US Department
of Transportation

**Federal Railroad
Administration**

Collision of Amtrak Passenger Train and Norfolk Southern Freight Train—November 30, 2007, Chicago, Illinois

Office of Research
and Development
Washington, DC 20005

DOT/FRA/ORD-13/45

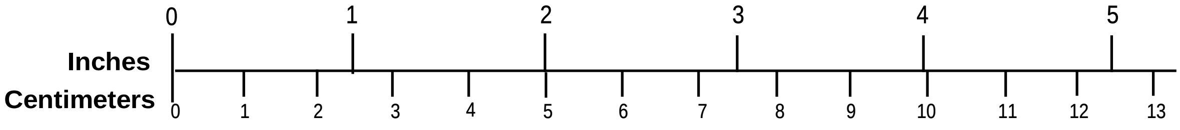
Final Report
October 2013

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.			
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE October 2013	3. REPORT TYPE AND DATES COVERED Final Report	
4. TITLE AND SUBTITLE Collision of Amtrak Passenger Train and Norfolk Southern Freight Train—November 30, 2007, Chicago, Illinois			5. FUNDING NUMBERS
6. AUTHOR(S) Patricia G. Llana, David Tyrell, Karina Jacobsen			
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Department of Transportation John A. Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142-1093			8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Research and Development 1200 New Jersey Avenue, SE – Mail Stop 20 Washington, DC 20590			10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD – 13/45
11. SUPPLEMENTARY NOTES			
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161. This document is also available on the FRA Web site at www.fra.dot.gov.			12b. DISTRIBUTION CODE
13. ABSTRACT (Maximum 200 words) On November 30, 2007, an Amtrak passenger train travelling at approximately 33 mph collided with the rear of a standing freight train in Chicago, Illinois. The locomotive of the passenger train overrode the rear car of the freight train and came to rest on top of the rear car. The rest of the cars in the passenger and freight consists remained on the tracks. There were no fatalities caused by the accident and no life-threatening injuries were incurred by the passengers or crew. The passenger locomotive bore the brunt of the impact and sustained most of the structural and interior damage, creating an almost life-threatening situation within the cab. This document is the U. S. Department of Transportation's Rail Accident Forensic Team's report on the Chicago accident. The document comprises a main report and four appendices. The main report summarizes the sequence of events of the accident, the casualties, and the structural and interior damage incurred. The appendices provide more information and greater detail about the accident, as well as results from preliminary collision dynamics analyses.			
14. SUBJECT TERMS Transportation, safety, collision, rail accident investigation, crashworthiness, structures, dynamics			15. NUMBER OF PAGES 61 16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

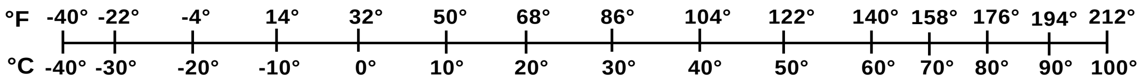
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA** (APPROXIMATE)	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT** (APPROXIMATE)	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME** (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
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 meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)		**TEMPERATURE** (EXACT)	
[(x-32)(5/9)] °F	= y °C	[(9/5) y + 32] °C	= x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



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

Contents

Illustrations

Tables

Preface

On November 30, 2007, an Amtrak passenger train travelling at approximately 33 mph collided with the rear of a standing freight train in Chicago, Illinois. There were no fatalities caused by the accident and no life-threatening injuries were incurred by the passengers or crew. The passenger locomotive bore the brunt of the impact and sustained most of the structural and interior damage, creating an almost life-threatening situation within the cab.

This accident was investigated by the National Transportation Safety Board with the objective of determining probable cause and issuing safety recommendations aimed at preventing future accidents [1]. The accident was also investigated by the U. S. Department of Transportation's Rail Accident Forensic Team. The role of the team is to evaluate the effectiveness of current train safety regulations, conduct research for improving train safety, and implement enhanced train safety regulations, if warranted by the concerns manifested by accidents and supported by research.

This report describes the preliminary reconstruction, based on data gathered from the field investigation, of the Chicago collision. The field investigation has provided preliminary data on the structural damage and the occupant injuries resulting from the impact. A one-dimensional collision dynamics model was developed to estimate the primary longitudinal motions experienced by the occupants. The results correlated with data collected from the accident investigation.

This work was performed as part of the Equipment Safety Research Program sponsored by the Federal Railroad Administration's (FRA) Office of Research and Development. The authors would like to recognize Jeff Gordon, Program Manager, Eloy Martinez, former Program Manager, and Kevin Kesler, Chief, both of the Equipment and Operating Practices Research Division, Office of Research and Development, FRA, for their support. The authors would like to thank FRA's Primary Forensic Passenger Accident Investigation Team—Charles Whalen, Jennifer Schuster, Mark Sandler, and Peter Lapre—for its work investigating the Chicago train collision. The authors would also like to thank Dr. Benjamin Perlman of the Volpe Center for his technical expertise, helpful review, and suggestions.

THIS PAGE INTENTIONALLY LEFT BLANK

Executive Summary

On November 30, 2007, an Amtrak passenger train travelling at approximately 33 mph collided with the rear of a standing freight train in Chicago, Illinois. The locomotive of the passenger train overrode the rear car of the freight train and came to rest on top of the rear car. The rest of the cars in the passenger and freight consists remained on the tracks. There were no fatalities caused by the accident and no life-threatening injuries were incurred by the passengers or crew. The passenger locomotive bore the brunt of the impact and sustained most of the structural and interior damage, creating a close to life-threatening situation within the cab.

This accident was investigated by the National Transportation Safety Board with the objective of determining probable cause and issuing safety recommendations aimed at preventing future accidents [1]. The accident was also investigated by the U.S. Department of Transportation's Rail Accident Forensic Team. The role of the team is to evaluate the effectiveness of current train safety regulations, conduct research for improving train safety, and implement enhanced train safety regulations if warranted by the concerns manifested by accidents and supported by research.

This document is the team's report on the Chicago accident. The document comprises a main report and four appendices. The main report summarizes the sequence of events of the accident, the casualties, and the structural and interior damage incurred. The appendices provide more information and greater detail about the accident, as well as results from preliminary collision dynamics analyses.

The primary objective of a field investigation is to determine how the occupants were injured and to ascertain the causal mechanisms for their injuries. The data gathered includes the final position of the equipment, the structural damage to the equipment, the wayside evidence, the interior fixture damage, passenger injury evidence, occupant interviews, and medical records. The data are then interpreted in order to synthesize the impact sequence of events, the train dynamics, the colliding car interactions, the distribution of car crush, the loss of interior volume, and the occupant dynamics. This report includes an estimate of the sequence of events of the accident. Details on the structural damage and passenger injuries incurred during this collision can be found in Appendices A and B. Preliminary collision dynamics analysis results are provided in Appendix C. Details on the Amtrak seats and the seat rotating mechanism can be found in Appendix D.

Although no fatalities were caused by the accident, the operating engineer and relief engineer in the engineer's cab at the time of impact sustained more severe injuries than the passengers and crew in the coach cars. This was a result of the locomotive sustaining most of the exterior and interior structural damage and bearing the brunt of the impact. The locomotive underframe buckled and deformed upward causing the floor and the seats in the cab to be pushed up, resulting in a loss of occupied volume in the cab. Information from interviews of both the operating engineer and the relief engineer is provided in Appendix B.2. Preliminary collision dynamics analyses performed of the accident correlated with data collected from the accident investigation. The collision dynamics analyses can be found in Appendix C.

1. Introduction

The Volpe Center has been supporting the Federal Railroad Administration (FRA) in performing rail passenger equipment crashworthiness research. The overall objective of this research has been to develop strategies for incrementally improving structural crashworthiness and occupant protection in passenger trains. This goal can be achieved by preserving the occupant volume and limiting the forces and accelerations imparted to the occupants in passenger train collisions, thereby preventing life-threatening injuries.

The objective of the equipment crashworthiness research is to evaluate both the equipment structural behavior and the occupant response in passenger train collisions. Exterior and interior configurations that warrant improvement are identified, and then improved crashworthiness strategies for those configurations are developed [2]. The first step in the research process is to conduct accident field investigations to identify the most common collision scenarios, determine the related modes of deformation of the exterior and interior equipment, and ascertain the resulting occupant injuries and their severity. In subsequent steps, dynamic and quasi-static full-scale testing and computer modeling are conducted to measure the equipment behavior and occupant response and evaluate candidate crashworthiness strategies [3]. This approach utilizes the data obtained from accident investigations in order to prevent similar injuries in the future. The general approach to developing crashworthiness strategies is summarized in Figure 1.

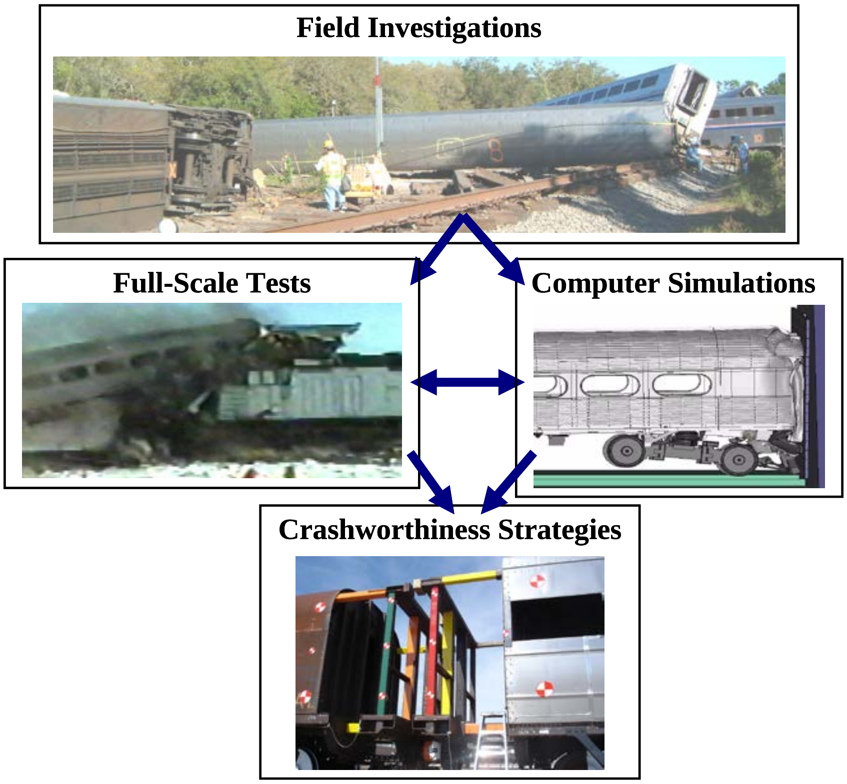


Figure 1. Approach to crashworthiness studies.

This paper describes the preliminary reconstruction, based on data gathered in the field investigation, of the Chicago, Illinois, collision between a passenger train and a freight train [1].

The primary objective of a field investigation is to determine how the occupants were injured and to ascertain the causal mechanisms for their injuries. The data gathered includes the final position of the equipment, the structural damage of the equipment, the wayside evidence, the event recorder data, the interior fixture damage, passenger injury evidence, occupant interviews, and medical records. The data are then interpreted in order to synthesize the impact sequence of events, the train dynamics, the colliding car interaction, the amount of car crush, the loss of interior volume, and the occupant dynamics.

