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Accident Report of Chicago Metra Commuter Train Derailment on September 17, 2005

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13. ABSTRACT (Maximum 200 words)

On Saturday, September 17, 2005, Metra commuter train 504 was heading north from Joliet to Chicago on the Rock Island District Line operated by the Northeast Illinois Regional Commuter Railroad Corporation, which is the commuter rail system that serves northeast Illinois. The train traversed a 10-mph switch at 69 mph, causing it to derail just south of the West 47th Street Bridge. This accident was investigated by the US Department of Transportation's Rail Accident Forensic Team to support the Passenger Equipment Safety Research Program of the Federal Railroad Administration (FRA). The Forensic Team's primary objective in investigating rail vehicle accidents is to estimate the complete underlying sequence of events and determine the specific causal mechanisms of injuries and fatalities. This report includes a detailed reconstruction of events, which is based on data collected at the scene and passenger interviews. The principal causal mechanism for the fatalities and serious injuries that occurred in the accident was the impact between the 4th car and the bridge girder, resulting in significant vertical forces on the rail car and structural damage to the car interior.

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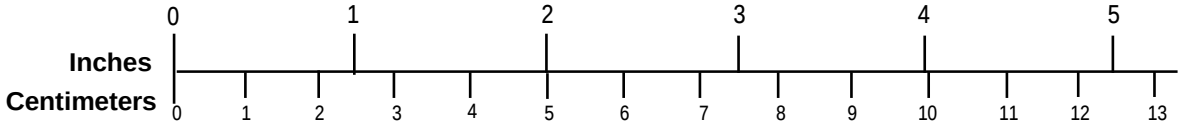

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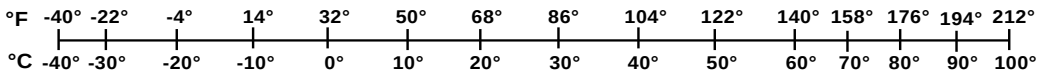

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Executive Summary

A field study of occupant injury in passenger train collisions and derailments is currently being conducted by the U.S. Department of Transportation's Rail Accident Forensic Team in support of the Equipment Safety Research Program of the Federal Railroad Administration (FRA). The Forensic Team's primary objective in investigating rail vehicle accidents is to estimate the complete sequence of events and determine the causal mechanisms of injuries and fatalities. The Forensic Team also gathers and organizes information needed to evaluate the effectiveness of current crashworthiness and emergency preparedness regulations and to develop future regulations and safety standards.

At approximately 8:35 AM on Saturday, September 17, 2005, commuter train 504 was heading North (railroad East) from Joliet to Chicago on the Rock Island District Line operated by Metra, the commuter rail system serving northeast Illinois. The train was operating in push-mode with a cab car leading, followed by four passenger cars and a locomotive. The train traversed a 10-mph switch at 69 mph, causing the train to derail just south of the West 47th Street Bridge. The derailed train proceeded to travel over the bridge with only minor damage along the side of the first three cars. The fourth car hit the bridge girder, causing significant damage to the right front section of the car body. The fifth car, which was unoccupied, decoupled from the front leading cars of the train when it rode up over the bridge girder and scraped along the barrier wall of the bridge. There were 185 passengers and 4 crew members aboard the train at the time of the derailment. Two passengers suffered fatal injuries; 4 passengers required hospitalization of more than one day; and 46 passengers were treated for minor injuries and released the same day from area hospitals.

This incident was investigated by the Forensic Team as part of the ongoing field study. The data collected at the scene, along with interviews with the passengers, assisted in providing an understanding of the events that transpired. The principal causal mechanism for the fatalities and serious injuries that occurred in the Chicago incident was the compromise of the occupied volumes of the passenger cars. While there were some secondary impact injuries, they were generally less severe.

1. Introduction

The Volpe Center has been supporting the Passenger Equipment Safety Research Program of the Federal Railroad Administration (FRA) in performing rail passenger equipment crashworthiness research. The overall objective of this research is to develop strategies for incrementally improving structural crashworthiness and occupant protection characteristics of the rail vehicles. The structural crashworthiness research involves both building an understanding of the performance of rail equipment and researching strategies for improving preservation of the occupied volume of the passenger rail vehicles. Once the occupied volume of the rail vehicle is compromised, serious injuries or fatalities may occur. If the occupied volume is preserved, strategic modifications to the interior structures can further improve occupant protection.

As part of this effort, a field study of occupant injury during rail collisions and derailments is currently being conducted. As opposed to the investigation conducted by the National Transportation Safety Board (NTSB), for which the main objective was to determine the root cause of the incident, the primary objective of the FRA field study is to determine the underlying causal mechanisms for the injuries and fatalities sustained by the occupants of the train. While the NTSB investigation may focus on prevention by issuing formal safety recommendations, the Forensic Team investigation focuses on injury mitigation. The information collected is used to identify the areas where occupant protection strategies can reduce the risk of injury, such as the design of specific interior features. The execution of this field study requires on-site investigations of collisions or derailments. Twelve such investigations have been conducted to date (Table 1).

The causal mechanisms for injury generally fit into two broad categories: loss of occupied volume and secondary impact. Injuries caused by loss of occupied volume occur when there is severe structural deformation, or crush, of the railcar. This crushing, which occurs as a result of impact with another rail vehicle or other right-of-way obstruction, is known as the “primary impact.” Equipment designed with crashworthiness features can be effective at absorbing and distributing the primary impact energy, which can limit crush to unoccupied areas of the car and mitigate injuries. One such design principle, referred to as “crash energy management” (CEM), has been developed and tested for single-level vehicle applications [1], along with a specification incorporating it for multi-level cars.

Typically, as a result of the primary impact, a rail vehicle will decelerate abruptly, causing the occupants to impact the seats, tables, or other structures inside the vehicle. These “secondary impacts” can cause life-threatening injuries to the head, neck, chest, abdomen, and extremities of passengers. Using information collected in the field study investigation, the injuries sustained by passengers can be correlated with the interior layout of the car, the initial position of the occupants, and the design of the seating arrangements. When a strong correlation is found, steps can be taken to mitigate the injury risk associated with the seating arrangement. For example, investigation of a collision in Placentia, California, indicated that workstation tables contributed to the fatal injuries sustained by two passengers. A proof-of-concept workstation table that will reduce the risk of thoracic and abdominal injury during collisions and derailments has been designed, developed, and tested [2].

This report presents the information collected during the investigation of the September 17, 2005 derailment in Chicago, Illinois. A reconstruction of the incident has been generated using this

supporting evidence, specifically in the areas of structural deformation, collision dynamics, and occupant response. This reconstruction, in turn, is being used to support ongoing research to improve passenger rail crashworthiness and develop additional occupant protection strategies.

Table 1. Rail Collisions and Derailments Investigated as Part of the Field Study of Occupant Injury

Collisions	
Incident	**Injuries**
Syracuse, NY – February 5, 2001 [3] • Locomotive-led passenger train rear-ended freight train.	62 injured
Placentia, CA – April 23, 2002 [4] • Standing passenger train impacted by freight locomotive on same track.	119 minor, 21 serious, 3 fatal*
Glendale, CA – January 26, 2005 [5] • Cab-led passenger train derailed, impacted standing freight train, sideswiped locomotive-led passenger.	79 minor, 15 moderate, 4 serious, 3 severe, 2 critical, 11 fatal
Chicago, IL – November 30, 2007 • Locomotive-led passenger train impacted, overrode standing flat-bed freight car.	3 moderate, 184 minor
Canton, MA – March 25, 2008 • Locomotive-led passenger train impacted single loaded center-beam flat car.	150 out of 300 passengers injured, none serious
Chatsworth, CA – September 12, 2008 • Locomotive-led passenger train impacted an oncoming freight train head-on, passenger locomotive intruded into the first coach car.	25 fatalities, 99 injuries
Derailments	
Incident	**Injuries**
Nodaway, IA – March 17, 2001 [6] • 13 passenger cars derailed.	78 injured, 1 fatal
Lake City, NC – August 21, 2001 [7] • Locomotive and 9 passenger cars derailed, but remained mostly upright	49 minor, 2 serious, 0 fatal
Crescent City, FL – April 18, 2002 [8] • 21 of 40 passenger cars derailed in a left-hand curve	106 minor, 36 serious, 4 fatal
Kensington, MD – July 29, 2002 [9] • 11 passenger cars derailed	79 injuries, 16 serious
Flora, MS – April 6, 2004 [10] • 9 passenger cars derailed, some fell off bridge embankment	41 minor, 10 serious, 1 fatal
Chicago, IL – September 17, 2005 [11] • 5 passenger cars and a locomotive derailed, impacted bridge girder	6 minor, 3 moderate, 2 fatal

*The third fatality occurred more than 30 days after the collision and thus was not attributed to the accident by the NTSB.

2. Reconstruction of Events

2.1 Initial Conditions

On Saturday morning, September 17, 2005, a Metra Rail Commuter Train on the Rock Island District Line was traveling from Joliet to Chicago, IL. At the time of the derailment, the train was between Gresham Station (at W. 87th Street) and Chicago (LaSalle Station), which is a 12-mile stretch before the final stop at LaSalle Station (see Figure 1 for station map). The site of the derailment was the bridge across W. 47th Street, directly adjacent to the Metra Equipment Facility and Yard (Figure 2).

