INJURY MECHANISMS TO MASS TRANSIT BUS PASSENGERS DURING FRONTAL, SIDE AND REAR IMPACT CRASH SCENARIOS.

Gerardo Olivares, Vikas Yadav
NIAR, Wichita State University
United States
Paper Number 09-0427

ABSTRACT

According to the Traffic Safety Facts reports from 1999-2003, an average of 40 fatalities and 18,430 injuries of bus occupants occurred per year. The objectives of this research are to characterize the kinematics and injury mechanisms of bus passengers during typical frontal, side and rear impact conditions. Accident data from the traffic Safety Fact Reports, Buses Involved in Fatal Accidents Report and Transit Agency data were review to define typical crash scenarios. A detailed finite element model of a low floor transit bus was used to calculate the crash pulses at the passenger compartment for typical frontal, side and rear impact conditions. A series of sled tests with 5th, 50th and 95th percentile occupants were conducted at NIAR's Crash Dynamics Laboratory in order to study the occupant kinematics and to identify injury mechanisms to bus passengers.

The results of this study show that the most common injury mechanisms to bus passengers are head (HIC) and neck injuries (neck extension, flexion and compression). These injuries are due to body-body contact between unrestrained passengers and/or body-to-seat structure contacts.

INTRODUCTION

According to the Standard Bus Procurement Guidelines [1], the passenger seating arrangements in mass transit buses shall be such that seating capacity is maximized and that it complies with the requirements defined in section 5.4.5.1. As shown in figure 1 there are several possibilities for the arrangement of seats. Passenger seats can be arranged in a transverse, forward facing configuration or arranged in longitudinal rows facing the centerline of the bus (perimeter seating configuration). A limited number of rearward facing seats can be used with the expressed approval of the procurement agency. Also it is possible to have a combination of forward facing and perimeter seating arrangements. The Procuring agency recognizes that ramp location, foot room, hip-to-knee room, doorway type and width, seat construction, floor level type, seat spacing requirements, etc. ultimately affect seating capacity and layout.

The objectives of this research are to characterize the kinematics and injury mechanisms of bus passengers during typical frontal, side and rear impact conditions. Accident data from the traffic Safety Fact Reports, Buses Involved in Fatal Accidents Report and Transit Agency data were review to define typical crash scenarios. A detailed finite element model of a low floor transit bus was used to calculate the crash pulses at the passenger compartment for typical frontal, side and rear impact conditions. A series of sled tests with 5th, 50th and 95th percentile occupants were conducted at NIAR's Crash Dynamics Laboratory in order to study the occupant kinematics and to identify injury mechanisms to bus passengers.

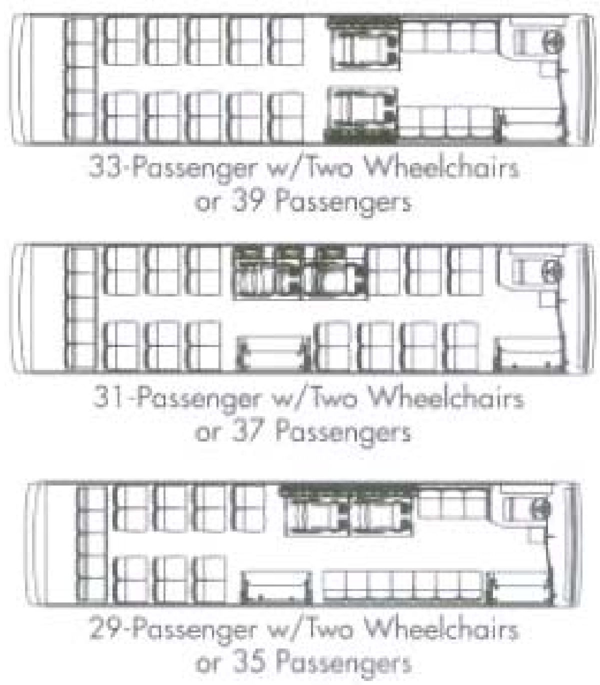

Figure 1. Typical Mass Transit Bus Seat Arrangement

ACCIDENT DATABASES REVIEW

This section presents a summary of statistics on bus crashes. Bus crash data was obtained from the Traffic Safety Facts report [2]-[3], years 1999-2003, and the Buses Involved in Fatal Accidents report [4]-[2], years 1999-2001.This statistical review was performed to gain insight into the types of bus crash mechanisms that result in occupant injuries and fatalities. As documented in

Reference [2], there is not a standard for collecting crash data for mass transit buses. Furthermore, not all agencies collect crash data. Based on inquiries to transit agencies by

NIAR, the experiences of the authors in Reference [2] and the scope of this project, NIAR researchers made the decision to proceed with the available crash data in the Traffic Safety Facts Reports and the Buses Involved in Fatal Accidents (BIFA) reports.

Traffic Safety Facts Report Bus Data

The Traffic Safety Facts report is an annual compilation of motor vehicle crash data presented by the National Highway Traffic Safety Administration (NHTSA). Data from the Fatality Analysis Reporting System (FARS) and the National Automotive Sampling System General Estimates System (GES) is combined to create Traffic Safety Facts. The FARS database, established in 1975, records data from traffic crashes involving a fatality. The GES database, established in 1988, records data from a nationally representative sample of police reported crashes of all severities, including those that result in death, injury or property damage [2, 3].

In the Traffic Safety Reports, buses are defined as "Large motor vehicles used to carry more than ten passengers, including school buses, inter-city buses, and transit buses". Data presented in the Traffic Safety Report is often grouped by crash severity, with the following categories: (1) Fatal Crash. A police-reported crash involving a motor vehicle in transport on a traffic way in which at least one person dies within 30 days of the crash. (2) Injury Crash. A police-reported crash that involves a motor vehicle in transport on a traffic way in which no one died but at least one person was reported to have: (i) an incapacitating injury; (ii) a visible but not incapacitating injury; (iii) a possible, not visible injury; or (iv) an injury of unknown severity. The following is a summary of the vehicle data [2, 3]:

- Sixty four percent of bus crashes involving fatalities result from a frontal initial point of impact. Rear impacts account for 16% and side impacts account for 14%.

- The initial point of impact in bus crashes involving injuries is evenly distributed, with frontal accounting for 37%, side for 36% and rear for 25%.

- Rollover occurs in less than 3.1% of buses involved in crashes with fatalities, and 0.1% of buses involved in crashes with injuries.

- Fire occurs in less than 0.3% of buses involved in crashes with fatalities, and less than 0.05% of buses involved in crashes with injuries.

- Thirty eight percent of buses involved in fatal accidents are School Buses, 36% Transit Buses, 11% other, 9% Intercity, and 6% is unknown.

The following is a summary of the occupant data:

- An average of 40 bus occupants per year were killed and 18,430 injured from 1999-2003.

- Forty seven percent male and 53% female were killed. 51% male and 49% female were injured.

