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Special Crash Investigation On-Site SKT Guardrail End Terminal Crash Investigation Vehicle: 1991 GMC Sonoma Location: Missouri Crash Date: April 2016

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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 be coupled with the investigator's expert knowledge and experience of vehicle dynamics and occupant kinematics 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 vehicles or their safety systems.

This report and associated case data are based on information available to the Special Crash Investigation team on the date this report was published.

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16. Abstract This report documents the investigation of a crash of a 1991 GMC Sonoma into an SKT guardrail end terminal. The GMC was occupied at the time of the crash by a 48-year-old belted male driver and an unbelted 48-year-old female seated in the front row right position. While the GMC traveled east on a limited-access roadway, it drifted right from its travel lane. The GMC's front plane struck the SKT impact terminal, which displaced the impact head and deformed the guardrail system. During impact engagement, the GMC rotated clockwise and rolled one quarter-turn left-side-leading into the guardrail system. Post-crash, the driver and front row right occupant were assisted from the vehicle by emergency personnel. They were then transported by ambulances to the local hospital for police-reported incapacitating (A-level) and non-incapacitating (B-level) injuries, respectively. The crash was identified by an engineer with the Missouri Department of Transportation, who in-turn submitted notification to the Federal Highway Administration, which determined that the crash type and guardrail end treatment met the criteria for further research and subsequently forwarded notification to the Crash Investigation Division of the National Highway Traffic Safety Administration in April 2016.			
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CRASH DATE: APRIL 2016

BACKGROUND

This report documents the investigation of a crash of a 1991 GMC Sonoma into an SKT guardrail end terminal (**Figure 1**). The GMC was occupied at the time of the crash by a 48-year-old belted male driver and an unbelted 48-year-old female seated in the front row right position. While the GMC traveled east on a limited-access roadway, it drifted right from its travel lane. The GMC's front plane struck the SKT impact terminal, which displaced the impact head and deformed the guardrail system. During the impact engagement, the GMC rotated clockwise and rolled one quarter-turn left-side-leading into the guardrail system. Post-crash, the driver and front row right occupant were assisted from the vehicle by emergency personnel. They were then transported by ambulances to the local hospital for police- reported incapacitating (A-level) and non-incapacitating (B-level) injuries, respectively. The crash was identified by an engineer with the Missouri Department of Transportation (MoDOT), which in turn submitted notification to the Federal Highway Administration (FHWA). The FHWA determined that the crash type and guardrail end treatment met the criteria for further research and subsequently forwarded notification to the Crash Investigation Division (CID) of the National Highway Traffic Safety Administration in April 2016. The CID assigned an on-site investigation of the crash to the Special Crash Investigations (SCI) team at Crash Research & Analysis, Inc., on the same day. The SCI team initiated contact and achieved cooperation with MoDOT to conduct an on-site investigation.

Figure 1: Left front oblique view depicting the deformation of the 1991 GMC Sonoma.

The on-site investigation occurred in April 2016, and consisted of an inspection of the SKT guardrail system and the damage it sustained during the crash. The physical plant of the roadway was documented using a total station mapping system and photographs. An inspection of the GMC was conducted to document its exterior and interior damage, inclusive of the measurement of structural deformation and intrusion, identification of occupant contact, and an evaluation of the manual restraint systems. The 1991 GMC was not equipped with supplemental restraint systems (air bags) or an event data recorder. Medical record data was obtained from the local hospital for both occupants.

CRASH SUMMARY

Crash Site

This road departure/fixed object crash occurred during the nighttime hours in April 2016 on a two-lane limited-access interstate highway. The police-reported environmental conditions at the time of the crash were clear, dark, and dry. Conditions in the locale as reported by the National Weather Service included clear skies with a temperature of 15.6 ºC (60 ºF), 62 percent relative humidity, and 9.3 km/h (5.8 mph) westerly winds.

The physical environment of the crash site and guardrail was documented during the SCI inspection using a Nikon Nivo 5.M+ total station mapping system. In the area of the crash, the asphalt-surfaced east/west interstate was straight and level. Respective travel directions were separated by a depressed grass median with a cable barrier guardrail system. The two eastbound lanes were delineated by broken white lines, with a solid yellow left lane line and a solid white right lane line. From left to right, the width of the left shoulder, left travel lane, right travel lane, and right shoulder measured 1.9 m (6.2 ft), 3.8 m (12.5 ft), 3.5 m (11.5 ft), and 2.8 m (9.2 ft), respectively. A rumble strip was cut into the pavement along the right lane line.

This section of the roadway approached a bridge overpass that was located approximately 0.4 km (0.25 miles) east of the crash site. As such, the respective sides of the roadway were bordered by W-beam guardrail systems. **Figure 2** depicts a west-facing lookback view of the GMC's approach, while **Figure 3** depicts the GMC's east trajectory toward the guardrail and end terminal. A Crash Diagram is included at the end of this report.

Figure 2: Westward lookback view of the GMC.

Figure 3: Eastward trajectory view of the GMC approaching the crash site.

Pre-Crash

The eastbound GMC was occupied by its 48-year-old belted male driver and the 48-year-old unbelted female front row right occupant. Manual restraint usage/non-use by the occupants was determined through the post-crash inspection of the vehicle, occupant kinematics, final rest

positions of the individuals, and the police-reported data.
For undetermined reasons, the GMC began to drift right as it traveled east on the limited-access roadway. The GMC departed the right travel lane and traversed across the shoulder, then departed the right edge of the roadway near the beginning of the end treatment and guardrail system. The estimated departure angle of the GMC with respect to the angle of the roadway was 5 degrees, with the right front corner of the GMC aligned with the SKT end terminal. There was no evidence of any attempted pre-crash avoidance maneuvers by the driver.

Crash

The crash occurred as the front plane/right corner of the GMC struck the impact-face of the SKT end terminal (Event 1). The width of the overlap from the left edge of the impact-face measured 13 cm (5.0 in). Forces associated with the impact displaced the impact head eastward and deformed the guardrail system. The impact head flattened the W-beam guardrail as it was displaced, resulting in the extrusion of 4.9 m (16 ft) of W-beam, separation of the beam from the posts, and deformation to the eight support posts that comprised the end treatment (**Figures 4 and 5**). The right bias of the impact caused the GMC to rotate clockwise, evidenced by divergent left tire yaw marks on the shoulder. The left rear tire mark measured 15.7 m (51.5 ft) long, while the left front tire mark measured 7.4 m (24.3 ft).