On November 30, 2007, a Norfolk Southern (NS) freight train was stopped on a main track of NS's Dearborn Division in Chicago, Illinois. A westbound Amtrak passenger train was routed to the same track. The passenger train consisted of a leading locomotive and three coach cars. At approximately 11:30 am C.S.T., the passenger train struck the rear end of the freight train at a speed of approximately 33 mph. The leading locomotive in the passenger train collided with the rear of the last freight car in the freight train and overrode it.

There were no fatalities caused by the accident and no life-threatening injuries were incurred by the passengers or crew. The passenger locomotive bore the brunt of the impact and sustained most of the structural and interior damage, creating an almost life-threatening situation within the cab.

This report includes an estimate of the sequence of events of the accident, from the initial impact to the resulting injuries and fatalities, determined from the data gathered at the field investigation. Details on the structural damage and passenger injuries incurred during this collision can be found in the Appendices. Information from interviews of both the operating engineer and the relief engineer is also provided in the Appendices.

Figure 2 shows a schematic of the accident just prior to impact. At the time of impact, the freight train was standing and the passenger train was in full emergency brake and travelling at approximately 33 mph. The passenger train consisted of a General Electric P42 four-axle locomotive and three Bombardier Superliner multilevel passenger cars. The end freight car was a three-unit articulated well car loaded with intermodal containers. The remainder of the freight train included 19 intermodal freight cars and 2 freight locomotives. The accident occurred on tangent track, with the passenger train just exiting a spiral.

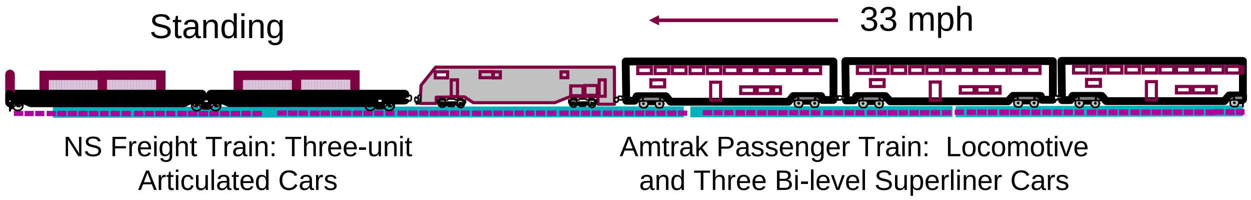
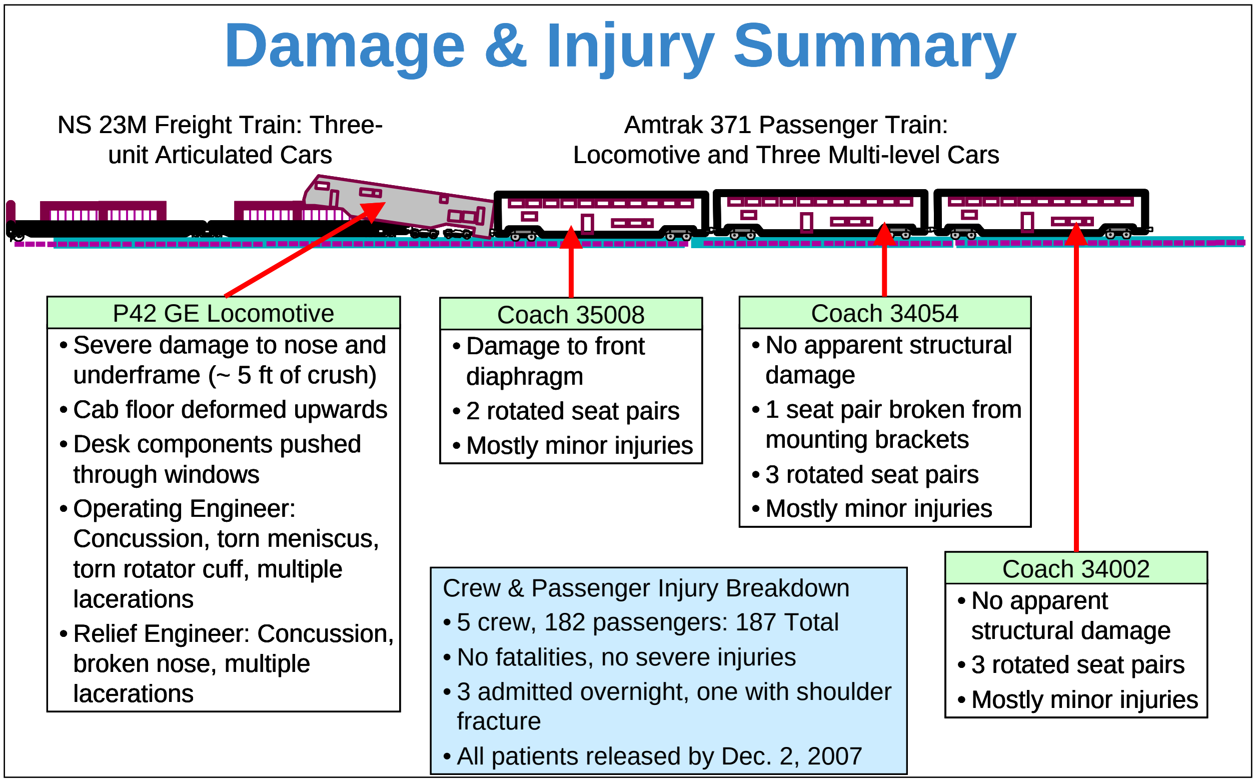


Figure 2. Schematic of initial impact conditions.

Figure 3 is an aerial photograph of the accident shortly after it occurred. On the left side, the photograph shows the end unit of the three-unit articulated car. Approximately half the length of the rear intermodal container is crushed. The passenger locomotive is resting on top of the intermodal container and the well car. The lead truck of the locomotive is detached from the body of the locomotive, derailed, and adjacent to the trailing truck. The end of the first passenger car can be seen on the right side of the photograph, with no visible structural damage.

Figure 3. Aerial photograph of accident [4].

Figure 4 shows a sketch of the post-accident layout of the two trains and provides a summary of the damage and injuries for each of the cars in the passenger train and the last freight car. There were no fatalities caused by the accident and only minor injuries were incurred by the passengers and crew. However, the engineers located in the operator's cab at the time of impact sustained more severe injuries than the passengers and crew located in the coach cars. This was a result of the locomotive sustaining most of the exterior and interior structural damage and bearing the brunt of the impact, creating an almost life-threatening situation within the cab. In addition, the damage incurred by the locomotive cab was such that the crew could not exit and had to be helped out by emergency responders. The crew of the freight train in the accident that occurred on September 12, 2008, [5] in Chatsworth, California, found themselves in similarly situated; they could not exit their cab without help from the emergency responders.



Damage & Injury Summary

NS 23M Freight Train: Three-unit Articulated Cars

Amtrak 371 Passenger Train: Locomotive and Three Multi-level Cars

P42 GE Locomotive
- Severe damage to nose and underframe (~ 5 ft of crush)
- Cab floor deformed upwards
- Desk components pushed through windows
- Operating Engineer: Concussion, torn meniscus, torn rotator cuff, multiple lacerations
- Relief Engineer: Concussion, broken nose, multiple lacerations

Coach 35008
- Damage to front diaphragm
- 2 rotated seat pairs
- Mostly minor injuries

Coach 34054
- No apparent structural damage
- 1 seat pair broken from mounting brackets
- 3 rotated seat pairs
- Mostly minor injuries

Crew & Passenger Injury Breakdown
- 5 crew, 182 passengers: 187 Total
- No fatalities, no severe injuries
- 3 admitted overnight, one with shoulder fracture
- All patients released by Dec. 2, 2007

Coach 34002
- No apparent structural damage
- 3 rotated seat pairs
- Mostly minor injuries

Figure 4. Damage and injury summary.

2. Sequence of Events

This section describes the estimated train-to-train collision dynamics from the time the two trains collided to when they came to rest. This sequence of events is based upon calculations of the known collision scenario and evidence gathered during the investigation. The computer simulation is described in more detail in Appendix C. The structural damage is described in detail in Appendix A and summarized in Section 4 of this report.

As stated previously, the intercity train was a locomotive leading three multilevel passenger cars. The end freight car was a three-unit articulated well car loaded with intermodal containers. The remainder of the freight train included 19 intermodal freight cars and 2 freight locomotives. At the time of impact, the passenger train was travelling at approximately 33 mph and the freight train was standing. The accident occurred on tangent track, with the passenger train just exiting a spiral.

The final position of the equipment, the structural damage to the equipment, the wayside evidence, and occupant interviews were interpreted in order to synthesize the following impact sequence of events, broken down into a series of phases:

Phase 1: Contact of the couplers;
Phase 2: Locomotive and freight car couplers moved back, both draft gears bottomed out;
Phase 3: Locomotive coupler carrier failed, locomotive began to climb rear of freight car;
Phase 4: Locomotive draft gear housing pushed back and up, locomotive lead truck engaged freight car;
Phase 5: Locomotive striker engaged freight car bolster, locomotive lead truck sheared off, rear roof of locomotive engaged lead passenger car collision posts;
Phase 6: Locomotive striker engaged the rear container, locomotive wheel cut fuel tank, locomotive lead truck pushed under locomotive;
Phase 7: Locomotive crushed two containers and passenger train came to a stop.

Configurations of the trains during all phases of the impact are depicted in Figure 5. Each phase is described in more detail with photographs in Appendix A.2.

Figure 5. Phases of the collision.

As a result of the accident, the passenger locomotive overrode the freight car. The end of the locomotive, including the engineer's cab, was significantly crushed. There remained just enough space for the two locomotive engineers to ride out the collision. What typically occurs in train collisions is lateral buckling of one or both of the colliding trains. However, in this accident, the passenger train overrode the freight train, with no lateral buckling of either consist. Considering that there were trains on adjacent tracks on both sides of the collision, the absence of lateral buckling prevented the accident from involving additional trains, which may have caused more severe injuries or fatalities in all of the trains involved.

3. Casualties

The occupants of the Amtrak train included five crew members and 182 passengers. The passenger cars were at or near capacity at the time of the accident. Because the train was approaching its last stop, some passengers and crew were standing upon impact. There were no fatalities, however. Two passengers and one crewmember were admitted to the hospital overnight, one with a shoulder fracture. All patients were released by December 2, 2007, 2 days after the accident. Details of the injuries incurred can be found in Appendix B.

The locomotive interiors sustained the heaviest damage, with minor damage incurred by the coach car interiors. As a result of the buckling of the locomotive underframe, the engineers in the locomotive cab sustained more severe injuries than the passengers and crew in the coach cars. The operating engineer sustained a torn left meniscus in his knee and a torn left rotator cuff. The relief engineer sustained a severely broken nose. Both engineers had concussions, multiple head lacerations and bruises. Details of their experience in the cab and the injuries they sustained can be found in the phone interview information in Appendix B.2.

4. Summary of Structural Damage

Most of the damage to the passenger and freight equipment was concentrated on the impacting passenger locomotive and last freight car. The passenger cars sustained little structural damage. Table 1 summarizes the structural damage to the equipment. The structural damage is described in more detail with photographs in Appendix A.

Table 1. Summary of structural damage to passenger and freight equipment.