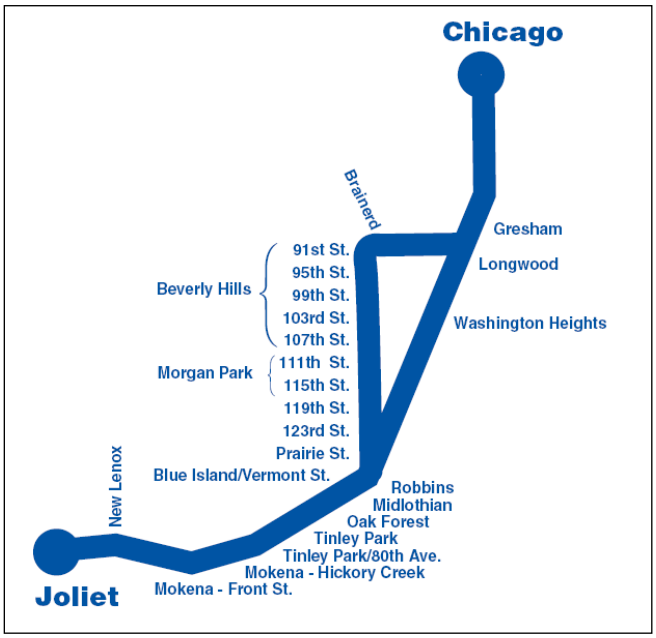


Figure 1. Station Map for Metra Rail Rock Island District Line

The derailment involved Metra train number 504, made up of a leading cab car, four coach cars, and a trailing locomotive (Figure 3). The leading cab car (8570) and trailing passenger car (7351) were not occupied by passengers. Each of the middle three cars occupied by passengers were gallery cars, which have bi-level seating. There is an entry vestibule at the center of each car, with stairs to the upper level both fore and aft of the vestibule. There are some variations, but in general, the main floor has two-by-two seating and the upper floor one-by-one seating. The gallery cars have a seating capacity of approximately 120. Each of the three occupied cars was roughly half full. When the derailment occurred, 185 passengers and 4 crew members were on board. Each phase of the accident is described in detail below (see Figure 4 for a schematic depiction of each phase).

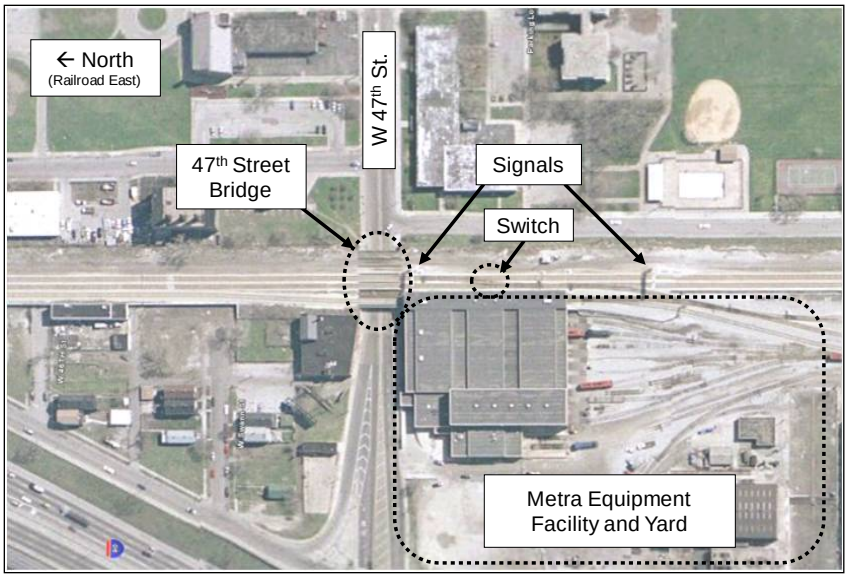


Figure 2. Overhead Photo of Accident Site

Direction of Travel

8570	7331	8548	7488	7351	409
Leading cab car Unoccupied except for engineer Manufactured by Nippon Sharyo New car, delivered in 2005 Designed to (49CFR238) - 800kip buff - 500kip end beam Weight – 125kip	1st coach car Occupied, roughly 60 passengers Manufactured by Budd Designed to - 800kip buff - 300kip collision post Weight – 112kip	2nd coach car (non-operational cab car) Occupied, roughly 60 passengers Manufactured by Nippon Sharyo Delivered in 2004 Designed to (49CFR238) - 800kip buff - 500kip end beam Weight – 125kip	3rd coach car Occupied, roughly 60 passengers Manufactured by Morrison-Knutsen; shell built by Nippon Sharyo Designed to (S580) - 800kip buff - 500kip collision post Weight – 118kip	4th coach car Unoccupied Manufactured by Budd Designed to - 800kip buff - 300kip collision post Weight – 112kip	Locomotive Manufactured by EMD Weight – 296kip

Figure 3. Makeup of the Trainset

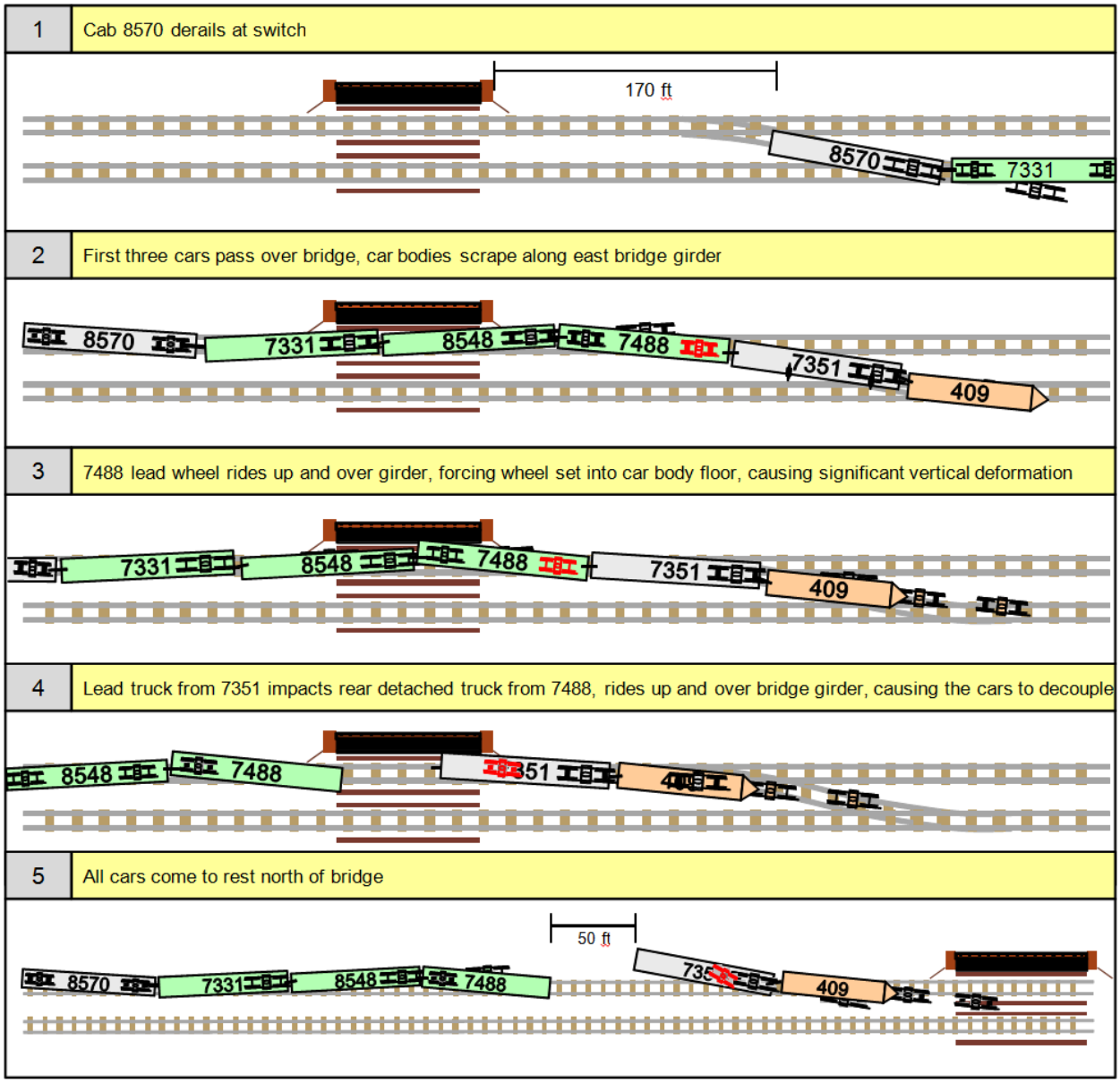


Figure 4. Chain of Events in the Chicago, IL, Derailment

2.2 Phase 1. First Interaction—Derailment

The leading cab car 8570 derailed at the switch and continued to follow the track on the right side of the rails. The trailing cars followed, plowing through the ties, rail, and ballast. The cab passed cleanly between the bridge girders on the 47th Street bridge, which was about two car lengths beyond the point of derailment. The cars likely experienced sawtooth buckling after the derailment occurred. The photo in Figure 5 shows the switch where the derailment occurred. The view is from the south, looking north down the track in the direction the train was heading.

Figure 5. Switch Where the Derailment Initiated

2.3 Phase 2: First Three Cars Pass Over the Bridge

The first coach car (7331) followed the cab over the bridge, but it passed closer to the bridge girder, incurring minor scraping on the rear right side of the car body just below the side sill (Figure 6). The scraping was likely caused by the top of the bridge girder, which is about two feet above the top of the rail. The bottom of the side sill is usually about three feet above the top of the rail, but since the car was off the rail and plowing through ties and ballast, contact was able to occur.

