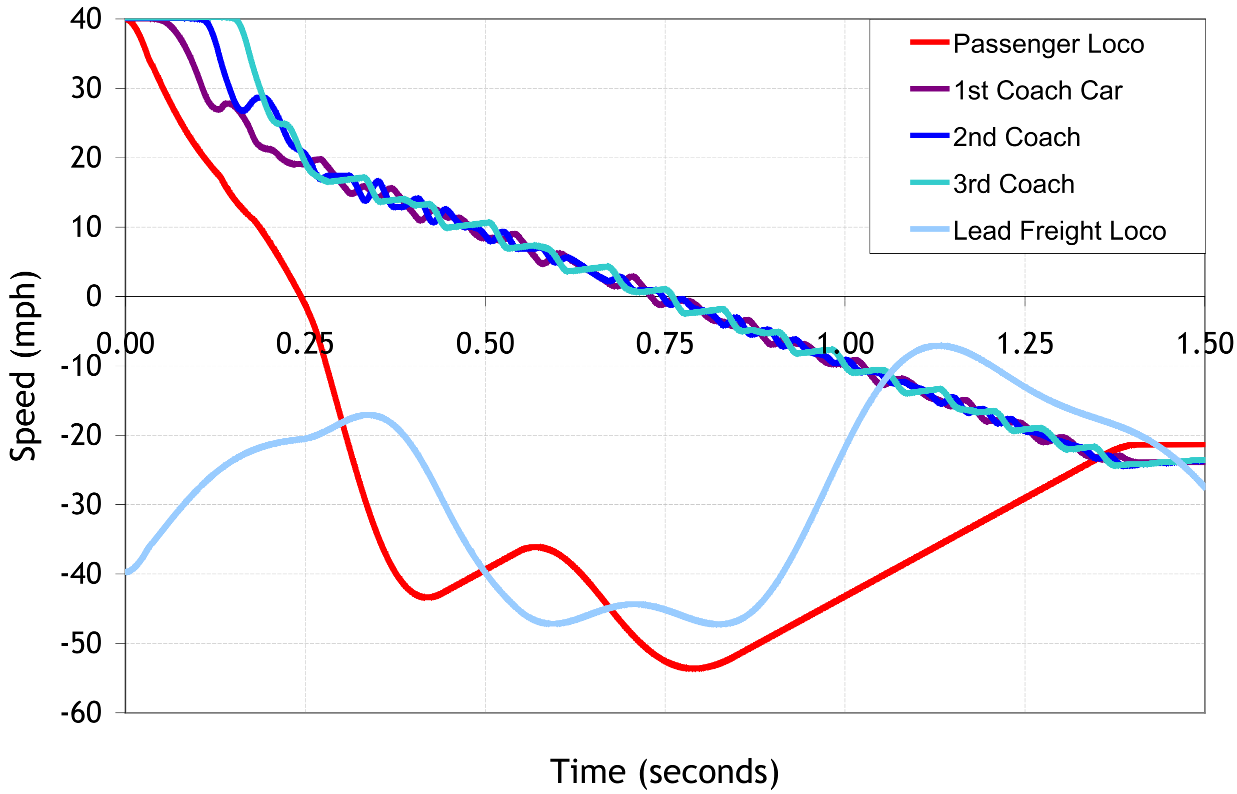

Figure A.4-4. Velocity-Time Histories for Each Vehicle Starting at the Time of Impact

Figure A.4-4 shows the velocity-time history of the passenger train and the first locomotive in the freight train. The two trains were traveling toward each other, with a closing speed[3] of about 80 mph. In the first 0.05 seconds after the impact, the passenger locomotive slowed to about 30 mph, a rate of approximately 7.3 gs.[4] There is about a 0.05-second delay before the following passenger cars begin to decelerate. The passenger train then decelerates at a rate of about 1.8 gs. The approximate timing of the simulation collision event correlates to timing estimated from reviewing the onboard locomotive cameras, as described in Appendix A.5.

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[3] Closing speed is calculated as the speed differential between two vehicles traveling toward each other. In this case, calculated as the sum of the speeds of both trains.

[4] One "g" is the amount of force exerted upon an object by the earth's gravity. In this accident, the passenger locomotive decelerated under a force about seven times greater than the force of earth's gravity.