Equipment	Summary of Structural Damage
Lead Passenger Locomotive	• Locomotive reduced in length by ~5 feet • Engineer's cab floor raised by at least 1½ feet • Lead truck detached • Fuel tank breached
First Passenger Car	• Lead-end doorway diaphragm damaged • No significant structural damage
Second and Third Passenger Cars	• No significant structural damage
Trailing Freight Car	• Coupler knuckle broken off • End walkway crushed and torn off • Draft sill bent downward slightly • Rear intermodal container crushed approximately halfway lengthwise • Front intermodal container crushed a small amount
Remaining Freight Equipment	• No significant structural damage

Figure 6 is a photograph of the impact locomotive after it had been separated from the freight car and the lead truck had been moved back under the front end. The locomotive was reduced in length by approximately 5 feet. The collision caused the underframe to deform into a 'Z' pattern, as illustrated in the figure. This deformation promoted the locomotive overriding the freight car, and also pushed the floor of the engineer's cab upward by approximately 1½ feet. The majority of the deformation was in the longitudinal and vertical directions, with very little lateral deformation.

Figure 6. Locomotive nose and underframe deformed inward and upward.

Figure 7 shows the impacted end of the rear freight car. The draft sill is deformed downward at a slight angle. It is likely that this downward deformation occurred when the locomotive began to climb the freight car. The downward deformation of the freight car draft sill along with the ‘Z’ deformation of the locomotive underframe likely promoted override of the freight car by the locomotive. Normally, there is a transverse walkway at the end of the freight car. This walkway does not carry suspension or train loads and was completely destroyed during the impact. Other than the slight downward bend of the draft sill, there was no significant structural damage to the freight car body. The body bolster and side sills remained essentially intact, and the truck remained attached. However, there was significant damage to the rear intermodal container and some damage to the front intermodal container. The structure of the intermodal containers is not intended to carry train or suspension loads and is weak compared with the locomotive and freight car structures. The rear intermodal container held bags of sand, which likely provided little crush resistance during the impact. Video taken of the accident indicates that the freight train did not move as a result of the collision.

Figure 7. Deformed draft sill of freight car.

During the collision, the locomotive fuel tank was breached by the rear wheel of the front truck as the locomotive climbed the freight car. The damage to the fuel tank, along with a diagram of how the damage occurred, is shown in Figure 8. The rear wheel of the locomotive front truck was still spinning when it contacted the slope sheet of the fuel tank. As the locomotive climbed the freight car, the spinning wheel fractured the slope sheet then penetrated the corner of the fuel tank baffle. Approximately 300 gallons of diesel fuel spilled from the tank as a result [1].

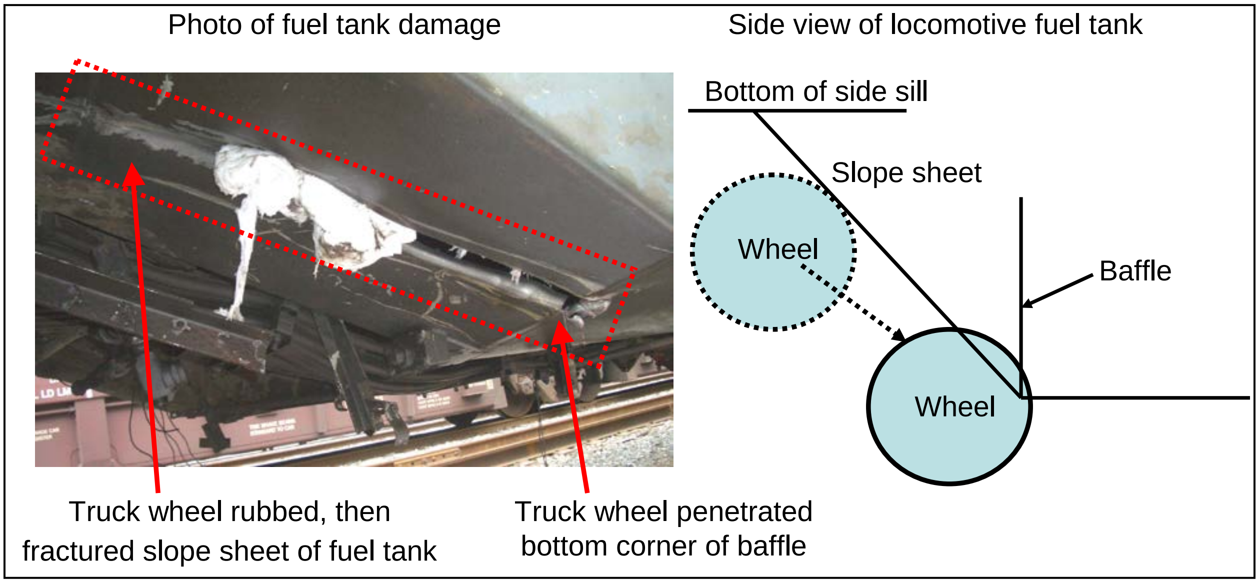


Figure 8. Fuel tank damage.

5. Summary of Interior Damage

The impact between the locomotive and the freight car caused the nose of the locomotive to roll under and push up, causing the underframe to buckle upward towards the engineer’s cab. The deformation of the underframe caused failure of the floor of the cab, resulting in the floor and the seats in the cab to be pushed upward. As can be seen in Figure 9, the floor of the cab is raised sufficiently for the operating engineer’s and the relief engineer’s seats to be pushed into the ceiling of the cab. The deformation of the underframe and cab floor also caused the desktop components of the cab to roll forward and push through the front windows of the cab compartment, as shown in Figure 9. The interior damage is described in more detail with photographs in Appendix B.1.

Figure 9. Locomotive interior cab damage and raised floor from impact.

The structural damage to the interiors of the coach cars was minor compared with the damage to the locomotive interior. All of the coaches were equipped with seat pairs that can be rotated 180 degrees to face either forward or backward. After the accident, two seat pairs in the first coach car, three seat pairs in the middle coach car, and three seat pairs in the last coach car were rotated with respect to their original positions. Although it appeared that the seat latches had failed to secure those seat pairs in the locked position, it was difficult to determine whether the collision had actually caused the seat latch failures. The seats may not have been latched properly prior to the collision. There is no positive feedback to suggest that the seat latch is engaged after the seat is rotated; the seat latches on the rotated seats may in fact not have been engaged at the time of the collision, allowing the force of the collision to rotate the seats out of position. Details on the seats and their locking mechanism can be found in Appendix D. Figure 10 shows one of the rotated seat pairs in the third coach car. The blood and other forensic evidence suggest that there was an injured passenger initially seated in the rotated seat. It is difficult to estimate what influence the rotating seat had on the injuries. Most of the injuries sustained by the passengers in the coach cars consisted of bloody noses, cuts, and bruises.

Figure 10. Rotated seat pair in third coach car.

In addition to the three rotated seat pairs, the middle coach car also had a seat pair that had separated from the wall and floor due to fastener failure, as shown in Figure 11. The interior damage is described in more detail with photographs in Appendix B.1.

Figure 11. Failed seat pair in middle coach car.

6. Discussion and Next Steps

This report describes the information gathered from an investigation of the Chicago, Illinois, rail collision of November 30, 2007, in which an Amtrak passenger train struck the rear end of a Norfolk Southern freight train at a speed of approximately 33 mph. The passenger train, consisting of a leading locomotive and three coach cars, collided with the rear of the last car in the freight train.

An accident field investigation was conducted to collect data to determine the impact sequence of events. After knuckle-to-knuckle contact, both couplers moved back and their draft gears bottomed out. The draft sill of the freight car deformed downward and the locomotive began to climb the rear of the freight car. The locomotive lead truck engaged the freight car and the locomotive draft gear housing crushed backward and upward. This caused the nose of the locomotive to roll under and the underframe to buckle upward, resulting in loss of occupant volume in the cab compartment. As the locomotive continued to climb the freight car, the lead truck of the locomotive was sheared off, the locomotive rear roof engaged the lead passenger car collision posts, and the rear wheel of the lead truck cut the fuel tank of the locomotive. The locomotive lead truck was left behind as the locomotive striker engaged the rear freight container. The locomotive crushed both freight containers and came to a stop on top of them. The locomotive of the passenger train derailed but the coach cars did not and all of the cars remained upright. The freight train did not move as a result of the collision.

There were no fatalities caused by the accident and only minor injuries were incurred by the occupants. Due to the loss of occupant volume in the locomotive cab, the operating engineer and relief engineer in the engineer's cab at the time of impact sustained more severe injuries than the passengers and crew in the coach cars. The locomotive underframe deformed upward causing the floor and the seats in the cab to be pushed upward as well. This created a situation close to life-threatening within the cab.

Small changes in the initial conditions of the impact could potentially have resulted in significantly more severe consequences. For example, if the accident had occurred with a slightly higher impact speed, the locomotive may have crushed further, resulting in the complete loss of survival space in the cab. The interactions of colliding conventional equipment are variable and unpredictable [6] [7]. In the accident, the locomotive overrode the freight car. Small changes in alignment at initial contact may have allowed the freight car to override the locomotive or the freight car and locomotive may have remained engaged. If the freight car had overridden the locomotive, it may have resulted in the engineer's cab being crushed underneath the freight car. If the locomotive and freight car had remained engaged, the decelerations of the trailing equipment may have been significantly greater, potentially resulting in more numerous and more severe injuries. The locomotive and freight car remaining engaged could also have led to the trailing passenger equipment derailing and laterally buckling [7] [8]. If the cars had derailed and buckled laterally, it is possible that the train would have collided with the trains running on both adjacent tracks, resulting in more severe injuries and possibly fatalities in all of the trains involved.

The next step in the equipment crashworthiness research program is to employ computer models to simulate the Chicago accident and the behavior of the locomotive and coach cars involved. Finite element analysis is being considered to evaluate the deformation of the locomotive nose and underframe and how they folded under and upward to displace the cab compartment floor. As described in Appendix C, preliminary collision dynamics analyses were conducted to recreate the crash pulse of the accident, to simulate the gross motions of the locomotive and coach cars, and to determine the accelerations imparted to the occupants. Further train collision dynamics analyses are being considered to evaluate the effectiveness of Crash Energy Management features [9] [10] in controlling colliding equipment interactions and occupant compartment decelerations. Occupant dynamics analyses are also being considered to understand the environment within the locomotive cab during the impact, to estimate how the injuries were incurred by the two engineers, and to investigate alternative means of protecting the cab occupants. Passenger seats and their performance in accidents are also being reviewed using data from this and other accidents.

In the event of a collision between two trains, as was the case in this Chicago accident, a considerable amount of energy must be dissipated. One of the potential consequences of such a collision is that one vehicle overrides the other, which occurred in this accident. Locomotives, because of their great longitudinal strength and stiffness, are particularly susceptible to override when they collide with another vehicle, and the consequences can be catastrophic. Research has shown that the addition of a few structural features to the forward end of a locomotive can greatly reduce the propensity for override [11]. Such features include push-back couplers and deformable anti-climbers, both of which can be integrated into the end structure of a locomotive. Push-back couplers allow the ends of the vehicles to engage prior to the buildup of large forces and moments that might lead to lateral buckling of the vehicles with respect to one another. Deformable anti-climbers provide sufficient vertical load carrying capacity as they deform gracefully and predictably to prevent the formation of a ramp. Crushable zones within deformable anti-climbers absorb collision energy and prevent uncontrolled deformation of interlocking features that might cause formation of a ramp. Research is currently being conducted [12] to evaluate the effectiveness of these components in mitigating the effects of a collision, particularly where the possibility of override is concerned. Acting together, the crashworthy components would allow the ends of the vehicles to engage and deform gracefully and predictably, preventing the formation of a ramp. Had the locomotive in this accident been equipped with these crashworthy components, override might have been prevented.

7. References

[1] National Transportation Safety Board , “Collision of Amtrak Passenger Train 371 and Norfolk Southern Railway Company Freight Train 23M, Chicago, Illinois, November 30, 2007,” NTSB Railroad Accident Report, PB2009-916301 NTSB/RAR-09/01, March 2009.

