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Special Crash Investigations On-Site SKT Guardrail End Treatment Crash Investigation Vehicle: 2004 Buick Century Location: Missouri Crash Date: August 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 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. This report and associated case data are based on information available to the Special Crash Investigation team on the date the report was published.

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16. Abstract This report documents the on-site investigation of the crash of a 2004 Buick Century into a sequential kinking terminal (SKT) guardrail end treatment. The Buick was traveling south on a divided three-lane, limited-access highway on approach to an exit, when it departed the right side of the road and struck the guardrail end treatment. The SKT end terminal was displaced along a portion of the guardrail, which deformed the W-beam. The Buick separated from the guardrail and subsequently rolled over. The vehicle was on its top plane at final rest. The unbelted 25-year-old male driver and the unbelted 22-year-old female front row right occupant were injured as a result of the crash and transported by ambulances to a local hospital for treatment.			
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CASE NO.: CR16025
ON-SITE GUARDRAIL END TREATMENT CRASH INVESTIGATION
VEHICLE: 2004 BUICK CENTURY
LOCATION: MISSOURI
CRASH DATE: AUGUST 2016

BACKGROUND

This report documents the on-site investigation of the crash of a 2004 Buick Century into a sequential kinking terminal (SKT) guardrail end treatment. The Buick was traveling south on a divided three-lane, limited-access highway on approach to an exit, when it departed the right side of the road and struck the guardrail end treatment. The SKT end terminal was displaced along a portion of the guardrail, which deformed the W-beam. The Buick separated from the guardrail and subsequently rolled over. The vehicle was on its top plane at final rest. The unbelted 25-year-old male driver and the unbelted 22-year-old female front row right occupant were injured as a result of the crash and transported by ambulances to a local hospital for treatment. The crash was identified by the Missouri Department of Transportation (MoDOT), who in-turn notified 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 the notification to the Crash Investigation Division (CID) of the National Highway Traffic Safety Administration (NHTSA) in August 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 cooperation with the MoDOT and the on-site investigation took place in August 2016.

Figure 1: South-facing view of the struck SKT guardrail end treatment and crash site. Image supplied by MoDOT.

The on-site investigation consisted of the documentation of the guardrail system and the damage it sustained during the crash. The environment of the roadway and the guardrail was documented using a total station mapping system. Following inspection of the crash site, the Buick was located at a local towing facility. Cooperation was obtained to inspect the vehicle, which included the measurement of its structural deformation and intrusion, identification of occupant contact, assessment of manual restraint systems, and an evaluation and inspection of the supplemental restraint deployment/actuation. The Buick was equipped with an event data recorder (EDR) supported by the Bosch Crash Data Retrieval (CDR) tool, and its data was imaged during the SCI vehicle inspection.

CRASH SUMMARY

Crash Site

This single-vehicle crash occurred during the nighttime hours of August 2016 on the southbound lanes of a three-lane, divided, limited-access interstate highway. A concrete median separated the flow of the north and south traffic. There was an interchange with a right exit lane and ramp at the crash site. The interstate highway speed limit was 97 km/h (60 mph). The police–reported environmental conditions at the time of the crash were dark, clear and dry. The National Weather Service reported a temperature of 20.6 ˚C (69 ˚F), 65% relative humidity, south- southeast winds at 14.8 km/h (9.2 mph) and clear skies.

The physical environment of the crash site and guardrail were documented during the SCI inspection using a Nikon Nivo 5.M+ total station. In the area of the crash, the interstate was constructed of concrete and was oriented in the north/south direction. The roadway was straight and level (**Figures 2 and 3**). The three southbound lanes were separated by broken white lines. The widths of the right and center lane each measured 3.6 m (11.8 ft) and the width of the left lane measured 3.8 m (12.5 ft). At the crash site, there was a 3.7 m (12.1 ft) wide exit-only lane adjacent to the right travel lane. The exit lane was delineated from the right travel lane by broken white lines that transitioned to a solid white line approximately 61 m (200 ft) from the beginning of the guardrail. A 3.1 m (10.3 ft) wide right shoulder supported the roadway. The roadside terrain sloped away from the roadway with a measured grade of 22%. The SKT W- beam end-treatment and guardrail was installed adjacent to the right shoulder. This guardrail protected traffic from entering a depressed area and a concrete drainage ditch in the right roadside at the exit. The 5.3 m (17.4 ft) wide concrete drainage ditch began 9.6 m (31.5 ft) north of end terminal and was centered 7.2 m (23.6 ft) right of the road edge.

Figure 2: South-facing trajectory view at the crash site.

Figure 3: North-facing lookback view at the crash site.

Pre-Crash

The Buick was traveling south in the exit lane of the interstate approaching the interchange. The vehicle was occupied by a 25-year-old male driver and a 22-year-old female in the front row right position. Neither occupant was utilizing the vehicle's manual 3-point lap and shoulder seat belt for restraint. The EDR-reported speed of the vehicle 5 seconds prior to Algorithm Enable (AE) was 111 km/h (69 mph).

For undetermined reasons, during its approach the Buick began to drift to the right at a shallow angle. The estimated departure angle was 2 to 3 degrees relative to the south heading to the roadway. Based on a straight line projection of the departure angle, the vehicle entered the right shoulder an estimated 150 m (492 ft) north of the guardrail Post 1 (approximately 5 seconds prior to AE). The Buick traversed through the shoulder in a tracking attitude and the right tires departed the road 48.5 m (159.0 ft) north of guardrail Post 1 (approximately 2 seconds prior to AE). The road departure was evidenced by rolling tire marks in the grass of the roadside (**Figure 4**). The vehicle continued along this errant trajectory with the left tires departing the road 2.9 m (9.5 ft) from Post 1. The EDR data indicated that the driver reacted to the vehicle's road departure by an application of the throttle and brake which were recorded during the 1-second interval prior to AE .Note, the application of the controls may not be simultaneous due to the synchronicity of the recording. A Crash Diagram is included at the end of this technical report.

Figure 4: South-facing trajectory view depicting the Buick's tire marks through the roadside.

Crash

The first crash event occurred as the left aspect of the Buick's front plane struck the end terminal. Associated forces resulted in the deployment of the vehicle's frontal air bags, and the left offset of the impact initiated a counterclockwise rotation to the Buick. The end terminal was displaced southward (**Figure 5**) along the W- beam, which extruded the W-beam to the field-side of the impact head and dissipated energy of the crash. The end terminal and deformed W-beam were displaced onto the right shoulder of the road as the Buick separated from the impact and rotated counterclockwise approximately 80 degrees.

Figure 5: South-facing view of the struck guardrail end treatment and southward trajectory of the Buick. Note that the position of the guardrail was moved to depict its post-crash deformed position.

During the vehicle's counterclockwise rotation, the parallel-rotating tire marks of the vehicle transitioned to diverging-sliding marks as Buick neared a broadside orientation. The right side tires furrowed into the soil surface of the roadside **(Figure 6)**, which tripped the vehicle into a right side leading rollover. The Buick rolled six quarter-turns along and down the roadside embankment into the concrete drainage ditch. During the sixth quarter-turn, the contour of the concrete ditch slowed and redirected the vehicle's rolling trajectory. The Buick rotated approximately 180 degrees clockwise and slid 6.3 m (20.7 ft) on its top plane. At final rest, the Buick was positioned on its top plane facing northwest, 28.5 m (93.5 ft) south of the point of initial impact with the end terminal (**Figure 7**).