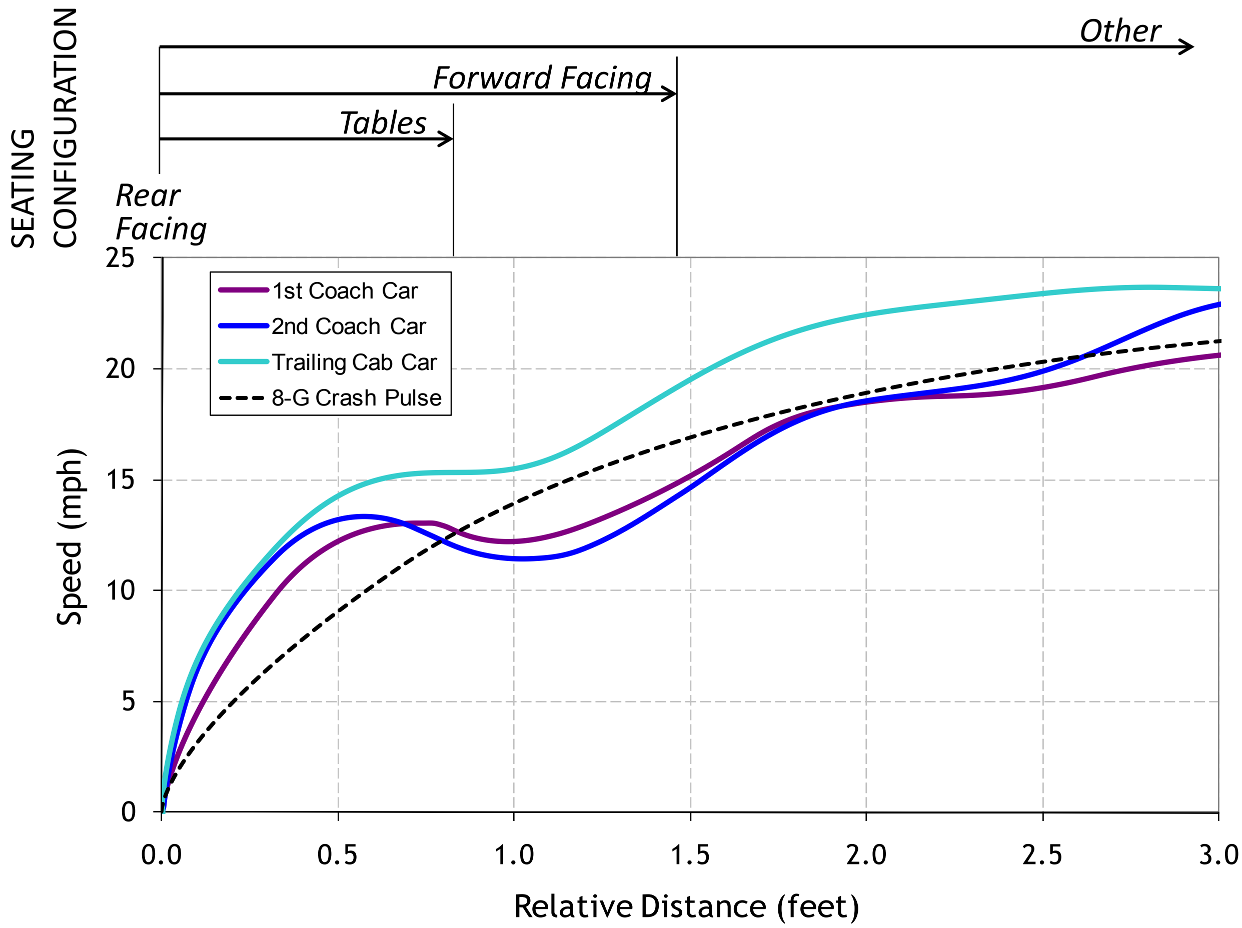


Figure A.4-5. Secondary Impact Velocities for Each Occupied Vehicle

Figure A.4-5 shows the SIVs for the passenger train. The horizontal axis at the bottom of the plot represents the distance travelled for an occupant in free flight with respect to the carbody (which varies with seating configuration as shown at the top of the plot). The vertical axis represents the velocity of an occupant in free flight, also with respect to the carbody. The first 0.3 seconds of the gross motions in Figure A.4-4 are used to plot the relevant SIV data for this accident. For comparison, the SIV plot associated with the 8-g crash pulse (used for passenger seat crashworthiness testing) is also plotted in the graph.

This plot can be used to estimate the relationship between seating configuration type, travel distance possible, and severity of secondary impact for passengers in each car. The arrows at the top of the figure show the approximate travel distances associated with different interior seating configurations in Metrolink's bi-level passenger cars: passengers in a rear-facing seats travel essentially no distance (if their backs are against the seat at the time of incident) in a collision event; passengers seated at tables can travel up to 1 foot; passengers in forward-facing seats can travel up to 1.5 feet; and passengers in other scenarios, with nothing to obstruct them, may travel through the car until striking a fixed object.

Generally, the SIVs of the Metrolink passengers increased with the relative distance they traveled before striking part of the interior. The graph shows that SIVs were highest in the trailing passenger car, and nearly equivalent in the first and second passenger cars. For passengers seated at forward-facing or facing seats without tables, the high end estimate of the SIVs was 21-24 mph. The results show that the last coach experiences a high deceleration, resulting in a more severe secondary impact. For passengers who are not compartmentalized, large travel distances correlate to an even higher SIV. In this accident, two fatalities were caused by long travel distances in the interior resulting in fatal impact with the interior.

These results correlate to the evidence of interior damage of the third passenger car, described in Appendix B.3.

Appendix A.5: Freight Locomotive Onboard Videos

This appendix summarizes a review of the onboard videos from the two freight locomotives. As described in the main report, the freight train was led by two UP locomotives. The first locomotive was oriented forward-facing, pulling the train, and the second locomotive was oriented rear-facing. Each locomotive was equipped with a digital video camera, mounted on the upper inner corner of the left front windshield. The following is a summary of observations from the video data that provides details of 1) the sequence of events during the collision and 2) the emergency egress events.

A.5.1 Approximate Time Range of Collision Event Based on Data from Camera in Windshield of Lead Freight Locomotive*

Collision

0:00:00.00	Brakes Applied.
0:00:03.27	Locomotive traveling at 41 mph.
0:00:03.33	Impact occurs. Passenger locomotive hood has begun to crush; evidence of ripple in passenger locomotive hood just under right window.
0:00:03.40	Passenger locomotive hood is crushed. Freight hood has climbed up passenger locomotive.
0:00:03.47	Roof of passenger locomotive has begun to crush; evidence of ripple in roof structure.
0:00:03.53	Front left window of freight locomotive cab cracks.
0:00:03.87	Freight locomotive hood comes into view as hood begins to crush.
0:00:04.60	Freight locomotive rolls onto its left side.

Egress

0:19:35.00 PM	Emergency Responder arrives and begins to get window open by means of repeated hits with an ax.
0:22:17.00 PM	Emergency Responder has successfully broken and pried open the front left cab window. Operators exit through window.

A.5.2 Approximate Time Range of Collision Event Based on Data from Camera in Windshield of Second Freight Locomotive*

0:00:00.00	Brakes Applied.
0:00:02.53	Significant inter-car vertical and horizontal motion.
0:00:03.00	Third car in freight consist, ARMX car, begins to override the second locomotive.
0:00:03.33	Front plate of ARMX car starts to deform, bending around locomotive hood.

0:00:03.67	ARMX continues to deform, conforming to the shape of the locomotive hood. Approximately 5-10 feet of crush.
0:00:04.00	Loss of visibility due to debris.
0:00:05.60	View of inside of locomotive window frame indicating locomotive cab is deforming.
0:00:05.67	Barrel of strawberries impacts window indicating cargo from freight cars is no longer contained.
0:00:06.87	Locomotive window shatters.
0:00:07.27	Camera goes out.

* Please note: Timestamps from cameras in this accident have been normalized to the moment that the brakes were applied. The timestamps indicated do not correspond with actual times and are presented here to provide information on the relative timing of the sequence of events in the two freight locomotives.

Appendix B.1: Interviews with Injured Passengers and First Responders

B.1.1. Introduction

As part of the forensic investigation, the team made contact with hospitals where victims of the accident were transported. The team conducted interviews with victims for the purposes of establishing their relative location in the car, severity of injuries sustained, and an account of the events of the accident. This information is correlated with observations of the damaged interiors of the passenger cars, in an effort to determine potential causal mechanisms for injury.

In some cases, the seats where passengers may have been sitting have been identified with numbers. These numbers correspond to seating schematics that are provided in Appendix B.3. The passenger numbers from this appendix are also included in the car diagrams in Appendix B.3 when applicable.

The following accounts have had information removed from them which could identify the persons interviewed. Interview notes were collected by multiple members of the forensics team during some interviews. In those cases, both sets of notes are provided for a given passenger.

Interviews were conducted at the following hospitals:

- Cedars-Sinai Hospital
- Simi Valley Hospital
- Northridge Hospital Medical Center
- Ronald Reagan UCLA Medical Center (University of California – Los Angeles)

Additionally, two passengers who had been released from the hospital were contacted and agreed to phone interviews. The team assigned numbers to passengers in the order the passengers were approached at the hospital (i.e., the first passenger contacted was recorded as Passenger #1).

B.1.2. Passenger Interviews

Passenger #1, Declined to be interviewed.

Passenger #2, 6'2", 185 lbs. – notes from one member of the forensics team

Pre-accident location: Car #185, upper level, rear-facing seat at table, left-hand side of car. Likely seated at seat 52 or 60.

- Boarded the train at Union Station in downtown LA. The coach was pretty much empty after Chatsworth. There were not many riders left in the car after Chatsworth.
- In response to the question about commuters sitting in the same seats and having knowledge about other commuters, described this as a "flex train" and not a typical commuter train.
- Was riding in the first car on the upper level at the left rear side of the car.
- Was sitting at a table on the aisle, left side of train riding backwards.