[2] Tyrell, D.C., K.J. Severson, and B.J. Marquis. Crashworthiness of Passenger Trains. Publication DT/FRA/ORD-97/10. Federal Railroad Administration, U.S. Department of Transportation, 1998.

[3] Tyrell, D. “Rail Passenger Equipment Accidents and the Evaluation of Crashworthiness Strategies,” presented at ‘What can We Realistically Expect from Crashworthiness?’ Rail Equipment Crashworthiness Symposium, Institute of Mechanical Engineers, May 2, 2001, London, England.

[4] Associated Press. Accessed December 4, 2007.

[5] Federal Railroad Administration, “Passenger/Freight Train Collision, September, 12, 2008, Chatsworth, CA,” FRA Accident Report.

[6] Mayville, R., Stringfellow, R., Johnson, K., Landrum, S., “Crashworthiness Design Modifications for Locomotive and Cab Car Anticlimbing Systems,” U.S. Department of Transportation, DOT/FRA/ORD-03/05, February 2003.

[7] Tyrell, D. “Rail Passenger Equipment Accidents and the Evaluation of Crashworthiness Strategies,” presented at ‘What can We Realistically Expect from Crashworthiness?’ Rail Equipment Crashworthiness Symposium, Institute of Mechanical Engineers, May 2, 2001, London, England.

[8] Mayville, R.A., Rancatore, R.J., Tegler, L., “Investigation and Simulation of Lateral Buckling in Trains,” Proceedings of the 1999 IEEE/ASME Joint Railroad Conference, Institute of Electrical and Electronics Engineers, Catalog Number 99CH36340, 1999.

[9] Tyrell, D.C., Perlman, A.B., “Evaluation of Rail Passenger Equipment Crashworthiness Strategies,” Transportation Research Record No. 1825, pp. 8–14, National Academy Press, 2003.

[10] Tyrell, D., Jacobsen, K., Martinez, E., “A Train-to-Train Impact Test of Crash Energy Management Passenger Rail Equipment: Structural Results,” American Society of Mechanical Engineers, Paper No. IMECE2006-13597, November 2006.

[11] Mayville, R., Stringfellow, R., Johnson, K., Landrum, S., “Crashworthiness Design Modifications for Locomotive and Cab Car Anticlimbing Systems,” U.S. Department of Transportation, DOT/FRA/ORD-03/05, February 2003.

[12] Llana, P., Stringfellow, R., “Preliminary Development of Locomotive Crashworthy Components”, American Society of Mechanical Engineers, Paper No. JRC2011-56104, March 2011.

[13] Web site: http://www.subwaynut.com/mnr/newrochelle/newrochelle13.jpg Accessed March 4, 2013.

[14] Web site:
http://www.gbrx.com/files/files/NAR/Stack_Cars/StackCarsMaxiIV.pdf. Accessed November 30, 2010.

[15] Priante, M. “Review of a Single Car Test of Multi-Level Passenger Equipment” American Society of Mechanical Engineers, Paper No. JRC2008-63053, April 2008.

[16] Tyrell, D., Severson, K.J., “Crashworthiness Testing of Amtrak's Traditional Coach Seat,” U.S. Department of Transportation, DOT/FRA/ORD-96/08, October 1996.

Abbreviations and Acronyms

ATD	Anthropomorphic Test Devices
BNSF	Burlington Northern Santa Fe
CEM	Crash Energy Management
DGSP	Double-Gimballed String Potentiometer
FRA	Federal Railroad Administration
HIC	Head Injury Criterion
SIV	Secondary Impact Velocity
THOR	Test Device for Human Occupant Restraint
TTC	Transportation Technology Center
TTCI	Transportation Technology Center Inc.
Volpe Center	John A. Volpe National Transportation Systems Center

Appendix A.
Structural Data

A.1 Train-Level Data

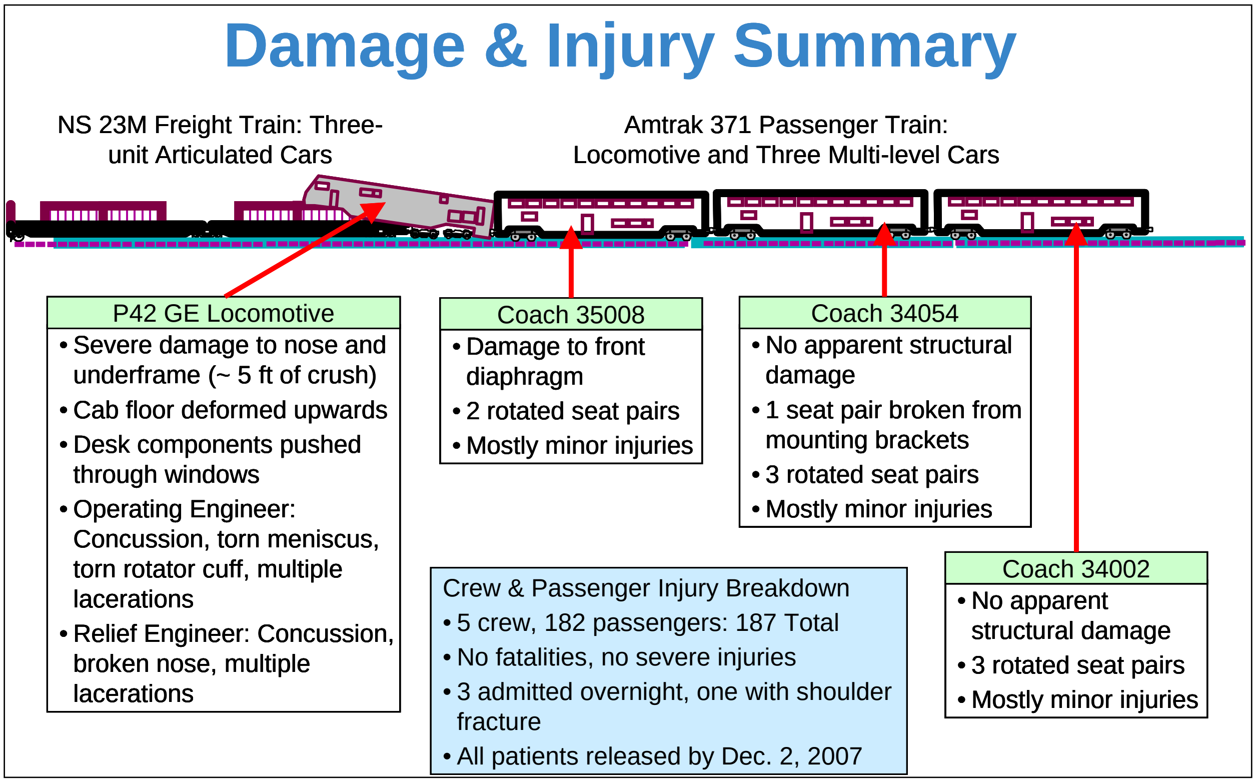
The photograph on the left in Figure A-1 shows an undamaged locomotive very similar to the one involved in the accident. The photograph on the right in Figure A-1 shows the damage incurred by the locomotive as a result of the accident.

Figure A-1. Undamaged locomotive (left) [13] and locomotive involved in the accident (right).

The photograph on the left in Figure A-2 shows an undamaged freight car very similar to the equipment involved in the accident. The photograph on the right in Figure A-2 shows the damage incurred by the freight car as a result of the accident.

Figure A-2. Undamaged freight car (left) [14] and freight car involved in the accident (right).

In the last phase of the impact, the passenger train came to a stop with the locomotive resting on top of the last freight car. Figure A-3 provides a sketch of the post-accident layout of the two trains, as well as a summary of the damage and injuries sustained..



Damage & Injury Summary

NS 23M Freight Train: Three-unit Articulated Cars

Amtrak 371 Passenger Train:
Locomotive and Three Multi-level Cars

P42 GE Locomotive

- Severe damage to nose and underframe (~ 5 ft of crush)
- Cab floor deformed upwards
- Desk components pushed through windows
- Operating Engineer: Concussion, torn meniscus, torn rotator cuff, multiple lacerations
- Relief Engineer: Concussion, broken nose, multiple lacerations

Coach 35008

- Damage to front diaphragm
- 2 rotated seat pairs
- Mostly minor injuries

Coach 34054

- No apparent structural damage
- 1 seat pair broken from mounting brackets
- 3 rotated seat pairs
- Mostly minor injuries

Coach 34002

- No apparent structural damage
- 3 rotated seat pairs
- Mostly minor injuries

Crew & Passenger Injury Breakdown

- 5 crew, 182 passengers: 187 Total
- No fatalities, no severe injuries
- 3 admitted overnight, one with shoulder fracture
- All patients released by Dec. 2, 2007

Figure A-3. Final positions of passenger train and freight train with damage and injury summary.

A.2 Car-Level Data

The final position of the equipment, the structural damage to the equipment, the wayside evidence, and the occupant interviews were interpreted in order to synthesize the following impact sequence of events, broken down into a series of seven phases in Figure A-4 and described in detail in the following sections.

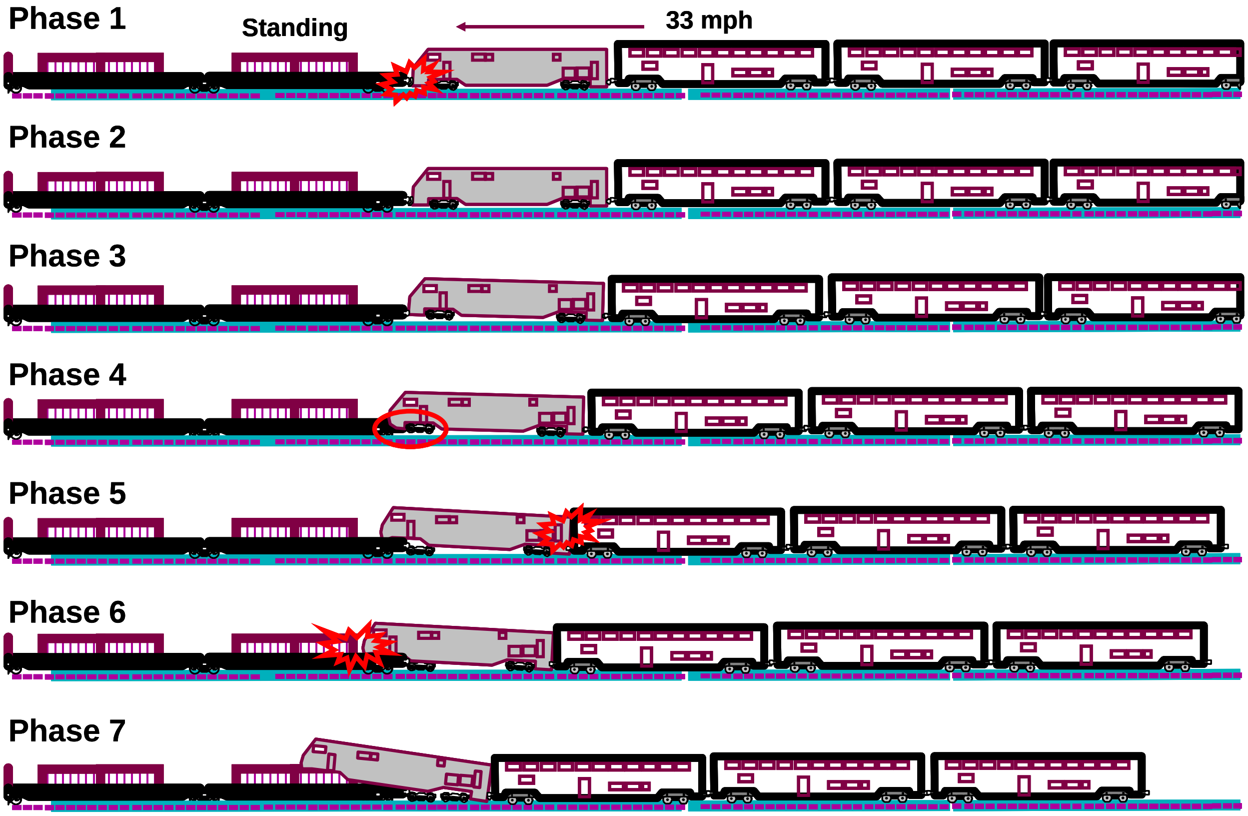


Figure A-4. Phases of the collision.

