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VERIDIAN ON-SITE SCHOOL BUS INVESTIGATION
SCI TECHNICAL SUMMARY REPORT

VERIDIAN CASE NO. CA03-020

VEHICLE: 1991 CARPENTER SCHOOL BUS

LOCATION: FLORIDA

CRASH DATE: MARCH 2003

Contract No. DTNH22-01-C-17002

Prepared for:

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points are coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics in order to determine the pre-crash, crash, and post-crash movements of involved vehicles and occupants.

Because each crash is a unique sequence of events, generalized conclusions cannot be made concerning the crashworthiness performance of the involved vehicle(s) or their safety systems.

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VERIDIAN ON-SITE SCHOOL BUS INVESTIGATION
VERIDIAN CASE NO. CA03-020
VEHICLE: 1991 CARPENTER SCHOOL BUS
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BACKGROUND

This on-site investigation focused on the performance of the roof structure of an 83-passenger Type-D 1991 Carpenter school bus. The bus was operated by a 50-year old female driver and was involved in a run-off-road rollover crash **(Figure 1)**. There were no students on board the bus at the time of the crash. The roof of the school bus collapsed to the beltline **(Figure 2)** during the two-quarter turn rollover event. The school bus driver was seated in a high-back suspension seat and was restrained by the manual 3-point lap and shoulder belt system. She sustained a fracture of the left femur, multiple rib fractures, a superior scalp laceration, and multiple soft tissue contusions. The driver was transported to a local hospital where she was admitted for a period of four days for surgical repair of the femur fracture. She was transferred to a rehabilitation facility for five days prior to discharge to her residence. Following an inspection of the collapsed roof on the school bus by local transportation officials, all similar Carpenter school buses (13) were removed from service by the county operated school bus transportation district.

Figure 1. CCW trajectory and final rest position of school bus.

Figure 2. Collapsed roof of the 1991 Carpenter school bus.

A representative of the Florida Department of Education notified NHTSA's Office of Defects Investigation (ODI) of the March 2003 crash. The crash was assigned to the Veridian Special Crash Investigation team on Wednesday March 26th as an on-site investigative effort. The Veridian SCI team established cooperation with the county school bus transportation administration and representatives from the Florida Department of Education. Due to a scheduled spring break for the county school district, the on-site investigation was scheduled for Monday, April 7th. The investigation included a detailed inspection and documentation of the involved school bus, documentation of the crash site, a detailed interview with the school bus driver, and an inspection of a sample of exemplar Carpenter school buses.

SUMMARY

Crash Site

The crash occurred during daylight hours in a residential area on a divided two lane state route at the transition point of a designated left turn lane. The driver of the school bus was traveling in a westerly direction on the two-lane roadway that was straight and level. The travel lanes were 3.7 m (12.1') in width and were separated by a painted flush median that measured 3.5 m (11.5') in width. The north (right) edge of the roadway was bordered by a 1.3 m (4.3') wide asphalt shoulder with a grassy area adjacent to the shoulder that transitioned to a shallow drainage ditch. The south (left) road edge was bordered by a 1.1 m (3.6') wide asphalt shoulder with a 20.1 m (51.1') wide grassy area adjacent to the shoulder. The travel lanes were marked with solid white edge lines and double yellow painted median/center lines. A westbound left turn lane originated near the point of control loss for the bus and was 3.5 m (11.5') in width. A solid white lane line delineated this lane from the travel lanes.

The driver reported that the weather was clear on her approach to the impending crash site. She further noted that she detected a heavy rain shower ahead of her pre-crash trajectory, resulting in a wet asphalt road surface and possible pooling of surface water. The road surface was in good condition and was free of defects. The posted speed limit was 72 km/h (45 mph).

Vehicle Data

The involved school bus in this rollover crash was a 1991 Carpenter bus body mounted on an International Harvester chassis. The chassis Model No. was 3900FC with a Date of Manufacturer of 5-15-91 and a Vehicle Identification Number (VIN) of 1HVBCNUN8NH (production number deleted). The chassis consisted of a Navistar 466 diesel engine linked to a 4-speed Allied MT-643 automatic transmission built on a 581.7 cm (229.0") wheelbase. The Gross Vehicle Weight Rating (GVWR) for this vehicle was 14,615 kg (32,220 lb) with a 5,997 kg (13,220 lb) front axle GVWR and a 8,618 kg (19,000 lb) rear weight rating. The front tires were specified at 10.00-20G with 20x8.0 rims at 90 PSI cold pressure. The dual rear tires were specified as 10.00-20F with 20x7.5 rims at 75 PSI cold pressure.