- Was possibly positioned on top of the passenger locomotive that had intruded into the passenger car following the collision.
- It took about 45 minutes to an hour to be taken from the car and then put on a helicopter to the hospital.
- Injuries:
  - Bruised lungs
  - Bruised heart
  - Broken scapula
  - Broken right wrist, with displaced radial bone
  - Broken ribs, right and left
  - Broken sternum
  - Broken T-12 vertebra

Passenger #2, 6'2", 185 lbs. - notes from another member of the forensics team

- Passenger is a daily rider of the train.
- Mentioned this train was an off-hours train…"who gets out of work at 3 PM anyway?"
- Does not think conductor made a passenger count after leaving station prior to accident.
- Car #185, seated on left-hand side of upper level, aisle seat, thinks was rear-facing, thinks was at a table.
- Car was fairly empty at the time.
- Seated catty-corner across from 20-something passenger.
- Remembers person in professional clothing (possibly white shirt) seated at table across aisle before impact.
- Recalls telling self to breathe after impact, not thinking had head injury. Continues to find debris in hair/ears.
- Left arm was pinned, remembers an arm lying across body, experiencing numbness, thought arm was detached from socket. Realized arm on chest had different colored shirt (white) than passenger's shirt (green), must belong to another passenger.
- Felt like was in debris field, possibly near locomotive. When looked up, could see the sky above while trapped in wreckage.
- Remembers firefighters looking down from above.
- Remembers firefighters talking to/about self, does not remember being placed on ground.
- Injuries:

- Extensive bruising on right leg (calf, upper thigh, outside of leg)
- Bruised lung
- Bruised heart
- Broken ribs
- Broken scapula
- Broken T-14 (though later in interview said T-12)
- Broken right wrist (passenger believes this was from bracing self)
- Facial cuts
- EKG was negative

Passenger #3, 5'-5", 250 lbs. - notes from one member of the forensics team

Pre-accident location: Car #185, rear mezzanine, likely seat 1

- Boarded at Union Station and was traveling to Moorpark (end of the line).
- Was seated in the 2nd coach, lower level but did not remember which side of the coach was sitting on. Remembered very little of the events that occurred before, during, and after the accident.
- Was seated, looking toward friend during conversation.
- Remembered talking with friend and then awoke in the hospital.
- Friend **Passenger #4** has an excellent recall of the accident.
- Injuries:
  - Broken toe, left pinky
  - Concussion
  - Bruises-large on right front and back of left leg
  - Bruise in the middle of back
  - Laceration of the top of head that required staples to close
  - Numerous bruises on arms and the back of both shoulders

Passenger #3, 5'-5", 250 lbs. - notes from another member of the forensics team

- Passenger was riding in middle car of consist with coworker (**Passenger #4**). **Passenger #3** was seated in lower level, seated facing forward, in window seat. Interview with **Passenger #4** indicated both were seated in rear of car 185.
- Remembers being in hospital after accident. Was told by **Passenger #4** that they walked out together, and **Passenger #4** went back to get their bags for ID purposes.
- Injuries:
  - Broken pinkie toe
  - Concussion

    - Large bruises on thighs
    - Bruises on back, between the clavicles
    - Head laceration
    - Bruises on right forearm
- Passenger's spouse indicated that passenger continues to have short-term memory loss.

Passenger #4, 168 lbs. – notes from one member of the forensics team

Pre-accident location: Car #185, rear mezzanine, likely seat 2

- Boarded at Union Station with friend (**Passenger #3**).
- Was riding in the first car in the last two seats on the lower level by the emergency window. Was in the left seat on the aisle and friend was next to the window.
- A man and a woman were in the seats in front of them.
- Thought a train was coming at them and then woke up and the car was turned on its side.
- Was thrown diagonally across the car and friend was several rows behind. Ended up six seats ahead of original seat and on the windows, as the car had rolled onto its side.
- A man in a blue shirt came and opened the door for passengers to escape.
- Had no recollection of having trouble getting out of the car. *Interviewer Note: This description is confusing because Passenger #3 said that they were in the second coach and it remained upright, and that Passenger #s 3 and 4 were helped out of the car and went out and sat on some rocks until help arrived. A man in a brown suit was sitting on the rocks with them.*
- Stated no ill-will toward Metrolink and would ride tomorrow—not afraid.
- Comments:
    - People riding are not identified—there should be some way to identify passengers
    - The Metrolink webpage was not helpful
- Injuries:
    - Broken L-4
    - Broken ribs
    - Long abrasion on left leg
    - Bruises on right triceps and both buttocks
    - Bruises on right side of face
    - Slight concussion

Passenger #4, 5'-7", 164 lbs. - notes from another member of the forensics team

- Passenger is coworker of **Passenger #3**.

- Was seated with coworker in last row of Car #185. **Passenger #4** seated on aisle side, **Passenger #3** seated on window side.
- Saw other train through window (likely seated on left hand side of car).
- After collision, ended up six rows ahead of original seat, on opposite side of car, seated on a window.
- Saw the staircase railing nearby.
- Saw a man trapped with two broken legs.
- Coworker was also thrown across the aisle.
- Did not observe any windows further ahead of post-collision position, only the staircase.
- Believes could see the curve of the top of the exit door.
- Could smell diesel fuel.
- Could see out pass-through door, realized that the next car (#207) was detached and a long distance away from Car #185.
- Saw a man from outside the car, wearing a blue shirt, kick out the pass through door and enter the car. Helped another passenger get up, and then exit the car.
- Saw another passenger on the mezzanine clutching abdomen. This other passenger was helped outside by the man in the blue shirt as well.
- A man in a yellow shirt also came from outside and helped a male passenger from the mezzanine off as well. This male passenger had a suit on, possibly a brown one.
- **Passengers #3 and #4** exited through pass-through door. **Passenger #4** then returned for their bags with IDs.
- Does not remember struggling to exit the car.
- Injuries:
    - Broken L-4 in back
    - Six broken ribs (posterior)
    - Long abrasion to left leg
    - Muscle trauma to legs
    - Large bruises to the biceps and right triceps
    - Large bruises to the right and left buttocks
    - Bruising to upper face
    - Mild concussion
    - Bruised lung

Passenger #5, 150 lbs. - notes from one member of the forensics team

Pre-accident location: Car #207, lower level, right-hand side, likely in one of three seats: 120, 128, or 132

- Boarded at Union Station.
- Was riding in the second car (#207) facing forward on the right side.
- Was in a window seat in the four-occupant configuration.
- There was perhaps a couple in front; and teenager and father on the opposite side of the car.
- Was looking out the window at the time of impact.
- Hit the seat in front when the train came to a sudden stop.
- Came to rest on the floor across the aisle.
- Needed help getting out of the car and waited for the fire department for assistance out of the car.
- Was transported to the hospital by helicopter.
- Injuries:
    - Broken lower left leg and kneecap
    - Claimed major bruising over entire body

Passenger #5, 5'-4", 150 lbs. - notes from another member of the forensics team

- Seated in Car #207, lower level, right-hand side, forward-facing window seat.
- Thinks there might have been a couple seated in the row ahead, and a father/teenage son seated on opposite side of aisle.
- Passenger was looking out window before crash, possibly with legs crossed.
- Passenger remembers a jarring blow and flying forward at the impact.
- Lowered self to floor and laid across the aisle.
- Remembers being in the car for a long time after the crash.
- Injuries:
    - Broken left leg
    - Broken kneecap
    - Bruising across entire body
    - Right leg uninjured
    - No observed facial bruising or lacerations
    - Passenger indicated no abdominal injuries present

Passenger #6, 6', 180 lbs. (200 lbs. at time of accident, wearing work-related attire) - notes from one member of the forensics team