- School age occupants, ages 5-20, account for 24% of bus occupants killed.

- Occupants over the age of 55 years account for 43% of bus occupants killed.

- Sixty eight percent of bus occupant injuries occur during two vehicle crashes.

- Sixty one percent of bus occupant fatalities result from frontal crashes, 17% from side crashes and 9% from rear crashes.

- Thirty percent of bus occupant injuries result from side crashes, 33% from frontal crashes and 30% from rear crashes.

- Twenty eight percent of bus occupant fatalities result from occupant ejection, 53% from non-ejected fatal impacts and 19% were unknown.

- An average of 49 pedestrians and 9 pedal-cyclists per year are killed in crashes with buses.

- Forty percent of bus occupant injuries result from school bus crashes, 24% from intercity bus crashes and 23% from transit bus crashes.

- Thirty percent of bus occupant fatalities result from intercity bus crashes, 24% from school bus crashes and 14% from transit bus crashes.

- An average of 11 bus occupants per year are killed in two vehicle crashes while 162 occupants per year of other vehicles are killed.(102 occupants in passenger cars, 49 in light trucks 9 in motorcycles, 2 in large trucks).

- An average of 12,000 bus occupants per year is injured in two vehicle crashes while 8,800 occupants per year of other vehicles are injured. (6,000 in passenger cars and 2,800 in light trucks).

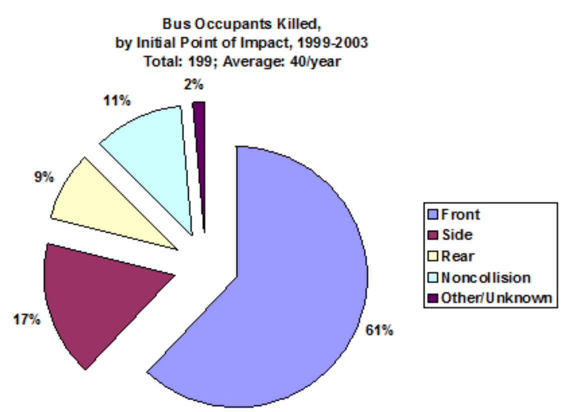

Figure 2. Bus Occupants Killed, by Initial Point of Impact, 1999-2003.

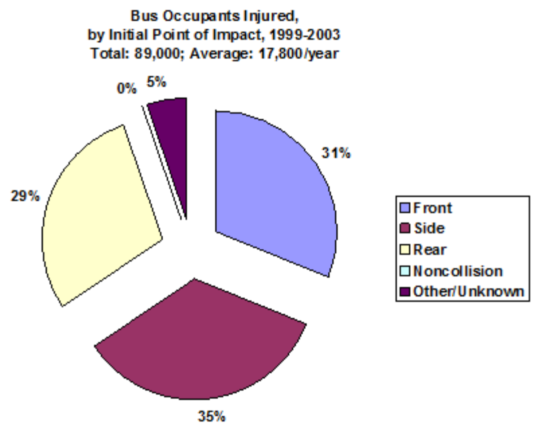

Figure 3. Bus Occupants Injured, by Initial Point of Impact, 1999-2003.

<u>Buses Involved in Fatal Accident (BIFA) Report Data</u>

The Buses Involved in Fatal Accidents (BIFA) report presents aggregate statistics for buses involved in traffic accidents, compiled by the University of Michigan Transportation Research Institute (UMTRI). The BIFA database is a census of all buses involved in a fatal accident in the United States, and provides coverage of buses recorded in the Fatality Analysis Reporting System (FARS) file. BIFA combines vehicle, accident, and occupant records from FARS with information about the physical configuration and operating authority of the bus from the BIFA survey. Modeled after UMTRI's Trucks Involved in Fatal Accidents (TIFA) program, the BIFA survey collects detailed information on all buses involved in all fatal traffic accidents. Buses are defined as motor vehicles with seating for nine or more, including the driver, that are not operated as personal transportation, and all motor vehicles with seating for 16 or more. The BIFA file is produced annually, beginning with the 1999 data year, from a survey of bus records extracted from the FARS file, compiled by the National Center for Statistics and Analysis at the National Highway Traffic Safety Administration [2, 4].

Accident, vehicle, and driver records that appear to involve a bus are selected from the FARS file. Police reports for each accident represented are requested from the appropriate states. The BIFA file is a census file, meaning there is one record for each bus involved in a fatal accident. The data presented in BIFA reports includes all bus type involvements. The data summarized in this paper is focused on transit bus involvements only. Involvements; counts of the buses involved in a fatal accident. Fatalities; counts of fatalities of occupants of bus and/or other vehicle involved. Transit; an entity providing passenger transportation over fixed, scheduled routes, within primarily urban geographical areas [2, 4].

The following is a summary of the BIFA report trends for transit buses for the period from 1999 to 2001:

- An average of 111 transit buses is involved in a fatal traffic accident each year.

- A total of 246 fatalities resulted from transit bus involvements from 1999-2000. 43% of the fatalities were drivers of other vehicles, 37% were pedestrians, and 13% percent were passengers of other vehicles.

- About 50% of fatal transit bus involvements occur during rush hour, from 6:00 to 9:59 a.m. and from 3:00 to 6:59 p.m.

- Eighty percent of transit bus fatal involvements occur during the work week. The lowest percentages of involvements, 7.8%, occur on Sunday.

- Eighty eight percent of fatal transit bus involvements occurred in urban environments.

- Sixty two percent of fatal transit bus involvements occur in daylight, 29% in dark but lighted conditions.

- Eighty two percent of fatal transit bus involvements occur on dry roadway surface conditions.

- Eighty nine percent of fatal involvements occur under "normal" weather conditions (i.e. no rain, snow, fog, or other adverse condition).

- Fifty eight percent of fatal transit bus involvements occur on local streets (township or municipality), 15% on state highways, and 8% on county roads.

- Fifty five percent of fatal transit bus involvements occur on 2 travel lanes.

- Sixty three percent of fatal transit bus involvements occurred between 25-35 mph.

- Ninety nine percent of single vehicle fatal transit bus involvements hit an object in the road.

- Eighty two percent of two vehicle fatal transit bus involvements on the same traffic-way, same direction resulted from a rear-end, bus struck.

- Eighty eight percent of two vehicle fatal transit bus involvements on the same traffic-way, different direction resulted from a head-on collision in the buses lane.

- Seventy seven percent of two vehicle fatal transit bus involvements on intersecting paths, both going straight resulted from the bus crashing into the side of the other vehicle.

- Fifty two percent of fatal transit bus by first harmful event, collision with non-fixed object, occurred with a motor vehicle in transport, 41% with other type non-motorist.

- Sixty eight percent of the fatal transit bus involvements by vehicle role in accident occurred from the vehicle striking the bus.

- Shorter, heavy-duty, transit buses accounted for 73% of fatal transit bus involvements.