The school bus body was manufactured by Carpenter Manufacturing on 7-18-91 at the Mitchell, Indiana facility. The bus model data was placarded on the front bulkhead and was as follows:

Model Year: 91
Body Model: SFT-3906
Body Serial No.: 912387
Passenger Capacity: 83 Passengers
Body Completed: 7/18/91

Adjacent to the above manufacturer label was a Service Campaign Sticker that identified the following:

Campaign No.: 92,506
VIN: NH (6-digit production number deleted)

Completed: 10/5/92
Service Location Code: 101637744

The glazing of the Type-D bus body consisted of a two-piece gasket mounted laminated windshield. The right door consisted of two panels that were outward hinged and pneumatically controlled by a switch located to the left of the driver's position. The doors contained four gasket mounted tempered glass glazing panels. All side windows, with the exception of the two emergency window exits, consisted of two tempered glass panels with an opening (sliding) top panel. The emergency window exits, located on each side between pillar I and J, consisted of laminated glazing. These emergency windows were hinged at the top with a locking lever at the mid bottom aspect. Two roof-mounted emergency exits/vents were centered in the roof between the F- and G-pillars and the M- and N-pillars. These roof exits identified by the following:

Dual Purpose Safety Vent
Transpec Inc.
A028925

The roof exits were 57.8 cm (22.75") square and hinged at the fore and aft aspects for venting with an emergency release lever located at the aft aspect of the unit. The rear of the bus was equipped with a single right hinged door that opened to the outside of the vehicle. Two tempered/gasket mounted glazing panels were mounted in this door.

The interior of the bus was equipped with an aftermarket high-back suspension driver's seat that was installed approximately one year prior to the crash. This seat replaced the low-back pedestal mount OEM seat. The driver's suspension seat was manufactured by Bostrom on 8-26-99 and identified by a bar-coded label as S790559385. This seat had a manual fore and aft track adjustment, a manual seat back recline feature, lumbar adjustment, front edge height adjustment, and the pneumatic vertical/suspension adjustment via a rocker switch.

The steering wheel was equipped with a tilt feature and was mounted on a rigid column (non-energy absorbing column) with a measured angle of 35 degrees aft of vertical. In the inspected position, the steering wheel was set at an angle of 25 degrees off horizontal.

The driver's seat position was equipped with a 3-point lap and shoulder belt system. The buckle was mounted to the driver's seat frame and tethered to the floor by two 40.6 cm (16.0") lengths of belt webbing. The lap belt retracted into a locking retractor that was mounted to the outboard aspect of the seat frame and tethered to the floor via dual 40.6 cm (16.0") webbing tethers. The shoulder belt webbing extended from a B-pillar mounted emergency locking retractor (ELR) with a webbing sensitive mode and routed through a fixed D-ring. The latch plate was sewn-on to both the lap belt and shoulder belt webbings. This belt system did yield evidence of frequent usage and was worn by the driver at the time of the crash.

The passenger compartment of the bus was configured with 13 rows of three-passenger high-back bench seats and a back row of two, two-passenger bench seats to facilitate egress through the rear emergency door. The 13 rows of high-back bench seats were equipped with cushions that measured 95.3 cm (37.5") in width and 39.4 cm (15.5") in depth. The seat backs measured 64.8 cm (25.5") in height and were spaced approximately 63.5 cm (25.0") apart. This bus was not equipped with lap belts for the passenger positions.

Side/Roof Construction of the Carpenter School Bus

The roof of the 1991 Carpenter school bus was constructed of a roof bow that spanned the width of the bus, terminating at the top of the side structure, above the side windows at the top of the side pillars. The roof bows were formed (stamped) from 10-12 gauge sheet metal [measured at approximately 32 mm (0.125")] in the shape of a U-channel with two 90 degree flanges at each side. The face of the bow measured 3.5 cm (1.375") in width with side depths of 4.1 cm (1.625"), and 1.9 cm (0.75") wide flanges. The exterior roof panels were screwed and/or riveted to the flanges while the interior roof panels were screwed into the face of the bows. On the crash involved bus (and similar exemplar buses), the roof bows were positioned over every pillar (A-Q-pillars) with additional bows spaced evenly between the pillars on 35.6 cm (14.0") centers, except at the locations of the emergency roof exits (pillars F- and G-, and M- and N-pillars) and emergency side window locations (I- and J-pillars). Pillar locations E- and F-, G- and H-, and H- and I- were also void of the additional roof bows. Fiberglass batt-type insulation was cut to fit between the roof bows.

The roof bows were welded to an angle iron side rail that measured 6.0 cm (2.375") vertically, 4.4 cm (1.75") horizontally, and 32 mm (0.125") in thickness. The vertical aspect of the angle iron was positioned inboard with respect to the bus, with the open aspect of the angle facing outward. The 3.5 cm (1.375") wide faces of the roof bows were welded to the inside angle aspect of the vertical angle iron.

An additional angle iron strap was welded to the bottom aspect of the angle iron side rail and was positioned on top of the vertical pillars. This component measured 4.4 cm (1.75") horizontally with a formed 90-degree angle and a vertical leg of 9.5 mm (0.375") in height. This angle was positioned over the angle of the side rail and was welded with approximate 2.5 cm (1.0") long welds spaced on 15-18 cm (6-7") centers. This additional angle iron was 9.5 mm (0.375") in thickness.