Figure 4: Trajectory view of the GMC at the point of impact with the end terminal.

Figure 5: West lookback view beyond the final rest position of the GMC toward the point of impact.

As the impact continued, the end terminal and W-beam were displaced to the southeast over the top of the posts as the front plane of the GMC progressively struck the support posts. The vehicle rotated along the line of posts, and the left aspect of its front plane engaged Post 4 as the GMC achieved approximately 50-degrees of rotation (Event 2). The end terminal was thrown 18.1 m (59.4 ft) to the east, which caused the W-beam to wrap around Post 7 and form a knuckle. Subsequently, the left plane/left door of the GMC struck the knuckle as the GMC slid broadside to the east (Event 3). The left door deformed and the sheet metal surrounding the door lock tore due to the overload force of the impact. This buckled and intruded the door, allowing the W-beam to penetrate the front row left interior space of the GMC.

The sudden application of the crash forces by the intrusion of the knuckled W-beam exacerbated the GMC's clockwise rotation. An instability was created with respect to the vehicle's center of mass, which caused the GMC to initiate a left side leading rollover (Event 4). The GMC rolled one quarter-turn onto its left plane as the penetrated knuckled end remained engaged in the front row left position. The GMC rotated about the knuckled end on its left plane and slapped against the face of the guardrail with the pickup bed's tailgate (Event 5). The GMC came to final rest on the right shoulder of the roadway (**Figure 6**), with the knuckled portion of the guardrail system intruded into the GMC's interior and the left plane of the GMC engaged against the guardrail system.

Figure 6: On-scene police image of the GMC at final rest looking toward the northeast.

Post-Crash

Law enforcement, fire department, and emergency medical services (EMS) personnel responded to the crash scene. Upon the arrival of the police, it was observed that the unbelted female was displaced from her seat and positioned on top of the driver as a result of the rollover crash forces and the positioning of the overturned vehicle. Her left leg was partially ejected through the left door opening that was created as a result of the door panel's deformation and intrusion. The intruded door and guardrail created a void at the left aspect of the foot well (kick panel) and the driver's left leg was partially ejected as he was displaced forward. The driver's pelvis remained in the left front seat and restrained by the seat belt. Due to their positioning, neither occupant was able to move free from the vehicle.

Emergency personnel used hydraulic rescue tools to cut the pillars of the GMC's occupant compartment structure. They removed the windshield and roof from the GMC. Hydraulic tools, wooden blocks, and pneumatic bags were used to stabilize and then partially elevate the vehicle. Once the GMC was lifted, the female occupant was able to free herself with minimal assistance. The rescue operation was reassessed and the GMC was elevated higher. This enabled the driver's legs to be freed, and he was then removed from the vehicle by EMS personnel. Both occupants of the GMC were transported by ambulances to a local hospital for evaluation. The male driver was hospitalized for 14 days for the treatment of incapacitating (A-level) injuries. The female passenger sustained non-incapacitating (B-level) injuries and was hospitalized for five days. The GMC was removed from the crash scene by a towing agency to a local facility and held by the investigating law enforcement agency pending the SCI vehicle inspection.

SKT END TERMINAL AND GUARDRAIL

The SKT End Terminal was an energy absorbing end treatment (**Figure 7**). It was manufactured by Road Systems, Inc. and met the requirements for NCHRP 350 Test Level 3. The manufacturer's literature and installation manuals can be found at: http://roadsystems.com/skt.html. This SKT installation was 15 m (50 ft) long and consisted of the SKT end terminal, two hinged posts at post locations 1 and 2, an anchor cable, and seven standard steel posts that supported the W-beam with a composite block-out and carriage bolt at post locations 3 to 9. The struck guardrail was a tangent system with a measured W-beam height of 69 cm (27.3 in). This height was measured at an undamaged section of the beam between Post 9 and 10. The impact face measured 51 x 51 cm (20.0 x 20.0 in), width x height.

Figure 7: East-looking image depicting an exemplar SKT guardrail end treatment located on the left side of the interstate highway across from the crash site.

The GMC struck the impact-face of the end terminal, resulting in direct contact damage to the impact-face referenced to the lower left corner that measured 13 x 38 cm (5.0 x 15.0 in). The force of the impact displaced the end terminal to the east (Figure 8) and extruded 4.9 m (16.0 ft) of the W-beam from the impact head. The W-beam curled toward the field side, away from traffic. Post- crash, the end terminal was located 18.1 m (59.4 ft) east of Post 1. Minor deformation was noted to the feeder channel. All the welds of the end terminal remained intact. Posts 1 to 8 of the installation were deformed with 15 m (50 ft) of damage to the W-beam that extended to the splice at Post 9. The deformed guardrail was inspected and documented through measurements and photographs. A diagram depicting the deformed guardrail is included on Page 16. The FHWA Guardrail Form documenting the crash and installation is included at the end of this report as **Appendix**.

Figure 8: Final rest location of the displaced end terminal.

Figure 9: Image depicting the impact-face of the end terminal looking to the west.

Post 1 consisted of a 15 x 15 cm (6.0 x 6.0 in) box-beam that was attached via a hinge bolt to a lower post section, which was embedded into the ground. The end terminal was attached to the box-beam by two shear bolts. The force of the impact overloaded the two shear bolts, allowing for the displacement of the end terminal and separation from Post 1. The impact force also caused the lower aspect of the box-beam to shear at the hinged connection, which separated the box-beam and displaced it 44.7 m (146.7 ft) to the east from the original location. The cable anchor, originally attached between Post 1 and the W-beam, was displaced 25.0 m (82.0 ft) to the east by the impact.

Post 2 consisted of two I-beam elements that were connected by a hinge bolt located approximately at ground level. At this post, the W-beam was originally bolted through a slot in the flange of the upper section. During the crash, the W-beam separated from the post and the hinged upper section of Post 2 rotated to the east.

