LARGE SCHOOL BUS SAFETY RESTRAINT EVALUATION

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ABSTRACT

This paper describes ongoing research conducted by the National Highway Traffic Safety Administration (NHTSA) to evaluate the potential of safety restraints on large school buses.

School bus transportation is one of the safest forms of transportation in the United States. Large school buses provide protection because of their visibility, size, and weight, as compared to other types of motor vehicles.

Additionally, they are required to meet minimum Federal motor vehicle safety standards (FMVSS) mandating compartmentalized seating, emergency exits, roof crush and fuel system integrity, and minimum bus body joint strength.

INTRODUCTION

During the rulemaking process in the early 1970's to establish school bus safety standards, NHTSA evaluated available injury and fatality data, and existing research and public comments to determine what system(s) of occupant protection should be required in school buses. It was determined that the best method to provide crash protection to children on large school buses was to implement the concept called "compartmentalization." This method provides a protective envelope consisting of strong, closely-spaced seats, which have energy absorbing seat backs. Compartmentalization is regulated under FMVSS No. 222, and is applicable to all school buses with a GVWR (gross vehicle weight rating) greater than 4,536 kg (10,000 lbs). In addition to the energy absorbing seats and seat anchors required by FMVSS No. 222, small school buses with a GVWR less than 4,536 kg (10,000 lbs) are required to have a lap belt assembly at each seating position. Compartmentalization, along with other enhanced safety standards required for school buses, make these vehicles the safest on the road.

Although compartmentalization has proven to be an excellent injury mitigation concept, NHTSA has initiated an extensive research program to evaluate the next generation of occupant protection system(s). The agency's research plan consists of (1) determining the real-world effectiveness of the current federal requirements for school bus occupant protection, (2) evaluating alternative means of providing occupant protection by conducting simulations of real-world school bus crashes in controlled laboratory tests, (3) ensuring that proposed new restraint systems do not adversely affect existing occupant protection system(s), and (4) if justified, proposing the next generation of occupant protection requirements for school buses.

This paper will present the results from the three phases of the research program: (1) the definition of the problem, (2) the two full-scale dynamic crash tests conducted with large school buses, and (3) the series of dynamic sled tests conducted to evaluate restraint alternatives.

PHASE I - PROBLEM DEFINITION

The NHTSA reviewed several sources of information in an effort to define the effectiveness of the existing FMVSS requirements applicable to school buses. Data from the agency's FARS (Fatality Analysis Reporting System), NASS (National Automotive Sampling System)-GES (General Estimates System), and SCI (Special Crash Investigations), along with state and local officials' crash information and data from the NTSB (National Transportation Safety Board) were analyzed. The agency also issued a request for input from the public concerning school bus safety.

Based on GES data, it is estimated that 8,500 injuries per year occur involving school buses. Of this total, 7,285 (86%) are classified as minor; 885 (10%) are classified as moderate; and 350 (4%) are classified as serious to critical.

FARS data from 1988 through 1997 were analyzed to determine the number of school bus passenger fatalities in crashes in an effort to evaluate the crashworthiness characteristics of large school buses. The data was sorted to included cases in which the large school bus was being used for either school related activities or other purposes. It was determined that, in the 10 year time period, 115 fatalities were passengers of large school buses.

Results of Phase I - Problem Determination showed that (1) 115 fatalities occurred for occupants of large school buses over a 10 year period from 1988-1997, and (2) the most significant factors in fatal, two-vehicle crashes are that they occur on roadways where the posted speed limit is 88.5-96.5 kph (55-60 mph) and involve heavy trucks (83% frontal impacts and 15% side impacts).

PHASE II - SLED TEST PULSE DEVELOPMENT

Based on the analytical results from Phase I, two full scale crash tests were defined to be representative of the real-world environment of large school bus crashes.

Frontal Crash Test

The first crash test was conducted by frontally impacting a conventional style school bus (Class C) into a rigid barrier at 48.3 kph (30 mph). The impact speed was chosen to ensure that sufficient energy would be imparted to the occupants in order to evaluate the protective capability of compartmentalization, plus provide a level at which other methods for occupant injury mitigation could be evaluated during sled testing. A 48 kph (30 mph) impact into the rigid barrier is also equivalent to two vehicles of similar size impacting at a closing speed or delta V of approximately 96 kph (60 mph), which was found to be prevalent in the crash database files under Phase I.