A.2.1 Phase 1: Contact of the couplers

In Phase 1, there was knuckle-to-knuckle contact of both couplers, as shown in Figure A-4. The knuckle of the locomotive coupler broke off and a piece of the knuckle of the freight car also broke off. Figure A-5 shows what remained of both couplers after the accident.

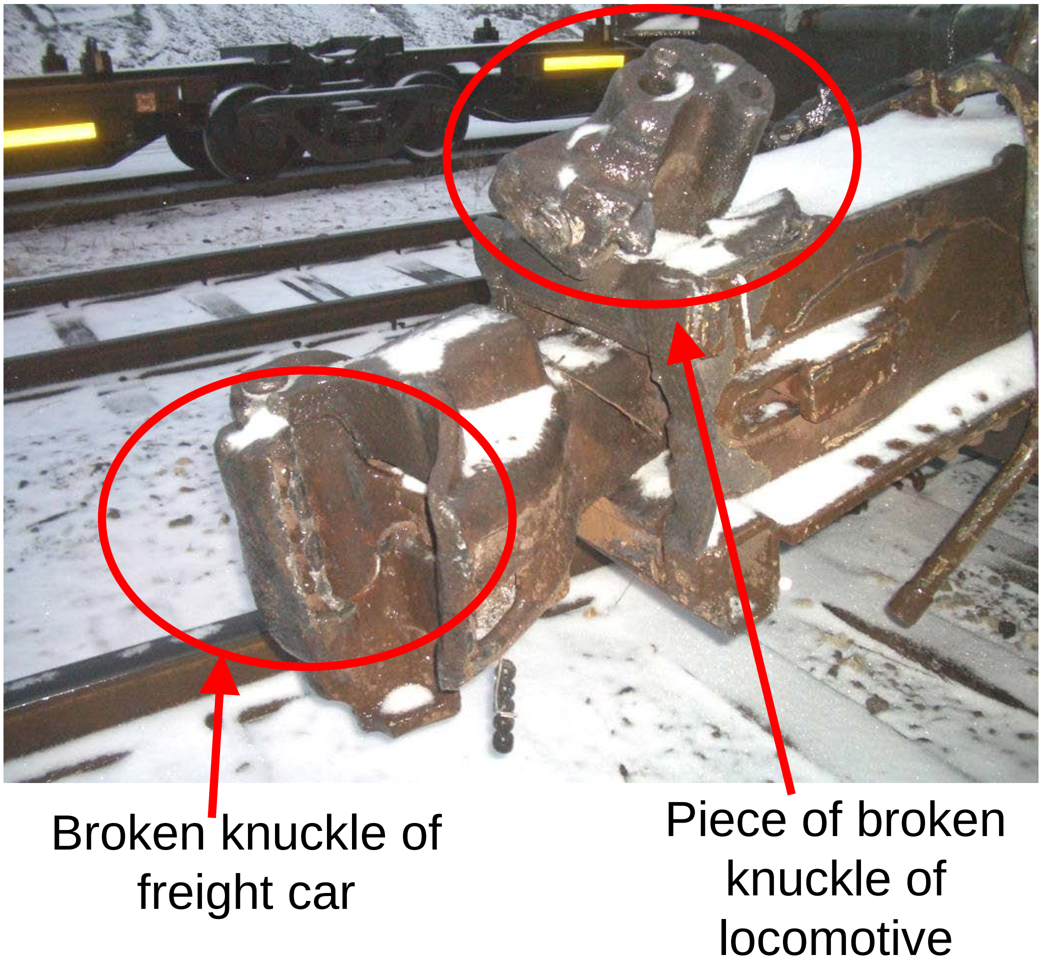


Figure A-5. Locomotive and freight car couplers.

A.2.2 Phase 2: Locomotive and freight car couplers moved back, both draft gears bottomed out

In Phase 2, the locomotive and the freight car couplers moved straight back and both draft gears bottomed out, as shown in Figure A-4. Both couplers remained in line and did not swing out laterally. There is little damage to either bellmouth. This was instrumental in keeping both trains mostly in line during the collision sequence. Had either of the couplers swung out, it is very likely that the passenger train would have derailed laterally. This lateral motion would have caused the passenger train to collide with the trains passing by on the adjacent tracks, resulting in a much more severe accident. Figure A-6 shows the broken coupler shank of the locomotive.

Figure A-6. Deformed locomotive draft gear housing and coupler.

A.2.3 Phase 3: Locomotive coupler carrier failed, locomotive began to climb rear of freight car

In Phase 3, the locomotive coupler carrier failed and the draft sill of the freight car deformed downward. Figure A-7 shows the failed coupler carrier on top of the deformed draft sill of the freight car. The deformed draft sill effectively acted as a ramp to enable the locomotive to begin to climb the freight car, as shown in Figure A-4. Figure A-8 shows the freight car draft sill deformed downward at an angle. The locomotive climbed the freight car, which allowed the trains to remain in line. Had the cars sawtoothed or zigzagged with respect to each other and derailed, it is possible that the train would have collided with the trains running on both adjacent tracks, resulting in more severe injuries and possibly fatalities in all of the trains involved.

Figure A-7. Failed locomotive coupler carrier shown on top of freight car.

Figure A-8. Deformed draft sill of freight car.

A.2.4 Phase 4: Locomotive draft gear housing pushed back and up, locomotive lead truck engaged freight car

In Phase 4, the locomotive draft gear housing crushed back and up and the locomotive lead truck engaged the freight car. Figure A-6 shows the broken coupler shank of the locomotive and the fractured sides of the draft gear pocket. Figure A-6 also shows the indentation that the coupler shank left on the front truck of the locomotive. The coupler shank was most likely pinned between the lead truck of the locomotive and the rear of the freight car. The deformation of the locomotive draft gear housing caused the nose of the locomotive to roll under and push up towards the operator's cab compartment, as shown in Figure A-9. Figure A-9 also illustrates the resulting deformation of the underframe, which caused a loss of occupant volume in the cab compartment. The nose rolling under also caused the desktop components of the cab to roll forward and push through the front windows, as shown in Figure A-10. Again, the majority of the motion and deformation was in the longitudinal direction, with very little motion or deformation laterally.

Figure A-9. Locomotive nose and underframe deformed inward and upward.

Figure A-10. Desktop components pushed through windows of locomotive cab.

A.2.5 Phase 5: Locomotive striker engaged freight car bolster, locomotive lead truck sheared off, rear roof of locomotive engaged lead passenger car collision posts

In Phase 5, the locomotive striker engaged the freight car bolster, the lead truck of the locomotive was sheared off, and the rear of the roof of the locomotive engaged the lead passenger car collision posts as the locomotive tilted in its climb. The damage to the diaphragm of the first passenger car is shown in Figure A-11. This was the extent of the exterior damage incurred by the coach cars; there was no other exterior damage. The coach cars and their couplers stayed in line for the duration of the accident with no damage occurring at the coach car interfaces.

Figure A-11. Damage to diaphragm of first passenger car.

A.2.6 Phase 6: Locomotive striker engaged the rear container, locomotive wheel cut fuel tank, locomotive lead truck pushed under locomotive

In Phase 6, the locomotive striker engaged the rear container of the freight car and the locomotive wheel cut into the fuel tank. The angled freight car draft sill and tucked-in locomotive nose acted together to allow the locomotive to continue to climb the freight car. The locomotive motion/movement was forward rather than lateral.

In this phase, the locomotive fuel tank was damaged by the rear wheel of the front truck as the locomotive climbed the freight car. The damage to the fuel tank, along with a diagram depicting how the damage occurred, is shown in Figure A-12. The rear wheel of the locomotive front truck was still spinning when it contacted the slope sheet of the fuel tank. As the locomotive climbed the freight car, the spinning wheel fractured the slope sheet then penetrated the corner of the fuel tank baffle. Approximately 300 gallons of diesel fuel spilled from the tank as a result [1].

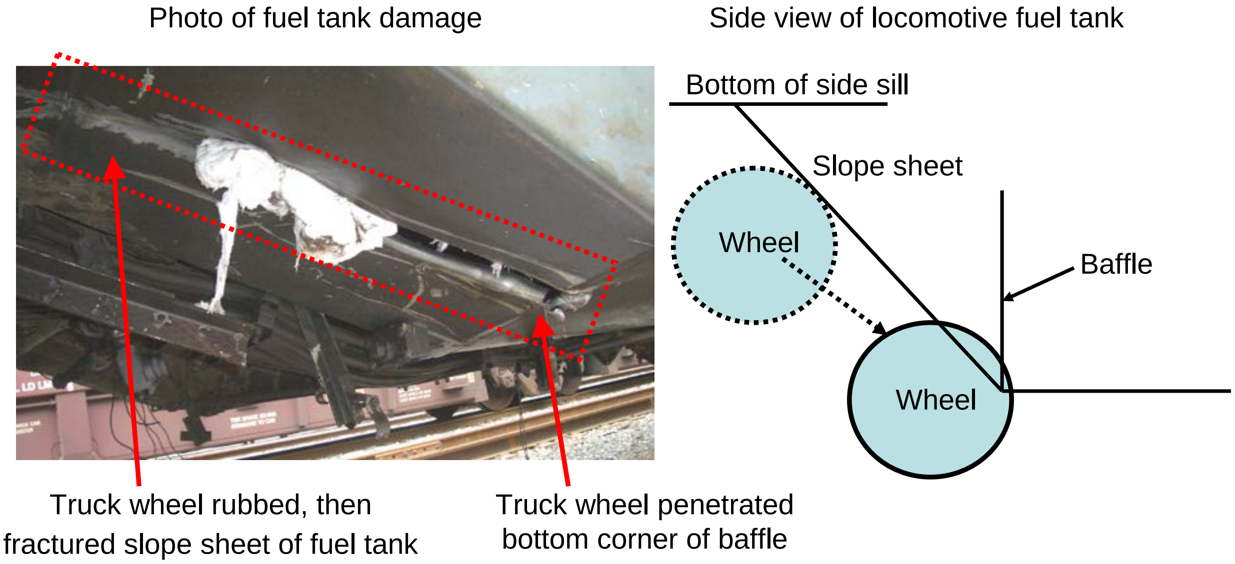


Photo of fuel tank damage

Side view of locomotive fuel tank

Truck wheel rubbed, then fractured slope sheet of fuel tank

Truck wheel penetrated bottom corner of baffle

Figure A-12. Fuel tank damage.

The post-impact locations of the lead and rear trucks of the locomotive are indicated by the two small red circles in Figure A-13. The lead truck was left behind as the locomotive climbed over the rear of the freight car. The photograph shows the lead truck of the locomotive located underneath the locomotive, just in front of the rear truck.