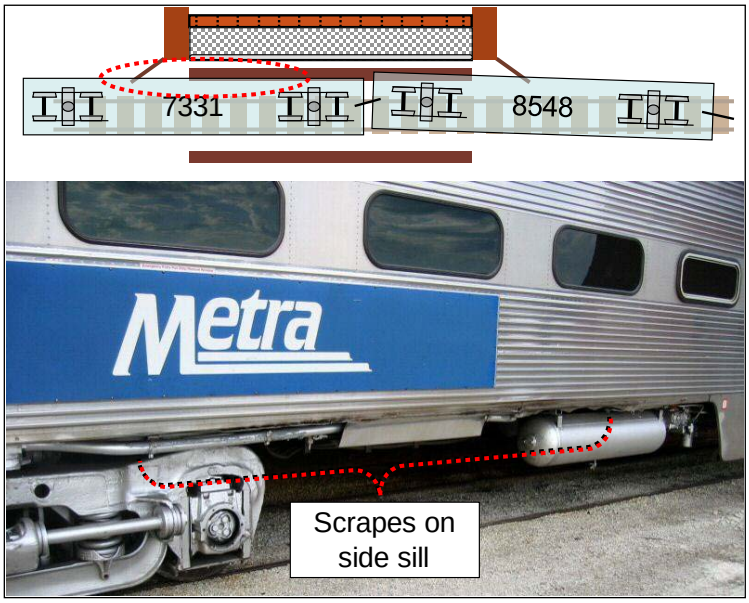


Figure 6. Evidence of Contact Between Car 7331 and the Bridge Structure

The second coach car (8548), which was originally a cab car but was utilized as a passenger car after the new cab cars were put in service, passed over the bridge even closer to the bridge girder. There was contact between the bridge girder and the front, right corner of the car, which caused bending of the right corner of the plow and damage to the electrical boxes. There was also some damage to the frame of the leading truck and scraping on the side sill (Figure 7).

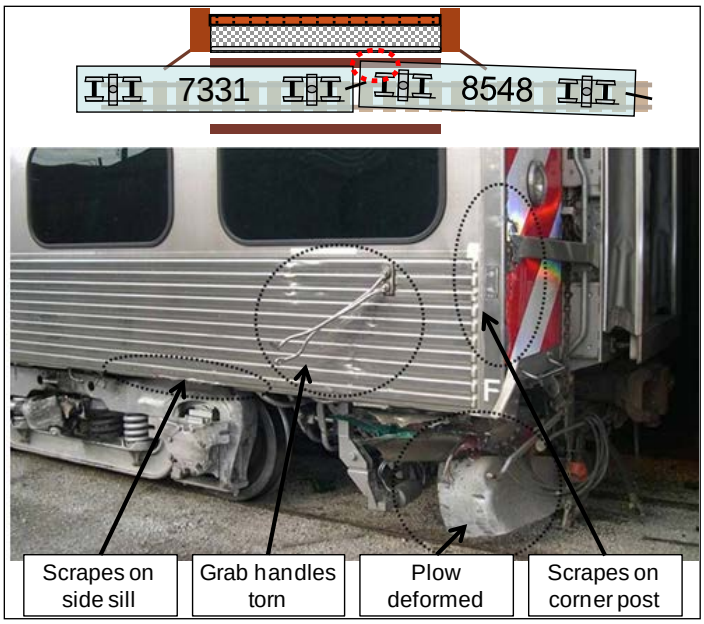


Figure 7. Minor Damage to the Front Right Corner of Car 8548 after Contact with the Bridge

2.4 Phase 3: Third Coach (7488) Impacts the Bridge Girder

The photos in Figure 8 show the bridge structure before (approximate) and after impact. The most significant damage to the train occurred when the third coach car (7488) encountered the bridge. It appeared that the right wheels of the leading truck were in line with the bridge girder, as indicated by wheel gouges in the steel ballast retention plate (Figure 8, right photo). The leading truck of car 7488 impacted and rode up and over the girder, forcing the truck into the bottom of the car. The impact caused significant vertical deformation of the floor but did not significantly lift the car body. The interior floor on the right side of the car, forward of the bolster, deformed 16” to 20” vertically, causing the right side wall of the car to bulge outward (Figure 9, left photo). Both wheel sets separated from the lead truck and the truck bolster was severely fractured (Figure 9, right photo). The right front corner of the car body impacted a tubular steel hand rail, which dented the right corner post and penetrated the occupant compartment. The corner post and end beam were displaced about 8 inches longitudinally (Figure 10). All cars remained coupled up to this point (as shown in Phase 3 of Figure 9).

The car continued to slide along the girder, shearing off rivets on top of the girder. The right front buffer wing inboard of the corner post (Figure 11) shows indents that match the spacing of the bolts on the top of the girder. The rear truck of car 7488 impacted the corner of the bridge girder, causing the front wheel set to detach from the truck and the truck to detach from the car.

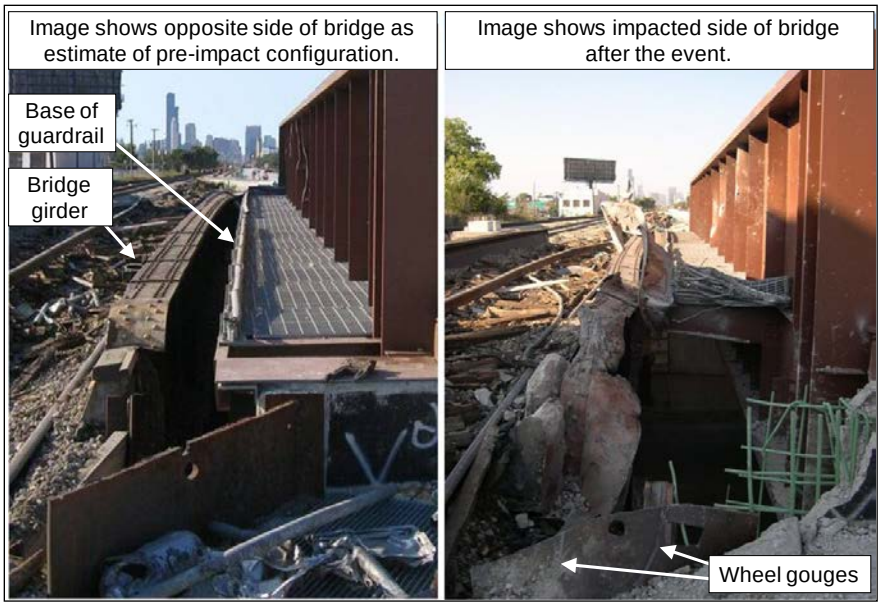


Figure 8. Damage to the Bridge Structure

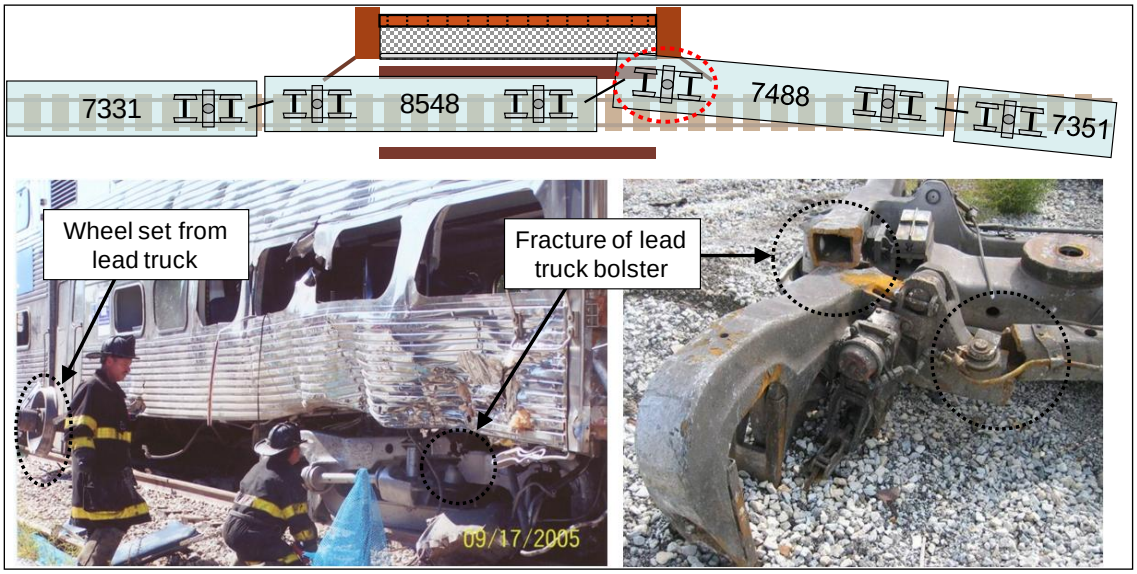


Figure 9. Front Right Corner of Car 7488, Showing Front Truck When the Car Came to Rest and When It Was Later Removed