Pre-accident location: Car #617, lower level, likely seat 145

- Was seated in the rear car (#617) facing sideways on a bench seat. (This would be on the lower level of the car).
- Was talking with a man who was the only one in the area.
- Was slammed into the partition. It was not broken; it was cracked.
- Right side took the brunt of the trauma.
- Stated that could not imagine how it could have happened so suddenly; going from 40 mph to a dead stop in about a second. Described the collision as "sudden impact."
- Was able to leave the train, was stunned, but tried to help others.
- There were screams that the cars were on fire. Continued to help others off the train. Cab car and the one in front were not in danger from fire since they were disconnected from the engine.
- Walked up to the engine and looked at the first car. By that time emergency people were on the scene.
- Comment:
  - Wished there had been airbags to cushion the impact.
- Injuries:
  - Broken hand, surgery planned for following week
  - Laceration to left shin but not serious
  - Broken clavicle (collarbone) right side
  - Broken scapula (shoulder blade) right side
  - Broken ribs
  - Punctured lung
  - Lacerated liver
  - Broken left arm

Passenger #6, 6', 180 lbs. (200 lbs. wearing equipment) - notes from another member of the forensics team

- Seated in Car #617, lower level, facing sideways in fold down seat.
- Recalls the collision as, "Bam – dead stop" and describes as "unreal."
- Recalls a young man screaming that the car was on fire.
- Could see no immediate fire damage.
- Injuries:
  - Broken left hand
  - Left shin laceration

- Broken right clavicle (collarbone)
- Broken right scapula (shoulder blade)
- Broken ribs on the right hand side
- Punctured right lung
- Lacerated liver
- Facial bruises

Passenger #7, 6'1", 190 lbs.

Pre-accident location: Car #207, lower level, likely seat 142

- Was seated in the middle coach car (#207), lower level, left side, in aisle seat 142, forward-facing on a flip down seat in the handicapped seating area.
- There was no bulkhead in front, just ~10' of open space between passenger and the bathroom wall ahead.
- Friend was seated across the aisle in seat 143. **Passenger #7** stated that friend had a laceration on the back of head that required 5-6 staples. (Friend declined to be interviewed).
- **Passenger #7** and friend initially boarded the lead coach car, but it was too crowded, so they moved back to the second car and sat together.
- Stated that the car suddenly stopped. Went flying into the wall next to the bathroom door.
- With a huge surge of adrenaline, stood up and walked off the train, then dropped to the ground. Friend was with **Passenger #7** outside until help arrived.
- Injuries:
  - Four fractured ribs
  - Four fractured vertebra
  - Fractured tibia
  - Fractured forearm
  - Fractured finger

Passenger #8, 6'2", 282 lbs.

Pre-accident location: Car #617, upper level, likely seat 54

- Rides the train every day. The upper lever of the cab car was fairly empty (Note: friend, **Passenger #9**, stated the upper level was half full).
- More people tend to sit on the left side of the train, possibly because it is warmer from the sun in the afternoon.
- Was seated in the trailing cab car (#617), upper level, right side, forward-facing in aisle seat (likely seat 54), near the longitudinal center of the car.

- **Passenger #9** was seated catty-corner, rear-facing, in the window seat (likely seat 59).
- Was talking with **Passenger #9**, then woke up at the bottom of the stairs in the front mezzanine. Was lying perpendicular to the train, with head near the trash can on the right side of the train.
- When passenger woke up, saw a passenger in a black wheel chair blocking the stairs leading down from the front mezzanine to the lower level. Had likely been sitting in the handicapped seating area (seats 148/149). Travel distance from back of flip-down seat to bottom of stairs measured 15'5."
- *Interviewer's Note: the seat pan of seat 94 was cracked nearly across the entire width of the seat. It is likely that **Passenger #8** flew head first from the middle of the upper level, through the aisle, and down the stairwell, landing on or near seat 94. There were also rubber skid marks on the left stair wall, possibly left by shoes.*
- Injuries:
  - Fractured left fibula
  - Fractured left tibia
  - Fractured left rib
  - Fractured head of left humorous
  - Dislocated left shoulder
  - Laceration on right side of head

Passenger #9, 5'8"

Pre-accident location: Car #617, upper level, likely seat 59

- Was seated in an open bay seat with **Passenger #8**, in Car #617, upper level, right side, rear-facing in window seat (likely seat 59).
- Heard a loud bang, then everything stopped.
- **Passenger #9** never moved from seat, was just pushed into the seat back by inertia.
- Head whipped backwards. Eyes were shut for 3-5 seconds. When opened eyes, **Passenger #8** was gone.
- Most people were on the floor after the collision.
- There was a person on the floor reaching for help.
- Chair cushions were thrown about.
- Thought **Passenger #8** had quickly tried to exit the train. Found **Passenger #8**. at the bottom of the stairs in the front mezzanine. There were 6-7 bodies lying in same area, unconscious.

- Helped ~ 10 people to get off the car. It took about 5-10 minutes from the time of the accident until exited the car, via the front mezzanine, and out the side door on the lower level.
- Estimated that the upper level was ~ half full, maybe 30 people, at the time of the accident.
- Injuries:
  - Stiff neck and back
  - Headache

Passenger #10, 5'9", 200 lbs.

Pre-accident location: Car #207, lower level, likely seat 113

- Rides the train 3-4 times per week.
- Was seated in the middle coach car (#207), lower level, left side, forward-facing in aisle seat 113.
- There was no warning of the impending accident, no noise.
- Was reading with glasses at time of impact. Went into free-flight. Hands and book hit the facing seat back, and face hit the book. Glasses did not break.
- Left knee smashed into the facing seat in front. Fell to the floor, ending up in a sitting position with left leg under the forward seat and right leg in the aisle.
- There was a large person on top of **Passenger #10**. Possibly the person had been seated in the adjacent window seat, or across the aisle on the flip down bench seat.
- The facing seat pair facing had been unoccupied prior to the accident.
- Impacted seat 115 had small cracks in the head rest handles, no visible damage to the seat pan.
- Waited approximately 1 hour to be carried off the train on a stretcher. Emergency rescue personnel were attending to the more critically injured passengers first.
- Injuries:
  - Fractured left femur, near knee, lots of bone fragments requiring seven pins
  - Lacerations to face, nose, right leg, left arm
  - Slight concussion
  - Possible nerve damage to hands/wrists

Passenger #11, 5'4", 160 lbs.

Pre-accident Location: Car #185, trailing mezzanine, likely seat 10

- Was seated in the leading coach car (#185) in the rear mezzanine, left side, forward-facing in aisle seat 10 at table.
- Recalled two people talking together in the seats behind **Passenger #11**.

- Recalled a person with a nose ring in the front, right corner of the rear mezzanine, who was seated in the single seat facing the aisle, seat 19.
- Upon impact, struck the table. As the car rolled onto its right side, ended up in the right rear corner of the rear mezzanine.
- Was assisted in exiting by someone from the fire department.
- Injuries:
  - Seven fractured ribs
  - Lacerated liver
  - Bump on head

Passenger #12, 6’-1”, 210 lbs.

Pre-accident location: Car #617, upper level, likely seat 24

- Seated in Car #617, upper level, forward-facing left-hand side window seat, toward rear of car, bulkhead seat.
- Passenger seated in middle of an area of 2x2 seats.
- Passenger’s part of the car was relatively unoccupied at the time of the accident.
- Remembers one male passenger seated directly across aisle.
- Thinks no more than five passengers on upper level of car.
- Passenger thought more people were downstairs.
- Passenger estimates a dozen people on the lower level of Car #617.
- Recalls seeing adjacent emergency window with a pull-ring.
- Passenger had briefcase on lap, with one end placed against seat ahead. Believes briefcase acted as restraint during accident.
- Head impacted seatback ahead, causing nosebleed.
- Cushion on adjacent seat went flying.
- Saw people seated at opposite end of car in quad seating thrown into bulkhead.
- Spoke to man across from aisle, thought the other passenger was okay. Went downstairs, checked with conductor, talked to Deputy Sheriff before exiting train.
- Remembers conductor on the floor, next to desk, in some pain. Conductor was calling dispatch. Passenger does not think conductor could have opened doors based on physical condition. Passengers tried to get everyone off the car, then conductor followed. Went to pre-triage, then official triage.
- An anonymous passenger that was not interviewed was on feet, but “not really looking good.”