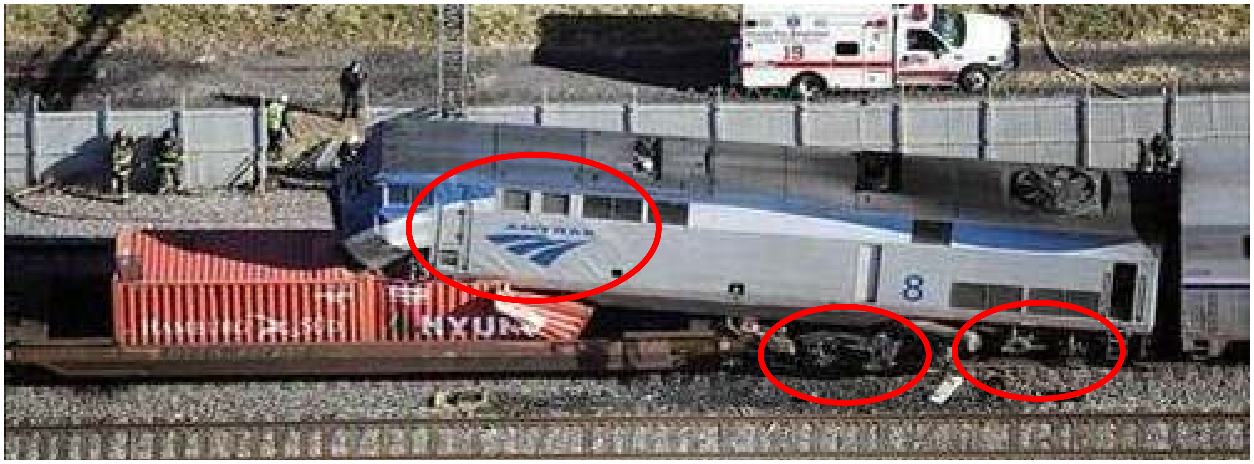


Figure A-13. The locomotive lead truck was sheared off and left behind.

A.2.7 Phase 7: Locomotive crushed two containers and passenger train came to a stop

In Phase 7, the locomotive crushed the rear container and part of the front container of the freight car. A photograph of the locomotive at rest on top of the freight car is shown in Figure A-13. The crushing of both containers absorbed the last of the passenger train kinetic energy and the passenger train finally came to a stop with the locomotive resting on top of the freight containers at an angle. The three trailing coach cars remained upright and their couplers remained coupled. Only the locomotive derailed; the three coach cars remained on the track. Almost all of the exterior damage to the passenger train was sustained by the locomotive. The locomotive experienced severe damage to its nose and underframe, with approximately 5 ft (1½ m) of total crush, as well as wrinkling of both side walls, damage to the rear roof due to contact with the first coach car, and shearing off of its lead truck. The wrinkles on the side of the locomotive body can be seen in the large circle in Figure A-13. The exterior damage to the coach cars was limited to the diaphragm of the first coach car, as shown in Figure A-11.

Figure A-14 shows the adjacent tracks on both sides of the trains involved in the collision. At the time of the collision, there were trains running on both adjacent tracks. Had the passenger train not climbed the freight car, the couplers would have caused the cars to sawtooth laterally. This lateral buckling is typical and if it had occurred in this accident, the passenger train could have impacted the trains running on both adjacent tracks, resulting in a more severe accident.

Figure A-14. The locomotive came to a stop on top of the freight car [4].

A.3 Emergency Egress

Since the passenger cars remained upright throughout the impact, most of the passengers were able to exit through the doors with no difficulty. However, a total of four emergency windows were pulled, with at least one pulled in each coach car. Figure A-15 shows evidence of the two emergency windows pulled in the first coach car, Figure A-16 of the emergency window pulled in the second coach car, and Figure A-17 of the emergency window pulled in the third coach car. The egress situation was very different for the two engineers located within the locomotive cab. Despite the large upward displacement of the locomotive cab floor, the engineers were not pinned within the cab. However, the position of the locomotive on top of the freight car made rescue more difficult. Because of the damage to the locomotive, the rescue crew was unable to open the doors on either side of the cab at the front of the locomotive, but was able to gain access through the rear left side door. Since the right-side cab window was broken, the relief engineer climbed out through this window and climbed down the emergency ladder. The operating engineer walked back through the engine room to the door at the rear of the locomotive. He was helped into a rescue basket and lowered to the ground. Details of their experience in the cab and the injuries they sustained can be found in the phone interview information of Appendix B.2.

Figure A-15. Emergency windows pulled in first coach car.

Figure A-16. Emergency window pulled in second coach car.

Figure A-17. Emergency window pulled in third coach car.

Appendix B.
Injury Data

The locomotive interiors sustained the heaviest damage, and the coach car interiors incurred the least. Figure A-3 provides a summary of the interior damage and the injuries of passengers within the locomotive and each of the coach cars. The occupants of the Amtrak train included 5 crew members and 182 passengers. There were no fatalities caused by the accident and only minor injuries were incurred by the occupants. Three people were admitted to the hospital overnight, one with a shoulder fracture. All patients were released by December 2, 2007, 2 days after the accident.

The engineers located within the locomotive cab sustained more severe injuries than the passengers and crew located in the coach cars. Details of their experience in the cab and the injuries they sustained can be found in the phone interview information of Appendix B.2.

B.1. Car Interior Inspection

B.1.1. Locomotive Interior Damage

The impact between the locomotive and the freight car caused the nose of the locomotive to roll under and push upward, resulting in the underframe buckling upward towards the operator’s cab. This deformation caused the desktop components of the cab to roll forward and push through the front windows of the cab compartment, as shown in Figure A-10. The deformation of the underframe also caused failure of the floor of the cab, resulting in the floor and the seats in the cab being pushed upward. Figure A-18, Figure A-19, and Figure A-20 are photos of the cab interior that show the desktop components pushed through the windows, the raised floor of the cab, the operating engineer’s desk and seat, and the relief engineer’s seat displaced upward and pushed into the ceiling of the cab. The broken right-side cab window shown in Figure A-19 is the window through which the relief engineer climbed to exit the cab.

Figure A-18. Locomotive interior cab damage and raised floor from impact.

Figure A-19. Operating engineer's desk and seat.

Figure A-20. Relief engineer's seat pushed into ceiling of locomotive cab.

Figure A-21 shows the distance, approximately 1½ ft (0.45 m), the floor of the cab was raised at the location of the door. Measurements taken of the cab interior indicated that the floor was raised approximately 27 in on the left side and 24 in on the right side. Figure A-22 shows a wrinkle in the floor of the locomotive engine room. The longitudinal position of this wrinkle corresponds to the position of the wrinkles in the side walls of the locomotive seen earlier in Figure A-13. Details of the operating and relief engineers' injuries can be found in the phone interview information of Appendix B.2.

Figure A-21. Side view of raised floor of locomotive cab interior.

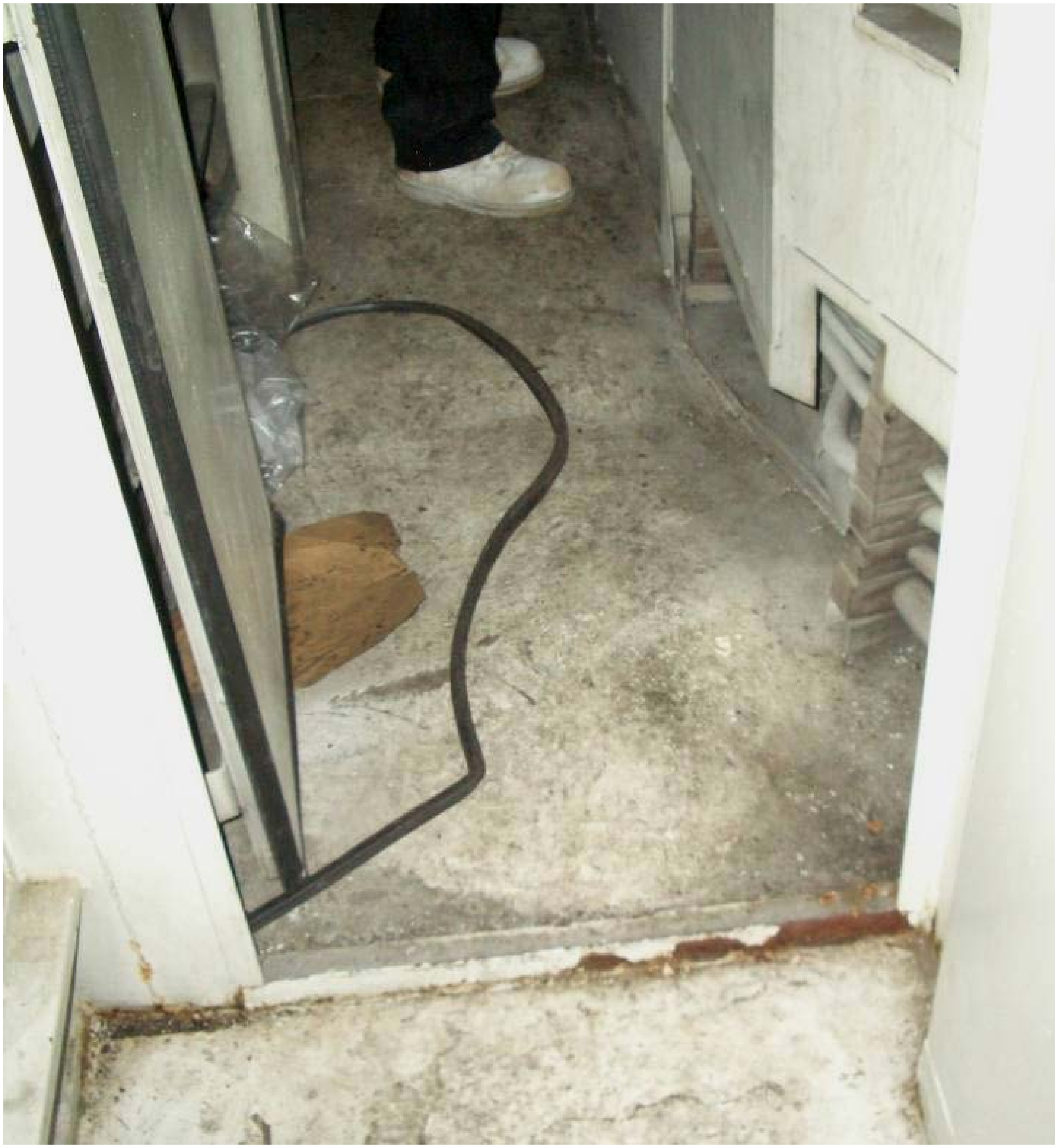


Figure A-22. Wrinkle in floor of locomotive engine room.

B.1.2. Coach Cars Interior Damage

The structural damage to the interiors of the coach cars was minor compared with the damage to the locomotive interior. All of the coaches were equipped with seat pairs that can be rotated 180 degrees to face either forward or backward. After the accident, two seat pairs in the first coach car, three seat pairs in the middle coach car, and three seat pairs in the last coach car were rotated with respect to their original positions. It appeared that the seat latches had failed to secure the seat pairs in the locked position. However, it is difficult to determine if the collision actually caused the seat latch failures. There is no positive feedback to suggest that the seat latch was engaged after the seat rotated; therefore, the seat latches on the rotated seats may not have been engaged at the time of the collision, allowing the force of the collision to rotate the seats out of position. Details on the seats and their locking mechanism can be found in Appendix D. Figure A-23 shows one of the rotated seat pairs in the third coach car.

Figure A-23. Rotated seat pair in third coach car.

In addition to the three rotated seat pairs, the middle coach car also had a seat pair that had separated from the wall and the floor due to fastener failure, as shown in Figure A-24. The failed seat pair and the rotated seat pairs may have been caused by impact from standing occupants.