Figures 1 and 2 show pre-impact and post-impact photographs, respectively, for the frontally impacted bus. As typical of large school bus manufacture, the body of the bus was mounted to the frame rails of the chassis by a series of clips or clamps. This non-rigid mounting feature allowed the bus body to slide forward approximately 92 cm (36 in.) during impact (see Figure 3). This dissipation of impact energy over a longer time duration acted to reduce the acceleration levels seen by the vehicle's occupants

Figure 5 shows the dummy seating positions for this test.

Figure 1. Pre-Test Photograph of Frontal Rigid Barrier Crash Test

Figure 2. Post-Test Photograph of Frontal Rigid Barrier Crash Test

Figure 3. Movement of Bus Body Along the Frame (Rear of Bus Body and Frame)

The dummies used were the Hybrid III 50th percentile adult male (representing adult and large teenaged occupants), the Hybrid III 5th percentile adult female (representing an average 12 year old occupant), and the Hybrid III 6 year old.

For the crash tests and the subsequent HYGE sled tests, the dummies were placed into their seated positions by ensuring that they were as upright as possible and as rearmost on the seat cushion as possible. There currently is no specific seating

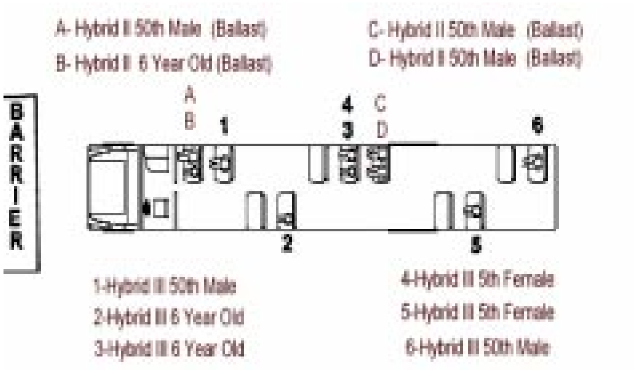

Figure 4. Seating Diagram for Frontal Rigid Barrier Crash Test

procedure, such as there is under FMVSS Nos. 208 and 214, for positioning dummies in school bus seats.

Table 1 contains the dummy injury values for the frontal crash tests. The neck injury (Nij) value is calculated based on the criteria being used for the revised FMVSS No. 208 "Occupant Protection." The pass/fail criterion for Nij is 1.0, which is the onset of serious injuries. The head injury criterion (HIC) value is based on a 15 millisecond (msec) duration, with FMVSS No. 208 criteria being 700 for the 50th percentile adult male, 5th percentile adult female, and 6 year old dummies. The chest acceleration value is based on a 3 msec duration, with pass/fail criteria being 60 g's for 50th, 5th, and 6 year old dummies.

Table 1.
Frontal Crash Test Results

Dummy	Nij	HIC	Chest G
#1 (50th M)	0.91	244	26.0
#2 (6 yo)	1.57	93	30.8
#3 (6 yo)	1.06	251	30.9
#4 (5th F)	1.15	105	No Data
#5 (5th F)	1.38	330	22.6
#6 (50th M)	0.84	150	22.3

Accelerometers were positioned along the center aisle of the bus body to record accelerations during the crash. Figure 5 shows the x-axis acceleration time histories for the four locations (including the vehicle's lateral center of gravity (CG)). Note that all traces are quite similar in shape and peak values. These acceleration time histories were filtered to 10 Hz to eliminate the frequency nodes introduced by the sheet metal floor and to give a relatively smooth trace that can be replicated with the sled impactor. Upon deriving these acceleration time histories, a metering pin was designed and fabricated by HYGE, Inc. to be used in the sled impactor. The derived sled acceleration pulse is shown overlaid with the center of gravity pulse (circle symbols) from the school bus crash test in Figure 6. The sled pulse agrees very well with the time duration (approximately 210 msec) and the peak acceleration (approximately 12-13 g's). The