- Someone was yelling “fire.” Passenger realized fire was not in Car #617.Passenger noticed the disconnected Car #185 separate from the remaining two cars. Passenger remembers someone else taking the fire extinguisher from car.
- Injuries limited to facial injuries.

Passenger #13, 5’-9”, ~200 lbs.

Pre-accident location: Likely Car #207, likely seat 89

- Claims to have been seated in Car #617, lower level, left-hand side, facing forward at a table. *Interviewer’s note: Based on description of events and condition of the cars, it is likely that this passenger was sitting in Car #207 in seat 89. The table is bent and the emergency window is open at this location.*
- Sitting alone at the table, a tall lady was seated at the table across the aisle.
- Saw the moving freight train and braced self with hands on the table.
- Put body on the table.
- Heard the sheriff asking if anyone was alive and instruct one of the guys to open the window.
- Was removed through the window.
- Injuries:
    - Abdomen
    - Bowel
    - Mesenteric tear
    - Liver
    - Spleen
    - Pain in right elbow
    - Pain in left shoulder

B.1.3. Emergency Responder Interviews

During the on-scene portion of the investigation, members of the forensics team conducted interviews with emergency personnel that had responded to the accident (from the Los Angeles Fire Department and Los Angeles Sheriff’s Department). Questions chiefly focused on the subject of the passenger injuries the responders had observed.

Los Angeles Fire Department Responder A

Observed passengers found in front lower level of middle coach car (#207):

- One male with massive head injury, indicated by raccoon eyes, appeared to be in critical condition, probably sitting in handicap area prior to the accident.
- One male with apparent leg injury. He wore an ankle brace prior to the accident.

- One woman with abdominal injury, possible rib fracture.
- One male with bruised chest.
- 69-year old female with hip injury.
- Several people with facial injuries.
- One male apparently fatally injured.
- Three passengers transported to Holy Cross.
- Three passengers transported to Kaiser, including man with ankle brace.

Los Angeles Fire Department Responder B

Observations:

- Approximately 20 helicopter flights to hospitals, 3-5 people per flight, for those with most serious injuries.
- Many fractured limbs, some compound fractures.
- Lots of abdominal and chest injuries.
- One passenger sitting with large chunk of metal lodged in head.
- Several head injuries.
- He praised the work of the Los Angeles Police Department.

Los Angeles Fire Department Responder C

Observations:

- Large passenger ~ 6’3”, 250 lbs. with abdominal injury.
    - Cut and torn from left clavicle (collarbone) to lower right abdomen (like seat belt).
    - He had sore back, walked off train.
- Several lower-leg injuries, front and back of legs.
- Several fractured arms and legs.
- Several people bleeding from back of heads.
- Several people with bruises/pain on sides of back (possibly from fiberglass armrests between seat pairs).

Los Angeles County Sheriff’s Department Responder

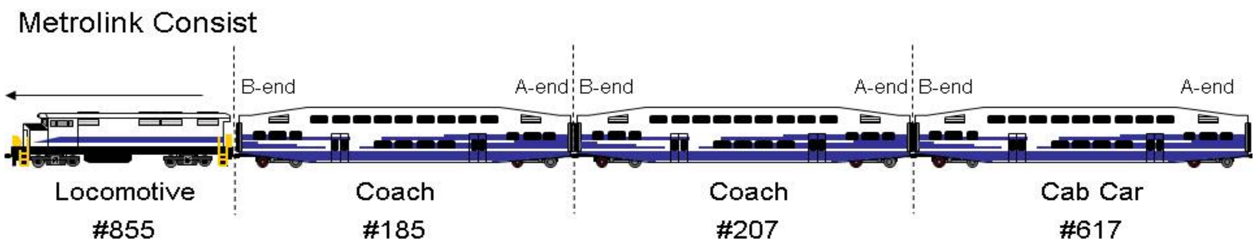
Had interviewed Metrolink conductor and reported that when the impact occurred, conductor was standing in the trailing cab car (#617), lower level, on the left side of the car, at the shelf behind the bulkhead. Conductor had injuries to legs and back.

Observations:

- 16 Personnel from LA County Sheriff's Department responded on the scene.
- 40 passengers flown to area hospitals.
- ~115 passengers treated on-scene.
- 165 total passengers on train (estimated by Metrolink conductor).

Appendix B.2: Indications of the Use of Emergency Egress/Response Features

This appendix discusses evidence of use of emergency tools and features in the passenger cars.



Car #185

Emergency release handles

The red handle on the right side A-end (trailing end) was pulled.

Jaws of Life

Emergency responders used the "jaws of life" to cut open the B-end (leading end of car), end door (opposite of door handle) and then used a saw to cut off the top portion of the door near the top of the window.

Saw

Emergency responders also used a saw to cut the sheathing between the right #4 and #5 windows on the upper level.

Car #207

Emergency release handles

Doors L (1 and 2) and R (1 and 2) exterior emergency release handles were activated. In the interior, A-end number 5 and 6 door emergency release handles were used.

Emergency tools

All B-end emergency tools (including first aid materials) had been removed from the locker, except for the saw.

Fire extinguishers

A-end lower level fire extinguisher was used. A and B end fire extinguishers were still in place.

Emergency windows

Upper level B-end left side emergency window was pulled. Upper level middle of car R side emergency window was pulled.

Car #617

Emergency release handles

Doors L (number 1) and R (number 1) exterior emergency release handles were activated. In the interior, emergency release handles for doors number 3, 4 and 5 were used.

Emergency tools

B-end lower level emergency equipment, the saw and the first aid kit were not used. The other tools, which may have included a pry bar and handheld flashlight, were used.

Fire extinguishers

F lower level fire extinguishers were used but the B-end fire extinguishers were still in place.