The right C- through Q- and left B- through Q-pillars were formed of 10-12 gauge sheet metal in the shape of a U-channel with two side flanges similar to the roof bows. The face of the pillar measured 5.7 cm (2.25") with 90-degree bends that measured 3.8 cm (1.5") in depth. An outward 90-degree flange was bent at both sides and measured 1.6 cm (0.625"). The pillars were mounted to the bus with the face exposed to the interior surface of the bus and the open channel facing the exterior of the bus body.

The vertical pillars butted to the bottom surface of the additional angle iron section and arc (stick) welded to this surface. It should be noted that the face and both side surfaces

of the pillars (U-channel) were welded to this angle iron side rail. In general, the quality of these welds were poor, with occasional voids in the "continuous bead" weld and blow (burn) holes through the pillar material. The flux that adhered to the weld was not chipped off the pillar prior to the painting process; therefore the flux would crack giving the appearance of a cracked weld. These flux cracks could be easily chipped away to reveal the weld itself. (This flux issue was prevalent on this bus and observed on the exemplar buses.)

The bus window units were fastened to the body via four screws into the pillars. An adhesive was applied to the window opening to prevent water leaks.

Interior sheet metal panels were screwed longitudinally to the roof bows to form the interior ceiling of the bus. Aluminum side panels were screwed to the pillars of the bus to form the interior sidewalls. Similar panels were screwed and riveted to the exterior flanges of the roof bows and pillars to form the exterior "skin" of the school bus.

Tire Data

The 1991 International chassis/Carpenter body school bus was equipped with Goodyear G159A Radial tires sized at 11R 22.5 at all six wheel positions. All tires and steel wheels remained intact and were not damaged by the rollover event. The following table identifies the tread depth, inflation pressures, and DOT numbers documented at the time of the SCI investigation.

Location	***Tread Depth***	***Inflated Pressure***	***DOT Number***
Left Front	5.5 mm (7/32") full width	699.4 kPa (102.0 PSI)	MC3T 275W 2100
Right Front	4.8 mm (6/32") full width	689.1 kPa (100.5 PSI)	Unknown, not visible
Left Rear, outer	2.4 mm (3/32") full width	682.3 kPa (99.5 PSI)	MC3T 275W 489
Left Rear, inner	4.0 mm (5/32") outer two grooves, 2.4 mm (3/32") inner two grooves	Unknown, gauge not compatible with stem configuration	Unknown, not visible
Right rear, outer	4.0 mm (5/32") outer two grooves, 2.4 mm (3/32") inner two grooves	Unknown, gauge not compatible with stem configuration	Unknown, not visible
Right rear, inner	6.4 mm (8/32") outer two grooves, 4.0 mm (5/32") inner two grooves	Unknown, gauge not compatible with stem configuration	Unknown, not visible

Crash Sequence

Pre-Crash

The driver of the 1991 Carpenter school bus was traveling in a westerly direction on the two-lane state route at a driver estimated speed of 64-72 km/h (40-45 mph). On her approach to the impending crash site, the driver noted that a heavy rain shower had passed through the area ahead resulting in a wet asphalt road surface. As she entered the area of wet pavement, the driver stated that she looked down at the speedometer to check her travel speed. As she redirected her attention forward to the road surface, the driver stated that the bus broke traction on the wet asphalt surface and initiated a counterclockwise (CCW) yaw. Although the driver was trained to steer into a skid, she was reluctant to attempt a clockwise steering input to the bus. She backed-off the accelerator pedal and maintained her grip on the steering wheel rim as the bus continued to yaw CCW. The driver did not attempt avoidance actions. The Crash Schematic is attached as **Figure 26** on Page 21.

Figure 3. CCW yaw marks of the school bus.

The bus yawed across the painted median and left turn lane **(Figure 3)** and departed the south (left) shoulder. As the school bus departed the south road edge line, the bus had rotated approximately 42 degrees CCW. The SCI inspection of the crash site occurred 19 days post-crash. Substantial physical evidence remained at the crash site to reconstruct the trajectory of the school bus. Both front tire yaw marks and the dual right rear tire marks remained evident on and off the asphalt road surface. The right front yaw mark was 35.9 m (117.8') in length and ended 9.75 m (24.8') into the grassy roadside. The left front tire mark began in the eastbound travel lane and extended 17.25 m (43.8') in length, ending 10.3 m (33.8') south of the south road edge line. The right rear dual tire yaw marks were 26.5 m (86.9') in length and terminated 3.9 m (12.8') south of the reference edge line. As the bus entered the wet grassy off-road surface, the tires furrowed into the earth which tripped the school bus into a lateral right side leading rollover event. At the on-set of the rollover, the school bus yawed approximately 109 degrees in a CCW direction.

Crash

The school bus initiated a lateral side-over-side rollover event, leading with the right side. There was minimal contact evidence on the school bus and no distinct gouges in the grassy area, thus supporting a "soft rollover". The initial contact probably involved the right roof side rail area of the school bus. This contact resulted in an angular (non-horizontal) impact force to the side rail area which resulted in a lateral component to the roof structure's loading force. As a result of this force, combined with the roof construction and possible fractured welds of the pillar/side rail juncture, the roof subsequently collapsed laterally left and vertically downward. As the roof structure

collapsed, the bus rolled onto the roof and came to rest in an inverted attitude. At rest, the bus was facing in a southeasterly direction, resting on the right beltline.