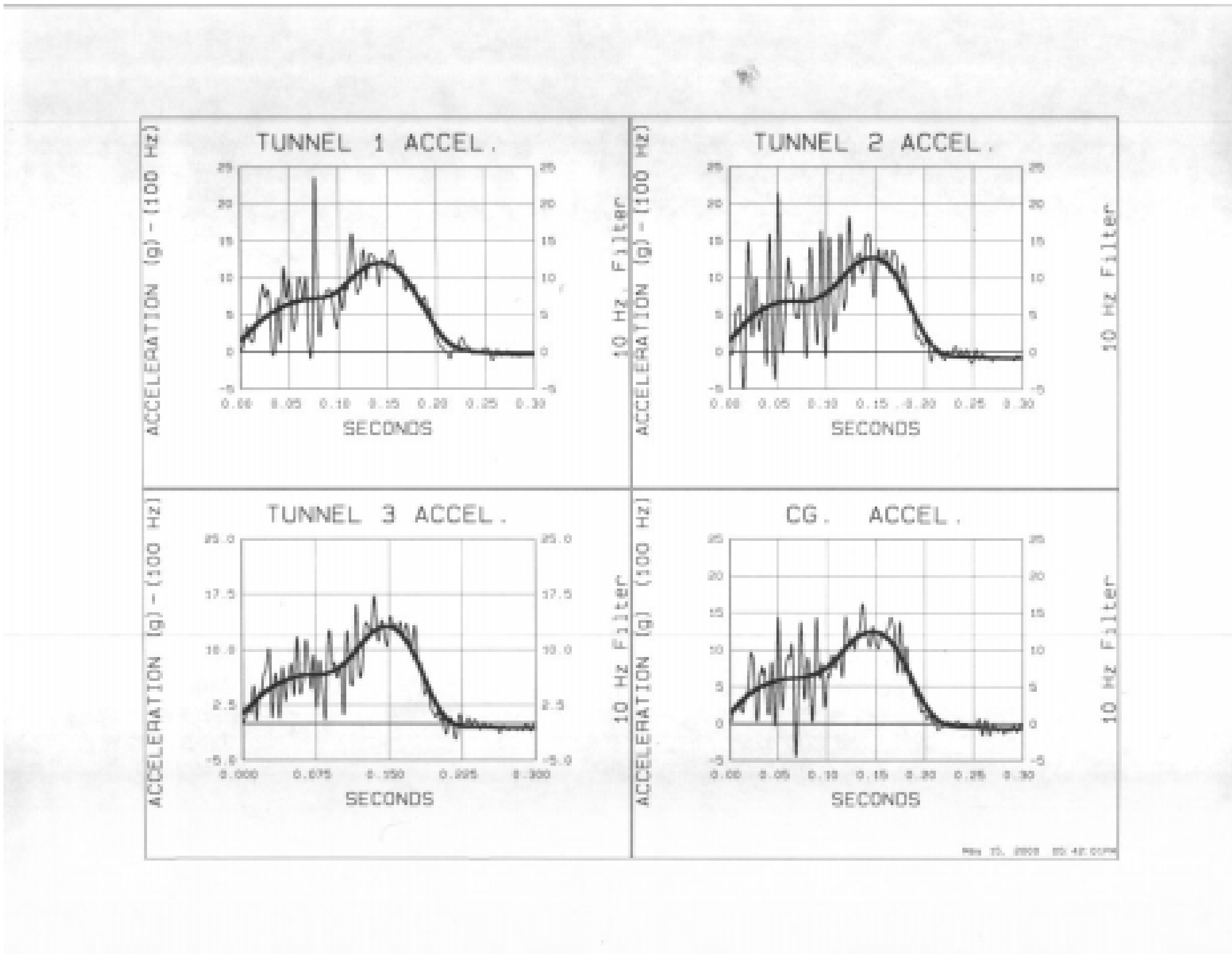

Figure 5. School Bus Acceleration Profile (X-axis) Class 60 Filtering with 10 Hz Filter Overlay