Posts 3 to 9 of the installation were standard 15 x 10 cm (6 x 4 in) I-beams that supported the W-beam with a composite block-out and carriage bolt. During the crash, the heads of these bolts pulled through the W-beam by deforming the slot in the rail. The composite block-outs remained attached to all the posts except Post 5. This block-out was separated from Post 5 by contact with the vehicle, and was found on the ground adjacent to the cable anchor. Posts 3 to 6 deformed by bending at ground level in the travel direction of the GMC. Post 3 and Post 4 were deformed nearly 90 degrees, with evidence of direct contact on the field side of the flanges of these I-beams. This evidence consisted of flange of deformation with overlying black transfers from the GMC's right front tire/suspension. Similar direct contact evidence was observed to the road-side I-beam flanges of Post 5 and Post 6, which were bent approximately 60 degrees east.

The impact head and W-beam separated from the struck posts of the end terminal and were propelled southeastward by the crash forces. This displacement deformed and wrapped the W-beam around Post 7 (**Figure 10**), which formed a knuckle. During the crash, the GMC struck this knuckle in the area of its left front door. The door buckled as the sheet metal surrounding the latch overloaded and tore, which allowed the W-beam to penetrate and pocket into the front left interior space of the vehicle in the area of the driver's foot well. Engagement of the knuckle with the GMC further deformed the guardrail, and Post 7 was deflected approximately 30 degrees to the east. This engagement exacerbated the vehicle's clockwise rotation and instability, which induced a one quarter-turn, left side-leading rollover to the GMC. The GMC's left plane

Figure 10: East-looking image of the deformed W-beam wrapped around Post 7.

struck the face of the guardrail between Post 7 and 9. Minor deformation was noted at Post 8, and the guardrail damage ended at the Post 9 splice.

1991 GMC SONOMA

Description

The 1991 GMC Sonoma pickup truck (**Figure 11**) was manufactured in April 1990. It was identified by the vehicle identification number 1GTCS1973M2xxxxxx. This extended cab, rear-wheel drive pickup was configured on a 312 cm (122.9 in) wheelbase. Its powertrain consisted of a 4.3-liter V6 gasoline engine that was linked to a 3-speed automatic transmission. Service brakes were a front disc/rear drum configuration. The gross vehicle weight rating was 1,905 kg (4,200 lb), with gross axle weight ratings of 1,134 kg (2,500 lb) front and 1,045 kg (2,300 lb) rear. Its curb weight was 1,837 kg (4,050 lb).

Figure 11: Overhead view of the GMC depicting its frontal damage.

The GMC manufacturer's recommended tire size and pressure were P205/75R14 and 241 kPa (35 PSI), respectively. At the time of the SCI vehicle inspection, the GMC was equipped with Hercules Avalanche Extreme tires of the recommended size, mounted on OEM steel wheels. Specific tire data were as follows:

Position	Measured Tire Pressure	Measured Tread Depth	Restricted	Damage
LF	131 kPa (19 PSI)	6 mm (11/32 in)	No	Rim edge abraded
LR	241 kPa (35 PSI)	6 mm (11/32 in)	No	Rim edge abraded
RR	207 kPa (30 PSI)	6 mm (11/32 in)	No	None
RF	Flat	6 mm (11/32 in)	Yes	Rim deformed

The interior of the GMC was configured for the seating of up to four occupants. The front row consisted of front bucket seats with a fixed center console. At the time of the SCI inspection, the driver's seat was adjusted to a track position between middle and rear that measured 3 cm (1.0 in) forward of full rear. The front row right seat was adjusted to its full-rear track position. The driver's seat back was reclined 10-degrees aft of vertical and the front row right seat was reclined 25-degrees. Both front seats were equipped with integral head restraints. The second row was equipped with folding, inward-facing seats. Safety systems in the GMC consisted of manual 3-point lap and shoulder belts for the front row and lap belts for the second row positions. Due to its age, the GMC was not equipped with air bags or seat belt pretensioners.

Exterior Damage

The exterior of the GMC sustained impact damage to its front and left planes consistent with the dynamics of the crash. The direct contact damage to the front plane extended across the entire 142 cm (55.9 in) end width. Two regions of unique deformation were identified on the front plane resultant to the prolonged engagement with the yielding structure. The first was the area of the end-terminal impact, located at the right aspect of the GMC's front plane (**Figure 12**). Direct contact damage measured 9 cm (3.5 in) wide, beginning 63 cm (24.8 in) right of center. The impact had crushed the right frame rail 15 cm (5.9 in), separated the right aspect of the front bumper from the frame, and deformed the right side structure of the engine compartment. The right fender was free-floating, only attached to the right A-pillar structure. Direct contact with the end terminal was also observed at the right front wheel assembly. The right front wheel rim was deformed and the tire was both flat and restricted by contact with the aft aspect of the wheel house, which reduced the wheelbase 9 cm (3.5 in). The collision deformation classification (CDC) assigned to this damage pattern was 12FREE3.

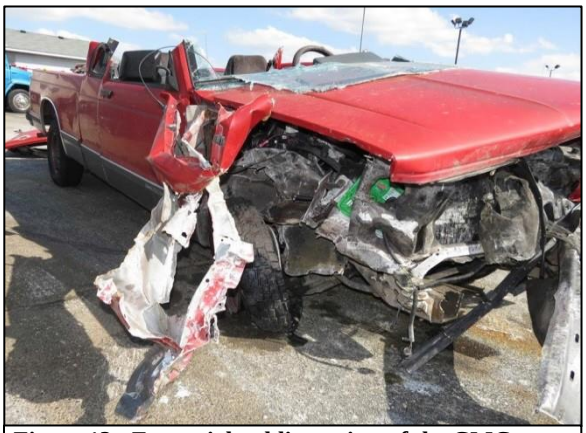


Figure 12: Front right oblique view of the GMC depicting the impact damage.

The second region of distinct front plane deformation resulted from the vehicle's clockwise rotation along the W-beam and corresponding engagement with the support posts (1-3). The crash reconstruction determined that Post 4 pocketed immediately to the left of the left frame rail (**Figure 13**). This contact was evidenced by a right angle deformation of the bumper beam that measured 8 cm (3.1 in). This pattern began 38 cm (15.0 in) left of center and extended 30 cm (11.8 in) to the left corner. There was no measurable crush to the left frame rail. The CDC representative of this damage was 10FDEW1.

Figure 13: Left front oblique view of the GMC depicting its damage.

Figure 14: Left view of the GMC depicting the impact damage and intrusion at its left door.