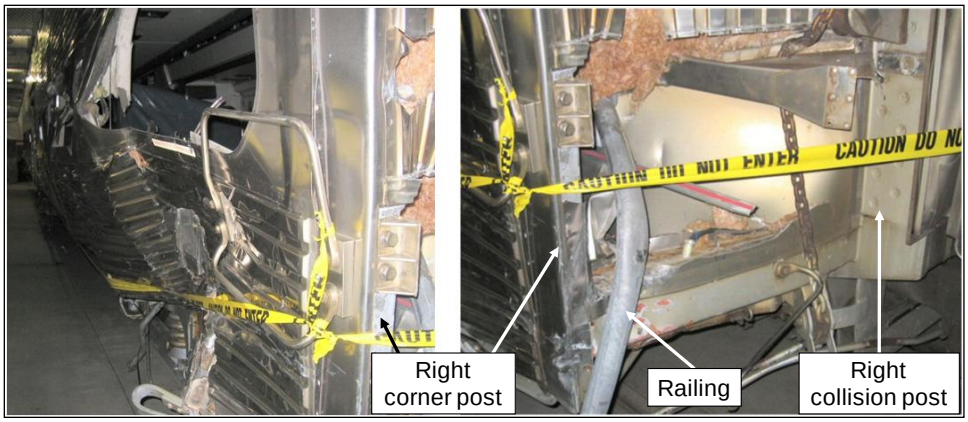


Figure 10. Front Right of Car 7488, Looking Head-on

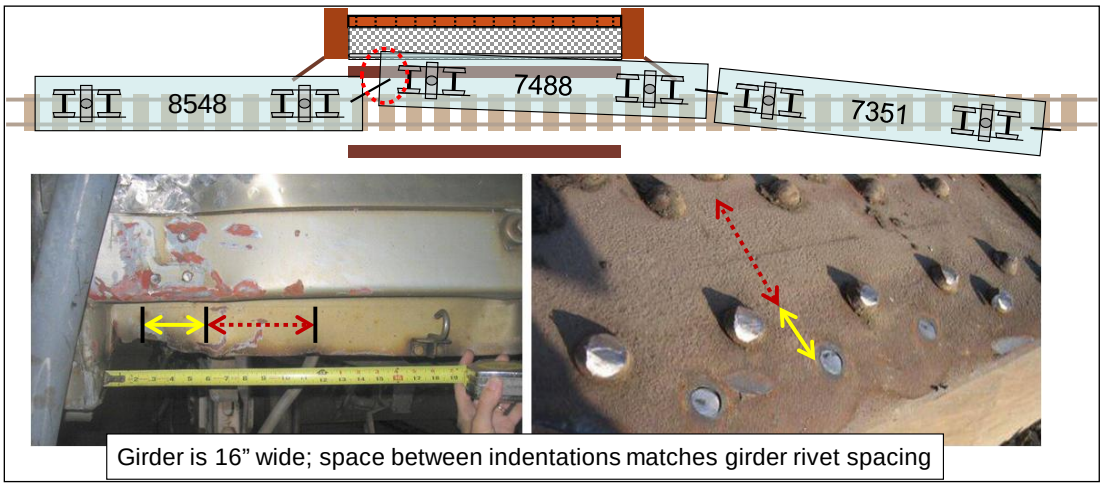


Figure 11. Front of Car 7488

2.5 Phase 4: Fourth Coach (7351) Impact with Bridge

The lead truck of the fourth coach car (7351) impacted the detached truck from car 7488 at the bridge entrance and climbed up and over the truck and bridge girder. This vertical motion caused cars 7488 and 7351 to decouple. The lead truck of car 7351 scraped along the top of the girder for the length of the bridge. The right corner post and end beam scraped along the side gussets of the retaining wall. The corner post scraped along the top of the wall, as evidenced by paint transfer. The impact with the wall gussets caused the junction of the corner post end beam attachment to displace downward about 8 inches (Figure 12). The rear truck of car 7351 derailed, remained on the ground, impacted the detached rear truck from car 7488, and continued to drag it along the track. The front of the car fell off the girder and down on the track near the end of the bridge.

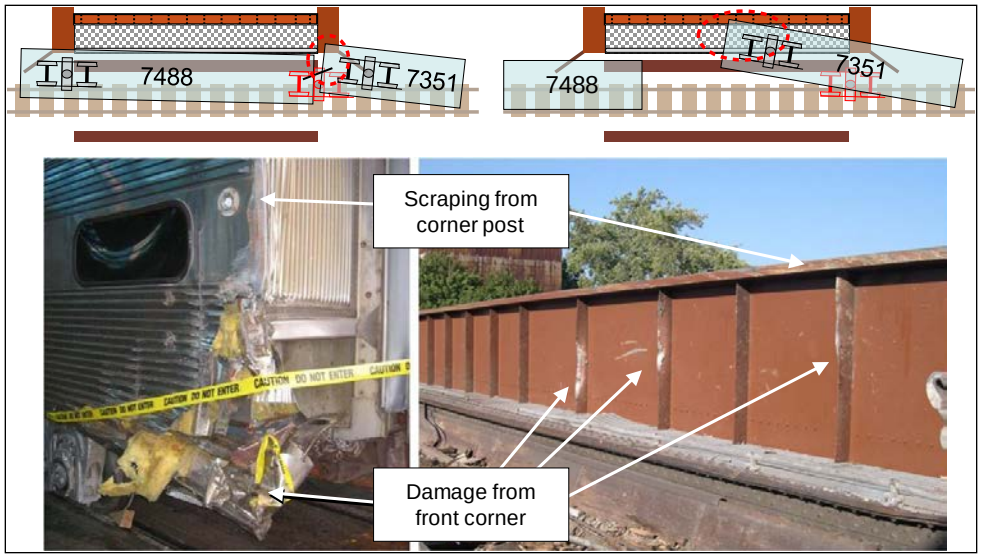


Figure 12. Front of Car 7351, Showing Damage from Impact with Bridge Girder (left) and Damage to the Gussets of the Retaining Wall (right)

2.6 Phase 5: All Cars Come to Rest North of 47th Street Bridge

The photos in Figure 13 and the diagram in Figure 14 depict the final resting positions of the cars. The left photograph in Figure 13 shows cars 8570, 7331, 8548, and 7488 (from left to right, looking north). The right photograph shows car 7351 and the locomotive 409 looking back to the south. All the cars remained upright, with a small amount of yaw resulting from sawtooth buckling and roll resulting from the derailment and subsequent plowing into ballast. The leading cab (8570) traveled approximately 780 feet from the point of derailment. As described above, the third and fourth coach cars (7488 and 7351) decoupled and were separated by 50 feet when the cars came to rest.

Figure 13. Final Resting Positions of Cars 8570, 7331, 8548, and 7488 (left) and Car 7351 and Locomotive 409 (right)

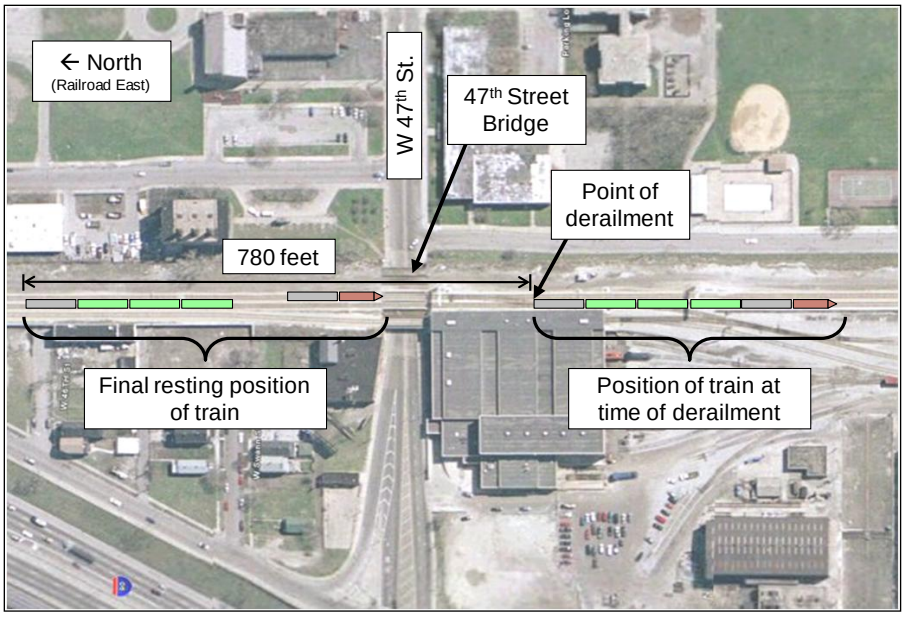


Figure 14. Overhead View of the Scene, Showing Initial and Final Positions of the Cars

3. Vehicle Structures

In the Chicago collision, structural deformation resulted from the impact of the end frames and side sills of the passenger cars with the structure of the 47th Street Bridge. This deformation led to intrusion into the occupied volumes of the cars.

3.1 Cab Car (8570), First Coach Car (7331), and Second Coach Car (8548)

The first three cars passed over the bridge with scraping between the car bodies and the bridge girders on either side. The cab car (8570) was the least affected, showing only minor scraping on the trucks and the equipment suspended below the car body as a result of plowing into the ballast subsequent to derailment. On the right side of the first coach car (7331), there was a scrape at the bottom corner of the body that spanned from just aft of the entry doors to the rear truck. This scrape punctured the outer shell of the car in several places, but did not penetrate into the occupied volume. The front right corner of the second coach car (8548) showed the most damage of the first three cars. The right corner of the plow, the grab handles on the side of the car, several components suspended beneath the car, and the rear step ladder were deformed from impact with the bridge structure (Figure 15).

Figure 15. Images of the Opposite Side of the 47th Street Bridge (left), Damage to the Front Right Corner of Car 7488 (right), and the Impact Point of the Top Edge of the Railing to the Corner Post (inset right)

3.2 Third Coach Car (7488)

The fourth car in the passenger consist (7488) impacted the right bridge girder, causing significant deformation of the right front corner of the car body. The initial point of impact appears to have been with the railing that was attached to the west side of the bridge (see similar railing in Figure 15 and diagram of the bridge in Figure 20). The leading edge of the railing, which measured 3 feet from the bottom rail to the top rail, impacted the corner post (Figure 15, inset right). The railing then impacted the lateral beam connecting the corner post to the collision post, which detached completely at the corner post connection and partially at the collision post connection (Figure 16). The railing penetrated the occupied volume; however, the magnitude of penetration is not known, because the railing was partially removed during the initial response to

the derailment. (The top photos in Figure 16 simulate the end frame of car 7488 before the crash by mirroring photographs of the left side of the car.)