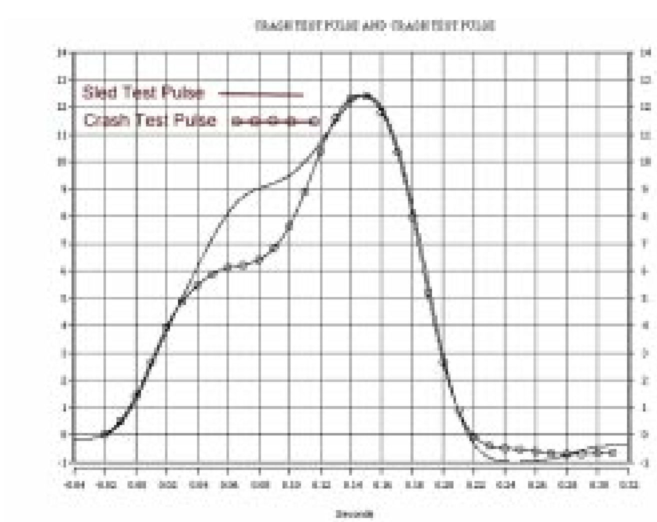

Figure 6. Crash Test Acceleration Pulse With Sled Pulse Overlay

leveling off of the acceleration pulse of the crash test from about 40-90 msec is a result of the bus body sliding along the chassis. The sled metering pin did not exactly replicate this plateau, allowing a somewhat higher acceleration level at this point in the curve. This resulted in a slightly more severe test pulse since the peak velocity of the sled was approximately 6.4-8 kph (4-5 mph) higher than the barrier equivalent velocity measured during the frontal crash test.

Side Impact Crash Test

The second crash test was conducted by towing a 11,406 kg (25,265 lb) cab-over truck, at 72.4 kph (45 mph) and 90º, into the side of a transit style school bus (Class D). The school bus was stationary at time of impact. The impact point was chosen such that the left front edge of the truck was directly behind the front axle of the school bus to eliminate contact with rigid structures on the frame during the initial penetration of the truck into the bus body. Figure 7 shows the pre-impact positioning of the heavy truck relative to the side of the school bus. A post-impact photograph showing the positioning of the school bus and truck is contained in Figure 8. During impact, the truck penetrated the bus side approximately half way into the compartment, and remained engaged while rotating 180^0 before coming to a stop. The front axles were severed from both vehicles (Figure 8).

Figure 7. Pre-Test Photograph **-** Side Impact Crash Test

Figure 8. Post Test **-** Side Impact Crash Test

The seating positions of the dummies are shown in Figure 9. As in the frontal crash tests, the Hybrid III 5^{th} female and 6 year old dummies were used. Replacing the Hybrid III 50^{th} male dummies were two 50^{th} male SID/Hybrid III dummies which are capable of measuring lateral head, chest and pelvic accelerations. One of the SID/Hybrid III dummies was positioned a row behind the direct impact zone of the truck (position 2 in Figure 9). One Hybrid II 50^{th} male dummy with a single tri-axial accelerometer array in the head was positioned directly centered at the point of impact to determine "survivability" within the impact zone (position 1 in Figure 9).

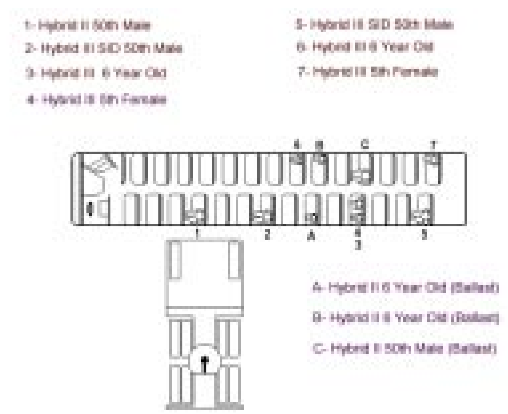

Figure 9. Schematic of Dummy Seating for Side Impact Crash

Table 2 presents the results for the side impact crash test. HIC values are based on a 15 msec duration and chest accelerations values are based on a 3 msec duration, with the same pass/fail criterion as in the frontal tests. For the SID dummies, the Thoracic Trauma Index (TTI) is recorded. A value of 85 g's indicates the onset of serious injuries and is a pass/fail criterion under FMVSS No. 214 "Side Impact Protection."