Due to its clockwise rotation, the forward and center aspects of the left plane sustained direct contact damage from the guardrail. The direct contact damage was located from the GMC's forward left corner to the leading aspect of the pickup bed adjacent to the left C-pillar. The left door of the GMC struck the deformed/knuckled guardrail at Post 7 (**Figure 14**). Due to the clockwise rotation of the GMC, the corresponding direction of the impact force was in the vehicle's 8 o'clock sector. Crash forces overloaded and tore the sheet metal surrounding the door latch. Although the latch remained secured to the striker, the door structure buckled and separated as it intruded into the left front occupant space. The residual length of the buckled door measured 46 cm (18.1 in). For comparison purposes, the length of the undamaged right door was 114 cm (44.9 in). The CDC assigned to this contact pattern was 08LYAW4.

An instability was created by the GMC's engagement with the knuckled guardrail that caused the vehicle to roll one quarter-turn to the left. The rollover was interrupted by subsequent engagement of the vehicle's left and top planes with the face of the guardrail between Posts 7-9. Damage from contact with the W-beam was noted to the upper aspect of the B- and C-pillars, as well as along the left roof side rail. Lateral deformation of the pillars was estimated at 15 cm (6.0 in). The CDC assigned to the rollover was 00LDAO2. With respect to the vehicle's top plane, the tail gate was crushed vertically 24 cm (9.5 in) into a V-pattern from its impact with the face of the guardrail. The CDC assigned to the tailgate damage was 00TBYN1.

The impacts sustained by the GMC were beyond the scope of the WinSMASH program and could not analyzed by the program for reconstruction purposes. The damage for the Event 3 guardrail impact, Event 1 end terminal impact and Event 4 were rated as moderate severity. The Event 2 support post impact and Event 5 tailgate impact were rated as a minor severity.

Event Data Recorder

The GMC Sonoma was not equipped with an event data recorder. No crash data was available.

Interior Damage

The GMC's interior damage was primarily related to the severe intrusion of the left door and secondarily related to the activities of emergency response personnel. Post-crash activities included the cutting of the vehicle's pillars and the removal of its entire roof structure. The laminated windshield was also removed. During the SCI inspection, the GMC's roof was repositioned for documentation purposes.

The left door was observed to be buckled and compressed forward into the driver's foot well, attributable to the crash forces associated with the engagement of the GMC and the knuckled guardrail at Post 7. Residual lateral intrusion measured 41 cm (16.1 in). The inner surface of the intruding door structure contacted, cut, and abraded the outer aspect of the driver's seat. Red paint transfers were noted on the cloth upholstery of the seat and on the seat belt webbing. The

lower sector of the steering wheel rim was struck by the intruded door and deformed forward approximately 15 cm (5.9 in). The jammed position of the door hampered the inspection of its interior surface, the lower left instrument panel and foot well. Based on the on-scene police images, a gap was created in the area of the driver's foot well during the crash. The front right occupant's leg was displaced through this hole and was observed to be outside of the occupant compartment by emergency response personnel when they arrived at the crash scene.
Figures 15 and 16 depict the intruded left front door and occupant compartment at the time of the SCI vehicle inspection.

Figure 15: Left oblique view of the GMC depicting the left door intrusion.

Figure 16: Right lateral view across the GMC depicting the intrusion of the left door.

Manual Restraint Systems

The manual restraint systems in the front row of the GMC consisted of 3-point lap and shoulder seat belts with two retractable webbing sections. Each webbing section (lap and shoulder) spooled from separate retractors and were attached together by a sewn-on latch plate. The driver's latch plate was still latched in the buckle, and each portion of webbing had been cut by the emergency responders during their removal of the driver. The lap portion of the front row right webbing was retracted, while the shoulder belt was cut. The shoulder portion was cut due to the extrication efforts to cut the GMC's pillars and remove the roof structure.

Both the driver and front right latch plates exhibited signs of historical use. Examination of the webbing also revealed historical usage. However, these historical indicators were unrelated to these occupants, as the neither individual was the registered owner of the GMC. Physical evidence of loading was observed on the driver's seat belt system, which was related to the crash. However, there was no loading evidence on the front right seat belt system. Based on the observations of the SCI vehicle inspection, the driver was belted and the front row right occupant was unbelted at the time of the crash. The police report also documented that the driver was restrained by the seat belt. Law enforcement documentation for the restraint status for the front row occupant was coded as unknown.

Supplemental Restraint Systems

The GMC was not equipped with any supplemental restraint systems.

1991 GMC SONOMA OCCUPANT DATA

Driver Demographics

Age/Sex:	48 years/male
Height:	183 cm (72 in)
Weight:	77 kg (170 lb)
Eyewear:	Unknown
Seat Type:	Forward-facing bucket seat with integral head restraint
Seat Track Position:	Mid-to-rear track
Manual Restraint Usage:	3-point lap and shoulder seat belt system
Usage Source:	Vehicle inspection, PAR
Air Bags:	None; not equipped
Alcohol/Drug Involvement:	None
Egress From Vehicle:	Extricated from the vehicle due to perceived serious injury
Transport From Scene:	Ambulance to a local hospital
Type of Medical Treatment:	Hospitalized for 14 days

Driver Injuries

Inj. No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Fractures of anterolateral left 3rd-7th ribs with displacement of 5th and 6th ribs; Fractures of posterior left 6th-8th ribs with displacement of 6th and 7th ribs, producing a flail segment	450211.3	Intruding left door, rear upper quadrant	Certain
2	Left-sided hemopneumothorax	442205.3	Intruding left door, rear upper quadrant	Certain
3	Pneumomediastinum	442209.2	Intruding left door, rear upper quadrant	Certain
4	Closed comminuted fracture of left proximal shaft of femur	853271.3	Intruding left door, rear upper quadrant	Certain
5	Closed displaced fracture of left lesser trochanter of femur	853151.3	Intruding left door, rear upper quadrant	Certain
6	Contusions and ecchymosis to proximal left thigh	810402.1	Intruding left door, rear upper quadrant	Certain
7	Abrasions on proximal left thigh	810202.1	Intruding left door, rear upper quadrant	Certain
8	Multiple superficial abrasions to right lower extremity	810202.1	Intruding left door, rear upper quadrant	Certain

Inj. No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
9	Multiple superficial abrasions to left lower extremity	810202.1	Intruding left door, rear upper quadrant	Certain
10	Diffuse contusions to abdomen	510402.1	Seat belt system	Possible

Source: Hospital records

Driver Kinematics

The 48-year-old male driver was positioned in the driver's seat of the GMC, with the seat track adjusted to a middle-to-rear position. He was restrained by the manual 3-point lap and shoulder belt, as determined through the post-crash SCI inspection of the manual restraint system's condition. For unknown reasons, the driver allowed the GMC to drift right as he operated the vehicle eastbound on the limited-access roadway. The GMC departed the right roadway edge without any attempted avoidance maneuver by the driver.