- Buses accounted for 99% of fatal transit bus involvements.

- Low platform buses accounted for 65% of fatal transit bus involvements.

- Flat from buses accounted for 96% of fatal transit bus involvements.

- Thirty to forty foot buses accounted for 61% of fatal transit bus involvements.

- Buses with 25,001-30,000 lb. empty weights accounted for 70% of fatal transit bus involvements.

- Buses with gross weight greater than 33,001 lb accounted for 62% of fatal transit bus involvements.

- Eighty nine percent of fatal transit bus involvements were from buses with 2 axles.

- Fifty five percent of fatal transit bus involvements occurred in buses with a passenger seating capacity of 36-45, excluding the driver.

- Eighty eight percent of fatal transit bus involvements occurred in buses with no passenger restraints available, excluding the driver.

- Eighty four percent of fatal transit bus involvements occurred on local trips.

- For the most harmful event, collision with non-fixed object, of fatal transit bus involvements, 53% were with a vehicle in transport and 41% with a pedestrian.

Nearly two-thirds of bus occupant injuries occur during two vehicle crashes. The crash types are evenly distributed between side, frontal and rear. An average of 12,000 bus occupants per year are injured in two vehicle crashes while 8,800 occupants per year of other vehicles are injured. (6,000 in passenger cars and 2,800 in light trucks).

The majority of fatal crashes involving buses result from frontal crashes. Half of bus fatalities occur during either morning or evening rush hour. An average of 11 bus occupants per year is killed in two vehicle crashes while 162 occupants per year of other vehicles are killed. Transit bus crashes account for 14% of all bus occupant fatalities. The majority of transit bus fatalities occur during the work week, in urban environments, on dry roadway surfaces under normal weather conditions. Over half of fatal transit bus involvements occur on roadways with posted speed limits of 25-35 mph. Shorter, heavy-duty, low-floor transit buses account for the majority of fatal transit bus involvements. Most fatal transit bus involvements occurred on buses with 2 axles. Half of fatal transit bus involvements occurred on buses with a passenger seating capacity of 36-45 seats, excluding the driver. The majority of fatal transit bus involvements occurred in buses with no passenger restraints available, excluding the driver seat. An average of 49 pedestrians and 9 pedal-cyclists per year are killed in crashes with buses.

Based on the data reviewed, a typical transit bus accident occurred:

- in the afternoon, primarily during evening rush hour.

- under clear weather conditions

- on dry roadways

- in connection with another moving motor vehicle

- involving a rear-end or angle impact

- while the bus was either stopped or operating at a slow speed

CURRENT SEAT DESIGN STANDARDS

The passenger seat frame and its supporting structure shall be constructed and mounted so that space under the seat is maximized to increase wheelchair maneuvering room and is completely free of obstructions to facilitate cleaning [1]. The transverse seat structure shall be fully cantilevered from the sidewall with sufficient strength for the intended service. The lowest part of the seat assembly that is within 12 inches of the aisle shall be at least 10 inches above the floor. Foldaway or flip seats used in wheelchair securement areas, as well as, transverse seats mounted in locations at which cantilevered installation is precluded by design and/or structure, need not be cantilevered. The underside of the seat and the sidewall shall be configured to prevent debris accumulation and the transition from the seat underside to the bus sidewall to the floor cove radius shall be smooth. All transverse objects, including seat backs, modesty panels, and longitudinal seats, in front of forward facing seats shall not impart a compressive load in excess of 1,000 pounds onto the femur of passengers ranging in size from a 5th-percentile female to a 95th-percentile male during a 10g deceleration of the bus. This deceleration shall peak at .05 $\pm$ .015 seconds from initiation. Permanent deformation of the seat resulting from two 95th-percentile males striking the seat back during this 10g deceleration shall not exceed 2 inches, measured at the aisle side of the seat frame at height H. Seat back should not deflect more than 14 inches, measured at the top of the seat back, in a controlled manner to minimize passenger injury. Structural failure of any part of the seat or sidewall shall not introduce a laceration hazard [1].

The back of each transverse seat shall incorporate a handhold no less than 7/8 inch in diameter for standees and seat access/egress. The handhold shall not be a safety hazard during severe decelerations. The handhold shall extend above the seat back near the aisle so that standees shall have a convenient vertical assist, no less than 4 inches long that may be grasped with the full hand. This handhold shall not cause a standee using this assist to interfere with a seated 50th-percentile male passenger. The handhold shall also be usable by a 5th-percentile female, as well as by larger passengers, to assist with seat access/egress for either transverse seating position. The upper rear portion of the seat back and the seat back handhold immediately forward of transverse seats shall be padded and/or constructed of energy absorbing materials. During a 10g deceleration of the bus, the HIC number (as defined by SAE Standard J211a) shall not exceed 400 for passengers ranging in size from a 5th percentile female through a 95th percentile male. The seat back handhold may be deleted from seats that do not have another transverse seat directly behind and where vertical assist is provided in accordance with Section 5.4.5.2 [1]. Armrests shall not be included in the design of transverse seats. Longitudinal seats shall be the same general design as transverse seats but without seat back handholds. Longitudinal seats may be mounted on the wheelhouses. Armrests shall be included on the ends of each set of longitudinal seats except on the forward end of a seat set that is immediately to the rear of a transverse seat, the operator's barrier, or a modesty panel and these fixtures perform the function of restraining passengers from sliding forward off the seat. Armrests are not required on longitudinal seats located in the wheelchair parking area that fold up when the armrest on the adjacent fixed longitudinal seat is within 1-1/2 to 3-1/2 inches of the end of the seat cushion. Armrests shall be located from 7 to 9 inches above the seat cushion surface. The area between the armrest and the seat cushion shall be closed by a barrier or panel [1].

FRONTAL IMPACT INJURY MECHANISMS

A series of sled tests; as shown in figure 4; for a typical frontal crash were conducted for occupant sizes ranging from the 5th to the 95th percentile ATDs.

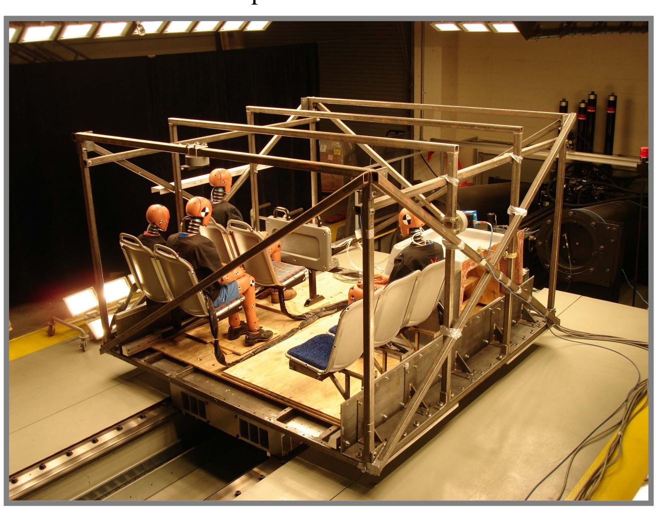

Figure 4. Frontal Sled Test Setup.