Figure 16. Damage to the Right End Frame of Car 7488: Simulated End Frame Before the Impact (top) and Actual End Frame After the Impact (bottom)

As the front truck of car 7488 impacted the bridge girder, both axles separated from the truck bolster; but the fractured bolster remained attached to the car body. The rear truck separated from the car body entirely. One of the axles showed signs of a direct impact and was bent to roughly a 5-degree angle; however, it is unclear whether this axle was detached from the front or the rear truck. This axle came to rest beneath the doors of the car (see Figure 7). The impact to the truck (Figure 17), in turn, deformed the front right side of the car, as evidenced by both an outward bulge of the car body (Figure 18), and an upward deformation of the floor of the car (Figure 19).

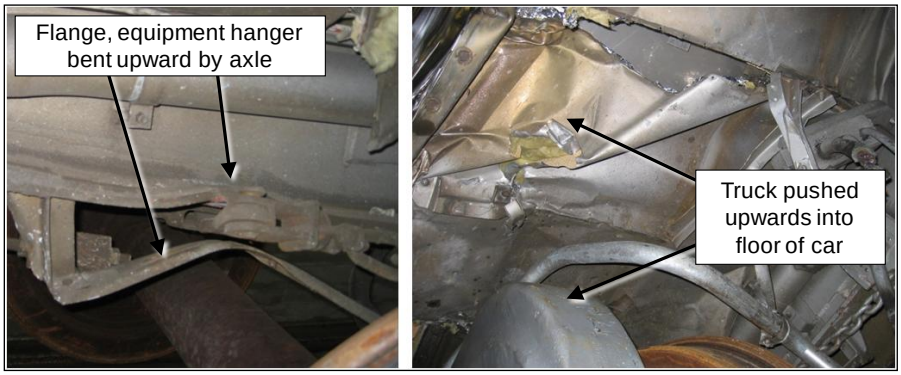


Figure 17. Impact of the Axle of the Front Truck of Car 7488 with the Floor of the Occupant Volume

Figure 18. Outward Deformation of the Right Side of Car 7488, Tearing the Sheet Metal and Exposing Jagged Edges

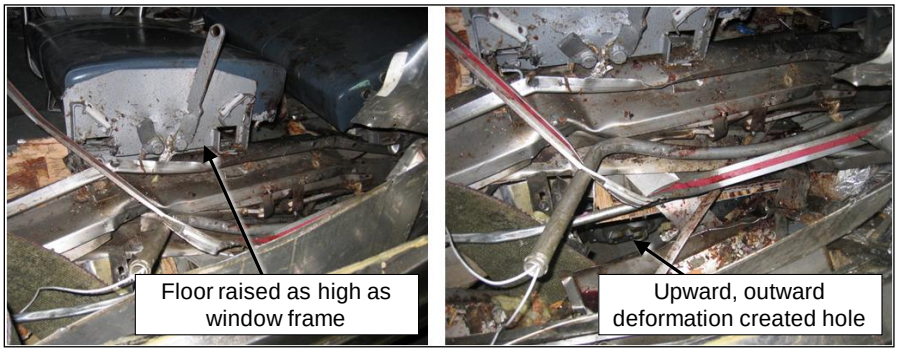


Figure 19. Upward Deformation of the Interior Floor, Resulting in a Breach of the Occupant Volume

3.3 Fourth Coach Car (7351)

The fifth car in the consist, 7351, showed damage to both trucks as well as to the right front corner of the car. The bottom of the right corner post displaced downward by roughly 8 inches, and the side of the corner post showed signs of scraping the retaining wall of the bridge (see Figure 12). There was no intrusion into the occupied space of this car.

3.4 Damage to Bridge

There was significant damage to the bridge that was impacted by cars 7488 and 7351 (see Figure 8). The ballast retaining plate, which shows the point of contact of at least one set of wheels, was significantly deformed. A large amount of concrete was obliterated down to exposed, bent rebar, and several lateral supports were deformed and detached from the structure. This damage created a hole in the bridge, through which debris fell to the road below. The damage pattern on the bridge (Figures 20 and 21) can be used to estimate the gross motions of the rail vehicles involved in the derailment.

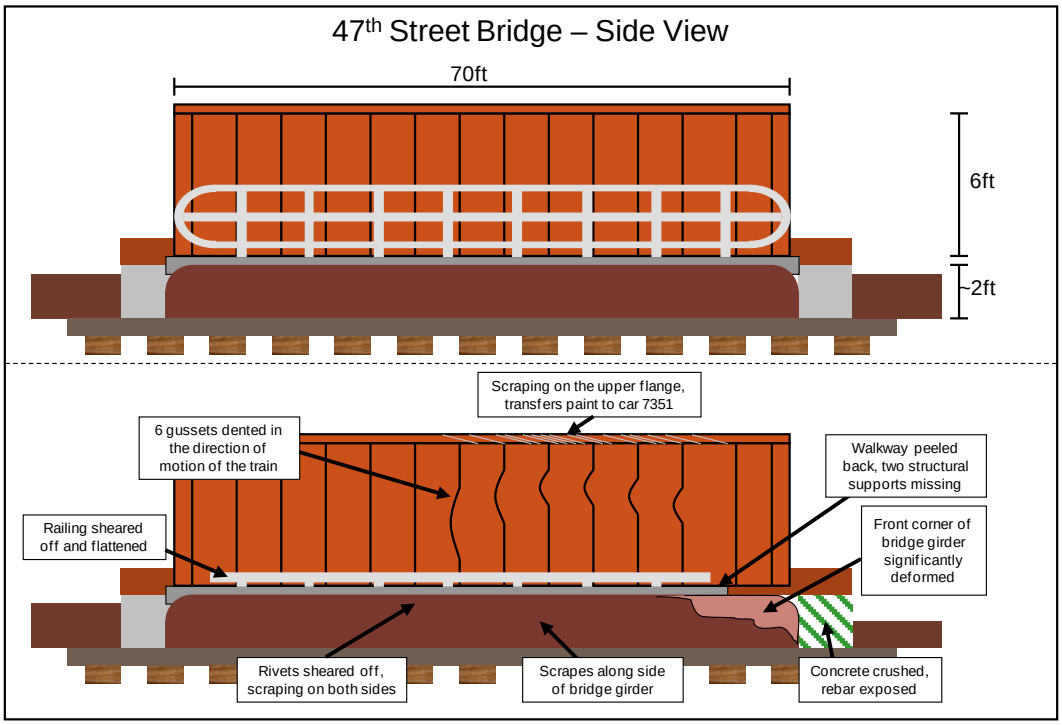


Figure 20. Side View of the 47th Street Bridge, Showing the Structure Before (Top) and After (Bottom)

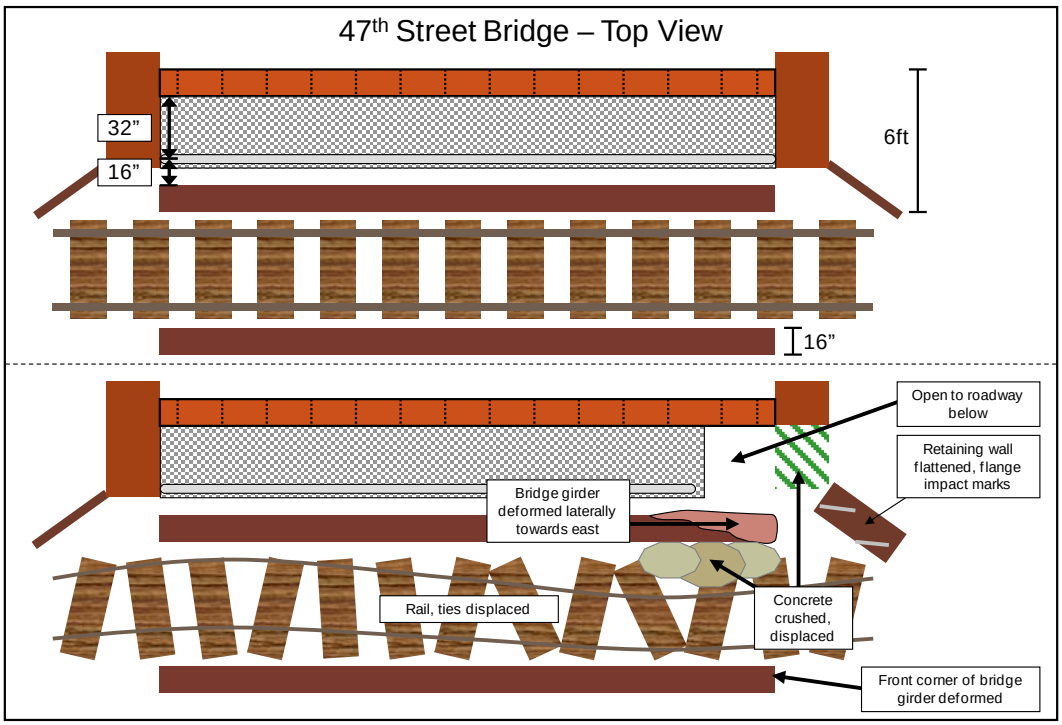


Figure 21. Top View of the 47th Street Bridge, Showing the Structure Before (Top) and After (Bottom)

4. Vehicle Interior

4.1 Cab Car (8570), First Coach Car (7331), Second Coach Car (8548)

Upon inspection of the car interiors the day after the incident, there appeared to be little damage or disruption to the interior of the first three cars. The seats and seat pedestals were intact, and there was little if any residual debris or personal items left behind. These observations indicate that the deceleration of the occupant compartment following the derailment was benign. It is unlikely that occupants in these cars would have experienced serious injuries due to secondary impact with the seats and other structures in the interior. The cars also experienced minor vertical and lateral motions due to the derailment and minor contact with the bridge structure. Passengers may have been jostled around in their seats, possibly sliding into the aisle or over seatbacks. Injuries included minor cuts and bruises, sore necks, and possibly a few fractures. Most passengers exited without assistance through the doors at the center of the cars.