Post-Crash

The school bus driver was restrained by the manual 3-point lap and shoulder belt system. The belt system restrained the driver within the high-back seat and prevented her from possible ejection.

Firefighter and paramedic personnel arrived on-scene within minutes of the rollover crash and immediately assessed the status of the driver. She was found in a conscious state with obvious pain from the femur and rib fractures. Rescue personnel cut the shoulder belt webbing 11.4 cm (4.5") above the latch plate and unbuckled the lap belt. A cervical collar was applied and the driver was placed on a backboard and removed from the bus through the windshield opening. She was placed on a cot and loaded in an ambulance where she was prepared for transport to a local hospital. The driver stated that she was administered morphine to alleviate pain at the scene of the crash.

Following the police investigation, the bus was up-righted and towed from the scene to the school bus compound. Personnel from the bus company subsequently used the tow truck to lift the roof of the bus. Wood braces were placed against the left wall/floor juncture of the bus and positioned diagonally to the right header area of the roof structure to support the roof in an upright position. In this position, the school bus personnel performed an inspection of the bus. This was also the position of the roof at the time of the on-site SCI inspection.

Vehicle Damage

Exterior

The school bus sustained severe structural integrity loss during the rollover event that resulted in a near total collapse of the roof. The primary damage to the Carpenter body school bus was isolated to the greenhouse (beltline area and above) area of the vehicle. The roof collapse resulted in damage to all vertical pillars, multiple glazing damage, and damage to the right door and the rear emergency door. Damage below the greenhouse area was rated as moderate. **Figures 4 and 5** are overall views of the exterior damage.

As the school bus yawed in a CCW direction across the grassy area off the south road edge, the right tires furrowed into the earth which tripped the vehicle into a lateral rollover event. Grass was embedded into bead of the right tires/wheels, however, the tires did not debead. Dirt was transferred onto the side surface of the bus in a spray pattern above the axle positions. Dirt and grass were also embedded into the right A-pillar at the beltline and at the rear bulkhead area of the bus.

Figure 4. Front left view of the 1991 Carpenter school bus.

Figure 5. Front right view of the bus with the roof repositioned.

The construction of the bus at the roof side rail/pillar juncture contributed to the structural collapse of the roof. Although the pre-crash condition of the welded joints was unknown, the post-crash inspection and documentation of these joints, and the identification of numerous cracked welds on exemplar buses, the roof structure on this bus was probably weak. The downward and lateral forces applied to the right roof side rail area during the rollover event swayed the roof laterally left. As the forces were exerted on the welded joints, the joints failed due to poor quality welds and stress overload of the design.

The right A- through I-pillars completely separated at the welded joints to the side rail **(Figure 6)**. The right J- through O-pillars sustained partial weld separations and/or tearing of the side surfaces of the pillar U-channel. The left upper A-pillar separated completely at the side rail. The left B-through Q-pillars exhibited a combination of cracked welds, torn side surfaces, and near complete separation of the pillars from the fabricated side rails. As the side surfaces of the formed pillars failed due to the weld separations or stress overload, the face weld of the pillar acted as a hinge point as the roof was deflected laterally left.

Figure 6. Separation of the right A- through I-pillars.

The upper pillar failures weakened the side structure of the bus body by defeating the structure's ability to distribute the lateral load through the roof bows and off-side. The loading initiated the lateral bending of the pillars at the beltline. Based on the on-scene images of the bus at final rest, all right side pillars deflected at the beltline, shifting the roof laterally left. The left pillars deflected outward at the beltline, decreasing in severity from front-to-back. The left rear corner area of the roof structure was minimally displaced. At final rest, the right beltline area of the bus was in near full contact with the ground. The left side of the bus roof was angled upward front-to-back supported by the deflected roof. **Figures 7 and 8** are on-scene images of the roof collapse.

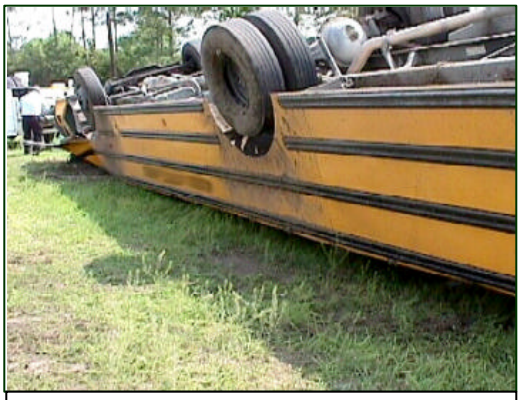

Figure 7. On-scene image of the roof collapse at the right side.

Figure 8. Left side roof collapse as viewed from the front of the Carpenter school bus.

The right side doors were displaced laterally left by the roof deflection. The lower right B-pillar separated from the sill, resulting in body panel separation. Six screw fasteners pulled through the sheet metal resulting in the separation of the lower panel.