Figure 6: South-looking image depicting the sliding right side tire marks and the trip point of the Buick.

Figure 7: North lookback view from the final rest location of the Buick along its rollover trajectory.

Post-Crash

Police, fire and emergency medical services (EMS) personnel responded to the crash scene. The driver and front right occupant were assisted from the vehicle by EMS and transported to the hospital with unknown injuries. The Buick was turned upright and removed from the scene to the secure yard of a local tow agency where it was located at the time of the SCI inspection.

SKT END TREATMENT AND GUARDRAIL

The SKT End Terminal was an energy absorbing end treatment used to terminate W-beam guardrail (**Figure 8**). The SKT installation was 15 m (50 ft) in length and consisted of a SKT end terminal, two hinged posts at post locations 1 and 2, an anchor cable, and six standard steel posts at post locations 3-8 that supported the W-beam with a composite block-out and carriage bolt.

Figure 8: Image depicting an exemplar SKT installation.

The SKT installation was manufactured by Road Systems, Inc. http://roadsystems.com/skt.html and met the requirements for NCHRP 350 Test Level 3. The struck guardrail was a tangent system with a W-beam height of 78 cm (30.8 in), measured at an undamaged section between Post 9 and 10. The Buick struck the impact-face of the end terminal originally located at Post 1. The impact face measured 51 x 51 cm (20.0 x 20.0 in). Direct contact damage to the impact face measured 33 x 41 cm (13.0 x 16.0 in), width by height, referenced to the lower right corner. The force of the impact displaced the end terminal to the south and extruded 4.7 m (15.3 ft) of the W-beam (**Figure 9**). The extruded W-beam curled to the field side, away from the road. During the crash sequence, the end terminal and damaged guardrail were displaced onto the roadway's shoulder adjacent to Post 5, as depicted in **Figure 1**, Page 1. Due to its hazardous location, the deformed components were moved onto the roadside by MoDOT prior to the SCI inspection.

Figure 9: Image depicting the struck end terminal and the extruded W-beam.

Figure 10: Top view of the end terminal depicting the deformation of the impact head.

The off-axis/right bias of the impact force deformed the impact head approximately 20 degrees at its connection with the feeder channel (**Figure 10**). Additionally, minor bending deformation was noted to the feeder channel. All the welds of the end terminal remained intact.

Posts 1 to 5 of the installation were damaged during the crash along with 9.6 m (31.4 ft) of damage to the W-beam. The W-beam was bent nearly 90 degrees due to the displacement of the damaged rail section onto the road. A minor kink in the W-beam was observed at the entrance to the feeder channel. The damage to the W-beam ended at Post 6. However, repair of the guardrail system required the replacement of the W-beam 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 at the end of this report. The FHWA Guardrail Form documenting the crash and installation is included at the end of this report as **Appendix A**.

Post 1 consisted of a 15 x 15 cm (6.0 x 6.0 in) upper (top) box-beam that was attached via a hinge bolt to the lower post section that 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, thus allowing the displacement of the end terminal. The impact force also caused the lower aspect of the box-beam to shear at the hinged connection. In this crash, the top section separated from the lower section and was displaced to the southeast. The cable anchor, originally attached between Post 1 and the W-beam, separated during the impact and was also displaced to the south. The exposed top portion of the post embedded in the ground was deformed by the separation of the components.

Figure 11: North-looking image from Post 5 of the damaged guardrail.

Figure 12: South-looking image from Post 5 of the damaged guardrail.

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 of the I-beam. This flange was deformed during the separation. The hinged upper section of Post 2 rotated 90 degrees to the south during the crash.

Posts 3 through 5 of the installation were standard 15 x 10 cm (6 x 4 in) I-beams and prior to the crash 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 deformation of the slot in the rail. The composite block-outs remained attached to the posts and were deformed. Posts 3 through 5 deformed by bending at ground level in the south direction of the Buick's travel. Post 3 was bent approximately 60 degrees with evidence of direct contact on the road side of the I-beam flange. Posts 4 and 5 were bent approximately 30 degrees. Additionally, Post 5 was rotated nearly 90 degrees counterclockwise.

Posts 6 through 9 were standard I-beam posts with composite block outs and carriage bolts that remained attached to the W-beam. The damage to the guardrail system ended at Post 6. The repair of the guardrail necessitated replacement of the W-beam to the splice at Post 9. **Figures 11 and 12** are overall views of the guardrail looking north ward and southward from Post 5, respectively.

2004 BUICK CENTURY

Description

Figure 13: Overhead view of the Buick Century.

The 2004 Buick Century was a four door sedan identified by the VIN: 2GAWS52J141xxxxxx. It was manufactured in December of 2003 and equipped with the custom level trim package. The digital odometer reading was 120,083 km (74,618 miles) at the time of the SCI inspection. The Buick (Figure 13) had a front-wheel drive platform that was configured on a 277 cm (109.1 in) wheelbase. It was powered by a 3.0 liter V6 gasoline engine that was linked to a 4-speed automatic transmission. The service brakes were power-assisted front disc/rear drum system with ABS. A placard declared that the vehicle's Gross Vehicle Weight Rating (GVWR) was 2,019 kg (4,452 lb), with front and rear Gross Axle Weight Ratings (GAWR) of 1,100 kg (2,425 lb) and 919 kg (2,027 lb rear), respectively. The curb weight was 1,528 kg (3,362 lb). The manufacturer's recommended tire size was P205/70R15 at all four axle positions, with recommended cold tire pressures of 221 kPa (32 psi). At the time of the SCI inspection, the two front tires were Multi-Mile Grand Tour LS tires and the two rear tires were Thunderer Ranger007 tires, all of the recommended size. Specific tire data were as follows:

	Measured Pressure	Measured Tread Depth	Restriction	Damage
LF	276 kPa (40 PSI)	9 mm (11/32 in)	No	None
LR	331 kPa (48 PSI)	6 mm (7/32 in)	No	None
RR	331 kPa (48 PSI)	6 mm (8/32 in)	No	None, Grass in bead
RF	276 kPa (40 PSI)	8 mm (10/32 in)	No	None, Grass in bead

The interior of the Buick featured leather upholstery and was configured with two rows for the seating of up to six occupants (3/3). The front seat was a split-bench, such that the left and center positions moved together on one seat track and the front row right position moved on its own seat track. The fold-down center console also served as a seatback for the center position. The driver/center seat was adjusted 3 cm (1.0 in) forward of the full-rear track position with the seatback reclined 25-degrees aft of vertical. The head restraint was fully down, and the center console was folded down. The front right seat was adjusted fully rearward, with the seatback reclined 35-degrees and the head restraint fully down. The second row was a non-adjustable bench seat, with integral head restraints in the outer positions. Manual restraint systems consisted of 3-point lap and shoulder seat belts for the outer positions of the front row and all second row positions, with a lap belt for the front row center position. Supplemental restraint systems consisted of driver and front right passenger frontal air bags.

Exterior Damage

The Buick sustained exterior damage to its front plane from the Event 1 impact with the guardrail, as well as damage to the right, top and left planes from the subsequent rollover (Event 2). Direct contact damage on the front plane was biased to the left, beginning 42 cm (16.5 in) left of the centerline and extending 41 cm (16.0 in) to the left corner (**Figures 14 and 15**). The combined width of the direct and induced damage extended across the vehicle's entire 165 cm (65.0 in) undeformed end width. The bumper fascia was fractured and separated from the vehicle during the impact. Damaged components included the bumper reinforcement bar, head lamp assembly, and the sub-structure at the left aspect of the engine compartment. The left fender was also compressed and buckled, but there was no change in the wheelbase dimensions.