The injuries of the passengers in the coach cars consisted mostly of bloody noses, small cuts, and bruises. Figure A-25 shows evidence of passenger facial impacts with seat backs (circled in red) in the third coach car, and Figure A-23 shows evidence of a bloody nose injury, also in the third coach car;

Figure A-24. Failed seat pair in middle coach car.

Figure A-25. Evidence of passenger injuries from impact with seat backs.

B.2. Phone Interviews

The operating engineer and relief engineer in the operator's cab at the time of impact sustained more severe injuries than the passengers and crew in the coach cars. The locomotive underframe deformed upward causing failure of the floor of the cab and resulting in the floor and the seats of the cab being pushed upward. Figure A-18 shows the damage from the impact to the interior of the cab. Note that there is very little space left within the cab after the impact. Telephone interviews were conducted with the operating engineer and the relief engineer.

B.2.1. Operating Engineer Interview

The operating engineer was a 50-year-old man, 6'2" tall and 265 lb. Figure A-26A shows the operating engineer's location before and after impact. Prior to impact, he indicated that his seat was in the back position and that he had his weight shifted forward. He had both arms extended to the control desktop as he was trying to apply the brakes on the train. The impact caused his body to travel forward and then upward, at which point he remembers hitting his head. He was then thrown backwards where he hit the rear panel of the cab compartment. He came to rest behind and to the left of his seat. Figure A-18 shows the damage from the impact to the interior of the cab. Note that there is very little space left within the cab after the impact. Figure A-18 shows the cramped space behind the operating engineer's seat where he came to rest. The operating engineer sustained a torn left meniscus in his knee, a torn left rotator cuff, a severe concussion, multiple head lacerations, bruises on his left elbow and left ribs, and a sore neck and back. After the accident, the operating engineer walked back through the engine room and was carried out through the rear door of the locomotive in a rescue basket.

B.2.2. Relief Engineer Interview

The relief engineer was a 43-year-old woman, 5'4" tall, and 125 lb. Figure A-26B shows the relief engineer's location before and after impact. Prior to impact, she indicated that her seat was in the midway position. She was fully seated and either looking forward or looking to the right at the operating engineer. She does not remember whether or not she extended her arms out to brace against the impact. She thinks that the impact caused her to slide off her seat and underneath the desk, which can be seen in Figure A-18. She came to rest on her hands and knees facing to the left. She sustained a severely broken nose, a head concussion, bruises on her left side, and multiple head lacerations on the left side of her head. She thinks that the head lacerations were caused by the heavy metal structure of her seat pedestal, shown in Figure A-18. Note that there is very little space left within the cab after the impact and the relief engineer's seat has been pushed into the ceiling of the cab. Had she remained in her seat, the relief engineer might have sustained severe head, neck, and spinal injuries from being pushed into the ceiling by her seat. After the accident, the relief engineer climbed out the right-side cab window, went down the emergency ladder, and walked away under her own power. Figure A-19 shows the broken right-side cab window through which she climbed to exit the cab.

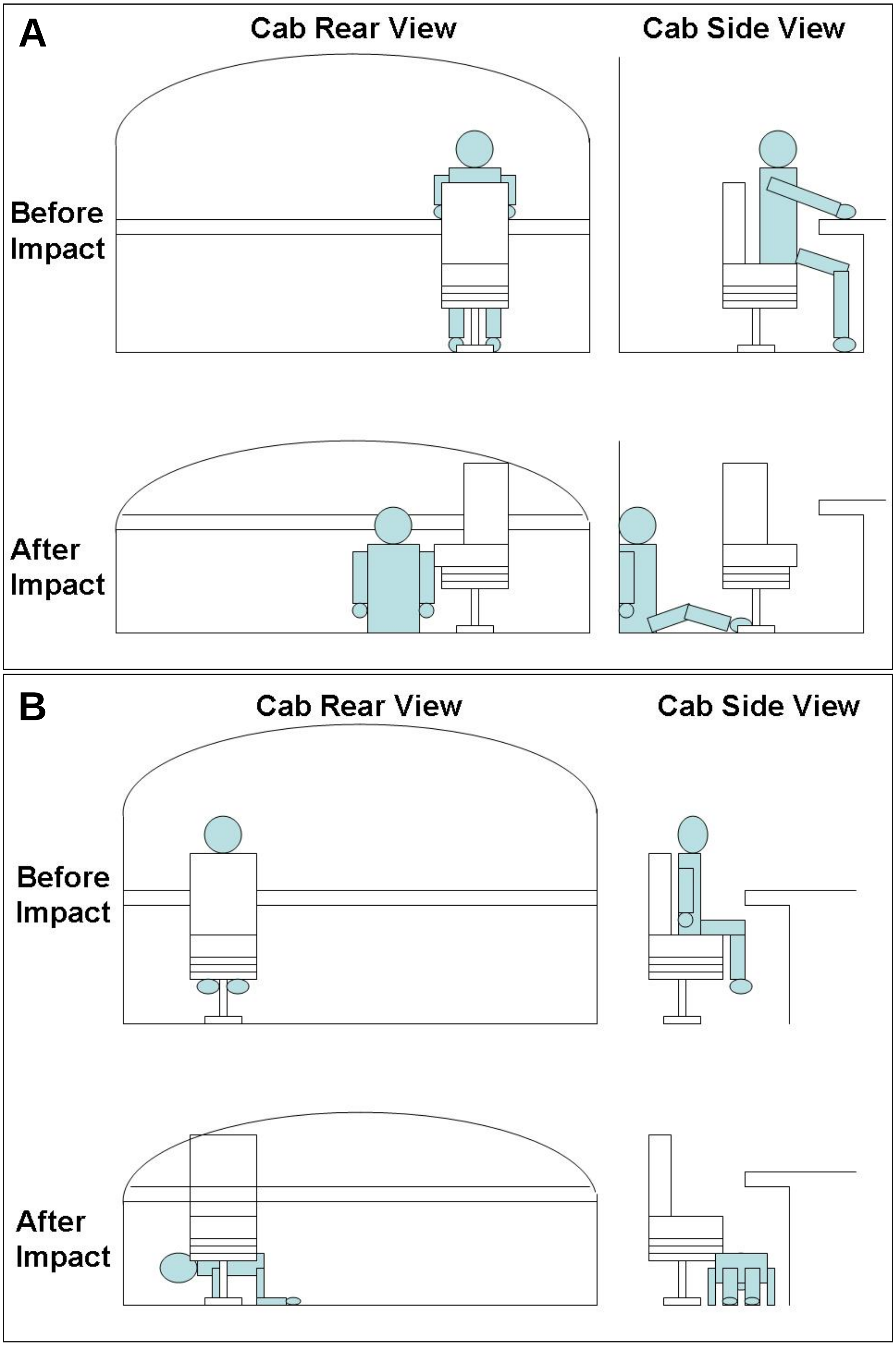


Figure A-26. Operating engineer (A) and relief engineer (B) locations within the cab before and after impact.

Appendix C.
Collision Dynamics Analysis

A key objective of an accident investigation is determining the cause of severe injuries and fatalities, if any. To aid in this task, a collision dynamics model was developed to identify how the collision events progressed and to estimate the gross motions of the train. Results from the collision dynamics model help estimate the gross motions of the colliding trains and also help reconstruct the sequence of events leading to intrusion of the occupant volume. Evidence collected from the on-scene investigation provides supporting evidence of the train motions. Determining the dynamics of the incident makes it possible to estimate the secondary impact velocities for each vehicle, which is useful for correlating the secondary impacts to the injuries observed and described in Appendix B.

A one-dimensional collision dynamics model was developed to estimate the primary longitudinal motions 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, as seen in Figure A-27.

Figure A-27. Schematic of one-dimensional lumped-mass collision dynamics model of Chicago accident.

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

Table A-1. Model input parameters of train makeup.

VEHICLE	**MASS (lb)**	**QUANTITY**	**INITIAL SPEED (mph)**
Three-Unit Articulated Well Car	486,100	3	Stationary Brakes Applied
Other Freight Cars	Variable	X	
Complete Freight Consist	***4,290,000***	----	
GE P42 Genesis Series 1 Diesel Electric Locomotive	268,100	1	33 mph No Braking
Superliner Bilevel Passenger Car	116,000	3	
Complete Passenger Consist	***616,100***	----	

An idealized force-crush behavior is defined at each car end. The structural behavior of each vehicle is estimated based on the damage measured during the accident investigation and on data from full-scale test results [15]. Table A-2 lists measured values of crush for each damaged vehicle end. Values of less than 1 foot account for smaller-scale damage observed on the coupler, coupler carrier, diaphragm, and surrounding end components.

Table A-2. Summary of measured crush per vehicle.

VEHICLE END	MEASURED CRUSH
Well Car Rear	~1 foot
Locomotive Front	~6 feet
Locomotive Rear	~6 inches
1st Bilevel Coach Front	3–4 inches
1st Bilevel Coach Rear	None
2nd Bilevel Coach	None
3rd Bilevel Coach	None

The force-crush characteristics used to characterize car crush behavior are shown in Figure A-28. Linear and nonlinear springs are used in the lumped-mass model to represent the force-crush behavior of each vehicle end (see Figure A-27). The spring characteristics are defined by the input parameters below.

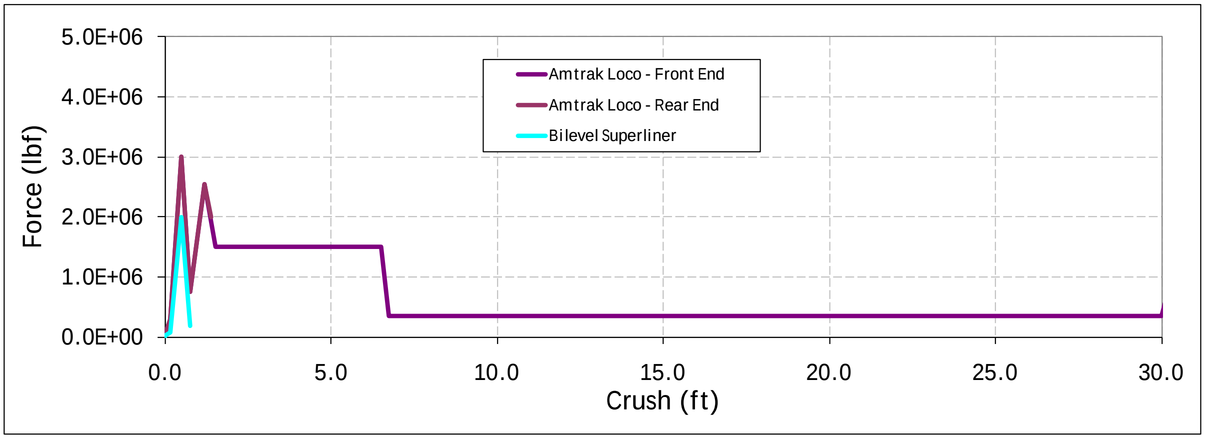


Figure A-28. Force/crush characteristics used in Chicago simulations.

Figure A-29 shows the velocity-time history of the passenger train and the last three cars of the freight train. The passenger train was travelling at approximately 33 mph when it impacted the standing freight train. The passenger locomotive slows to approximately 25 mph in the first 0.05 seconds after the impact. There is a 0.05-second delay before the following passenger cars begin to decelerate. The passenger train tries to rebound, as indicated by the increase in speed of the passenger train at 0.25 seconds. By 0.7 seconds all the vehicles in the passenger train are moving at about the same speed and decelerating at a constant rate and by 1½ seconds both trains have reached the same speed.