Emergency windows

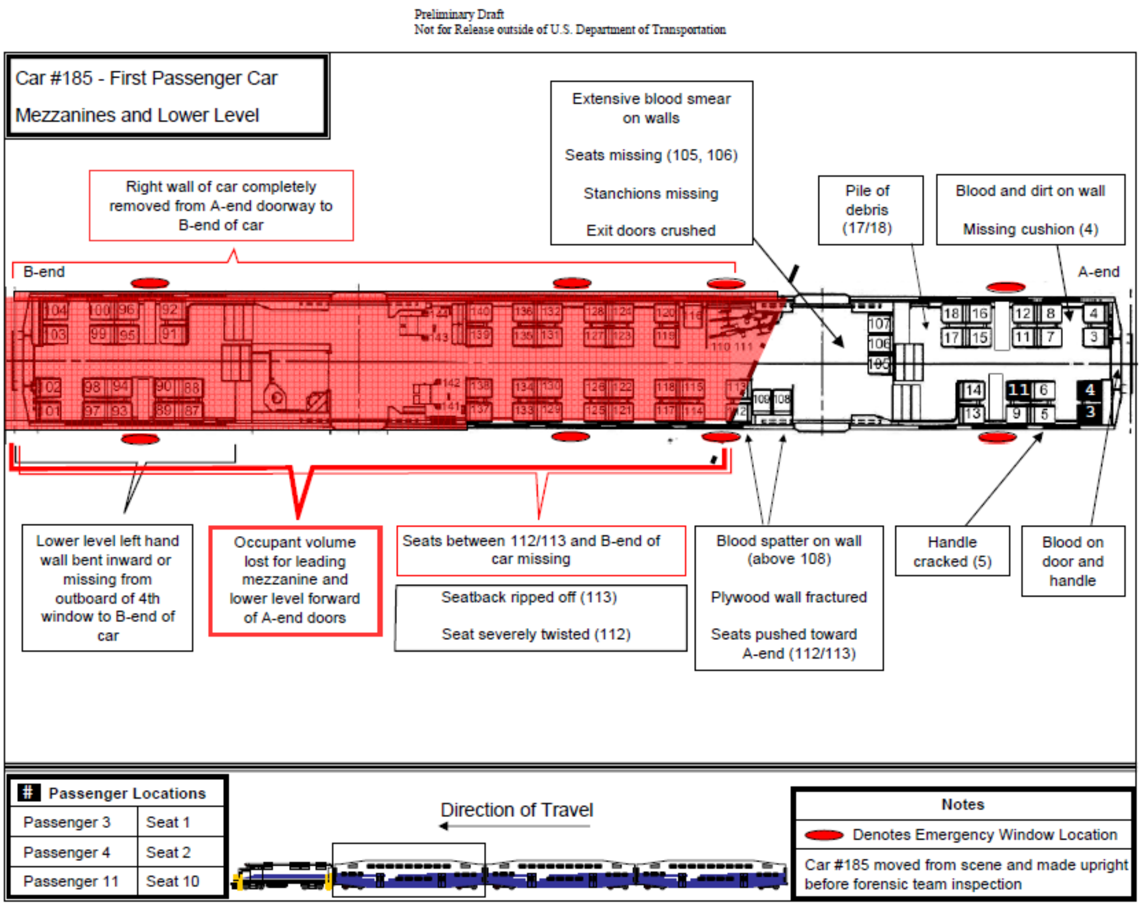
B-end R side emergency window lower level was pulled. Upper level by seat numbers 43 and 44, the window was pulled.

Appendix B.3: Interior Damage Diagrams

This appendix provides diagrams of interior damage in passenger cars, and estimated seat locations of passengers, based on passenger interviews.