Figure 14: Front view depicting the location of the Buick's impact damage.

Figure 15: Overhead view of the Buick's frontal deformation.

A residual crush profile along the bumper reinforcement bar produced the following resultant measurements: C1 = 41 cm (16.0 in), C2 = 40 cm (15.7 in), C3 = 28 cm (11.0 in), C4 = 19 cm (7.5 in), C5 = 9 cm (3.5 in), C6 = 0. The collision deformation classification (CDC) assigned to this damage pattern was 12FLEW3. Due to the yielding properties of the guardrail and the impact dynamics, a rigid analysis of this impact was beyond the scope of the WinSMASH model. However, for comparison purposes the severity of the impact (delta-V) was estimated by the WinSMASH Barrier Algorithm. The estimated total delta-V was 33 km/h (20 mph), with longitudinal and lateral components of -32 km/h (-20 mph) and 6 km/h (4 mph), respectively.

The rollover damage (Event 2) consisted of bi-directional abrasions to the surfaces of the side and top planes and body panel deformation. The extent of the damage and distance traveled during the rollover was consistent with a six quarter-turn event. The roof crushed down with minimal lateral shift and was uniform, measuring approximately 13 cm (5.0 in) at the support pillars. In the roof itself, there was a depression along the left aspect that measured 104 x 36 cm

(41.0 x 14.0 in), length x width. The maximum crush in this depressed region was located 15 cm (6.0 in) aft of the left B-pillar and 31 cm (12.0 in) right of the left roof side rail.

Figure 16 depicts the Buick and the observable roof crush associative to the rollover event. The maximum roof crush measured 20 cm (8.0 in). The windshield was fractured during the rollover and had sagged over time into the interior. The glazing of all the side windows and the backlight was disintegrated. The CDC assigned to the rollover damage was 00TDDO4.

Figure 16: Left rear oblique view depicting the Buick's roof deformation.

Event Data Recorder

The Buick Century was equipped with an Air Bag Control Module (ACM) that performed the diagnostic, sensing and deployment control functions for the vehicle's supplemental restraint systems. The module had EDR capabilities and was located under the front row right seat of the vehicle. The EDR component was imaged using the Bosch Crash Data Retrieval (CDR) tool and software version 16.6 via a hardware link to the Diagnostic Link Connector (DLC) located under the left aspect of the instrument panel. External 12-volt electrical power was applied to the Buick's battery. The imaged data was later reported with version 17.7.2, and is included at the end of this technical report as **Appendix B**.

The EDR was only capable of monitoring and recording acceleration in the longitudinal direction and could only record two event types, namely Non-Deployment events and Deployment events. Each event type was equipped with buffers that recorded Pre-crash and Crash data. The module could only store one Non-Deployment event which was unlocked, unless it was linked to a Deployment event. An unlocked Non-Deployment Event could be either cleared after approximately 250 ignition cycles or overwritten by a more severe event. Locked Non-Deployment events could not be overwritten. Deployment events by definition deployed air bags. The recorded data from a Deployment event became locked and could not be overwritten. A total of two Deployment events could be stored in memory. The imaged data indicated that the vehicle's EDR had recorded one Deployment event and one Non-Deployment event. These events were determined to be associated to the crash under investigation.

<u>Deployment Event</u>

A logic table in the data indicated that the Deployment event had occurred first. The system status at the time of the recording indicated that the event occurred on ignition cycle 19,741. The ignition count at the time of the investigation SCI investigation was 19,743. The air bag warning lamp in the instrument cluster was "Off." The seat belt status for the driver was "Unbuckled."

The maximum recorded longitudinal delta-V was -16.56 km/h (-10.29 mph) at 105 millisecond after AE. This event was attributed to the impact with the guardrail end terminal. The frontal air bag deployment criteria was met 15 milliseconds after AE.
The EDR recorded 5 seconds of Pre-Crash vehicle performance parameters which described the operation of the vehicle. The Pre-Crash data was measured asynchronously relative to Algorithm Enable (AE). The recorded Pre-Crash data is listed in the following table:

	-5 seconds	**-4.0 seconds**	**-3 seconds**	**-2 seconds**	**-1 seconds**
Vehicle Speed	111 km/h (69 mph)	111 km/h (69 mph)	113 km/h (70 mph)	111 km/h (69 mph)	81 km//h (48 mph)
Accelerator Percentage	11	11	11	22	100
Engine RPM	1920	1920	1920	1984	2624
Brake Switch Circuit Status	Off	Off	Off	Off	On

The pre-crash data trends leading up to AE were fairly constant with minimal variation in speed, engine rpm and accelerator percentage. It is possible that the Buick was operated on cruise control during this time period. Through a time/distance analysis of the data, it was determined that the Buick departed the right lane approximately 5 seconds prior to AE and subsequently departed the road edge 2 seconds prior to AE. The driver reacted to the road departure by an application of the accelerator (2 seconds prior to AE) and the brake (1 second prior to AE), as recorded by the status changes in the accelerator, brake, and engine RPM. It is possible that the 81 km/h (48 mph) vehicle speed recorded 1 second prior to AE was underreported due to ABS brake lock-up. The reported vehicle speed was not the speed at the vehicle's center of mass; rather, it was measured by a sensor in the driveline of the transmission. Based on SCI field experience, the estimated impact speed was approximately 97 km/h (60 mph).

Non-Deployment Event

The system status table of the Non-Deployment data indicated that this data was also recorded on ignition cycle 19,741, that the air bag warning lamp was "Off," and the driver's seat belt was "Unbuckled." The reported time between this event and the previous recognized event was 0.2 sec. However, the pre-crash data buffer indicated that this Non-Deployment event occurred approximately 2 seconds after the Deployment, due to the overlapping values of the recorded data. Combining this time-sequence logic, the recorded Non-Deployment event occurred approximately 2.2 seconds after the Deployment event as a result of ground contact during the rollover, and had overwritten a recognized Non-Deployment event of lesser severity. The recorded longitudinal delta-V was 0.0 km/h (0.0 mph). Refer to the attached data for further detail.

Interior Damage

The interior damage to the Buick consisted of occupant compartment intrusion, deployment of the frontal air bags, and occupant contact to interior components. The roof intruded vertically at all five seat positions, and the left B-pillar and left roof side rail intruded laterally. The measured intrusions are listed in the following table.

Position	Component	Magnitude	Direction
Row 1 Left	Roof	15 cm (5.9 in)	Vertical
	B-pillar	8 cm (3.1 in)	Lateral
	Roof side rail	10 cm (3.9 in)	Lateral
Row 1 Right	Roof	11 cm (4.4 in)	Vertical
Row 2 Left	Roof	24 cm (9.4 in)	Vertical
Row 2 Center	Roof	20 cm (8.0 in)	Vertical
Row 2 Right	Roof	17 cm (6.5 in)	Vertical

Occupant contact to the interior was identified at the left knee bolster and roof. A 5 cm (2.0 in) wide scuff was observed to the driver's knee bolster. It was centered 48 cm (19.0 in) above the floor and 23 cm (9.0 in) left of the steering column centerline. An area of blood was observed on the headliner above the front row right position indicative of probable occupant contact during the rollover (Figure 17). The pattern measured 6 cm x 6 cm (2.5 x 2.5 in) and was located 51 cm (20 in) aft of the windshield header and 42 cm (16.5 in) left of the right roof side rail. Blood evidence was also noted on the steering wheel rim, the left front door panel and at the trim surrounding the opening lever of the right front door. The tilt steering wheel was adjusted fully up. There was no deflection or deformation of the rim. There was no evidence of shear capsule displacement. Dirt and debris was dispersed through the interior and across the headliner hampering further identification of potential occupant contacts.