The upper pillar weld performance and post-crash pillar status are addressed in the table below. It should be noted that the roof was repositioned to the right and supported internally by wooden cross braces prior to the SCI inspection. This repositioning may have altered the welds and pillar damage by further cracking the welds and/or reducing the gaps/tears at the pillar/side rail junctures.

Table 1. Pillar/Weld Status

Left Pillars	***Post-Crash Status***	***Right Pillars***	***Post-Crash Status***
A	(1.5”) square stock pillar, steel fractured at side rail, complete separation. Lower A-pillar at beltline cracked at three sides, outer aspect hinged	A	(1.5”) square stock, complete separation at side rail/header
B	Same construction as C-Q-pillars. Top weld cracked at face, both side sheet metal surfaces torn	B	Upper B-pillar - 1.5” square stock with 1.25” square internal sleeve. Completely disengaged from side rail, no weld visible. Lower B-pillar separated from sill/step well (6 screws pulled through)
C	Both side surfaces separated from tears and weld separation, face weld held	C	Complete separation at welded joint, poor weld

Left Pillars	*Post-Crash Status*	*Right Pillars*	*Post-Crash Status*
D	Both side surfaces of pillar ripped below welds, face weld cracked	D	Complete separation, 3/8" of pillar face torn, remainder of weld separated as if "not welded" (Figure 11)
E	Near complete separation of pillar. Both side aspects of pillar torn, welds intact; face weld cracked	E	Complete separation, minimal sheet metal torn, poor weld
F	Near complete separation of pillar. Both side aspects of pillar torn, welds intact; face weld cracked (Figure 9)	F	Complete separation of weld (Figure 12)
G	Near complete separation of pillar. Both side aspects of pillar torn, welds intact; face weld cracked	G	Complete separation of weld
H	Near complete separation of pillar. Both side aspects of pillar torn, welds intact; face weld cracked	H	Complete separation of weld
I	Near complete separation of pillar. Both side aspects of pillar torn, welds intact; face weld cracked	I	Complete separation at weld
J	Near complete separation of pillar. Side welds cracked, aft aspect of face weld cracked	J	Leading side surface separated
K	Side welds cracked, face weld partially cracked and acted as hinge point (Figure 10)	K	Side surfaces of pillar torn, welds partially intact, face weld intact, side rail partially separated
L	Side welds cracked, face weld partially cracked and acted as hinge point	L	Side surfaces of pillar torn, welds partially intact, face weld intact, side rail partially separated
M	Side welds cracked, face weld partially cracked and acted as hinge point	M	Side surfaces of pillar torn, welds partially intact, face weld intact, side rail partially separated
N	Side welds cracked, face weld partially cracked and acted as hinge point	N	Side surfaces of pillar torn, welds partially intact, face weld intact, side rail partially separated

Left Pillars	*Post-Crash Status*	*Right Pillars*	*Post-Crash Status*
O	Side welds cracked, face weld partially cracked and acted as hinge point	O	Forward side and forward ½ of face weld cracked, poor weld with minimal surface engagement
P	Side surface of pillars torn, face welds partially cracked and acted as hinge points	P	Forward side and forward ½ of face weld cracked, poor weld with minimal surface engagement
Q	Header sliced forward of pillar, ¾" gap, welds held	Q	Header spliced forward of pillar, 1.25" gap, welds held

Figure 9. Crack at left F-pillar weld.

Figure 10. Tear and cracked welds at the left K-pillar

Figure 11. Separation of the right D-pillar.

Figure 12. Separation of the right F-pillar.

Interior Damage

The interior of the school bus sustained moderate severity damage that resulted from the severe intrusion of the roof. The roof collapsed onto the driver's high-back (integral head restraint) seat back, deflecting the upper aspect of the seat back forward. The collapse of the roof structure resulted in contact of the right side widow units against the top aspect of the high-back seat backs. Numerous right side glazing panels were shattered and several seat backs were deflected rearward. The compression of the seat frames resulted in the complete separation of numerous seat cushions. **Figure 13** is an overall view of the bus interior.

Figure 13. View looking rearward of the interior of the school bus.

Driver Demographics/Data

Driver Age/Sex:	50-year old female
Height:	160.0 cm (63.0")
Weight:	86.2 kg (190.0 lb)
Manual Restraint Usage:	3-point lap and shoulder belt system
Usage Source:	Vehicle inspection, observations of the first responders, driver interview
Driver License Status:	Current Commercial Driver's License (CDL)
School Bus Driving Experience:	17 years
Experience This Bus:	Possibly first time; however, the driver has driven numerous, similar Type-D Carpenter/International buses
Route Experience:	8 months, assigned this route September 2002; drives this particular route daily both work and personal (driver lives approximately 3.2 km from crash site)
Mode of Transport From Scene:	Removed from vehicle by rescue personnel and transported by ambulance to a local hospital
Type of Medical Treatment:	Admitted to hospital for treatment for a period of five days and transferred to a rehabilitation facility for five days prior to discharge to residence.