The objectives of these tests were to study the passenger kinematics and injury mechanisms for typical seat-to-seat and seat-to-divider layout configurations (see figure 6). Due to the number of tests conducted it was also possible to study the test-to-test variability of the occupant kinematics and injury mechanisms for the 50th and 95th percentile ATDs. The crash pulse for these tests was obtained from a previous structural analysis of typical frontal crashes [6]. Figure 5 shows the frontal crash configuration; a 30 mph head on collision between a low floor transit bus and a Dodge Caravan; and the pulse at the bus passenger compartment used for the testing.

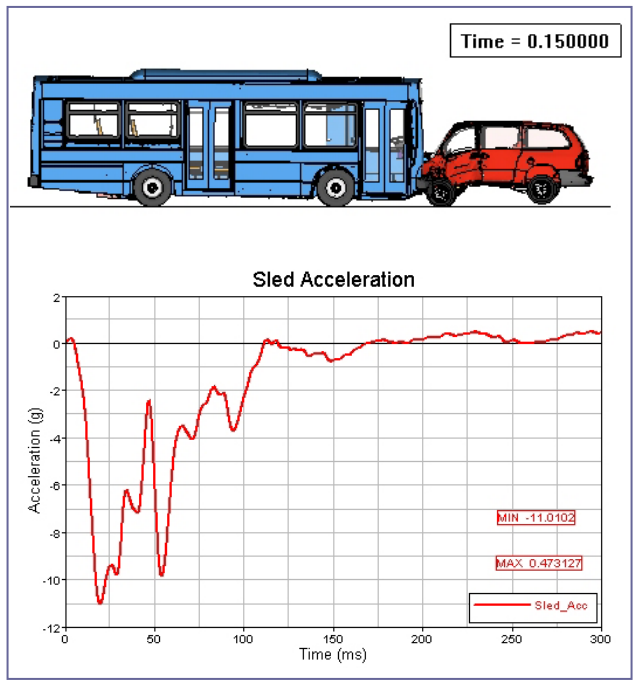

Figure 5. Crash Condition 30 mph Bus – 30 mph DC Head-on Collision 100% Overlap.

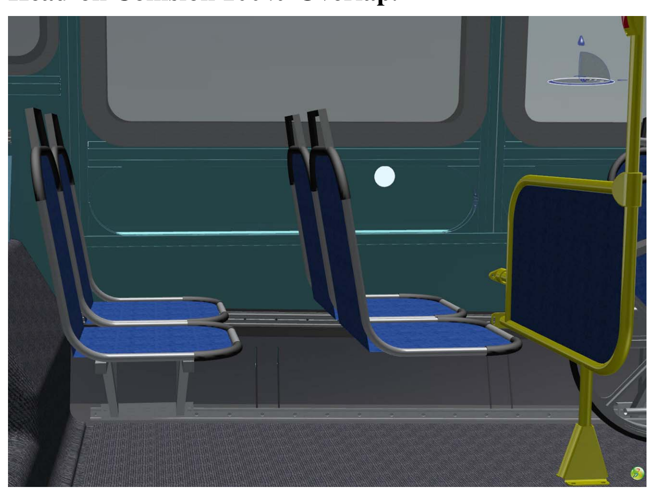

Figure 6. Seat-to-Seat Configuration (left), and Seat-to-Divider Configuration (right).

As shown in the figures 7, 8, and 9 bellow; the most common types of injury mechanisms for passengers seated in a Seat-to-Seat configuration are Neck Flexion or Extension. These injuries are due to the combination of the passengers being unrestrained and the low back seat designs. As shown in figures 7 and 10 even for the same ATD size (95th and 50th percentile in these cases) and similar setup configuration the severity of the neck flexion varies with the different seatback/head interactions; in the case shown in the left of figure 10 the neck of the ATD hits the seatback handle while for the second test the chin of the ATD hits the seatback handle. In order to reduce the severity of the injuries the design of the seatbacks needs to be improved by applying compartmentalization principles.

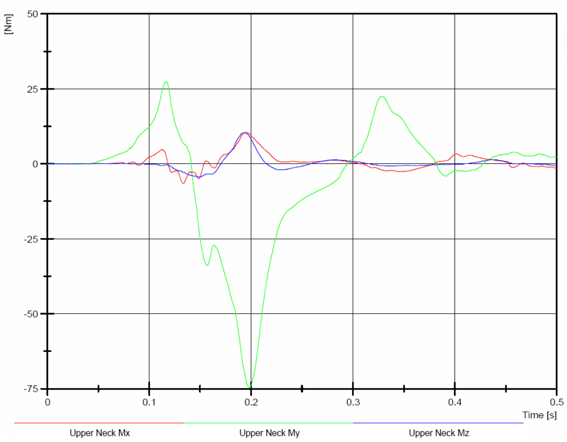

Figure 7. Sample Upper Neck Channel 50th percentile ATD Seat-to-Seat Configuration Frontal Sled Test

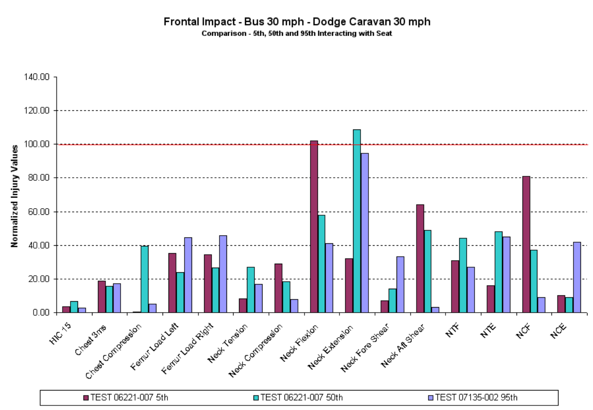

Figure 8. Bus to DC 30 mph Head-on Frontal Impact, FMVSS 208 Normalized Injury Values, Seat-to-Seat Configuration (5th, 50th and 95th percentile ATDs).