Figure 17: Right interior view of the Buick depicting the blood pattern on the headliner.

Manual Restraint Systems

The 3-point lap and shoulder seat belt systems for the driver and front row right occupant utilized continuous-loop webbing, a sliding latch plate, and an adjustable D-ring. The driver's seat belt system retracted onto an Emergency Locking Retractor (ELR), while the front right seat belt utilized an ELR/Automatic Locking Retractor (ALR). Both D-rings were adjusted fully up. At inspection, the webbings of both seat belts were stowed on their retractors. Each of the webbings could be extended from its retractor; however, the webbing did not freely retract. The webbing

was restricted by the crash-related deformation of the interior trim surrounding the respective B-pillars. The trim captured the webbing and created enough resistance to overcome the return spring of the retractor. The stowed position of the seat belt webbings at the time of the SCI inspection indicated to the investigator that the restraints were probably not in use at the time of the crash.

Examinations of restraint webbings and latch plate hardware were unremarkable for crash-related physical evidence. It was determined that neither the driver nor the front row right occupant was belted at the time of the crash. The unbelted status of the driver was in agreement with the imaged EDR data. The belt status for the front passenger was not reported by the EDR.

Supplemental Restraint Systems

The Buick was equipped with frontal air bags for the driver and front row right occupant. The driver's frontal air bag (**Figure 18**) deployed from a module located in the center hub of the steering wheel. There was no evidence of contact to the I-configuration cover flaps. In its deployed state, the air bag measured 56 cm (22.0 in). It was tethered and vented by two 1 cm (0.5 in) ports in the 9/3 0'clock sectors on the back side of the bag. At examination, there was no residual evidence of occupant contact to the bag.

Figure 18: View depicting the deployed driver's frontal air bag within the Buick.

Figure 19: View depicting the make-up transfer to the passenger's frontal air bag within the Buick.

The passenger's frontal airbag module was a top-mount design located in the right aspect of the instrument panel. The module cover flap was rectangular, measured 60 x 40 cm (23.6 x 15.8 in) and was hinged at the forward aspect. In its deflated state, the face of the deployed air bag measured 66 x 46 cm (26.0 x 18.0 in), width by height. The air bag was designed and shaped to provide protection to both the right and center positions of the front row. The rearward excursion of the tethered air bag measured 30 cm (12.0 in) from the vertical face of the instrument panel. A 15 x 20 cm (6.0 x 8.0 in) make-up transfer was observed on the air bag and was related to the contact from the front right occupant's face **(Figure 19)**. The contact was centered 30 cm (12.0

in) left of the right edge of the air bag. The silhouette of the eyes, nose and lips were prominent in the transfer.

2004 BUICK CENTURY OCCUPANT DATA

Driver Demographics

Age/Sex:	25 years/male
Height:	185 cm (73 in)
Weight:	104 kg (230 lb)
Eyewear:	Unknown
Seat Type:	Forward-facing split bench with adjustable head restraint
Seat Track Position:	Mid-to-rear track
Manual Restraint Usage:	None
Usage Source:	SCI Vehicle inspection, imaged EDR data
Air Bags:	Driver air bag available; deployed
Alcohol/Drug Involvement:	BAC = 0; no specimen test given
Egress From Vehicle:	Exited vehicle with some assistance
Transport From Scene:	Ambulance to a Level 1 trauma center
Type of Medical Treatment:	Admitted for one day

Driver Injuries

Inj. No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Concussion with LOC of unspecified duration	161002.2	Roof	Probable
2	Left 1st rib fracture near sternum, non-displaced	450201.1	Left roof side rail	Possible
3	Scalp abrasions, NFS	110202.1	Roof	Probable
4	Abrasions to left hand	710202.1	Left instrument panel	Probable
5	Abrasion to right posterior shoulder	710202.1	Roof	Probable
6	Abrasions to lateral right forearm	710202.1	Roof	Probable

Source – Emergency Room records

Driver Kinematics

The 25-year-old male driver of the Buick was seated in a mid-to-rear track position. He was not restrained by the manual seat belt system, determined by the lack of evidence observed during the SCI vehicle inspection and confirmed by the data imaged from the Buick's EDR. The driver operated the vehicle at an EDR-reported speed of 111 km/h (69 mph) 5 seconds prior to AE. For undermined reasons, the Buick drifted to the right at a shallow angle and departed the right side of the roadway. The EDR data indicated that the driver reacted to the errant trajectory of the vehicle with an application of the accelerator and the brake approximately 2 seconds prior to AE.

At impact with the guardrail end terminal, the Buick's frontal air bags deployed. The unbelted driver responded to the 12 o'clock direction of the impact force with a forward and slight left trajectory. His left lower extremity probably contacted the knee bolster, as evidenced by the scuff to the component, and his face and chest loaded the deployed frontal air bag.

The Buick decelerated and rotated counterclockwise as it displaced the end terminal to the south. In a near broadside orientation, the vehicle tripped and initiated a right side leading rollover. The driver was displaced about the interior in an uncontrolled manner, and probably contacted the roof and components of the left interior. His head probably contacted the roof, resulting in scalp abrasions and a concussion with loss of consciousness. The Buick came to final rest upside down, with its occupants on the roof. The driver was assisted from the overturned vehicle and transported by ambulance to a local hospital for the treatment of his injuries.

Front Row Right Occupant Demographics

Age/Sex:	22 years/female
Height:	168 cm (66 in)
Weight:	135 kg (298 lb)
Eyewear:	Unknown
Seat Type:	Forward-facing split bench seat with adjustable head restraint
Seat Track Position:	Full-rear track
Manual Restraint Usage:	None
Usage Source:	SCI vehicle inspection
Air Bags:	Front passenger air bag available; deployed
Alcohol/Drug Involvement:	BAC = 0; no specimen test given
Egress From Vehicle:	Unknown
Transport From Scene:	Ambulance to a Level 1 trauma center
Type of Medical Treatment:	Treated and released

Front Row Right Occupant Injuries

Inj. No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Abrasions on right lateral abdomen	510202.1	Right door panel	Probable
2	Abrasions to right lower back	410202.1	Roof	Probable