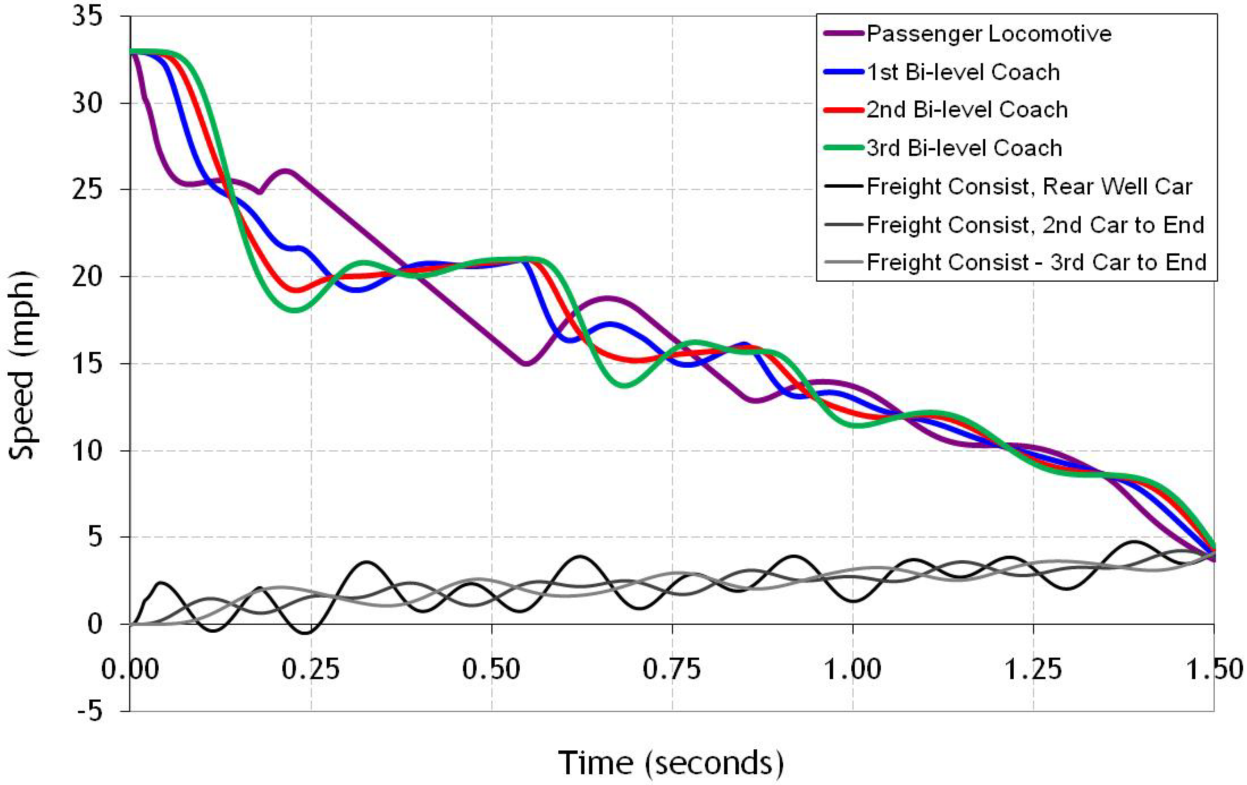


Figure A-29. Velocity-time histories for each vehicle starting at the time of impact.

Figure A-30 shows the secondary impact velocities (SIVs) for the passenger train. Secondary impact velocities provide an estimate of the severity of the collision as the occupants make contact with the interior structures. In the locomotive, the operators are seated at the console and have a possible travel distance of 8–12 inches. The results show that the operators impact the interior of the cab at approximately 8 mph. These results show that the longitudinal component of the impact is the most significant in the accident collision dynamics. It is worth noting that, as described in Appendix B.1.1, the cab floor was pushed upward as the locomotive underframe crippled, which added a vertical component to the cab environment. This component is not estimated in these model results.

For passengers in forward-facing seats in the trailing coaches, the SIVs range from 12 to 14 mph. The results show that the decelerations are progressively higher in each of the successive cars over this initial 0.23 seconds of the collision. The trailing coach experiences a higher overall deceleration over this timeframe, leading to a more severe interior environment. These results correlate with the evidence of interior damage described in Appendix B.1.2.

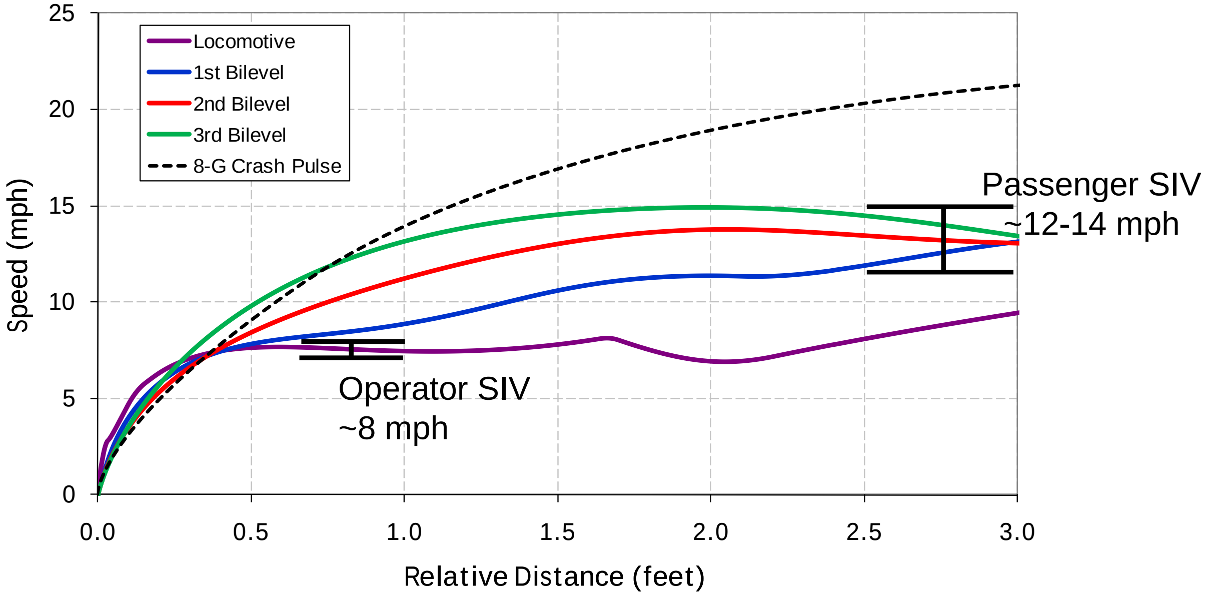


Figure A-30. Secondary impact velocities for each occupied vehicle.

Appendix D.
Amtrak Seat Description

(The contents of this appendix are excerpts from "Crashworthiness Testing of Amtrak's Traditional Coach Seat" [16].)

Figure A-31 is a schematic illustration of Amtrak's traditional seat pair. It shows the locations of the floor and wall mounts, the rotation mechanism, and the lock that keeps the seat from rotating. The seat is rotated by depressing the lock-pedal, pulling the seat by the outboard armrest directly away from the wall one to two inches, and pushing the outboard seat forward and around, reversing the direction of the seat pair. The seat is locked into place by pushing it sharply toward the wall, allowing the lock-pedal to snap into place.

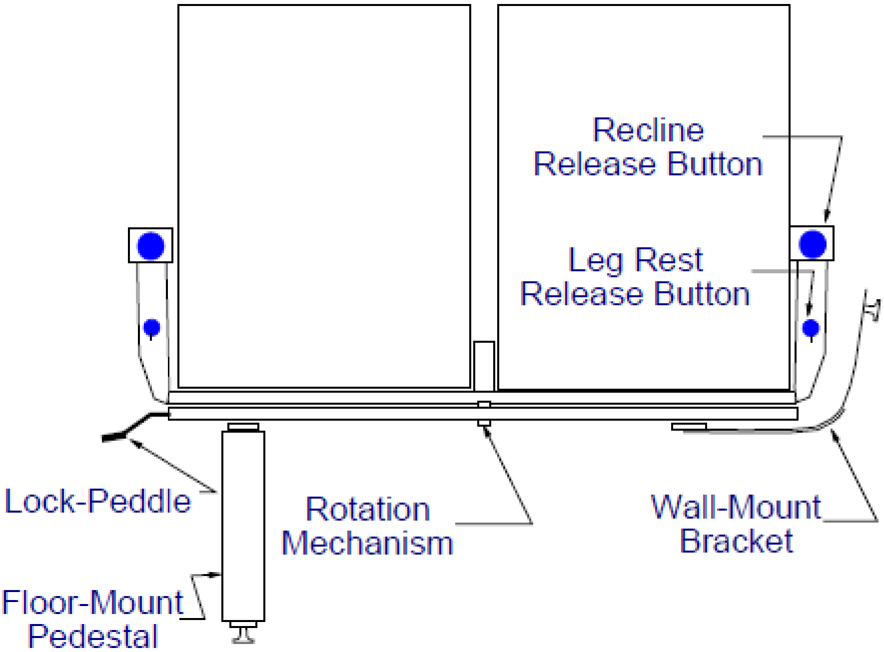


Figure A-31. Seat pair schematic, front view (leg rests not shown).

The locking mechanism consists of a paddle hinged on the inboard side of the lower seat pan. The paddle arm has a slot cut into it which engages the edge of the upper seat pan. There is a stop welded onto the upper seat pan which helps to keep the seat from rotating when the locking mechanism is engaged. A coil spring, acting torsionally about the hinge, pushes the paddle upward, and automatically engages the paddle arm with the edge of the upper seat pan when they align. A sketch of the locking mechanism is shown in Figure A-32 and a photograph of the locking mechanism in the engaged position is shown in Figure A-33.

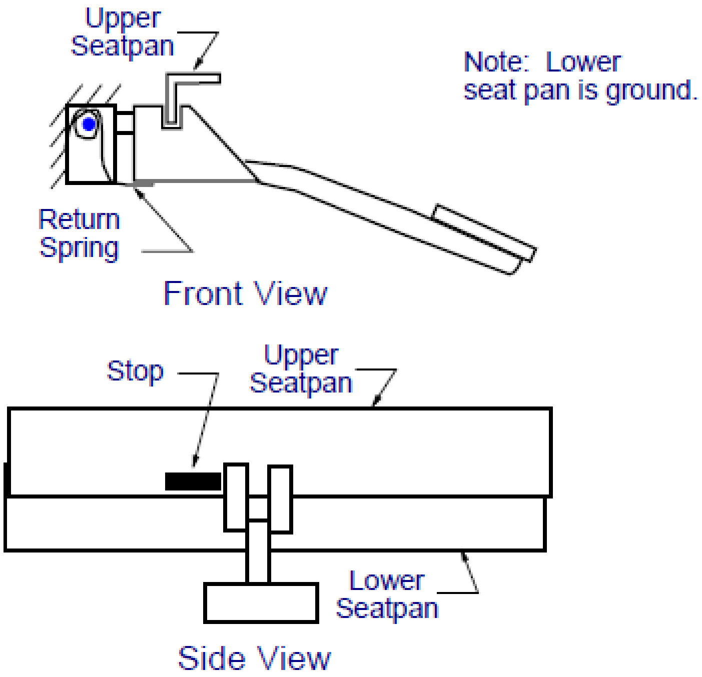


Figure A-32. Locking mechanism sketch.

Figure A-33. Locking mechanism photograph, mechanism in the locked position.