Driver Injuries

Injury	Injury Severity (AIS 90 Update 98)	Injury Severity
*Proximal fracture of the left subtrachanteric femur	Serious (851818.3,2)	Left side surface/radio
*Anterio-lateral left 4th and 5th rib fractures	Moderate (450220.2,2)	Shoulder belt webbing
+Sutured (8-9 staples) laceration of the left parietal scalp	Minor (190602.1,5)	Intruding roof/headliner
+Left anterior leg abrasion	Minor (890202.1,2)	Left side interior
#Multiple contusions (NFS)	Minor (990400.1,0)	Multiple sources

Source – ** Hospital Discharge Summary and radiology*
+ Emergency Room Report
 # Driver interview

Driver Kinematics

The 50 year old female driver of the school bus was seated in a mid track position in the high-back suspension seat and was restrained by the manual 3-point lap and shoulder belt system. She had both hands positioned on the steering wheel rim in a probable bracing action and her feet positioned over the foot pedals. She did not attempt to regain control of the bus or initiate avoidance action as the bus initiated the CCW yaw.

During the rollover, the driver loaded the manual 3-point lap and shoulder belt system. Although the belt system exhibited historical usage/wear indicators, there was no distinct loading evidence of the belt webbing or hardware components. The driver's loading of the belt system resulted in multiple rib fractures. Her left thigh loaded against the left side mounted two-way radio and/or the horizontally oriented steering wheel rim that resulted in a left femur fracture. As the roof of the bus collapsed, the driver's head contacted the intruding headliner/interior roof panel that resulted in a laceration of the driver's frontal scalp. She also sustained multiple contusions and noted that several contusions developed from medical intervention. **Figure 14** is an overall view of the driver seat back and her contact points.

Figure 14. Driver's seat and contact points.

Medical Treatment

The driver of the school bus was transported by ambulance to a local hospital where she was admitted for treatment of her injuries. The left femur fracture required open reduction/internal fixation with the placement of a rod and a pin to secure the fracture site. In addition to the femur fracture, the driver's scalp laceration was sutured with 8-9

staples within the hairline. The driver was hospitalized for a period of four days then released to a rehabilitation facility for an additional five days prior to discharge to her residence.

Exemplar School Bus Inspections

A sample of 14 exemplar Carpenter school buses was inspected during this on-site SCI investigation. These inspections included 12 Type-D buses that were manufactured within months of the crash involved bus and purchased within the same order as the crash bus, and two Type-C buses with manufacturer dates of 1994 and 1998. The Type-C buses were located in counties adjacent to the location of the crash. It should be noted that the Carpenter School bus manufacturing facility in Mitchell, Indiana was reportedly closed in August 1995 and all bus manufacturing was transferred to a facility in Richmond, Indiana. It was reported by school bus personnel in Florida at the time of this SCI investigation, an engineering change occurred in the roof bow/pillar design at the time of this plant transfer. A continuous one-piece pillar/roof bow was used in the post-August 1995 Richmond manufactured Carpenter buses that replaced the welded components found in the crash bus and pre-1995 exemplar buses.

The purpose of the inspection of the exemplar buses was to verify the preliminary findings of the school bus transportation personnel regarding cracked welds on the exemplar fleet and to document the potential problem for this SCI investigation. School bus fleet personnel removed the side panels covering the pillar/side rail areas to facilitate the inspection process. The exemplar bus data is provided below:

Exemplar Bus No. 1

1998 Carpenter Type-C Conventional
65 Passenger Carpenter/Crown
VIN: 1HVBBAAN1WH (production number deleted)
Model No: 01-3004-74
Serial No.: 473022
Date of Manufacture: 2/98

This Richmond, Indiana Carpenter body school bus was manufactured following the design change of the roof/pillar structure. This system utilized a continuous one-piece roof bow/pillar that extended from floor-to-floor of the bus **(Figure 15)**. An interior roof panel, pillar covering, and window assembly were removed from this bus to facilitate the inspection and photographic documentation of this design. There were no structural/manufacturing problems identified with this bus.

Figure 15. Continuous roof bow/pillar in the 1998 Carpenter bus.

Exemplar Bus No. 2

1994 Carpenter Type-C Conventional
32 Passenger (configured with a lift and three wheel chair positions)
VIN: 1HVBBPLN2RH (production number deleted)
Model No.: 01-2909-001
Serial No.: 117747
Date of Manufacture: 7/93
Odometer: 222,248 km (138,102 miles)

This Mitchell, Indiana Carpenter body school bus was purchased by an adjacent county school district in August 1993. The vehicle was modified from its original design with a wheel chair lift at the right rear side area of the body and three wheel chair restraint tie-down systems. To accommodate the Q-Straint wheel chair restraint systems, additional steel strapping was welded to the side rail area of the body. This strapping was 25.4 mm x 4.8 mm (1.0 x 3/16"), welded to the angle steel side rail and concealed by the interior paneling. This bus had a rated passenger capacity of 32, inclusive of the wheel chair positions.