Source – Emergency Room records

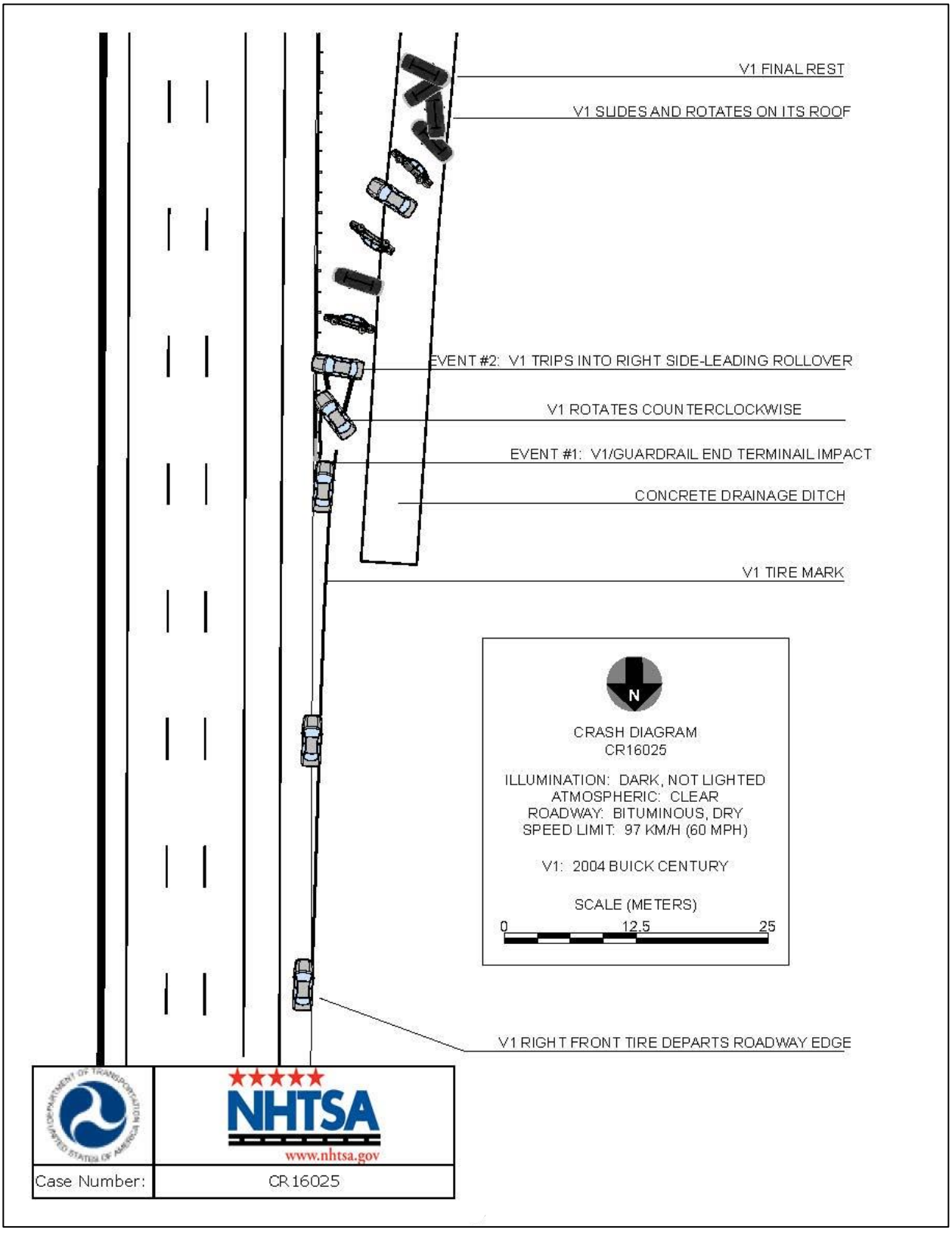
Front Row Right Occupant Kinematics

The unbelted 22-year-old female was seated in the front row right position with her seat adjusted to the full-rear track position. Her lack of manual restraint usage was determined by the observations of the SCI Investigator during the vehicle inspection process. The Buick's EDR was not capable of reporting the manual restraint usage status of the front row right occupant.

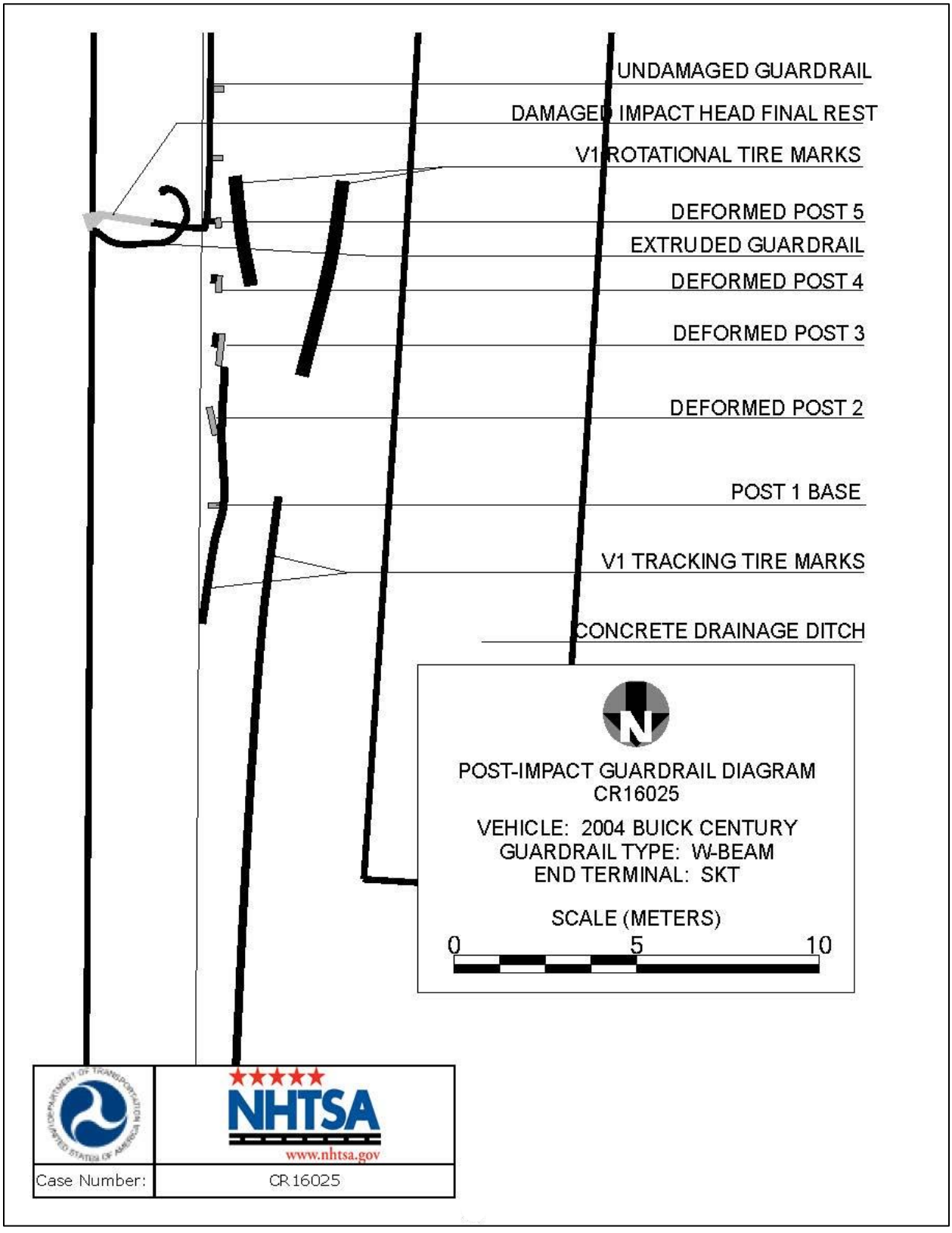
At impact with the guardrail's end terminal, this occupant initiated a forward and slight left trajectory in response to the 12 o'clock direction of the impact force. She contacted the deployed passenger's frontal air bag with her face, as evidenced by the make-up transfer to the face of the air bag. As the vehicle rotated counterclockwise, tripped and initiated the right side leading rollover, the unbelted occupant was displaced about the front interior in an uncontrolled manner.