Table 2.
Side Impact Crash Test Results

Dummy	HIC	Chest G	TTI
#1 (HII)	2164	N/A	N/A
#2 (SID)	277	N/A	54.7
#3 (5^{th} F)	85	27.7	N/A
#4 (6 yo)	124	11.1	N/A
#5 (SID)	133	N/A	7.1
#6 (6 yo)	54	22.7	N/A
#7 (5^{th} F)	1	7.4	N/A

Accelerometers were positioned along the length of the school bus. Figure 10 shows the acceleration time histories overlaid for this test. At the center of impact, a peak lateral acceleration of 72 g's was recorded. Acceleration levels drop significantly away from the point of impact. This is largely due to the amount of deformation that occurred at the point of impact. This deformation acted to absorb/dissipate much of the energy that would otherwise have been transmitted to the occupants of the bus.

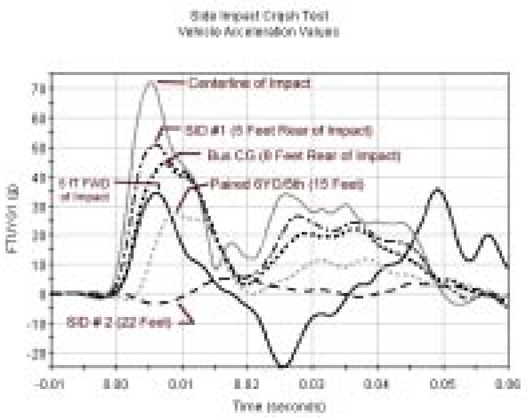

Figure 10. Side Impact Crash Test Vehicle Acceleration Pulses

Unlike the frontal crash, no single pulse is fully representative of the range of vehicle responses observed in the side impact crash. However, the overall pulse shape and pulse duration remain similar for most of the measured locations along the length of the bus.

PHASE III - SLED TESTING AND VALIDATION

The first series of sled tests were conducted to replicate the acceleration time history of the school bus full scale frontal impact test. As stated previously, a metering pin was designed and fabricated based on the pulses derived from the crash test. For the initial series of sled tests, a test buck was fabricated by mounting a section from the body of a large school bus to the sled. This was done to: 1) assess the degree of deformation/energy absorption by the bus floor and its interaction with the seats, and 2) assess any potential for occupant interaction with portions of the interior other than the seats themselves. The finished test buck is shown in Figure 11. The bus body section contained three rows of seats on both the right and left side of the center aisle, which allowed for testing a maximum of 2 rows of dummies per test.

Figure 11. Sled Buck - Frontal Crash Simulation Testing

Sled Test Matrix

The initial series of sled tests was designed to evaluate three main factors: (1) occupant size, (2) restraint strategies, and (3) loading conditions. The occupant sizes of interest were an average 6 year old, represented by the Hybrid III 6 year old dummy (114 cm/51.6 kg); an average 12 year old, represented by the Hybrid III 5th female dummy (150 cm/49 kg); and a large high school student, represented by the Hybrid III 50th male dummy (175.3 cm/78.2 kg).

Three different restraint strategies were evaluated: (1) compartmentalization, (2) lap belt only, and (3) lap/shoulder belts on a bus seat with a modified seat back.

For the initial test series, testing was conducted at a seat spacing of 48 cm (19 in.). Seat spacing is determined by measuring from the H-pt. of the SAE 3-dimensional H-pt. point machine to the back of the seat located in front of the dummy. This value was selected based on information obtained from FMVSS No. 222 compliance test data. FMVSS No. 222 allows a maximum seat spacing of 61 cm (24 in.). While 48-56 cm (19-22 in.) is the range observed for most seats spacing from the available data, 48cm (19 in.) is the minimum seat spacing that readily allows the normal seating of a Hybrid III 50th male dummy.

For the lap belt only tests, seats and belts were purchased directly from bus manufacturers. The OEM (original equipment manufacturer) lap belt modified seats had additional reinforcement in the seat bench to withstand the loading of the belted occupants. The seat back itself was identical to the OEM's standard seat. For the lap/shoulder belt tests, two bus seat manufacturers each provided a modified seat, designed for a 3-point restraint. The backs of these seats were strengthened to withstand the additional loading imposed by the restrained torso through the shoulder belt.

The last factor evaluated was the loading conditions on the occupants. Three different conditions were simulated: (1) restrained occupants without any loading from occupants seated behind them, (2) restrained occupants with loading from unrestrained occupants seated behind them, and (3) unrestrained occupants into seat back in front of them. Figure 12 contains a schematic showing the seating configuration for Condition #1 - restrained without rear occupant loading. Condition #2 - restrained with rear occupant loading, is shown in Figure 13. The schematic for Condition #3 - unrestrained into front seat back, is contained in Figure 14.