A preliminary visual inspection of the pillar/side rail welds was performed by the SCI investigator prior to the removal of the interior roof panels. This preliminary inspection resulted in the identification of several suspected weld issues. The school bus technician removed the interior roof panels that partially concealed the suspected welds at the pillar/side rail juncture. A flashlight and an inspection mirror were utilized to enhance the welded joints during the inspection process. The following table identifies the observations that were noted upon a closer examination of the welded joints.

Aspect/Location	***Observation***
Left D-pillar	Fore and aft sides of pillar weld cracked
Left E-pillar	Poor quality weld; sides of pillar weld cracked, possible crack on face of weld
Left F-pillar	Both side welds cracked, aft half of face weld cracked **(Figure 16)**
Right E-pillar	Both side welds cracked
Right F-pillar	No damage, this weld appeared better than most
Right G-pillar	Forward aspect of side weld cracked, forward 5/8" of face weld cracked, poor quality weld **(Figure 17)**
Right H-pillar	Both side welds cracked
Right I-pillar	Aft side weld cracked

Figure 16. Left F-pillar of Exemplar Bus No. 2.

Figure 17. Cracked weld at the right G-pillar of Exemplar Bus No. 2.

Exemplar Bus No. 3

1991 Carpenter Type-D
83 Passenger
VIN: 1HVBCNUN6NH (production number deleted)
Model No.: SFT-3906
Serial No.: 912381
Date of Manufacture: 6/19/91
Odometer: 409,680 km (254,570)

This Type-D Carpenter school bus was last in service as a replacement bus and was used on an as-needed basis. At the time of the SCI investigation, this bus had been removed from the active service fleet. Again, an initial inspection of the pillars was performed and the appropriate interior panels were removed following the identification of suspected problem areas. The following table identifies the observations of Exemplar Bus No. 3:

Aspect/Location	***Observation***
Left C-pillar	All three surfaces of the pillar weld were cracked, both sides and face
Left D-pillar	All three surfaces of the pillar weld were cracked, both sides and face **(Figure 18)**
Left E-pillar	All three surfaces of the pillar weld were cracked, both sides and face
Left F-pillar	All three surfaces of the pillar weld were cracked, both sides and face
Left G-pillar	All three surfaces of the pillar weld were cracked, both sides and face
Left H-through Q-pillars	Poor quality welds; however, welds appeared to be intact
Right B-pillar	Weld cracked

Aspect/Location	*Observation*
Right C-pillar	Weld intact
Right D-pillar	Weld intact
Right H-pillar	Poor quality weld, forward ¾" of face weld cracked
Right J-pillar	100 percent of weld cracked on all three surfaces **(Figure 19)**
Right K-pillar	Aft side surface cracked, face weld intact
Right L-pillar	100 percent of weld cracked on all three surfaces
Right M-pillar	Weld intact
Right Q-pillar	Aft aspect of pillar not welded

Figure 18. Cracked weld at the left D-pillar of Exemplar Bus No. 3.

Figure 19. Cracked weld a the right J-pillar of Exemplar Bus No. 3.

Exemplar Bus No. 4

1991 Carpenter Type-C
17 Passenger
VIN: 1HVBBNKL7NH (production number deleted)
Model No.: SB-2304
Serial No.: 912734
Date of Manufacturer: 10/21/91
Odometer: 143,522 km (89,183 miles)

This exemplar conventional Carpenter school bus was equipped with a wheel chair lift and three designated wheel chair positions. The bus had a rated passenger capacity of 17. A visual inspection of the pillars was performed and there were no visible fractures of the pillar welds. The flux on the welds was cracked and was easily chipped off. It should be noted that the welds at the pillar/side rail junctures were poor quality welds as illustrated in **Figures 20 and 21.**

Figure 20. Right F-pillar of Exemplar Bus No. 4.

Figure 21. Right H-pillar of Exemplar Bus No. 4.

Exemplar Bus No. 5

1991 Carpenter Type-D
83 Passenger
VIN: 1HVBCNUN3NH (production number deleted)
Model No.: SFT-3906
Serial No.: 912390
Date of Manufacture: 7/26/91
Odometer: 354,258 km (220,132 miles)

This out-of-service Carpenter school bus was last used as a replacement bus on an as-needed basis. The pillar welds of the 83 passenger bus were visually examined and all suspected cracked welds were closely examined following the removal of the interior roof panels. The observations are noted below.

Aspect/Location	***Observation***
Left F-pillar	Weld cracked at the midpoint of face extending to the full width of the aft side surface **(Figure 22)**
Left G-pillar	Weld intact
Left J-pillar	Weld intact; large weld, atypical of fleet
Left K-pillar	100 percent of weld cracked **(Figure 23)**
Left L-pillar	Weld intact
All right side pillars	Welds intact

Figure 22. Cracked weld at left F-pillar of Exemplar Bus No. 5.