At impact, the emergency mode of the seat belt retractor locked the driver's seat belt. The driver responded to the 12 o'clock direction of the impact forces with a forward trajectory. He contacted and loaded the seat belt with his left shoulder, torso, and pelvis. As the GMC displaced the end terminal, it decelerated and rotated clockwise. The driver initiated a left lateral trajectory toward the left door.

The GMC rotated clockwise and engaged the knuckled guardrail at Post 7. This abrupt increase in the GMC's deceleration exacerbated the driver's lateral trajectory. As the vehicle engaged the knuckled guardrail, the left door deformed inward and intruded into the occupant compartment of the GMC. The driver was contacted by the intruding door on his left flank, which displaced the driver's torso and lower extremities forward, and to the right. Contact and loading by the driver with the intruding left door resulted in numerous injuries, including multiple left-side rib fractures, multiple left femur fractures, a left hemo-pneumothorax, and soft tissue injuries. The jammed position of the door prevented visual inspection for definitive contact evidence.

Law enforcement reported that when they arrived on-scene and observed the vehicle at final rest, one of the driver's legs was beneath the GMC. It was partially ejected through a void at the left kick wall (left side of the foot well) created by the intruded left door.

As the GMC rolled one quarter-turn to the left, the force of gravity likely displaced the driver back to the left. It is highly probable that the driver experienced occupant-to-occupant interaction with the displaced unbelted front row right occupant following the rollover. The passenger appeared to be on top of the driver in the police on-scene images. There were no injuries to the driver attributed to this probable interaction. However, soft tissue injuries to the head and left arm of the displaced female occupant were coded to the interaction.

Following the crash, a process was performed by emergency response personnel using hydraulic rescue tools and pneumatic lift bags to remove the roof from the GMC and elevate it from ground level. The driver was then removed from the vehicle by EMS personnel and immobilized on a long spine board. He was transported by ambulance to a local hospital, evaluated, and admitted for 14 days.

Front Row Right Occupant Demographics

Age/Sex:	48 years/female
Height:	178 cm (70 in)
Weight:	77 kg (170 lb)
Eyewear:	Unknown
Seat Type:	Forward-facing bucket seat with integral head restraint
Seat Track Position:	Rearmost track
Manual Restraint Usage:	3-point lap and shoulder seat belt system available; Not used
Usage Source:	Vehicle inspection, PAR
Air Bags:	None; not equipped
Alcohol/Drug Involvement:	None
Egress From Vehicle:	Extricated from the vehicle by emergency response personnel
Transport From Scene:	Ambulance to a local hospital
Type of Medical Treatment:	Hospitalized 5 days

Front Row Right Occupant Injuries

Inj. No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Non-displaced closed rib fractures: anterior left 4th through 9th and anterior right 4th through 8th	450203.3	Right instrument panel	Probable
2	Right distal clavicle fracture	750731.2	Windshield	Possible
3	Flap-type laceration of right knee, apex left and base right, down to bone of patella	810802.1	Left lower instrument panel	Probable
4	Contusion right lateral scalp	110402.1	Windshield	Possible
5	Contusion left posterior scalp	110402.1	Roof	Possible
6	Contusion to left side of face with ecchymosis to the left upper eyelid	210402.1	Occupant-to-occupant	Probable
7	Contusion of left upper arm	710402.1	Occupant-to-occupant	Probable

Source: Hospital records

Front Row Right Occupant Kinematics

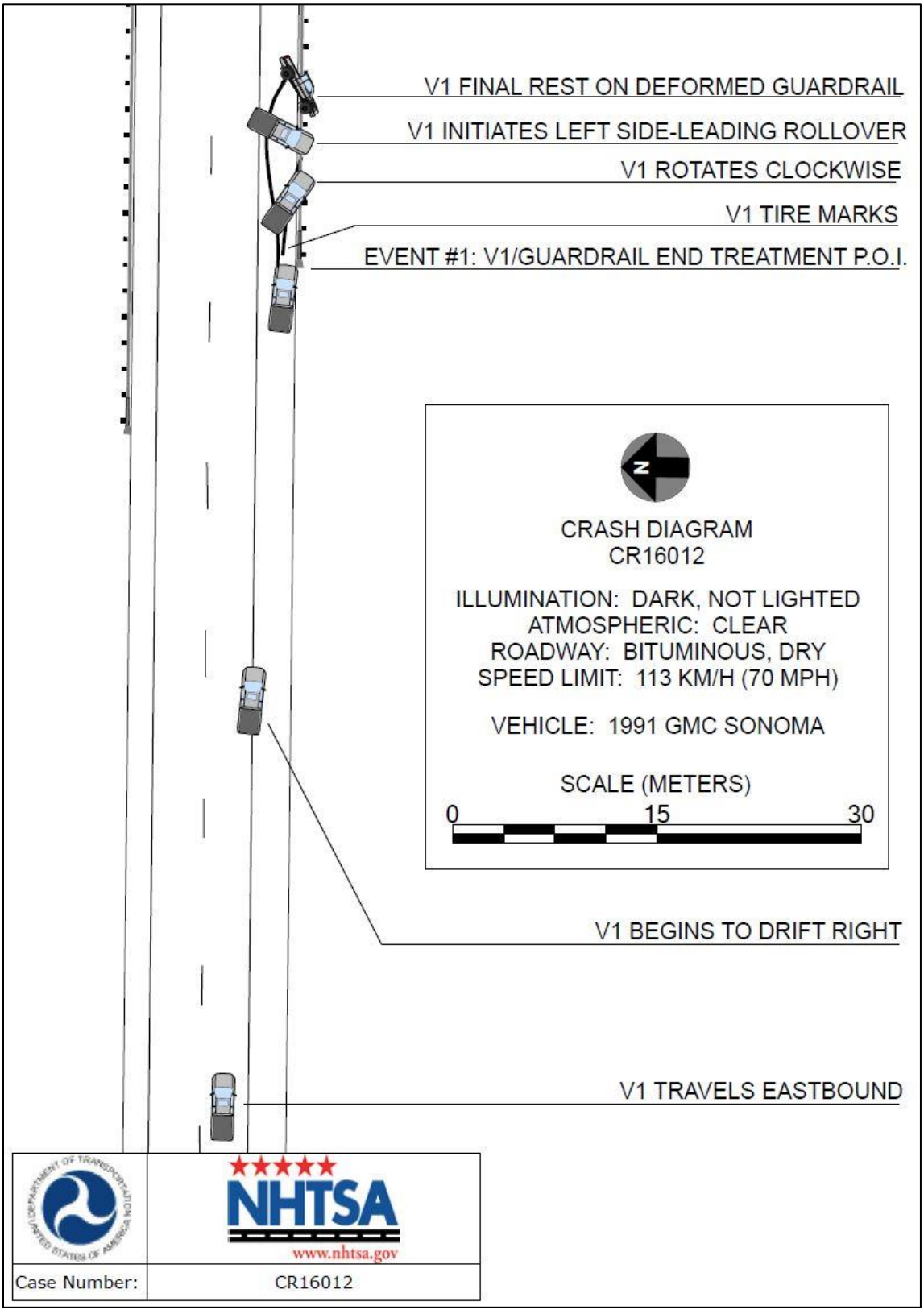
The 48-year-old female was seated in the front row right position, with the seat adjusted to a full-rear track position. Despite the availability of the manual 3-point lap and shoulder belt system, the front row right occupant was unbelted. Her lack of restraint usage was determined through a post-crash inspection of the seat belt system during the SCI vehicle inspection.