4.2 Third Coach Car (7488)

In contrast to the first three cars, there was severe damage to the interior of the fourth car in the consist (car 7488, also referred to as the third coach car). The integrity of the occupant compartment was compromised in the first three to four rows of seats on the right-hand side of the car, lower level. The floor of the car body was deformed vertically by 1 to 2 feet between the third and fourth rows of seats when the front truck impacted the bridge girder. The side wall was deformed inward by roughly 1 foot at the base and outward by roughly 1 foot at the bottom edge of the window frame. The occupant compartment was penetrated by fractured metal from the car body siding and the railing from the bridge. At least one fatality resulted from the loss of survivable space (Figure 22). There were also significant vertical and longitudinal car body accelerations that caused secondary impact injuries, as indicated by the residual blood and body matter on the seats, floor, and ceiling. The passengers throughout the car were thrown from seats into the aisle or ceiling, or over seatbacks. Many passengers needed assistance exiting the car; some exited through windows.

Most of the seat backs in the front half of the car were detached from the seat bases. Some of the seat backs may have been removed by rescue personnel, but several seat backs likely detached during the accident, which exposed the steel mounting posts— a severe secondary impact hazard (Figure 23). The seat design relies on gravity to keep the seatbacks on the mounting posts. The separation of the seat backs from the seat bases indicates a significant vertical component of the car body acceleration. Also due to significant vertical forces, five or six seat pedestals in the front of the car were crushed or deformed, and a railing fragment traversed several rows into the occupant volume at the front of car (Figure 24).

A. Front Right Corner

B. Rows 3 and 4

C. Rows 2 and 3

D. Rows 4 and 5

Figure 22. Interior View of the Front Right Corner of Car 7488

Figure 23. Interior View of Car 7488 From the Front of the Car Looking Backward

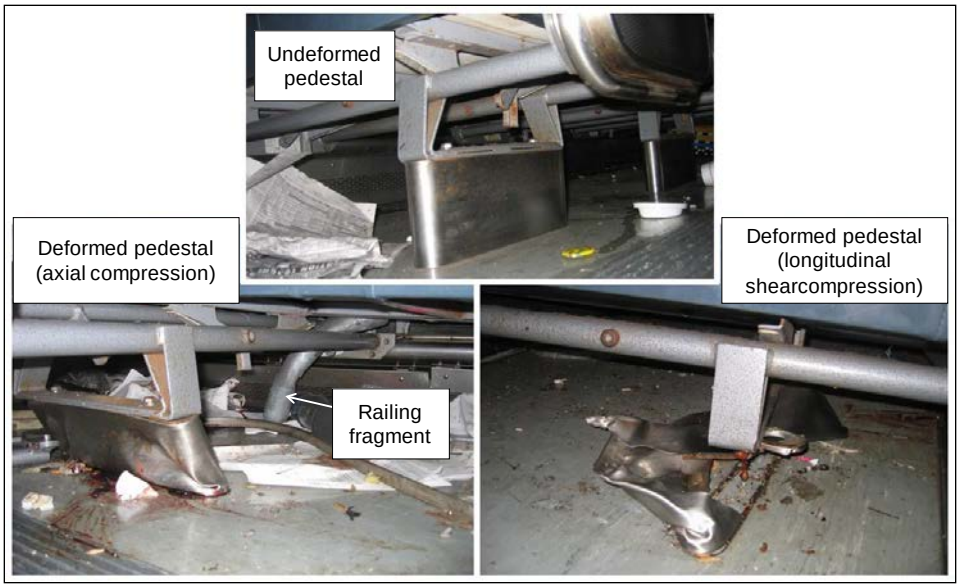


Figure 24. Seat Pedestals in Various States in Car 7488

4.3 Fourth Coach Car (7351)

Because the final coach car in the consist (7351) was unoccupied, a thorough evaluation of the interior of the car was not carried out.

5. Collision Dynamics

Using evidence available from the on-scene investigation, the dynamics of the collision can be analyzed in more detail. The evidence includes measurements of the final resting positions of the vehicles involved (Figure 11) and data from the event recorders in the locomotive and cab car.

5.1 Sequence of Events

Included in the event recorder data is the car body velocity at 1-second intervals (Figure 25). The car body displacement is calculated by integrating the velocity-time history (Figure 26). The car body acceleration is calculated by differentiating the velocity-time history (Figure 27). Due to the nature of this incident, several differences appear in the event recorder data obtained from the locomotive and from the cab car. As car 7488 strikes the bridge and decouples from car 7351, the vehicle responses begin to diverge. The impact of car 7488 with the bridge initially causes the cab car to decelerate, but it is subsequently accelerated by the momentum of the first three cars in the consist. The cab car, along with cars 7331, 8548, and 7488, travels roughly 780 feet from the point of initial derailment before coming to rest. The locomotive and car 7351, on the other hand, travel roughly 730 feet from the point of initial derailment of the cab car to the point of rest. This leaves a gap of roughly 50 feet between cars 7488 and 7351 after all the cars have come to rest.

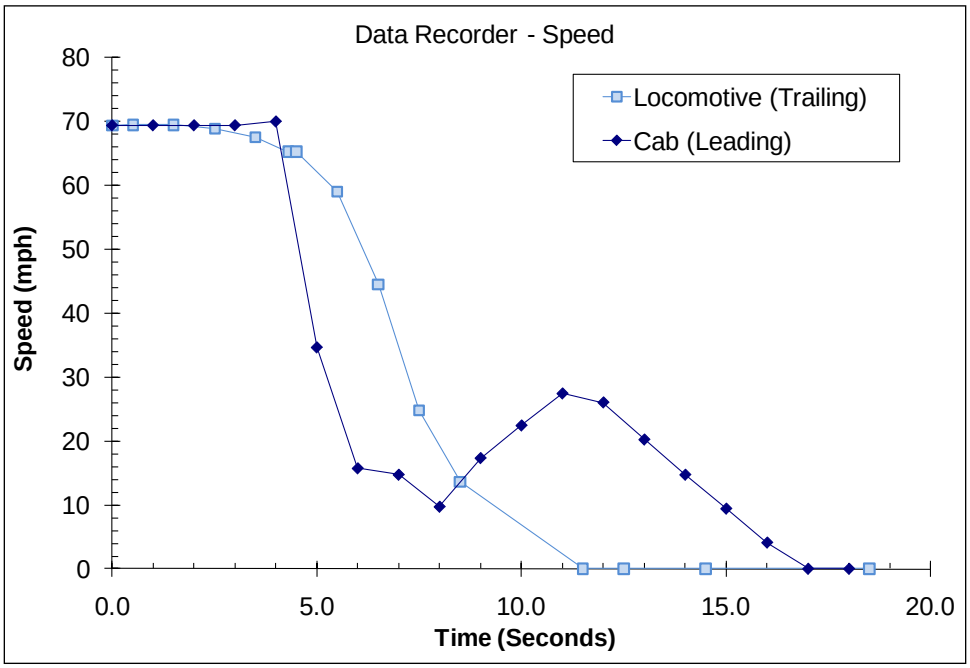


Figure 25. Velocity-Time History of yhe Lead Cab Car and Trailing Locomotive, Showing the Sequence of Events

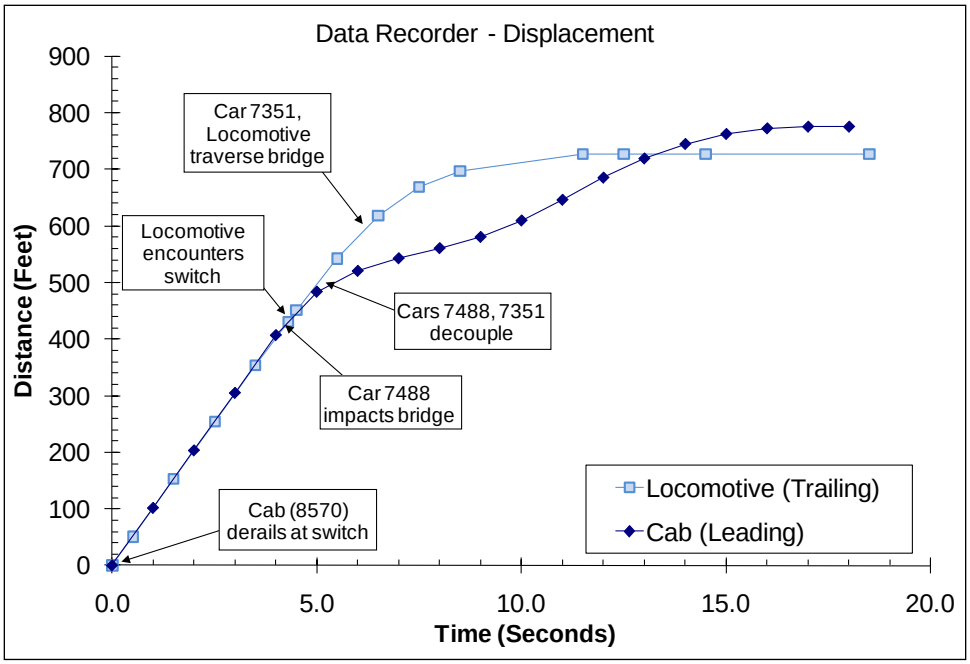


Figure 26. Displacement of the Locomotive and Cab Car (8570)