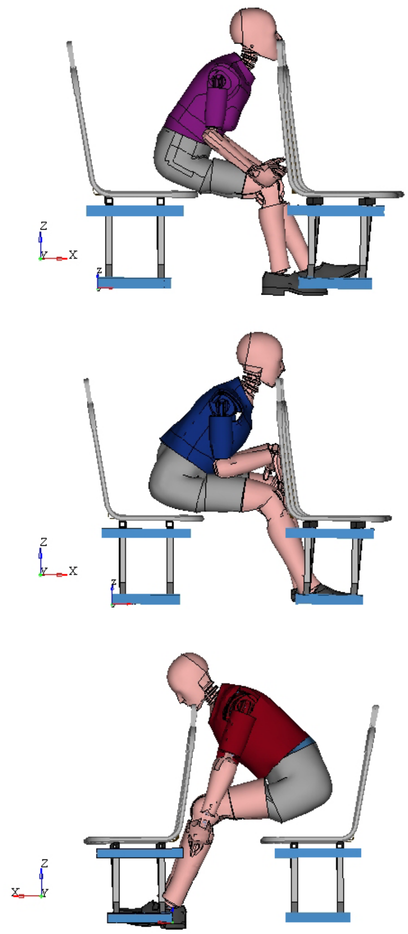

Figure 9. Example FE simulation results (5th, 50th and 95th percentile ATD) Frontal Impact Seat-to-Seat.

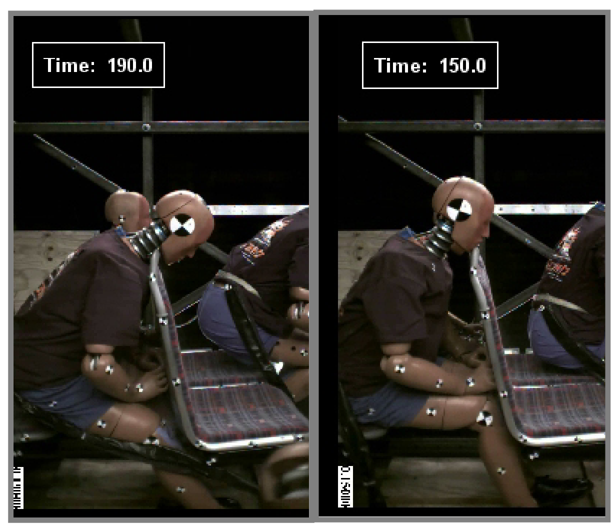

Figure 10. 95th Percentile Seat-to-Seat Configuration Frontal Sled Tests.

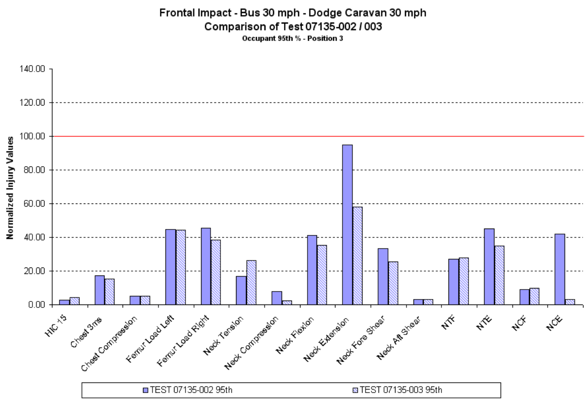

Figure 11. Bus to DC 30 mph Head-on Frontal Impact, FMVSS 208 Normalized Injury Values, Seat-to-Seat Configuration (Repeatability 95th percentile ATDs).

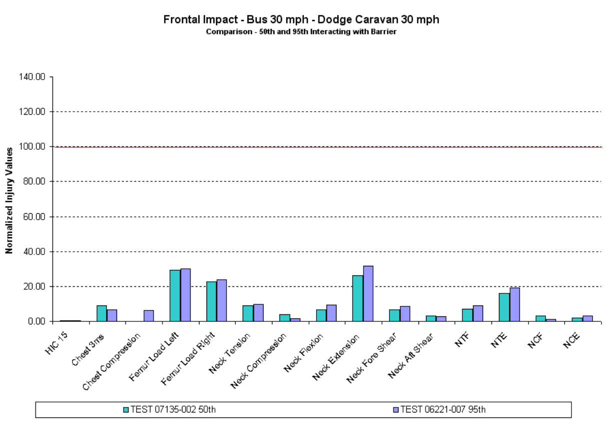

Figure 12. Bus to DC 30 mph Head-on Frontal Impact, FMVSS 208 Normalized Injury Values, Seat-to-Divider Configuration (50th and 95th percentile ATDs).

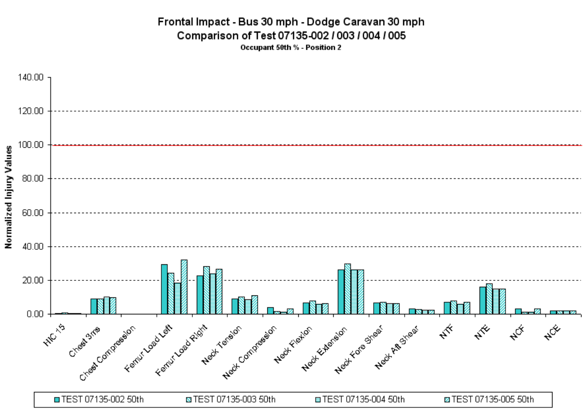

Figure 13. Bus to DC 30 mph Head-on Frontal Impact, FMVSS 208 Normalized Injury Values, Seat-to-Divider Configuration (Repeatability 95th percentile ATDs).

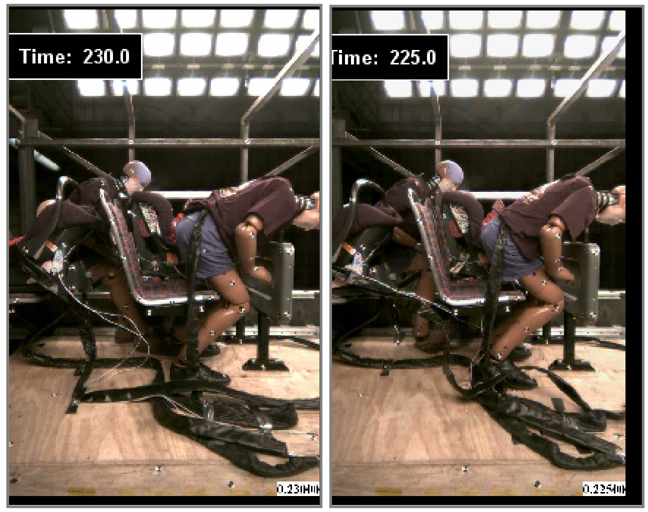

Figure 14. 95th Percentile Seat-to-Divider Configuration Frontal Sled Tests

As shown in figures 12 through 14 the normalized injury values for the Seat-to-Divider configuration are well bellow forty percent of FMVSS 208 values for both the 50 and the 95th percentile ATD.

SIDE IMPACT INJURY MECHANISMS

A series of side impact sled tests for the crash condition shown in figure 15 were conducted for occupant sizes ranging from the 5th to the 95th percentile ATDs.