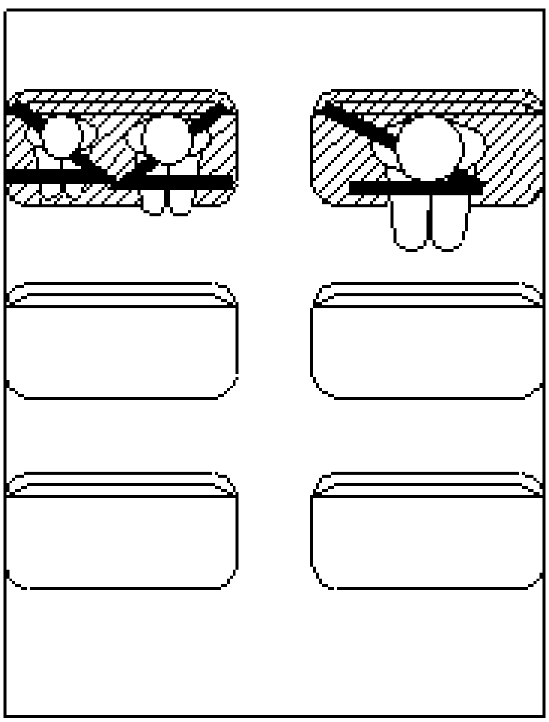

Figure 12 - Schematic For Condition#1 Seating (Restrained Without Rear Occupant Loading)

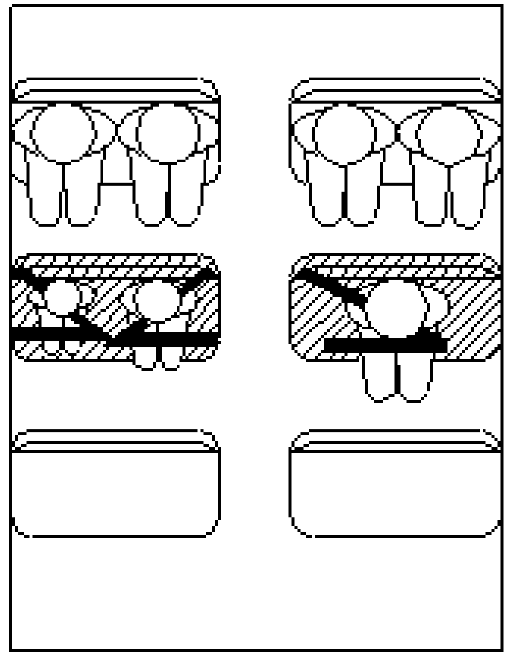

Figure 13 - Schematic for Condition #2 (Restrained with Rear Occupant Loading

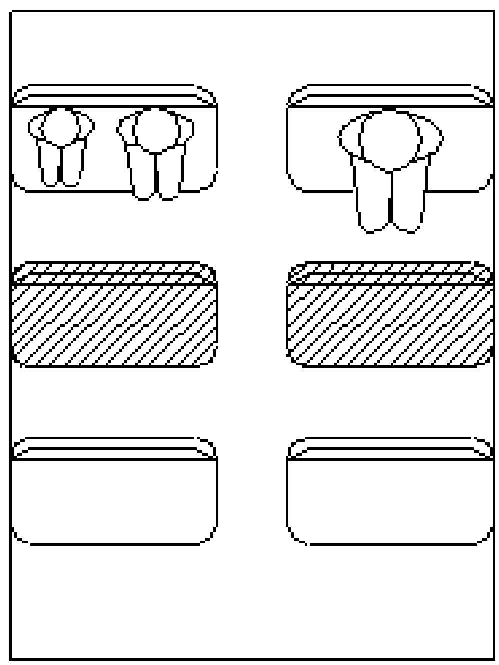

Figure 14-Schematic for Seating Condition #3 (Un-restrained into Seat Back)

Sled Test Results

A total of 13 tests were conducted in the initial test series. Note: For this test series, there are insufficient data for meaningful comparisons with the 50th male dummy. Subsequent testing will include belted 50th male dummy tests.