At impact with the guardrail end terminal and impact head, the front row right occupant responded to the 12 o'clock direction of the impact force with a forward trajectory. It is probable that she contacted the right instrument panel with her chest, and the windshield with her shoulder and head. The on-scene police photos depict that the windshield was fractured in a star-pattern at its center aspect. These probable contacts and the associated loading likely resulted in multiple rib fractures, clavicle fracture and soft tissue injuries.

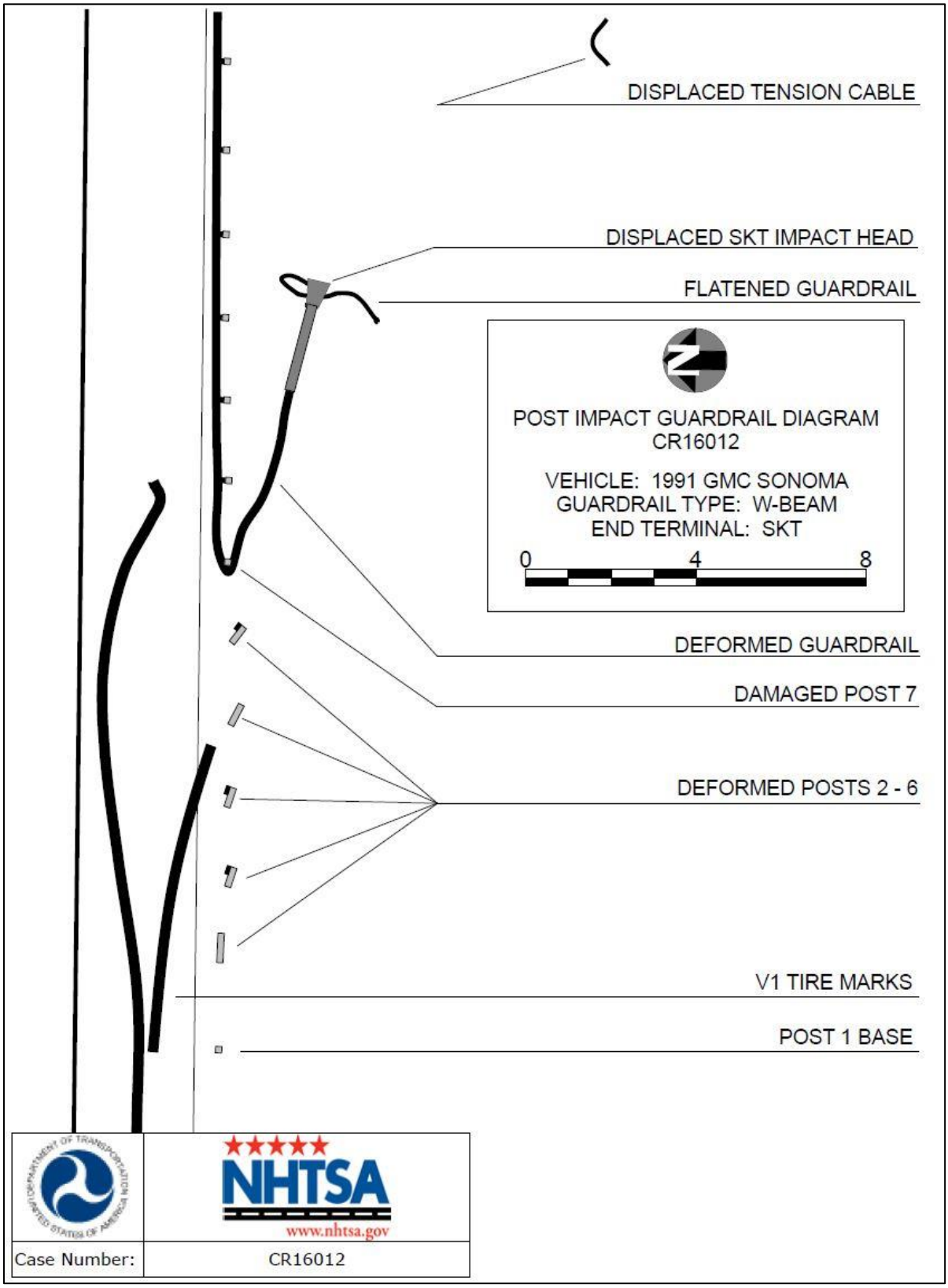
As the vehicle decelerated and rotated clockwise, the front row right occupant was displaced laterally to the left. She likely contacted the center console, though no apparent injuries resulted from this contact. Impact and engagement with the knuckled guardrail increased the unbelted front row right occupant's lateral displacement. In conjunction with the left side-leading rollover and the quarter-turn orientation of the vehicle, the front row right occupant maintained a left lateral trajectory and experienced occupant-to-occupant interaction with the driver evidenced by soft tissue contusions to the left upper arm and left aspect of her face. The medical records indicated that her right lower leg sustained a laceration at the knee. This injury was attributed due to probable contact with the left lower instrument panel during her displacement. It is possible that the front row right occupant contacted the roof with her head during the rollover and as the vehicle came to final rest.