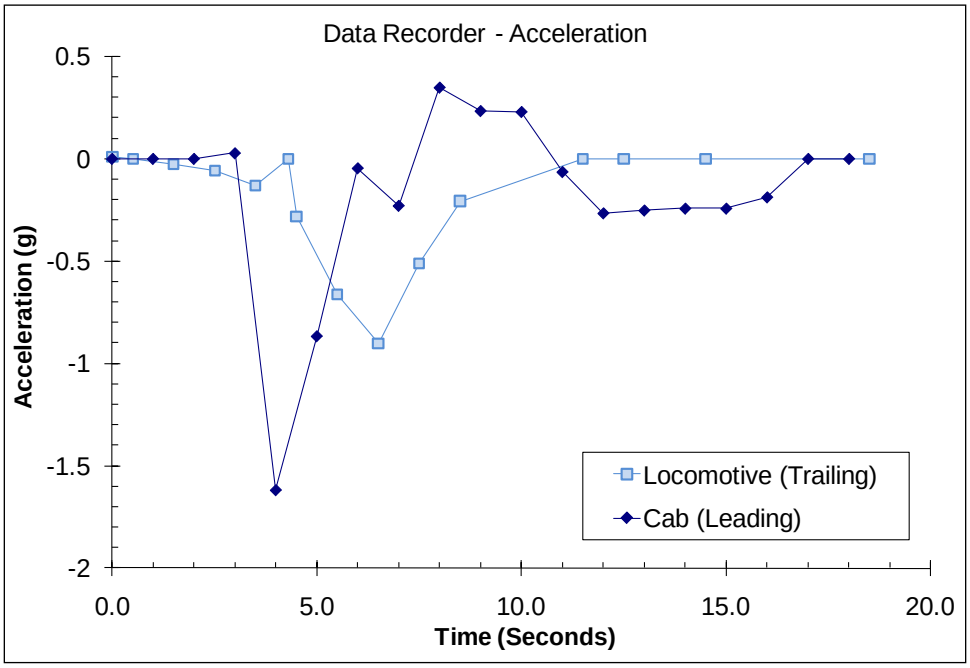


Figure 27. Acceleration of the Locomotive and Cab Car (8570)

The initial speed of the train upon traversing the switch was 69 miles per hour. The locomotive began to decelerate gradually due to the added friction in the system, as at least the front truck of the cab car was no longer on the rails. Additionally, the emergency brakes on the locomotive were applied immediately at the point of derailment, although it took 3 seconds for the brake signal to travel from the locomotive to the cab car. Four seconds after the cab car traversed the switch, there was a sudden drop in the speed of the cab car, from 70 miles per hour to 35 miles

per hour within 1 second. This is the most severe deceleration shown by the event recorder data, equating to an average of 1.6 times the acceleration due to gravity. Traveling at 70 miles per hour for 4 seconds, the consist traversed roughly 410 feet from the point of the switch. Given that the distance from the switch to the bridge was 170 feet and each car was roughly 80 feet long, the front of car 7488 would have reached the nearest corner of the bridge girder. Thus, the sudden deceleration of the cab car that occurred 4 seconds after the derailment is likely to correspond to the impact of the front of car (7488) with the bridge girder.

After the sudden deceleration, the cab car continued to decelerate gradually to 10 miles per hour. The cab car then accelerated to nearly 30 miles per hour over 3 seconds, an average acceleration of roughly 10 feet per second per second (around 0.3 times the acceleration due to gravity). This magnitude of acceleration is physically unrealistic for a passenger train, as typical accelerations are less than 5 feet per second per second (less than 0.1 times the acceleration due to gravity). Therefore, it is likely that this change in velocity resulted from an inconsistent/intermittent rotation of the axle with the speed sensor, caused by intermittent contact between the wheels of the cab car and the ground, which in turn resulted in erroneous data on the event recorder.

There are several limitations to this method of estimating the severity of the occupant environment. First, the frequency of data collection, at one sample per second or less, is sparse. It is possible that the motion of the car changes more frequently than once per second during an impact between two stiff structures, such as the end frame and the bridge girder. The peak acceleration could occur between two samples, which would not be captured by the event data recorder. Another limitation is that the motion of the car that experienced the most significant deformation (car 7488) is not accurately represented by the motions of the cab car or the locomotive, where the two data recorders on the train were located. Car 7488 is likely to have experienced a significant deceleration during impact with the bridge and a subsequent acceleration due to the momentum of the three coupled cars ahead of it. These events may not have been captured in the data recorder of the cab car due to the filtering effect of the coupled connections between two cars, as well as the low frequency of sampling compared to the high frequency of such events.

While the longitudinal acceleration pulse is relatively benign, there are significant contributions of acceleration in the lateral and vertical directions as well. Unfortunately, the event data recorder does not collect information that can be used to assess the off-axis motion of the car. One can make a speculative estimate of the magnitudes of the vertical and lateral motions based on the deformation patterns of the cars. The upward motion of the front truck of car 7488 and subsequent deformation of the occupied volume of the car suggest significant vertical motion during and after contact with the bridge. It is possible that the occupants were first accelerated downward toward the floor as the front end of the car was forced upwards, and subsequently accelerated upward toward the ceiling as the front end of the car dropped back to the track level. Evidence of occupant contact with the ceiling in the front of car 7488 supports this speculation.

In order to investigate thoroughly the collision dynamics in this complex motion brought about by interaction with the bridge structure, a validated model of the structure of the gallery cars under longitudinal, lateral, and vertical impact conditions would be necessary. However, such an effort is unwarranted, because the injuries due to secondary impact appear to have been less severe than those due to loss of survival space, as described in the following section.

6. Casualties

Based on the passenger manifest provided by Metra, there were 185 passengers and 4 crew members on the train at the time of the accident. The three occupied passenger cars, with a seating capacity of about 130 per car, were slightly less than half full, with an average of 60 passengers per car.

Medical records were obtained from the local hospitals via a subpoena issued by the FRA. Abbreviated Injury Scale (AIS) codes were assigned based on the medical data collected. The AIS is published by the American Association for Automotive Medicine [12] to provide a simple numerical method for ranking injuries. AIS scores range from 1 (minor) through 6 (not survivable). Injuries are categorized by the following body parts: head, neck, chest, abdomen, internal, and extremities. Each category is scored separately. The AIS score for a given occupant is simply the maximum AIS for any body part, not a cumulative scoring of multiple injuries.

Two passengers sustained fatal injuries, which included pelvic and rib fractures, internal organ lacerations, and severed body parts. Of the 50 passengers admitted to area hospitals, 46 were treated and released the same day. Injuries to the 46 passengers who were treated and released included minor lacerations, abrasions, and contusions; back, neck, or knee pain; and headaches. Four passengers were hospitalized for a day or longer. The two passengers with critical injuries suffered fractures to the skull, pelvis, clavicle, ribs, vertebrae, and face, as well as injuries to internal organs. Table 2 summarizes the maximum AIS code for each of the train occupants who were treated.

Table 2. Injuries to Passengers by Maximum AIS Score

Maximum AIS Score	Number of Passengers
AIS 6 - Unsurvivable	1
AIS 5 - Critical	2
AIS 4 - Severe	0
AIS 3 - Serious	1
AIS 2 - Moderate	3
AIS 1 - Minor	5
Less than AIS 1	40
Total	**52**

6.1 Passenger Interviews

As part of the accident investigation, passenger interviews were conducted. One interview was conducted in person in a hospital. The remaining interviews were conducted via telephone, or the passenger completed an interview form. The interview questions are presented in Appendix A. Summaries of the interviews are provided below. [*Comments in italics are from the author.*]

Passenger #1 was a male in his fifties, seated at a window on the left side, in the rear of the car on the lower level. He was seated forward-facing, most likely in car 7488. At the time of the derailment, he heard a loud bang. He grabbed the seat back ahead of him to brace himself and closed his eyes. He wound up on the floor in the aisle on top of another person. He climbed off the person, kneeled on all fours, stunned, and could not get up. He noticed he was dripping blood. He dragged himself to an adjacent seat. A fireman assisted his exit. He was placed in a

basket and carried through the train, exited through the side doors, and was carried to an ambulance. His injuries included a closed fracture of the right clavicle, pelvic fractures, and a 3-cm scalp laceration. He was admitted to the hospital for several days. His maximum AIS code was 5.

Passenger # 2 was a male in his forties, seated at a window on the left side, in the front of the car on the lower level. He was seated forward-facing, most likely in car 8548. He reported feeling a bump, but it seemed fairly normal. The vertical bouncing motion got worse. The car leaned to the right, and he thought the car might roll over. Then the car leveled out, slowed down, and came to a stop. He remained in his seat throughout the accident and exited through the side doors. He reported some bruising on his hip and mid-section, and some neck stiffness, but nothing severe. The passengers located around him seemed to be okay, with no visible injuries. His maximum AIS code was 0.