Hybrid III 6 Year Old and 5th Female 3 ms Chest Clip For all of the tests conducted, the chest clip criterion values were well below the FMVSS 208 injury criterion threshold tolerance limit of 60 g's.

Figure 15 is a comparison of the chest 3 ms acceleration values for the 6 year old and 5th female dummies. The data shown here are average response values for the unrestrained, lap belted, and lap/shoulder belted tests (individual values for each test can be reviewed in the tabulated data).

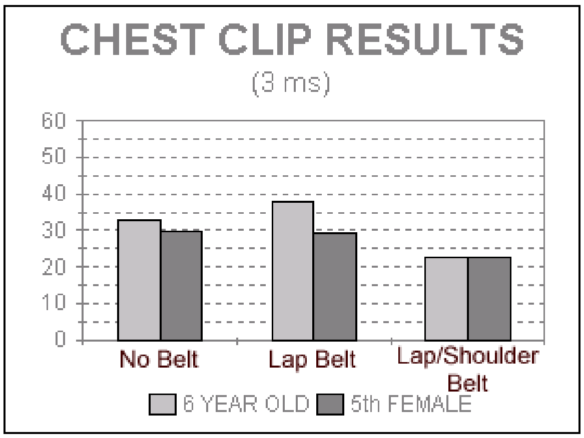

Figure 15 - Comparison of Chest Injury Criterion Results

The lap/shoulder belted tests resulted in slightly lower injury values than the lap belt only and compartmentalization tests.

Hybrid III 6 Year Old and 5th Female Head Injury (HIC) Results Figure 16 is a comparison of the HIC test results. These results are aggregate values and do not include those tests in which the unrestrained dummy impacted into the rear of the modified seat backs of the lap/shoulder belt seat systems tested. For this analysis, these seats were treated as a separate test condition.

The compartmentalized seating tests show essentially the same HIC response level as the lap belt tests. One

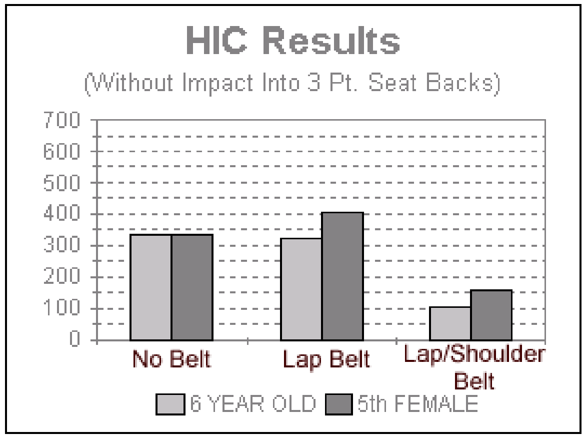

Figure 16- Comparison of Head Injury Criterion Results

notable difference not readily apparent in the averaged values is the high responses that occurred in some of the unbelted tests. When an unbelted 50th male dummy was seated behind either a 5th female or another 50th male dummy, the unbelted dummy could override the seat back to strike the head or back of the dummy seated in front of it. When this occurred, a high HIC value was typically observed. This tendency to override the seat back did not occur with dummies that were restrained with lap belt or lap/shoulder belt restraint systems. The high back seat design of the lap/shoulder belt seating systems also provided additional protection to the restrained occupant by limiting the possibility of a rear impact by an unrestrained occupant.

Tests with lap/shoulder belted occupants consistently produced lower HIC responses than those with lap belted and unbelted occupants. This was true for both the 6 year old and 5th female dummies.

Hybrid III 6 Year Old and 5th Female Neck Injury (Nij) Results Figure 17 shows the comparison of restraint performance based on the Nij results for the 6 year old and 5th female dummies.

The tolerance threshold limit for Nij is 1.0 for all dummy age groups. Both the 6 year old and 5th female dummies had average responses that exceed 1.0 for both the lap belted and the unbelted tests. The average Nij values were somewhat higher for the lap belted occupants than for the unbelted occupants. This difference was more pronounced for the 6 year old dummy than for the 5th female dummy.