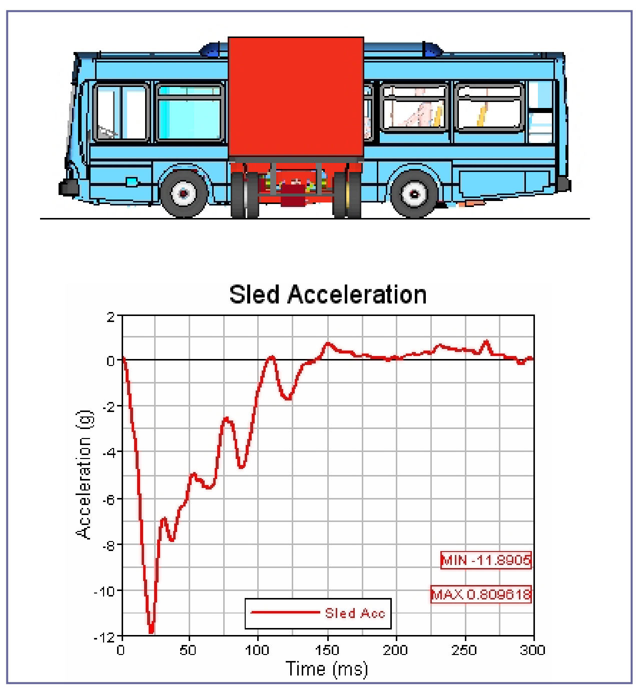

Figure 15. Crash Condition 0 mph Bus – 25 mph F800 Side Impact 90 degrees.

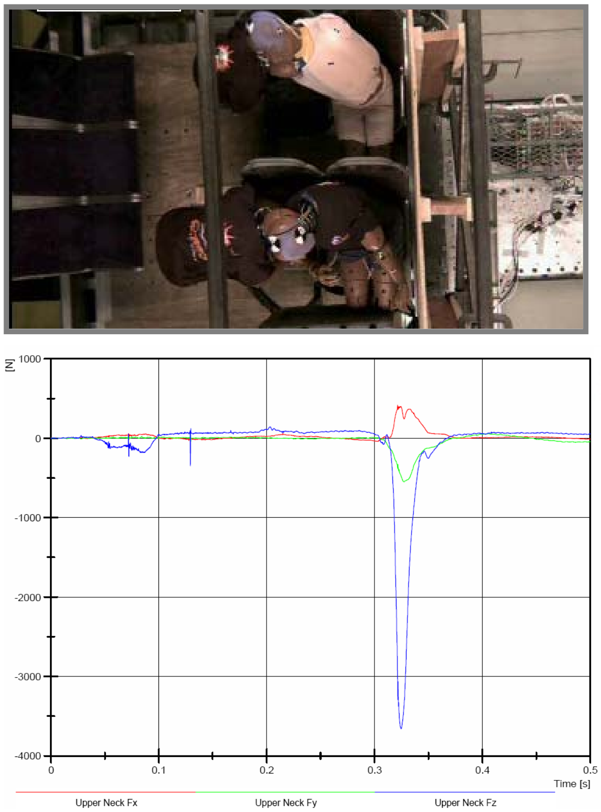

Figure 16. 5th percentile Neck Compression Injury Mechanism, due to Head-to-Head Contact.

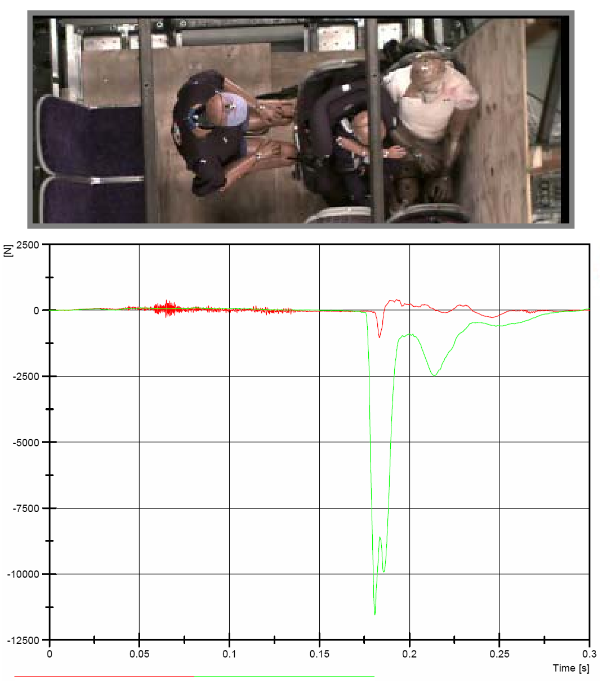

Figure 17. 95th percentile Femur Compression Injury Mechanism, due to Head-to-Head Contact.

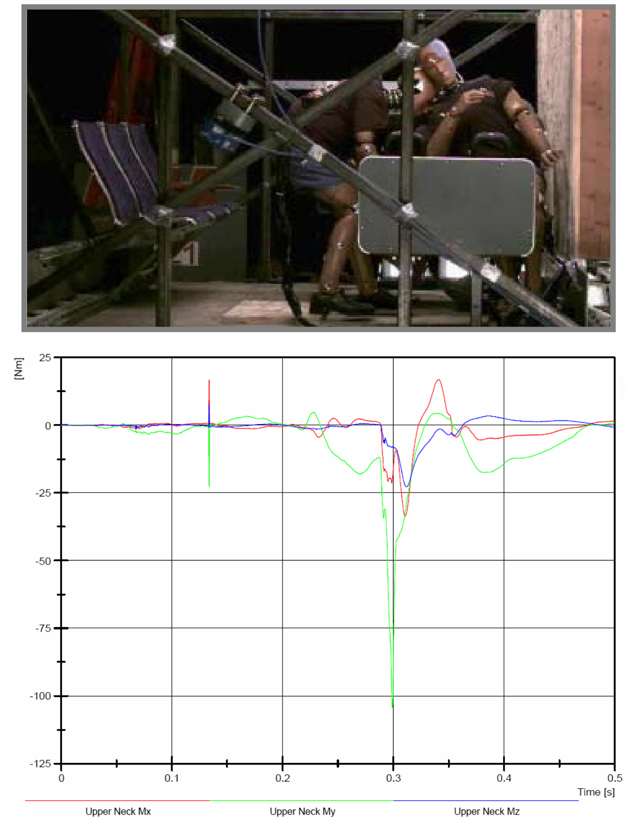

Figure 18. 50th percentile Neck Extension Injury Mechanism, due to Head-to-Head Contact.

The most common injury mechanisms for passengers seated on side facing seats during sided impact conditions are; head and neck injuries due to head-to-head or head-to-body contacts (see figures 16, and 18) and femur compression due to femur-seat contacts (see figures 18 and 19).