The on-scene police images depict that the passenger's left lower leg was partially ejected through the left door opening that was created by the intruding left door and penetration of the guardrail. The front row right occupant was able to free herself from the vehicle with some assistance by emergency response personnel following an extrication process that included removal of the GMC's roof structure and lifting the vehicle. She was transported by ambulance to a local hospital, where she was hospitalized for 5 days.

CRASH DIAGRAM



POST-IMPACT GUARDRAIL DIAGRAM



APPENDIX:

Federal Highway Administration Guardrail Forms

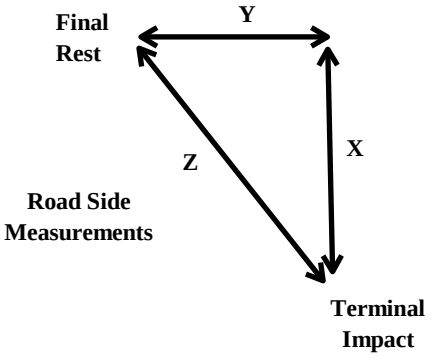
Case No.: CR16012

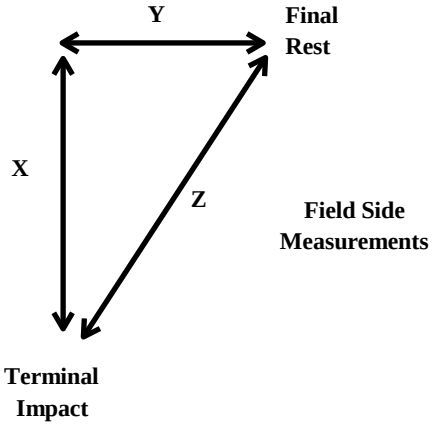
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	April 2016	**Time of Crash (Military)**	Overnight
Case Number	CR16012	**State**	MO
Traffic Route	Limited access	**Direction (Southbound = SB)**	EB
Ambient Conditions (at time of crash)			
Temperature (°F)	60°	**Lighting**	Dark
Atmospheric	Clear		

SCENE INFORMATION	
Type of area where crash occurred	❒Urban ❒Rural ■Suburban
Terminal on a horizontal curve?	■No ❒Curve/LT ❒Curve/RT
Estimated or Reconstructed Speed at Impact (mph)	Estimated impact speed 65 mph Speed Limit: 60 mph near transition to70 mph
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 40 ft ■Road side ❒Field Side
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 40 ft
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 0 ft
Super elevation	❒+2% ❒-2% ■ NONE or FLAT
Curve Radius (ft.)	N/A

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





Case No.: CR16012

ON-SCENE INFORMATION		
End Treatment	■Extruder	❒ET2000 ❒ET-PLUS 4in ❒ET-PLUS 5in ■SKT ❒FLEAT ❒SOFT STOP
	❒Telescope	❒X-LITE ❒X-TENSION
Curb?	■No ❒Yes	❒AASHTO Type A ❒AASHTO Type B ❒AASHTO Type C ❒AASHTO Type D ❒AASHTO Type E ❒AASHTO Type F ❒AASHTO Type G ❒AASHTO Type H
Curb Height: N/A		

GUARDRAIL INSTALLATION

Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type	Dim.	Type	Dim.					
	Steel Wood Other	D x W (in.) or	Steel Wood Composite	D x W (in.)	Yes No Unknown	Describe	Travel way	Curb	
0	-	-	-	-	-	-	-	-	-
1	Steel	6 x 6	None	N/A	No	N/A	10 ft 10 in	N/A	6 ft 9 in
2	Steel	6 x 4	None	N/A	No	N/A	10 ft 8 in	N/A	6 ft 1 in

Case No.: CR16012

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type	Dim.	Type	Dim.	Yes No Unknown	Describe	Travel way	Curb	
	Steel Wood Other	D x W (in.) or	Steel Wood Composite	D x W (in.)					
3	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 1 in	N/A	6 ft 0 in
4	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 1 in	N/A	6 ft 6 in
5 Splice	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 3 in	N/A	6 ft 5 in
6	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 1 in	N/A	6 ft 5 in
7	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 9 in	N/A	6 ft 2 in
8	Steel	6 x 4	Composite	7.5 x 4	No	N/A	11 ft 7 in	N/A	6 ft 4 in

Case No.: CR16012

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type	Dim.	Type	Dim.	Yes No Unknown	Describe	Travel way	Curb	
	Steel Wood Other	D x W (in.) or	Steel Wood Composite	D x W (in.)					
9	Steel	6 x 4	Composite	7.5 x 4	No	N/A	10 ft 7 in	N/A	6 ft 4 in

Additional Comments:

9-post installation
Two 50-ft sections of W-beam
Damaged damage ends at P9
Extruder head struck with 16ft of W-beam extrusion

Case No.: CR16012

EXTRUDER			
Feeder Channel Width at impact head	❒ 4inches ❒ 5 inches ■ Other 4.5 in		
Guide Chute Exit Height (in.)	13 in expands to 20 in		
Connection of feeder channels to head damaged?	■ No ❒ Yes	Are Welds Broken?	■ No ❒ Yes
Anchor Cable Present?	❒ No ■ Yes	Connected?	❒ No ■ Yes
Rail Extrusion?	❒ No ■ Yes	Length (ft. in.)	16 ft
Rail Extrusion Direction	❒ Traffic Side ■ Field Side		
Total Length of Rail Damaged (ft.) [total length would include extruded rail plus damaged rail downstream from head.]	**Total = 51.4 ft** *[16 ft (extruded) + 6.5 ft (within terminal) + 28.9ft (displaced W-beam to Post 9)]*		