It is probable that the front row right occupant contacted the components of the right interior and roof during the rollover sequence. The door panel and roof were the likely sources of the abrasions to her right abdomen and back, respectively. Following the crash, the front row right occupant exited the vehicle under her own power. She was transported by ambulance to a local hospital for evaluation and treatment, and released in hours of the crash.

CRASH DIAGRAM



GUARDRAIL DEFORMATION DIAGRAM



APPENDIX A:

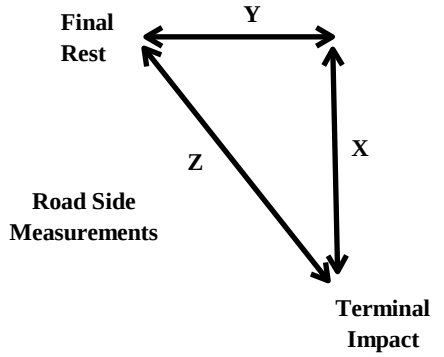
Federal Highway Administration Guardrail Forms

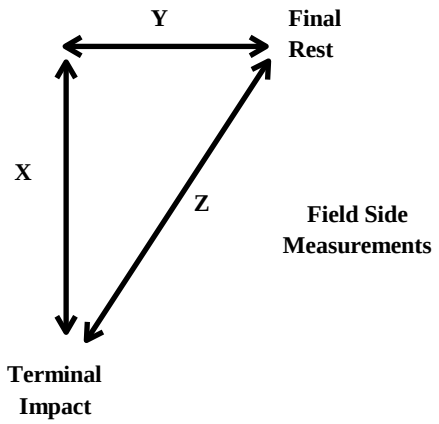
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	August 2016	**TIME OF CRASH (MILITARY)**	Nighttime
Case Number	CR16025	**State**	MO
Traffic Route	Limited Access	**Direction (Southbound = SB)**	SB
Ambient Conditions (at time of crash)			
Temperature (°F)	69 ºF	**Lighting**	Dark
Atmospheric	Clear		

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)	70 mph (EDR)
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 126.0 ft ❒Road side ■Field Side
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 121.4 ft
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 33.8 ft
Super elevation	❒+2% ❒-2% ■NONE or FLAT
Curve Radius (ft.)	N/A

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





Case No.: CR16025

ON-SCENE INFORMATION		
End Treatment Type	■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.	Yes No Unknown	Describe	Travel way	Curb	
	Steel Wood Other	D x W (in.) or Dia. (in.)	Steel Wood Composite	D x W (in.)					
0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	Steel	6 x 4	None	None	N/A	None	1 ft 2 in	N/A	6 ft 5 in
2	Steel	6 x 4	None	None	N/A	None	0 ft 11 in	N/A	6 ft 7 in

Case No.: CR16025

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type Steel Wood Other	Dim. D x W (in.) or Dia. (in.)	Type Steel Wood Composite	Dim. D x W (in.)	Yes No Unknown	Describe	Travel way	Curb	
3	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 5 in	N/A	6 ft 4 in
4	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 5 in	N/A	5 ft 11 in
5	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 3 in	N/A	6 ft 5 in
6	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 3 in	N/A	6 ft 2 in
7	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 3 in	N/A	6 ft 2 in
8	Steel	6 x 4	Composite	4 x 7.8	No	None	1 ft 2 in	N/A	6 ft 4 in

Case No.: CR16025

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 Dia. (in.)	Steel Wood Composite	D x W (in.)					
9	Steel	6 x 4	Composite	4 x 7.8	No	None	0 ft 11 in	N/A	6 ft 2 in
10	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Case No.: CR16025

EXTRUDER			
Feeder Channel Width at impact head	❒4inches ❒5 inches ■Other 4.5 in		
Guide Chute Exit Height (in.)	20.5 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.)	15 ft – 3 in
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 = 31 ft 5 in** *[15 ft 3 in (Extruded) + 6 ft 7 in (in impact head) + 9 ft 7 in (deformed W-beam to Post 6)]*		

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

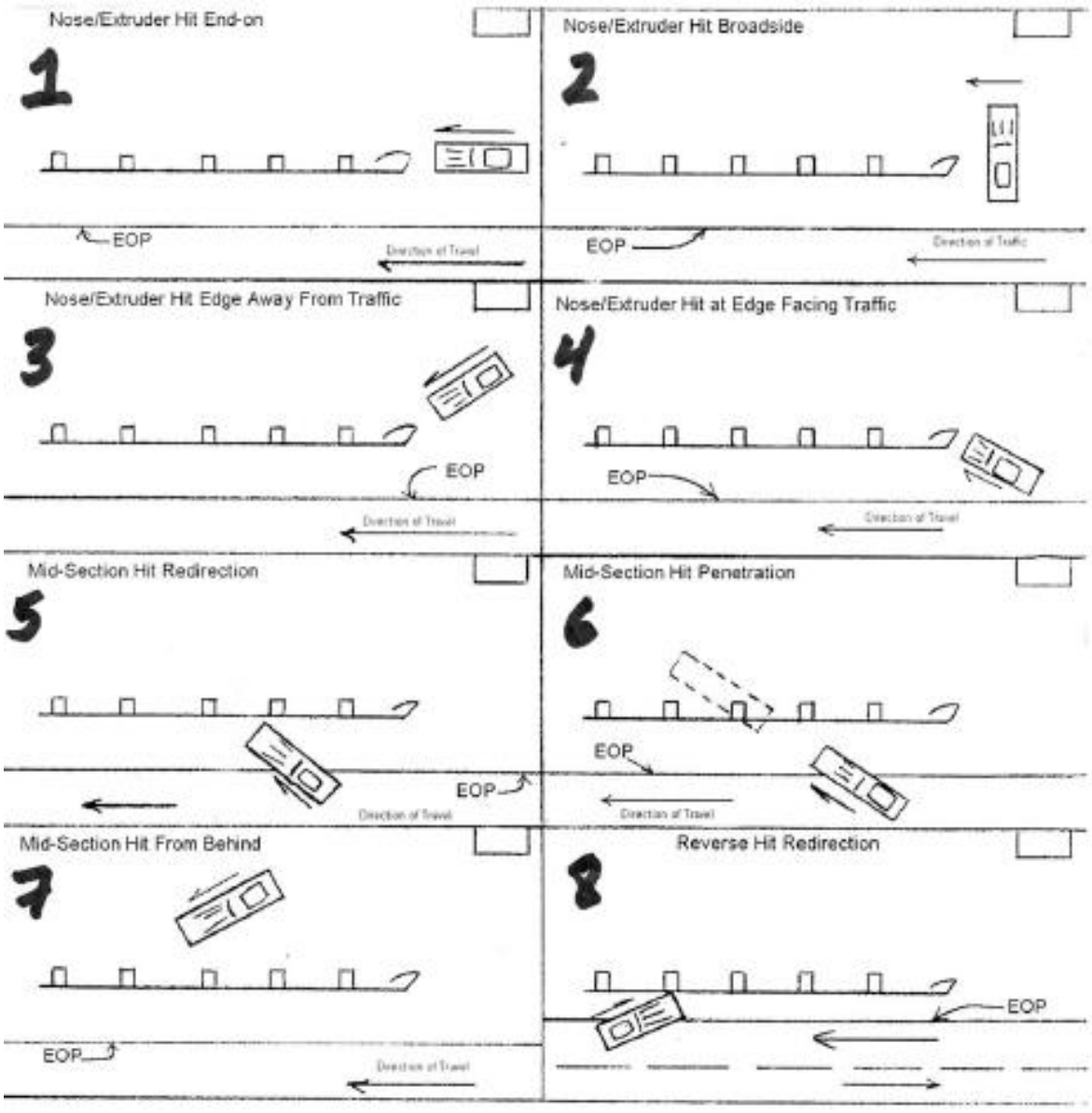
ALL-SYSTEM PERFORMANCE			
Railkinks Downstream of Head?	❒No	■Yes;	No. of Kinks in Rail: 2
Was there intrusion into the Occupant Compartment by foreign object (guardrail)?	■No ❒Yes		
Did vehicle impact other objects after impact with terminal?	❒No ■Yes		
Object Contacted	Ground during rollover		