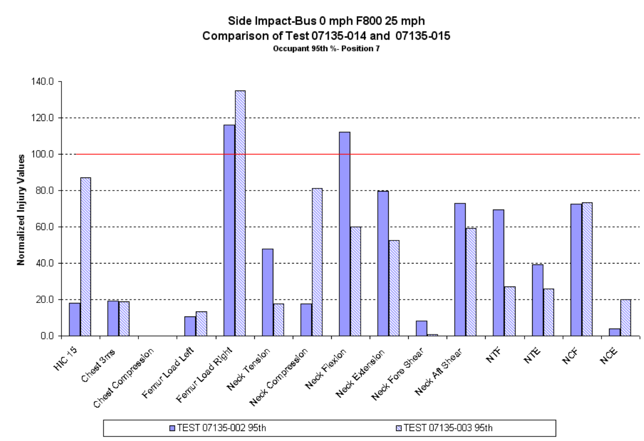

Figure 19. Bus 0 mph Bus – 25 mph F800 Side Impact 90 degrees (Repeatability 95th percentile ATDs).

REAR IMPACT INJURY MECHANISMS

A series of sled tests for rear impact configuration were conducted for occupant sizes ranging from the 5th to the 95th percentile ATDs.

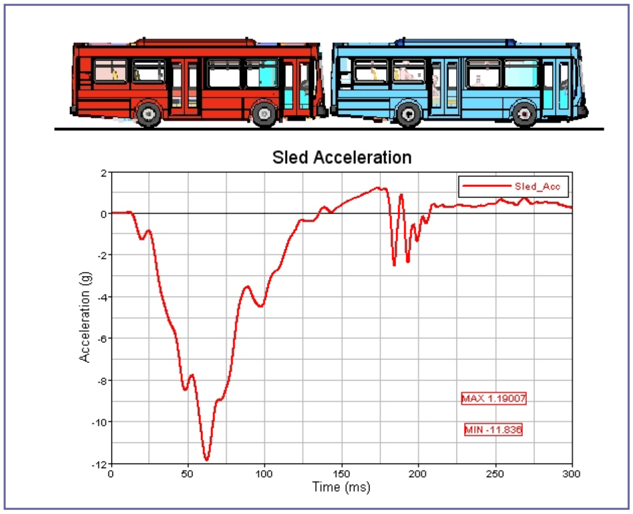

Figure 20. Crash Condition 20 mph Bus – 0 mph Bus Rear Impact

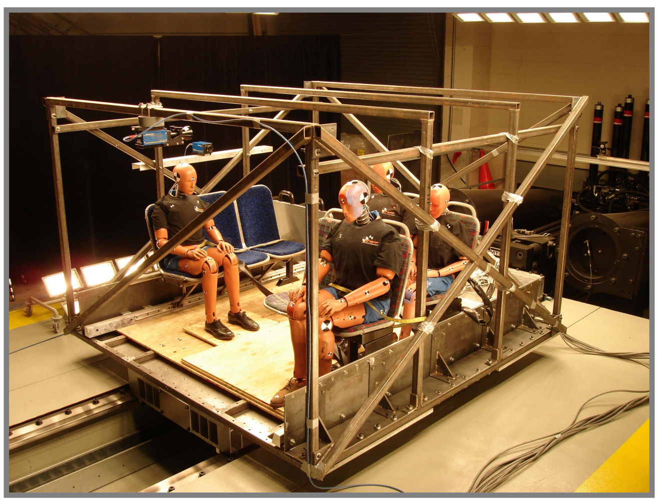

Figure 21. Crash Condition 20 mph Bus – 0 mph Bus Rear Impact

As shown in figures 24 the most common injury mechanism for occupants of all sizes (5th, 50th and 95th percentile) is neck extension. This injury mechanism is due to the low back seat designs and the rearward rotational stiffness of seatbacks. Current ongoing research at NIAR with modified high seat back designs has shown that the neck flexion moment can be significantly reduced to levels within FMVSS 208 due care values.

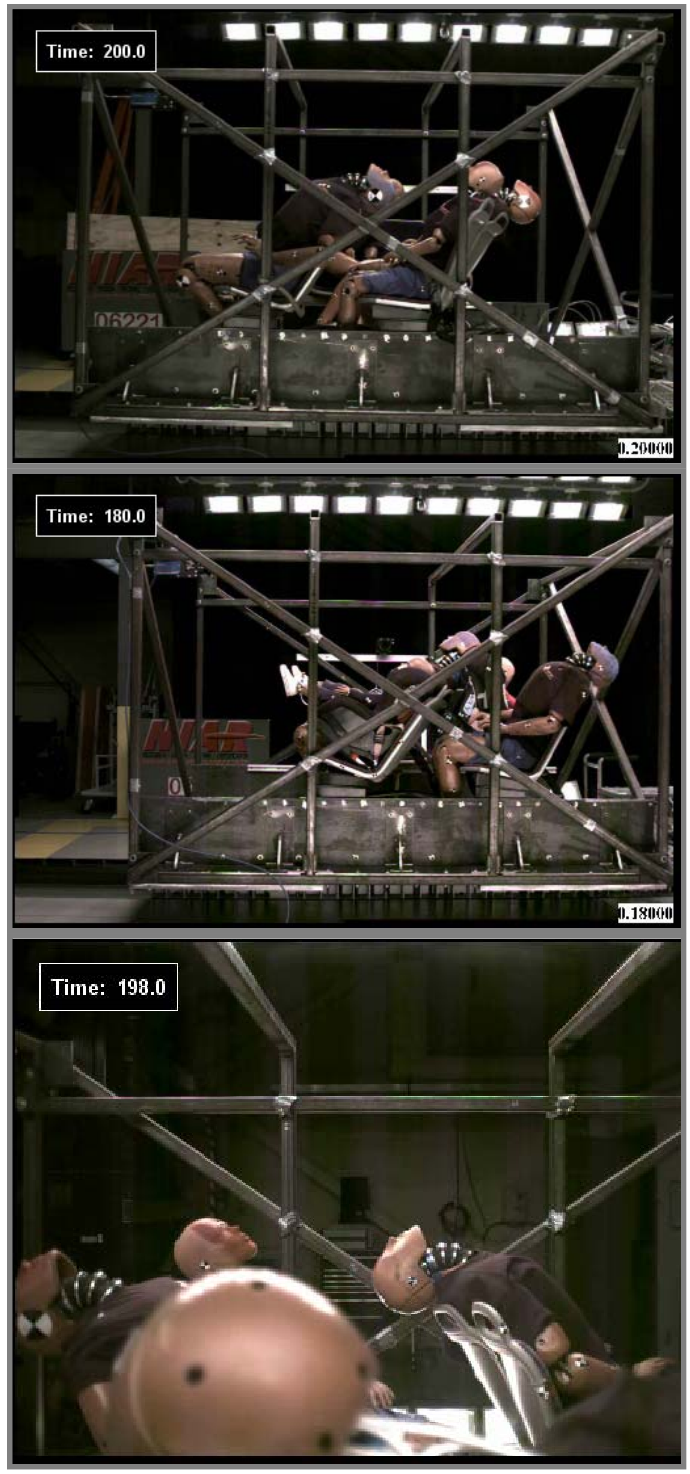

Figure 22. Crash Condition 20 mph Bus – 0 mph Bus Rear Impact (5th, 50th and 95th percentile Passenger Kinematics).