Passenger #3 was a male in his thirties, seated at a window on the left side, in the front of the car on the lower level. He was seated forward-facing, most likely in car 7331. He reported that the train was moving very fast and felt like a roller coaster, rocking back and forth until it stopped. He heard screaming. He struck the forward seat back, which articulated from a forward-facing position to a rear-facing position. He felt mostly longitudinal motion, not lateral or vertical. He did not notice anyone being thrown about during the accident. He exited through the side doors on the right side of the car. He did not perceive any injury at the time, but he experienced a sore lower back following the accident. His maximum AIS code was 0.

Passenger #4 was a male in his twenties, seated at a window on the right side, in the rear of the car on the upper level. He was seated forward-facing, most likely in car 7488. He reported hearing three loud booms after going over what felt like a switch. The car jerked first left, then right, then left before it stopped. He hit the forward seat with his face and fell into the aisle, while trying to pull himself up. He felt like the car was going to roll over. He hit his side and back on the forward seat back, which articulated from a forward-facing position to a rear-facing position. The seat base was dislodged as well. He did not notice vertical motion, only longitudinal motion. When the car came to a rest, he was on the floor facing the rear of the car. He exited without assistance through the side doors on the left side of the car. He experienced a bruise on his left thigh, an abrasion on his back, and a twisted arm. He was treated and released from the hospital. It appeared to him that most passengers from the upper level were able to exit under their own power. His maximum AIS code was 0.

Passenger #5 was a male passenger in his fifties, seated in an aisle seat on the left side, in the rear of the car on the upper level. He was seated forward-facing, most likely in car 8548. He stated that the train jerked to the left, and thus he was thrown to the right into the vertical luggage racks on the right side of the car, impacting his right ear. He attempted to stabilize himself by purposely sliding off the seat down onto the floor and held on to the luggage rack railing. He remained in that location until the train came to rest. Soon, a conductor entered the car and instructed the passengers to exit the train. He noted the smell of smoke and sounds of women screaming (and noted that a large number of the passengers were female). He exited through the center doors under his own power. His right ear was swollen, and he had a fracture of his right rib and contusions. He was treated and released from the hospital. His maximum AIS code was 1.

Passenger #6 was a female passenger in her teens, seated in a window seat on the right side, in the front of the car on the lower level. She was seated forward-facing, most likely in car 8548. She reported that she was sleeping at the time of the derailment and woke to side-to-side car rocking. People were sliding toward the right side of the car. She was bracing against the forward seat back, which did not rotate forward. She heard screeching, scraping sounds. She was bounced against the side window. She did not feel or notice pain and did not notice any sudden lateral jolts, just general side-to-side motion. Someone smelled smoke and said to get off the train. Everyone helped each other to exit the train. She had not realized the severity of the accident until she got off the train. Everyone from the front half of the 3rd car seemed mobile and was able to walk off the train unassisted. She called home immediately upon exiting the train, at 8:38 am. She heard sirens, then heard people screaming for help and stretchers, either from the rear of the 3rd car or the front of the 4th car. She suffered a right clavicle fracture, but no lacerations, bruising, or neck pain. Her maximum AIS code was 1.

Passenger #7 was a female in her thirties, seated on the right side, in the front of the car on the upper level. She was seated in an aisle-facing seat, in car 7488. She reported being thrown from her seat. The car was rocking back and forth, and she was trying to grab hold of the luggage rack bars but couldn't because of the car motion. When the car came to a rest, the train was full of dust. She and her traveling companions came down the stairs from the upper level and exited from the emergency window with assistance. She suffered minor cuts and bruises to both legs and right ankle. She was treated and released from the hospital. Her maximum AIS code was 0.

Passenger #8 was a pre-teen female, seated on the right side, in the front of the car on the upper level. She was seated forward-facing, in car 7488. She reported hitting something and being thrown from her seat. She believed her arm was broken when she hit the bar [*from luggage rack?*]. She climbed out the emergency window [*probably on the lower level*]. She suffered a broken right arm. She was treated and released from the hospital. Her maximum AIS code was 1.

Passenger #9 was a female in her thirties, seated on the right side, in the front of the car on the upper level. She was seated in an aisle-facing seat, in car 7488. She reported hearing a loud noise like a machine gun, very fast and loud [*likely the initial derailment*]. She heard a lot of noise, and then her friend fell toward her. There was rocking back and forth, and then she felt a huge jolt or impact [*likely the impact of the front truck with the bridge girder*]. The car continued to go back and forth. She had managed to grab hold of her young daughter. She tried to grab the rail and hang on, but was unable to do so. She reported that the ride-down seemed to last forever, but it was at least 30 to 45 seconds. People were being thrown around like rag dolls. People were trying to brace themselves. The train finally stopped, and it was quiet and smoky. She saw people on the lower level lying unconscious [*the lower level at the front right side of this car experienced the most interior damage*]. She made sure her daughter and friends were okay, and they tried to get out. They had to climb out a window [*probably on the lower level*], because the door was jammed shut. She suffered a bump on her head and a hematoma on her lower left leg. She was treated and released from the hospital. Her maximum AIS code was 0.

Passenger #10 was a pre-teen female, seated on the right side, in the front of the car on the upper level. She was seated in an aisle-facing seat, in car 7488. Her mother reported that she refuses to talk about the accident. She becomes very upset when the accident is mentioned. She climbed out the emergency window [*probably on the lower level*]. She suffered a bump on her head. She was treated and released from the hospital. Her maximum AIS code was 0.

To summarize the non-fatal injuries sustained by passengers: all the passengers who were interviewed reported injuries due to secondary impact. With the exception of two passengers who suffered AIS 5 injuries, most injuries were minor, generally occurring in the form of fractures of the extremities, single rib fractures, bruises, contusions, and abrasions. The magnitude of those injuries is consistent with the injuries expected from trip-and-fall incidents, which confirms the relatively benign longitudinal collision pulse (about equal to the acceleration due to gravity) to which the passengers were exposed.

7. Conclusion

A derailment involving a single train in Chicago, Illinois, on September 17, 2005, led to two fatalities and several injuries. This incident was investigated as part of a field study of occupant injury in passenger train collisions and derailments currently being conducted at the request of the Federal Railroad Administration. The data collected at the scene, along with interviews with the passengers, contributed to an understanding of the events that transpired.

In summary, the Chicago incident resulted from a cab car-led train traversing a 10-mile-per-hour switch at 69 miles per hour. This caused the consist to derail two car lengths from a bridge. The fourth car in the train impacted the corner of the bridge structure, resulting in significant vertical and lateral deformation of the front right corner of the car. Additionally, a steel railing intruded into the occupant volume though the gap between the front right collision and corner posts of the car.

The collision dynamics of the rail vehicles involved were analyzed by using the available evidence. The longitudinal deceleration of the cab car and locomotive were estimated to be benign and unlikely to cause any serious or fatal injuries. However, due to the complex vertical and lateral motions of the fourth car in the train, the severity of the longitudinal deceleration does not entirely describe the severity of the occupant environment. Despite the complex motions of the passenger vehicles involved, the principal causal mechanism for the fatalities that occurred in the Chicago incident was a loss of survival space. The front right corner of the fourth car in the train was compromised by intrusion of the steel railing from the bridge and a breach in the floor that may have led to partial ejection.

A secondary causal mechanism for injury was the secondary impact of the occupants with the exposed sharp structures of the walkover seats. The vertical contribution to the occupant environment acted to dislodge many seatbacks, leaving the sharp support structures exposed.

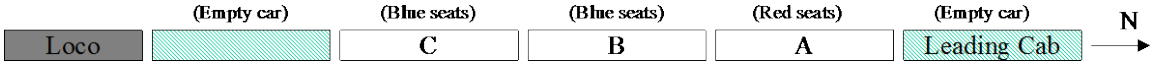
Appendix A. Questions from Passenger Interview Form

Gender: ☐ Male ☐ Female

Age: _____ Height: _____ Weight: _____

What is the name of the station where you boarded the train? _____

Which train car did you board (see diagram below)? ☐ A ☐ B ☐ C ☐ I don't remember



What part of the train car were you riding in? (the doors are in the middle of the car.)

☐ Front ☐ Rear ☐ I don't remember

Which level of the car were you in? ☐ Upper ☐ Lower ☐ I don't remember

Were you seated or standing? ☐ Seated ☐ Standing ☐ I don't remember

If you were standing, where were you?

☐ Vestibule ☐ Stairs ☐ Aisle ☐ I don't remember

If seated, which side of the aisle were you seated on?

☐ Left ☐ Right ☐ I don't remember

If seated, what was the orientation of your seat (with respect to the direction of travel)?

☐ Forward-Facing ☐ Rearward-Facing ☐ Aisle-Facing

If seated in a 2-passenger seat, which position were you seated in? ☐ Aisle ☐ Window

Did you notice the condition of any nearby window(s)? ☐ Intact ☐ Missing ☐ Partially detached

At the time of the accident, did you see any uniformed Metra employees in your car?

☐ Yes ☐ No ☐ I don't remember

If so, how many did you see? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ I don't remember

After the accident, did you see any uniformed Metra employees in your car?

☐ Yes ☐ No ☐ I don't remember

If so, how many did you see? ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ I don't remember

Please describe what happened during the accident. Include, to the best of your knowledge, what you saw and heard from the beginning of the incident until the train came to rest. Use the back of the page if you need more space.

If you were seated, did you remain in your seat after the train came to rest? _____

If you were standing, where did you end up after the train came to rest? _____

How did you exit the vehicle? _____

Did anyone assist you in exiting the vehicle? _____

What injuries did you sustain as a result of the accident? _____

Were you traveling with companions? _____

Were there any other passengers sitting near you? _____

Abbreviations and Acronyms

AIS	Abbreviated Injury Scale
FRA	Federal Railroad Administration
NTSB	National Transportation Safety Board

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