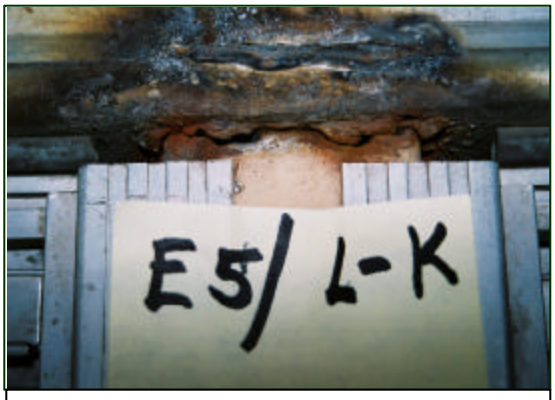

Figure 23. Complete crack of weld at left K-pillar of Exemplar Bus No. 5.

Exemplar Bus No. 6

1991 Carpenter Type-D
83 Passenger
VIN: 1HVBCNUN4NH (production number deleted)
Model No.: SFT-3906
Serial No.: 912383
Date of Manufacture: 7/17/91
Odometer: Unknown
(Instrument cluster had been replaced prior to bus taken out of service. 83 miles recorded on odometer)

This bus had been removed from the service fleet prior to the SCI investigation. A visual inspection of the pillar welds was performed and the suspected fracture sites were closely examined following the removal of the interior roof panels. The observations are as follows:

Aspect/Location	***Observations***
Left pillars	All welds appeared to be intact
Right B-pillar	Weld intact
Right C-pillar	Hairline crack through entire weld, all three surfaces **(Figure 24)**
Right D-pillar	Hairline crack of both side welds, extending ½" on face weld at both sides; mid aspect of face weld intact **(Figure 25)**
Right E- through Q-pillars	All welds appeared intact

Figure 24. Hairline crack at right C-pillar of Exemplar Bus No. 6.

Figure 25. Crack side and face welds of right D-pillar of Exemplar Bus No. 6.

An additional eight (8) 1991 Carpenter Type-C and Type-D school buses were inspected at the county school bus facility. All of these buses were of the same body construction of the crash involved bus and the exemplar buses that were documented above. A visual inspection of the pillar/side rail welds was performed on these buses with a random removal of the interior roof panels. None of the welds in these buses appeared to have been fractured. It should be noted that the quality of welds was poor and similar to the welds observed on the crash bus and documented exemplar buses.

Crash Schematic

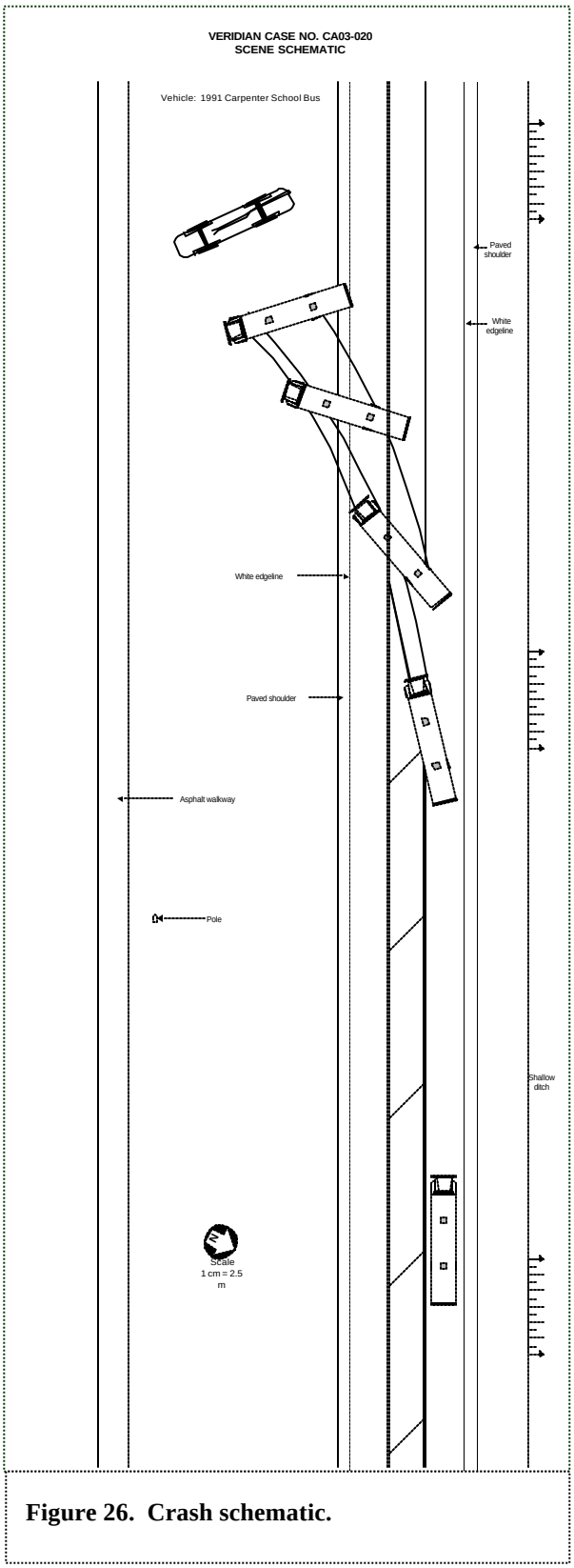

Figure 26. Crash schematic.