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	-22%	-22%	-28%
Adjacent Lane Width (ft)	12 ft 2 in		
Lane Type (NAS EDS Variable: Sur. Type)	Concrete		
Shoulder Type	Asphalt		
Shoulder Width (ft)	10 ft 4 in		
Guardrail Height (in)	30.75 in *(measured between Post 9 and 10)*		

Case No.: CR16025

VEHICLE INFORMATION		
Vehicle Type (NHTSA Input)	2004 Buick Century	
Vehicle Identification Number (VIN)	2G4WS52J141xxxxxx	
Vehicle Mass (NASS var.: veh.wgt)	3,369 lb	
Vehicle orientation upon impact	■Case Type 1 ❒ Case Type 2 ❒ Case Type 3 ❒ Case Type 4 ❒ Case Type 5 ❒ Case Type 6 ❒ Case Type 7 ❒ Case Type 8 ❒ Other	
If 'Other', describe	N/A	
Collision Deformation Classification	Event # 1 = 12FLEW2 Event #2 = 00TDDO3	
Delta-V	-10.09 mph (EDR recorded)	
Occupant Compartment Penetration of rail	■No	❒Yes; ~~Describe~~:
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)	Ground	
Rollover Type, Terhune Scale, (NASS EDS variable: rolintyp)	Trip-over	

Case No.: CR16025



APPENDIX B:

2004 Buick Century Event Data Recorder Report

The EDR report contained in this technical report was imaged using the current version of the Bosch CDR software at the time of the vehicle inspection. The CDR report contained in the associated Crash Viewer application may differ relative to this report.

BOSCH

CDR CRASH DATA RETRIEVAL

IMPORTANT NOTICE: Robert Bosch LLC and the manufacturers whose vehicles are accessible using the CDR System urge end users to use the latest production release of the Crash Data Retrieval system software when viewing, printing or exporting any retrieved data from within the CDR program. Using the latest version of the CDR software is the best way to ensure that retrieved data has been translated using the most current information provided by the manufacturers of the vehicles supported by this product.

CDR File Information

User Entered VIN	2G4WS52J141******
User Case Number	
EDR Data Imaging Date Crash Date	
Filename Saved on	CR16025_V1_ACM.CDRX
Imaged with CDR version Reported with CDR version	Crash Data Retrieval Tool 16.6 Crash Data Retrieval Tool 17.7.2
Reported with Software Licensed to (Company Name)	NHTSA
EDR Device Type	Airbag Control Module
Event(s) recovered	Deployment Non-Deployment

Comments

No comments entered.

Data Limitations

Recorded Crash Events:

There are two types of Recorded Crash Events. The first is the Non-Deployment Event. A Non-Deployment Event records data but does not deploy the air bag(s). It contains Pre-Crash and Crash data. The SDM can store up to one Non-Deployment Event. This event may be overwritten by another Non-Deployment Event. This event will be cleared by the SDM, after approximately 250 ignition cycles. This event can be overwritten by a second Deployment Event, referred to as a Deployment Level Event, if the Non-Deployment Event is not locked. The data in the Non-Deployment Event file will be locked, if the Non-Deployment Event occurred within five seconds before a Deployment Event. A locked Non Deployment Event cannot be overwritten or cleared by the SDM. The second type of SDM recorded crash event is the Deployment Event. It also contains Pre-Crash and Crash data. The SDM can store up to two different Deployment Events, if they occur within five seconds of one another. If a Deployment Level Event occurs within five seconds after the Deployment Event, the Deployment Level Event will overwrite any non-locked Non-Deployment Event. Deployment Events cannot be overwritten or cleared by the SDM. Once the SDM has deployed an air bag, the SDM must be replaced.

Data:

-SDM Recorded Vehicle Longitudinal Velocity Change reflects the change in longitudinal velocity that the sensing system experienced during the recorded portion of the event. SDM Recorded Vehicle Longitudinal Velocity Change is the change in velocity during the recording time and is not the speed the vehicle was traveling before the event, and is also not the Barrier Equivalent Velocity. For Deployment Events, the SDM will record 100 milliseconds of data after Deployment criteria is met and up to 50 milliseconds before Deployment criteria is met. For Non-Deployment Events, the SDM will record up to the first 150 milliseconds of data after algorithm enable. Velocity Change data is displayed in SAE sign convention.

-SDM Recorded Vehicle Speed accuracy can be affected by various factors, including but not limited to the following:

- -Significant changes in the tire's rolling radius
- -Final drive axle ratio changes
- -Wheel lockup and wheel slip

-Brake Switch Circuit Status indicates the open/closed state of the brake switch circuit.

-Pre-Crash data is recorded asynchronously. The 1.0 second Pre-crash data value (most recent recorded data point) is the data point last sampled before AE. That is to say, the last data point may have been captured just before AE but no more than 1.0 second before AE. All subsequent Pre-crash data values are referenced from this data point.

-Pre-Crash Electronic Data Validity Check Status indicates "Data Invalid" if:

- -The SDM receives a message with an "invalid" flag from the module sending the pre-crash data
- -No data is received from the module sending the pre-crash data
- -No module present to send the pre-crash data

-Engine Speed is reported at two times the actual value in the following vehicles, if the vehicle is equipped with a 6.6L Duramax diesel engine (RPO LB7, LBZ, LLY, or LMM):

- -2001-2006 Chevrolet Silverado
- -2007 Chevrolet Silverado Classic
- -2001-2006 GMC Sierra
- -2007 GMC Sierra Classic
- -2006-2007 Chevrolet Express

-2006-2007 GMC Savana
-2003-2009 Chevrolet Kodiak
-2003-2009 GMC Topkick

-Driver's Belt Switch Circuit Status indicates the status of the driver's seat belt switch circuit. If the vehicle's electrical system is compromised during a crash, the state of the Driver's Belt Switch Circuit may be reported other than the actual state.
-Passenger Front Air Bag Suppression Switch Circuit Status indicates the status of the suppression switch circuit.
-The Time Between This Event and the Previous Events is displayed in seconds. If the time between the two events is greater than five seconds, "N/A" is displayed in place of the time.
-If power to the SDM is lost during a crash event, all or part of the crash record may not be recorded.
-If the vehicle is a 2000 - 2002 Chevrolet Cavalier Z24 or a Pontiac Sunfire GT, with a manual transmission (RPO MM5) and a 2.4L engine (RPO LD9), the Brake Switch Circuit Status data will be reported in the opposite state than what actually occurred, e.g. an actual brake switch status of "ON" will be reported as "OFF".
-All data should be examined in conjunction with other available physical evidence from the vehicle and scene.