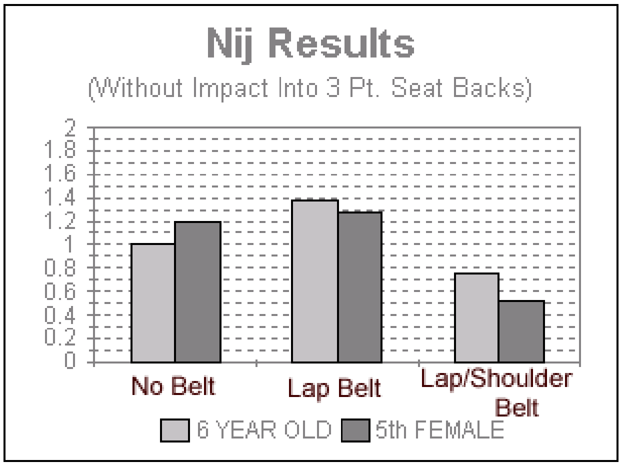

Figure 17- Comparison of Neck Injury Criterion Results

The lap/shoulder belted occupants had significantly lower Nij responses. None of the tests conducted in this series with a lap/shoulder belted occupant exceeded the Nij tolerance threshold limit of 1.0, however, several of these tests had values of 0.80 or higher.

Hybrid III 50th Male Results The 50th male Hybrid III dummy was used to provide rear loading for many of these tests. As a result, there is a relatively large body of data for the unbelted condition. However, there is very little data (1 test) for the lap belted condition. Comparison between the three restraint strategies is necessarily limited at this time.

Analysis of the 50th male results showed that a number of the unbelted tests had HIC values which exceeded the revised FMVSS 208 (15 msec.) HIC tolerance threshold limit of 700. Each of these high injury values were attributed to the incidental contact with the dummy seated in front of it. The greater mass and higher stature of the 50th male dummy increased the probability for override to take place and allowed incidental contact to occur. The high seat back design of the lap/shoulder belt seats reduced the probability of incidental contact even when a degree of override of the seat back took place.

In general, HIC and Nij values were notably reduced when the 50th male dummy was tested with the lap/shoulder belt restraint. The lap/shoulder belted 50th male dummy tended to have lower HIC and Nij responses than the 6 year old and 5th female dummies for the same test conditions. This observed benefit may be due to the relatively better fit of the currently available lap/shoulder belt restraint systems to the adult's stature.

56 cm (22 in.) Seat Spacing Results A single test was conducted in which the seat spacing was set at 56 cm (22 in.). Unbelted and lap belted conditions were examined using both the 6 year old and the 5th female dummies in this test. With one exception, seat spacing had little effect on dummy responses across the various test conditions (6 year old and 5th female dummies, lap belted and unbelted). The exception was for the lap belted 5th female dummy. For this condition (lap belted at a 56 cm seat spacing), the Nij response was significantly higher.

Examination of the high speed films for this test indicated a difference in loading on the neck that was apparently due to the difference in seat spacing. It became apparent that seat back spacing could have a significant effect on the lap belt restrained occupant. This effect appeared to be a result of occupant size (stature), belt compliance (belt fit, belt stretch, etc.), and seat spacing.

Based on these results, a second series of tests was conducted and the results are being analyzed at the time of this paper. This second series of tests specifically addressed the effects of seat back height, seat back spacing, and seat back padding (for a lap/shoulder seat back design). Additional testing also addressed the misuse of a lap/shoulder belt restraint system in which the shoulder portion of the system was placed behind the back, or under the arm, of the occupant.

DISCUSSION

The findings presented in this paper are preliminary. At most, they provide an indication of the performance of the various restraint configurations. At this time, there are not sufficient data to justifiably "rank" the individual types of restraints for comparative purposes, much less to determine a superior occupant protection method, or to propose that any particular method be required for school buses.

All three configurations tested provided some level of protection. Initial analysis indicates that the protection capabilities are affected by such parameters as occupant size, spacing between the seats, proper usage of the restraint system and construction of the seat.

RECOMMENDATIONS

Additional frontal impact research is needed to evaluate the effects of seat spacing and seat back design. Results from one test indicate that seat spacing can effect dummy kinematics and responses. In conjunction with the seat spacing, the design (rigidity, padding, height) of the seat back structure needs to be further evaluated to ensure that occupant injuries levels are not increased due to contact with the seat backs that have incorporated lap/shoulder belt restraints.

In addition to more frontal impact research, side impact research is needed to evaluate the effects of side wall padding and/or redesign of school bus side structure(s).