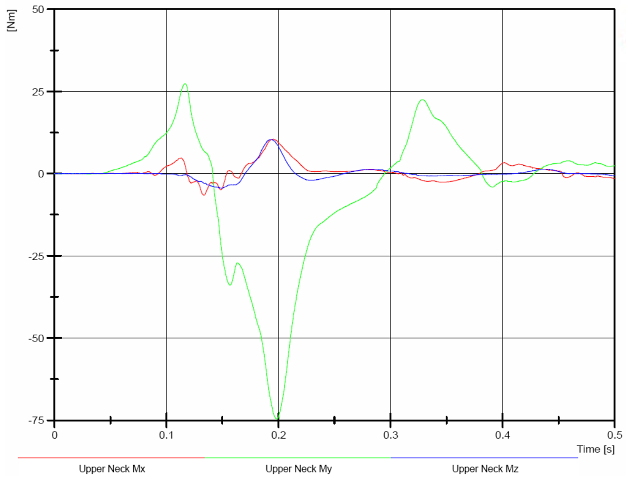

Figure 23. Crash Condition 20 mph Bus – 0 mph Bus Rear Impact (5th, 50th and 95th percentile Passenger Kinematics).

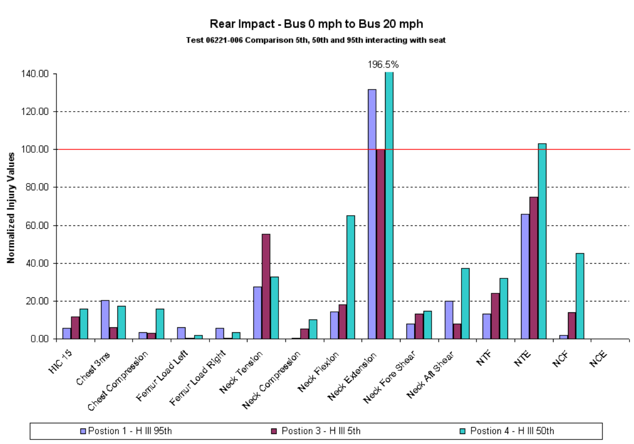

Figure 24. Bus 20 mph to Bus 0 Rear Impact Normalized Injury Values (5th, 50th and 95th percentile ATDs).

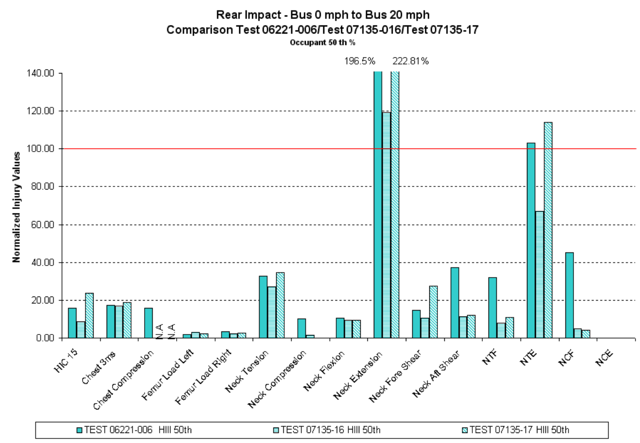

Figure 25. Bus 20 mph to Bus 0 Rear Impact Normalized Injury Values (Repeatability 50th percentile ATDs).

CONCLUSION

Buses are one of the safest forms of transportation. Nonetheless, bus crashes resulting in occupant injuries and fatalities do occur. According to the Traffic Safety Facts reports from 1999-2003, an average of 40 fatalities and 18,430 injuries of bus occupants occurred per year. The objectives of this research are to characterize the kinematics and injury mechanisms of bus passengers during typical frontal, side and rear impact conditions. Accident data from the traffic Safety Fact Reports, Buses Involved in Fatal Accidents Report and Transit Agency data were review to define typical crash scenarios. A detailed finite element model of a low floor transit bus was used to calculate the crash pulses at the passenger compartment for typical frontal, side and rear impact conditions. A series of sled tests with 5th, 50th and 95th percentile occupants were conducted at NIAR's Crash Dynamics Laboratory in order to study the occupant kinematics and to identify injury mechanisms to bus passengers.

The results of this study show that the most common injury mechanisms to bus passengers are head (HIC) and neck injury (neck extension, flexion and compression) mechanisms. The causes of these injury mechanisms are the following:

- For frontal impact conditions are due to head-seat back contacts. It should be noted that with current seatback designs it is difficult to maintain a consistent injury level, the interaction of the unbelted passenger with the seat yields either neck flexion or extension issues depending on the

- contact area. A compartmentalization approach should be used in order to provide head compliant surfaces for a wide range of passenger sizes.
- For passengers seated in side facing seats the most common injury mechanisms are head-neck injuries due to body-body contact and femur compression due to the passenger contact with seats across de aisle. These injuries could be improved if forward facing seats are used instead of side-facing configurations
- For rear impact conditions the most common injury type is neck extension. This injury mechanism is due to the low back seat designs and the rearward rotational stiffness of seatbacks. Current ongoing research at NIAR with modified high seat back designs has shown that the neck flexion moment can be significantly reduced to levels within FMVSS 208 due care values.

ACKNOWLEDGEMENTS

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the Federal Transit Administration (FTA), nor the U.S. Department of Transportation. The authors would like to acknowledge the financial support of the FTA.

REFERENCES

[1] Anon., Standard Bus Procurement Guidelines – 30-foot Low-floor Diesel Buses, American Public Transportation Association, 2002.

[2] Olivares, G., Herman T., "Mass Transit Crashworthiness Statistical Data Analysis", NIAR Technical Report No. FTA-0002, http://www.fta.dot.gov/documents/Crashworthiness_Report.pdf, December 2005.

[3] Anon., Traffic Safety Facts 1999: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System, National Highway Traffic Safety Administration, National Center for Statistics and Analysis, U.S. Department of Transportation, Washington DC 20590. December 2000.

[4] A. Matteson, D. Blower, D. Hershberger and J. Woodrooffe, Buses Involved in Fatal Accidents Factbook 2001, Center for National Truck and Bus Statistics, University of Michigan Transportation Research Institute, Ann Arbor, Michigan, 48109-2150, February 2005.

[5] Olivares, G., "Transit Bus Crashworthiness: Finite Element Modeling and Validation", International Crashworthiness Conference, Athens, Greece, July 4-7, 2006.

[6] Olivares, G., Yadav V., "Structural Crashworthiness of Mass Transit Buses During Frontal Collisions." International Crashworthiness Conference, Tokyo, Japan, July 2008.

[7] Olivares, G., Yadav V., "Mass Transit Bus Compatibility during Frontal and Rear Collisions." ESV Paper 07-487, Lyon, France, July 2007.