Data Source:
All SDM recorded data is measured, calculated, and stored internally, except for the following:
-Vehicle Speed, Engine Speed, and Percent Throttle data are transmitted by the Powertrain Control Module (PCM), via the vehicle's communication network, to the SDM.
-Brake Switch Circuit Status data is transmitted by either the ABS module or the PCM, via the vehicle's communication network, to the SDM.
-The SDM may obtain Belt Switch Circuit Status data a number of different ways, depending on the vehicle architecture. Some switches are wired directly to the SDM, while others may obtain the data from various vehicle control modules, via the vehicle's communication network.
-The Passenger Front Air Bag Suppression Switch Circuit is wired directly to the SDM.

Hexadecimal Data:
Data that the vehicle manufacturer has specified for data retrieval is shown in the hexadecimal data section of the CDR report. The hexadecimal data section of the CDR report may contain data that is not translated by the CDR program. The control module contains additional data that is not retrievable by the CDR tool.

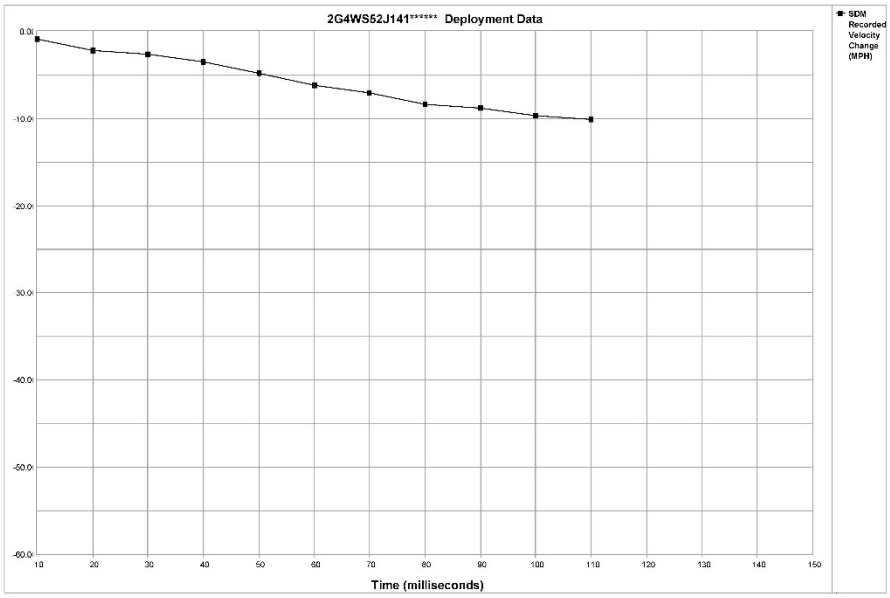
01025_SDMG-99JXZ09-10_r004

System Status At Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Passenger SIR Suppression Switch Circuit Status (if equipped)	Air Bag Not Suppressed
Ignition Cycles At Deployment	19741
Ignition Cycles At Investigation	19743
Maximum SDM Recorded Velocity Change (MPH)	-10.29
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	105
Time Between this Event and the Previous Event (sec)	N/A
Time From Algorithm Enable to Deployment Command Criteria Met (msec)	15

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	69	1920	11
-4	69	1920	11
-3	70	1920	11
-2	69	1984	22
-1	48	2624	100

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	OFF
-2	OFF
-1	ON



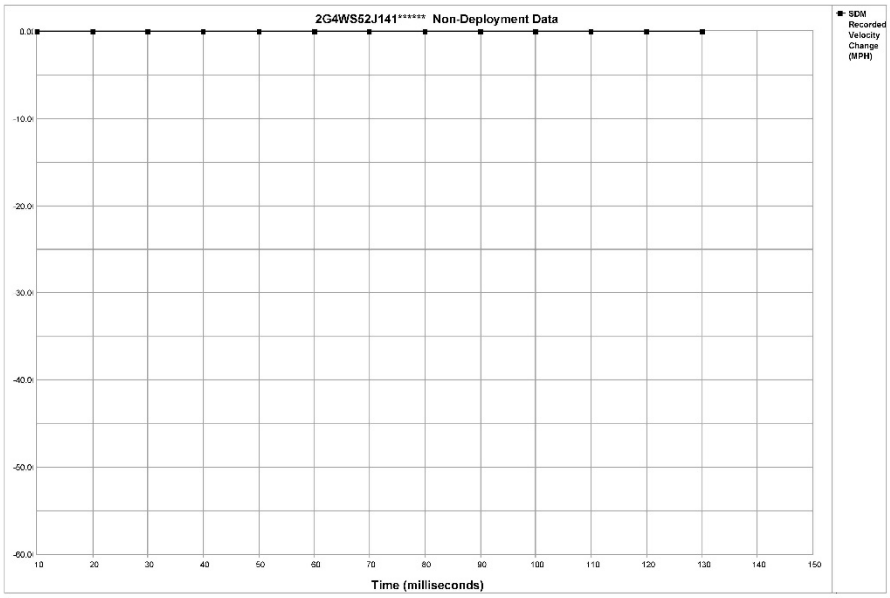
Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
SDM Recorded Velocity Change	-0.88	-2.19	-2.63	-3.51	-4.83	-6.14	-7.02	-8.34	-8.78	-9.65	-10.09	N/A	N/A	N/A	N/A

System Status At Non-Deployment

SIR Warning Lamp Status	OFF
Driver's Belt Switch Circuit Status	UNBUCKLED
Passenger SIR Suppression Switch Circuit Status (if equipped)	Air Bag Not Suppressed
Ignition Cycles At Non-Deployment	19741
Ignition Cycles At Investigation	19743
Maximum SDM Recorded Velocity Change (MPH)	0.00
Algorithm Enable to Maximum SDM Recorded Velocity Change (msec)	0
Time Between this Event and the Previous Event (sec)	0.2

Seconds Before AE	Vehicle Speed (MPH)	Engine Speed (RPM)	Percent Throttle
-5	70	1920	11
-4	69	1984	22
-3	48	2624	100
-2	14	1344	0
-1	5	576	0

Seconds Before AE	Brake Switch Circuit State
-8	OFF
-7	OFF
-6	OFF
-5	OFF
-4	OFF
-3	ON
-2	OFF
-1	OFF



Time (milliseconds)	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150
SDM Recorded Velocity Change	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	N/A	N/A

Hexadecimal Data

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$02  87 8A
$03  41 53 33 33 33 38
$04  4B 46 53 41 37 33
$05  00
$06  10 33 09 95
$10  F6 5C 80
$11  8E 91 90 D9 97 00
$14  03 04 2B 80
$18  86 85 86 B3 FF 00
$1C  34 32 57 42 46 53
$1D  59 34 32 57 4B 4C
$1E  4C 4C
$1F  FF 02 00 00 00
$20  A3 00 00 FF 80 FE
$21  FF BF FF FF FF FF
$22  FF FF FF FF FF FF
$23  7C 00 00 00 00 00
$24  00 00 00 00 00 00
$25  00 00 00 00 00 00
$26  FF FF 0D 08 17 4D
$27  6F 70 00 20 00 00
$28  00 FF 37 1D 00 09
$29  15 29 1F 1E 00 F6
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$2B  FF FF FF 00 00 00
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DOT HS 812 626
September 2018

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

13946-092418-v1c