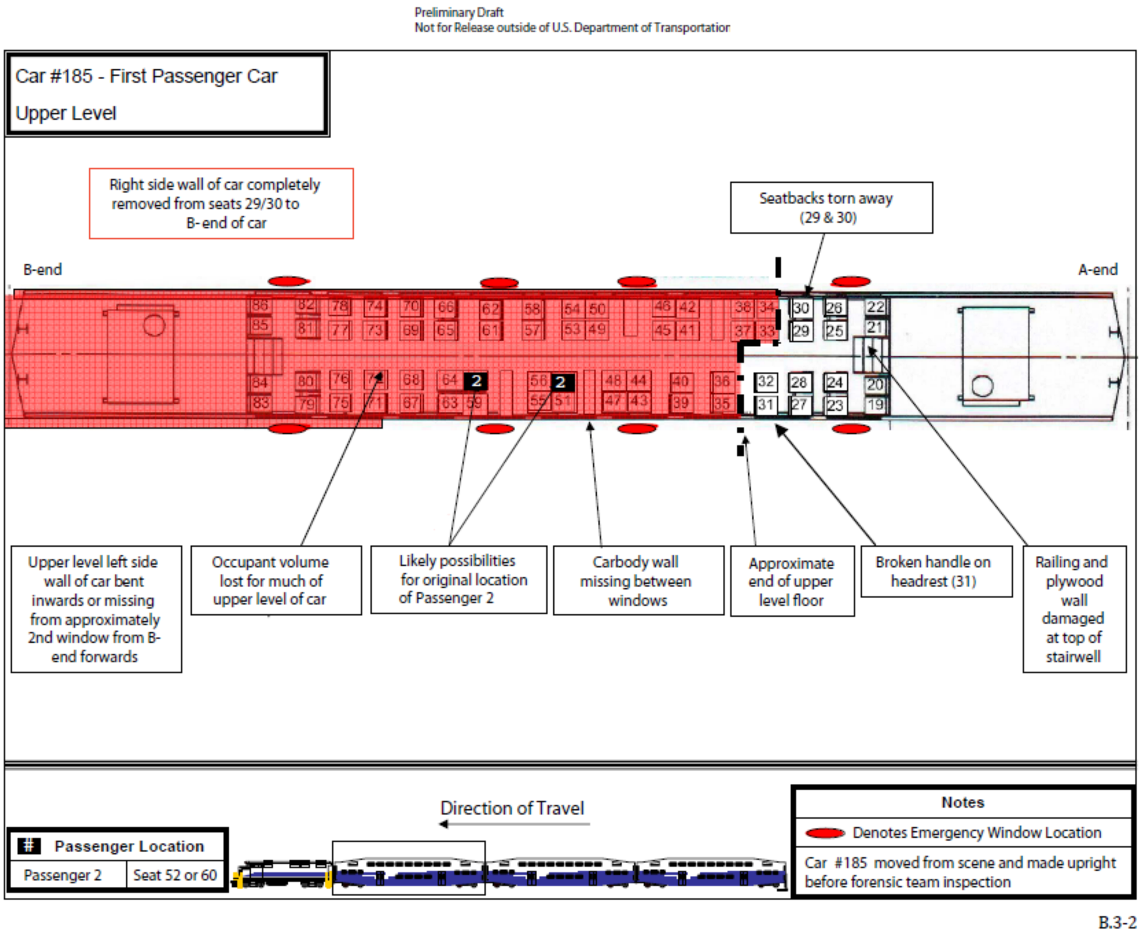
Car #185 – First Passenger Car

Mezzanines and Lower Level



B.3-1

Upper Level

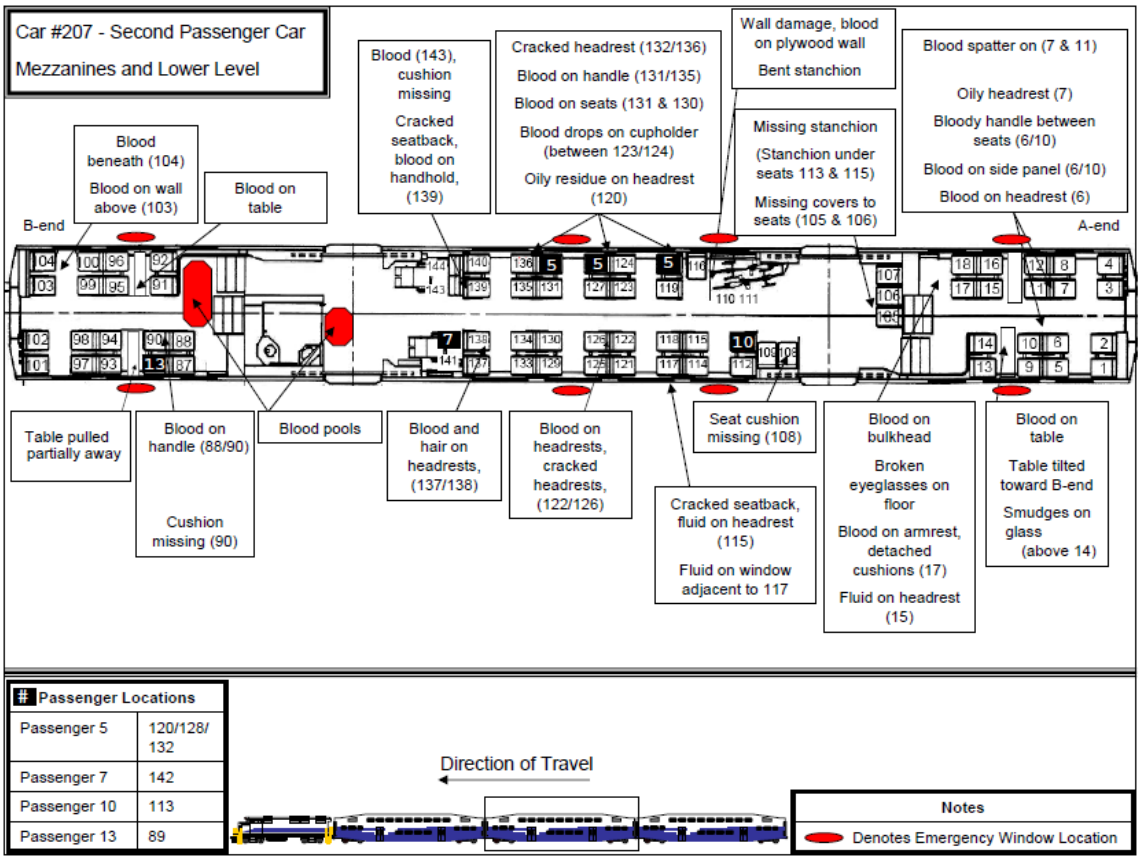


Preliminary Draft
Not for Release outside of U.S. Department of Transportation
Car #185 - First Passenger Car
Upper Level
Right side wall of car completely removed from seats 29/30 to B-end of car
Seatbacks torn away (29 & 30)
B-end
A-end
Upper level left side wall of car bent inwards or missing from approximately 2nd window from B-end forwards
Occupant volume lost for much of upper level of car
Likely possibilities for original location of Passenger 2
Carbody wall missing between windows
Approximate end of upper level floor
Broken handle on headrest (31)
Railing and plywood wall damaged at top of stairwell
Direction of Travel
Passenger Location
Passenger 2
Seat 52 or 60
Notes
Denotes Emergency Window Location
Car #185 moved from scene and made upright before forensic team inspection
B.3-2

Car #207 – Second Passenger Car

Mezzanines and Lower Level

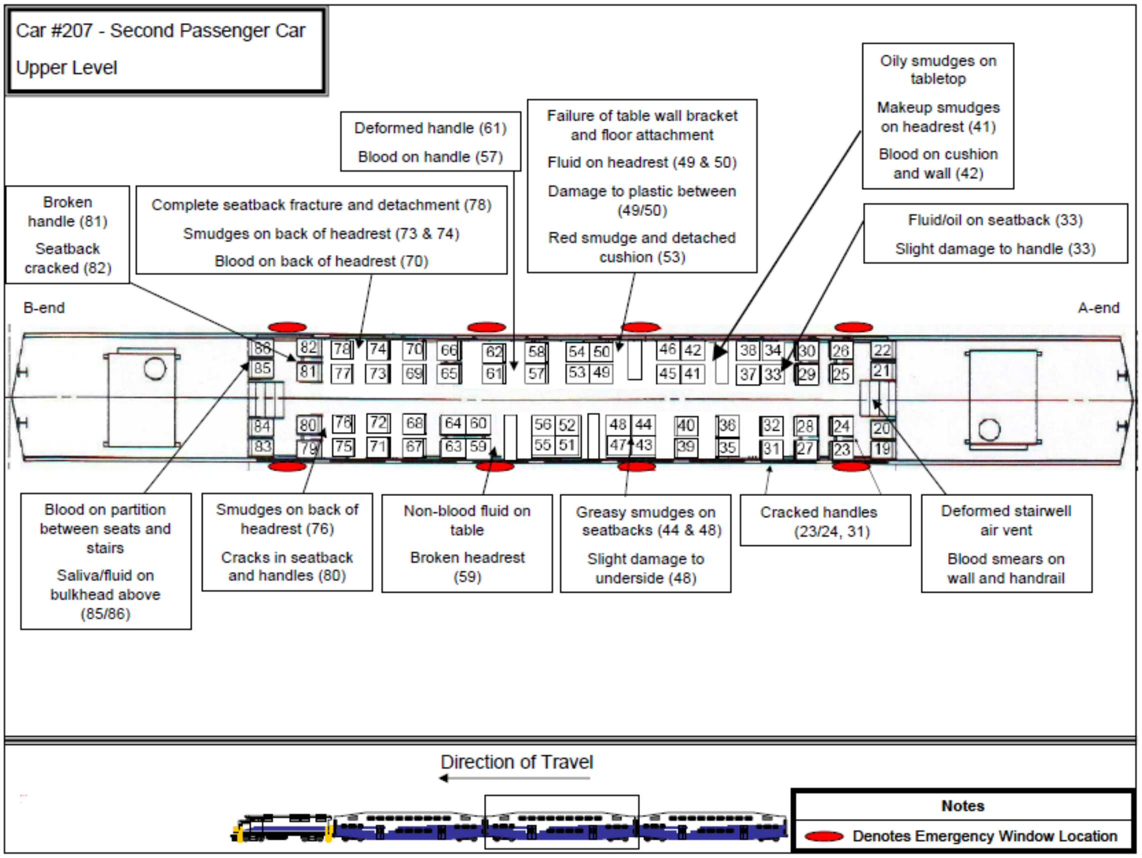
Preliminary Draft
Not for Release outside of U.S. Department of Transportation