TELESCOPE				
Rail Displacement	❒ No	❒ Yes; Length:	No of Panels Displaced	❒ 1 ❒ 2 ❒ 3 ❒ 4 ❒ 5 ❒ 6

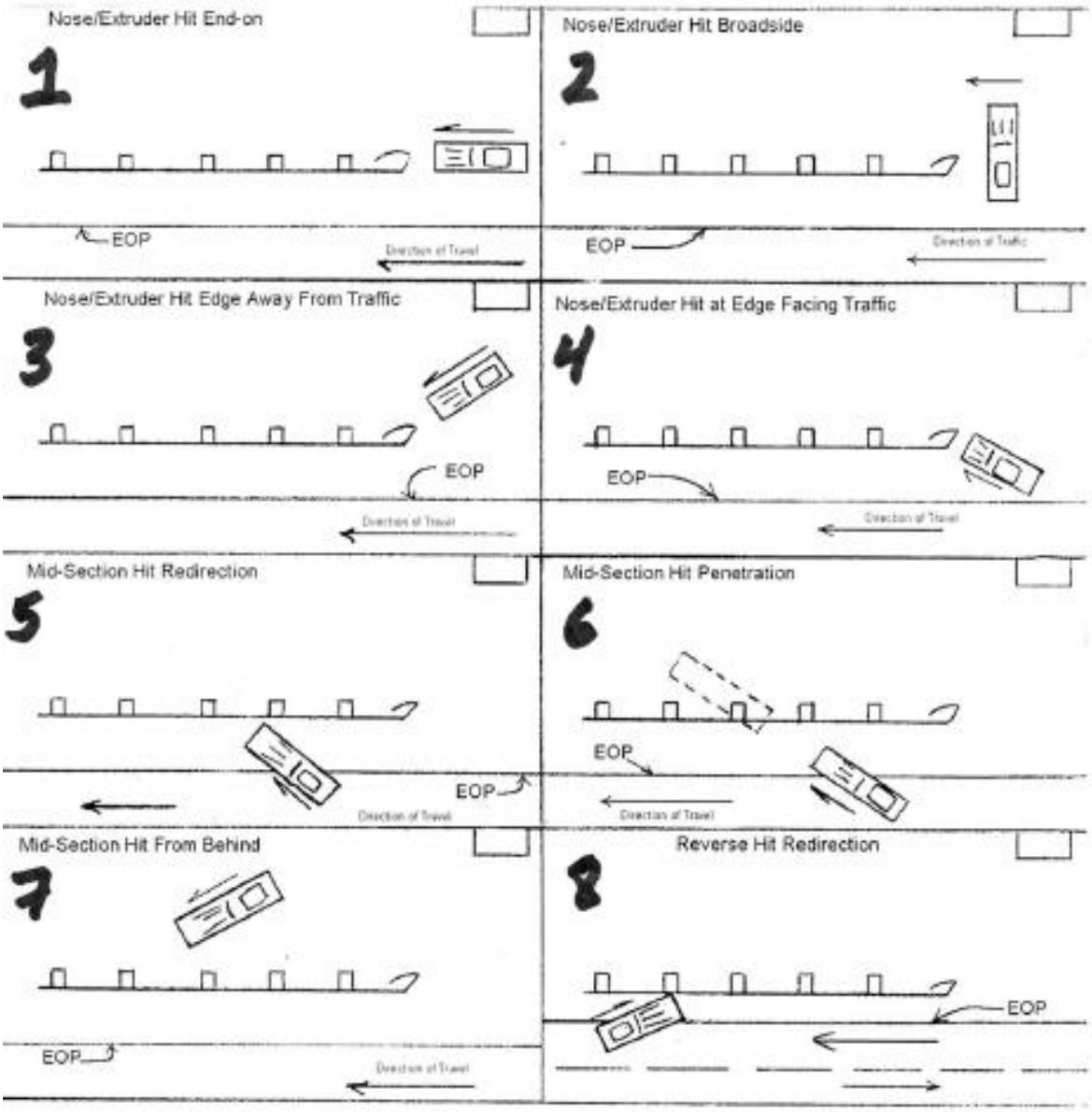
ALL-SYSTEM PERFORMANCE			
Railkinks Downstream of Head?	■ No	❒ Yes;	No. of Kinks in Rail: N/A
Was there intrusion into the Occupant Compartment by foreign object (guardrail)?	❒ No ■ Yes		
Did vehicle impact other objects after impact with terminal?	❒ No ■ Yes		
Object Contacted	W-beam of guardrail Posts 7-9		

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	35%	42%	33%
Adjacent Lane Width (ft)	11.5 ft		
Lane Type (NAS EDS Variable: Sur. Type)	Asphalt		
Shoulder Type	Asphalt		
Shoulder Width (ft)	9.2 ft		
Guardrail Height (in)	27.3 in (*measured downstream of Post 9*)		

Case No.: CR16012

VEHICLE INFORMATION		
Vehicle Type (NHTSA Input)	1991 GMC Sonoma	
Vehicle Identification Number (VIN)	1GTCS19Z3M2xxxxxx	
Vehicle Mass (NASS var.: veh.wgt)	2,764 lb	
Vehicle orientation upon impact	❒Case Type 1 ❒ Case Type 2 ❒ Case Type 3 ■ Case Type 4 ❒ Case Type 5 ❒ Case Type	
If 'Other', describe	N/A	
Collision Deformation Classification	Event 1 - 12FDEW1 Event 2 - 08LYEW4 Event 3 - 00LDDO2	
Delta-V	Moderate deformation	
Occupant Compartment Penetration of rail	❒No	■Yes; Describe: Deformed W-beam adjacent to Post 7 struck left door and intruded
Did the Vehicle Rollover?	■Yes ❒No	
Quarter Turns (NASS EDS variable: Rollover)	■1 ❒2 ❒3 ❒4 ❒5 ❒6 ❒7 ❒8 ❒9 ❒10 ❒11 ❒12 ❒13 ❒14 ❒15 ❒16 ❒17+	
Object Precipitating Rollover, (NASS EDS variable: Rollobj)	Guardrail Face	
Rollover Type, Terhune Scale, (NASS EDS variable: rolintyp)	Other: interaction with deformed guardrail	

Case No.: CR16012



DOT HS 812 609
August 2018

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**