B.3-3

Upper Level

Preliminary Draft
Not for Release outside of U.S. Department of Transportation

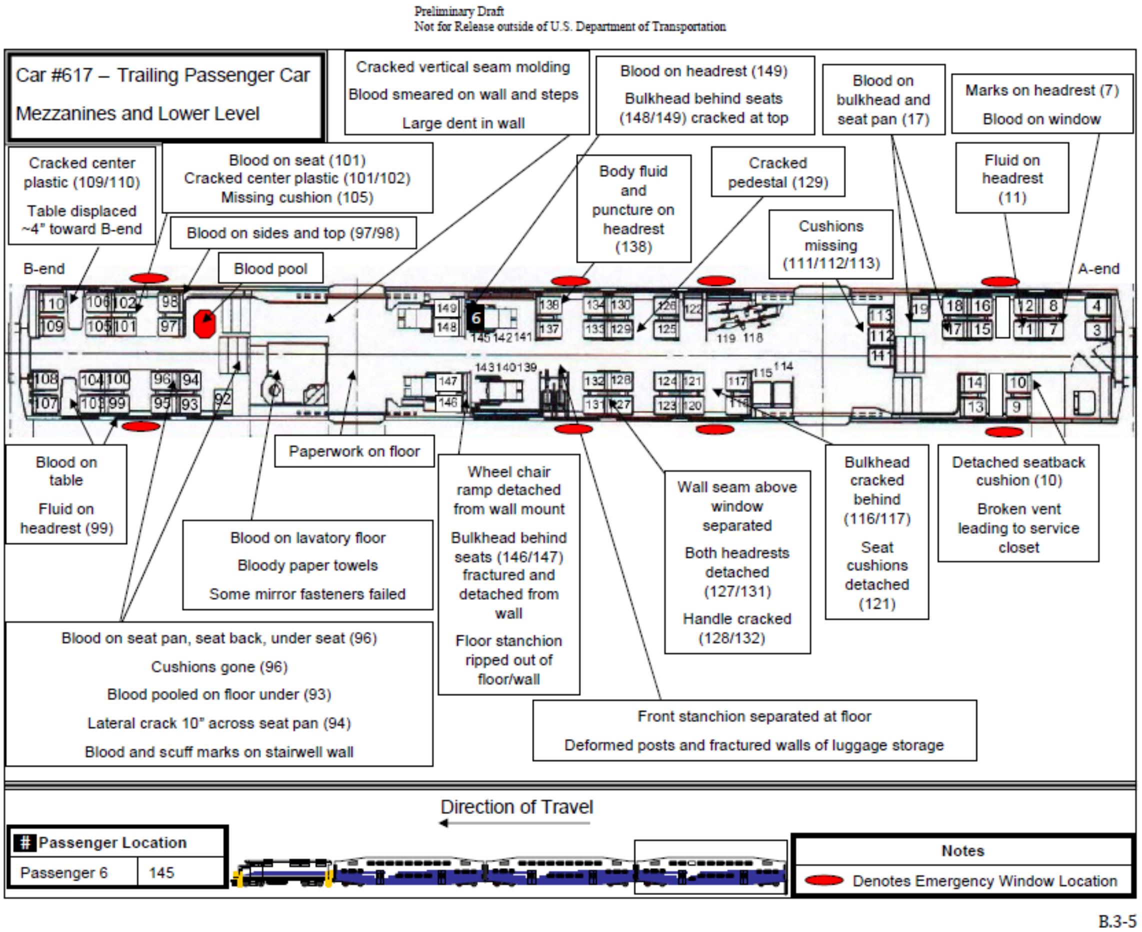


Passenger Locations

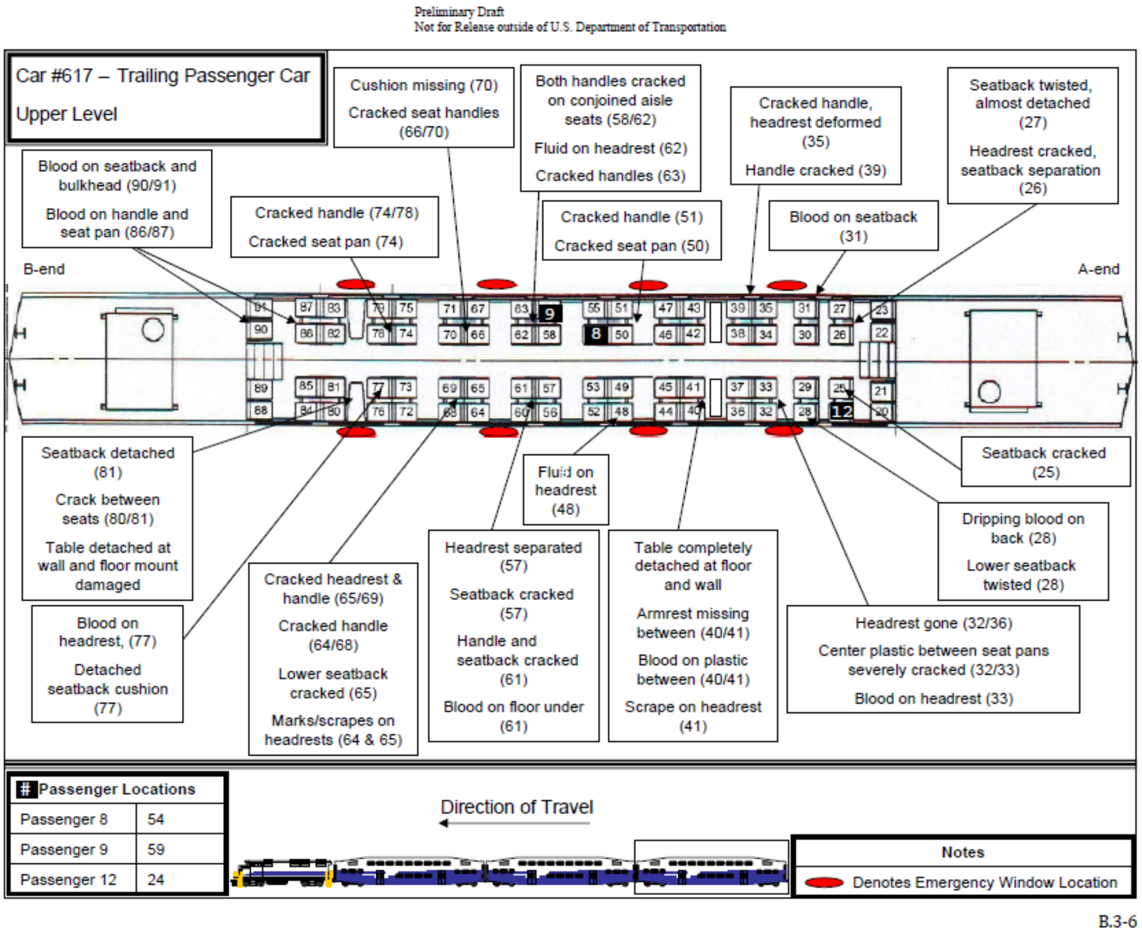
B.3-4

Car #617 – Trailing Passenger Car

Mezzanines and Lower Level



Upper Level


Preliminary Draft
Not for Release outside of U.S. Department of Transportation
Car #617 – Trailing Passenger Car
Upper Level
Cushion missing (70)
Cracked seat handles (66/70)
Both handles cracked on conjoined aisle seats (58/62)
Fluid on headrest (62)
Cracked handles (63)
Cracked handle, headrest deformed (35)
Handle cracked (39)
Seatback twisted, almost detached (27)
Headrest cracked, seatback separation (26)
Blood on seatback and bulkhead (90/91)
Blood on handle and seat pan (86/87)
Cracked handle (74/78)
Cracked seat pan (74)
Cracked handle (51)
Cracked seat pan (50)
Blood on seatback (31)
B-end
A-end
Seatback detached (81)
Crack between seats (80/81)
Table detached at wall and floor mount damaged
Blood on headrest, (77)
Detached seatback cushion (77)
Cracked headrest & handle (65/69)
Cracked handle (64/68)
Lower seatback cracked (65)
Marks/scrapes on headrests (64 & 65)
Fluid on headrest (48)
Headrest separated (57)
Seatback cracked (57)
Handle and seatback cracked (61)
Blood on floor under (61)
Table completely detached at floor and wall
Armrest missing between (40/41)
Blood on plastic between (40/41)
Scrape on headrest (41)
Seatback cracked (25)
Dripping blood on back (28)
Lower seatback twisted (28)
Headrest gone (32/36)
Center plastic between seat pans severely cracked (32/33)
Blood on headrest (33)
Passenger Locations
Passenger 8 54
Passenger 9 59
Passenger 12 24
Direction of Travel
Notes
Denotes Emergency Window Location
B.3-6

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.

Abbreviations and Acronyms

SIV	Secondary Impact Velocity
TOR	Top-of-Rail
UCLA	University of California – Los Angeles
UP	Union Pacific Railroad