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ON-SITE ROLLOVER INVESTIGATION

CASE NUMBER - IN10028
LOCATION - MISSOURI
VEHICLE - 2009 SCION tC
CRASH DATE - July 2010

Submitted:

January 3, 2011

Contract Number: DTNH22-07-C-00044

Prepared for:

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The crash investigation process is an inexact science which requires that physical evidence such as skid marks, vehicular damage measurements, and occupant contact points 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.

Technical Report Documentation Page

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16. *Abstract*

This on-site investigation focused on the rollover of a 2009 Scion tC. The Scion's restrained 21-year-old female driver was traveling east at night on a straight, unlit, 2-lane state highway during a heavy rain. The vehicle's right front wheel traveled off the south side of the roadway onto a low gravel shoulder and the right side wheels entered a ditch. The driver attempted to avoid the crash by steering left. The front right corner of the bumper and the right front wheel impacted a small concrete culvert (events 1 and 2) at a residential gravel driveway. The impacts were within the 12 o'clock sector and the impact force was sufficient to trigger a stage 2 deployment of the driver's frontal air bag. The driver's knee air bag also deployed. The impact caused the vehicle to vault over the driveway while rotating clockwise and the vehicle rolled over, left side leading eight quarter turns. The left side impact inflatable curtain (IC) air bag also deployed during the crash. The driver was transported by ambulance to a hospital where she was treated in the emergency room for minor injuries and released.

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This on-site investigation focused on the rollover of a 2009 Scion tC. This crash was brought to the National Highway Traffic Safety Administration's (NHTSA) attention on August 10, 2010 by the Transportation Research Center at Indiana University. This investigation was assigned on August 19, 2010. The crash involved only the Scion (**Figure 1**), which departed the roadway and rolled over after impacting a culvert. The crash occurred in July, 2010, at 2315 hours, in Missouri and was investigated by the Missouri State Highway Patrol. The Scion and the crash scene were inspected on August 25-26, 2010. A resident of the property where the crash occurred was interviewed on August 25, 2010. The driver was interviewed on August 30, 2010. This report is based on the police crash report, vehicle inspection, crash scene inspections, inspection of an exemplar vehicle, driver interview, occupant kinematic principles, and evaluation of the evidence.

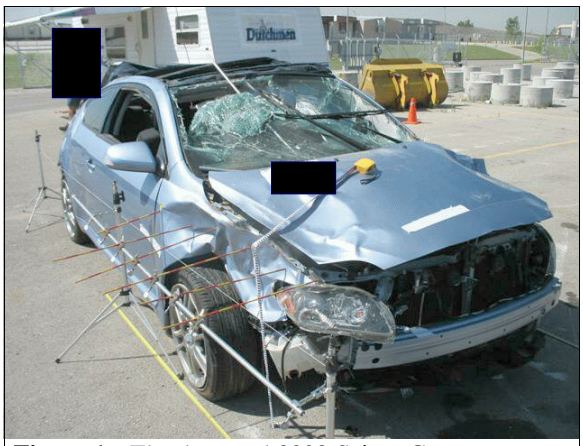

Figure 1: The damaged 2009 Scion tC

CRASH CIRCUMSTANCES

Crash Environment: This crash occurred on a 2-lane, state highway during night time hours and heavy rain. There was no artificial lighting. At the time of the crash, the roadway was under construction and the pavement was new bituminous. The police crash report indicated that the centerline and road edges were marked by raised reflectors. The driver stated during the SCI interview that no construction warning signs were present. The roadway traversed in an east-west direction and had two straight through lanes. The eastbound lane was 4 m (13.1 ft) in width. The westbound lane was 4.3 m (14.1 ft) in width. The roadway had a positive 5% grade to the east and was bordered by gravel shoulders. The north shoulder was 1.6 m (5.2 ft) in width, while the south shoulder was 0.5 m (1.6 ft) in width. Based on the SCI interview with a resident of the property where the crash occurred, at the time of the crash, the south shoulder surface dropped approximately 15 cm (6 in) from the roadway surface. A ditch 0.6 m (2 ft) in depth was adjacent to this shoulder. A culvert and residential driveway were located on the south side of the roadway where the initial impact occurred. The speed limit was 97 km/h (60 mph), which reduced to 48 km/h (30 mph) approximately 30 m (98 ft) prior to the impact. There was no traffic on the roadway at the time of the crash. The site of the crash was rural. The Crash Diagram is on page 10 of this report.

Figure 2: Approach of the Scion to area of roadway departure; arrow shows location of culvert impact

Pre-Crash: The Scion's restrained 21-year-old female driver was traveling east (**Figure 2**) with the cruise control engaged at a driver estimated speed of 97-105 km/h (60-65 mph). The driver stated that the visibility was poor due to the heavy rain and she was leaning forward to see the roadway. The vehicle's right front wheel traveled off the south side of the roadway onto the low gravel shoulder and the right side wheels entered a ditch. The driver attempted to avoid the crash by steering left.

Figure 3: Direct damage on the front right corner of the bumper fascia of the Scion from the impact with the culvert

Crash: Based on the police measurements, The Scion traveled 31.7 m (104 ft) in the ditch and the front right corner of the bumper (**Figure 3**, event 1) and the right front wheel (**Figure 4**, event 2) impacted a small concrete culvert at a residential gravel driveway. The impact was within the 12 o'clock sector and the impact force was sufficient to trigger a stage 2 deployment of the driver's frontal air bag. The driver's knee air bag also deployed. The impact caused the vehicle to vault over the driveway (**Figure 5**) while rotating clockwise and the vehicle rolled over (**Figure 6**, event 3) left side leading 8 quarter turns. The vehicle came to final rest on its wheels heading east. The driver's side impact inflatable curtain (IC) air bag also deployed during the crash.

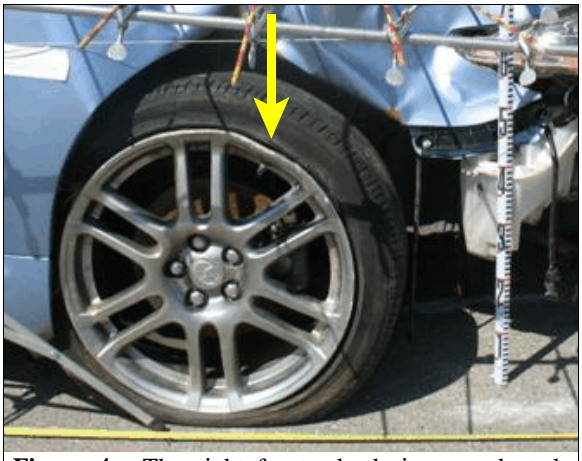

Figure 4: The right front wheel rim was dented (arrow) and the wheel displaced rearward 12 cm (4.7 in) from the culvert impact

Post-Crash: The driver exited the vehicle through the left door. The police were notified of the crash at 2325 hours and arrived on the scene at 2343 hours. The driver was transported by ambulance to a local hospital where she was treated in the emergency room for minor injuries and released. The vehicle was towed from the crash scene due to damage.

Figure 5: View east from the culvert to the path of the rollover; arrow shows the area of final rest of the Scion

CASE VEHICLE

The 2009 Scion tC was a front wheel drive, 2-door lift-back (VIN: JTKTDE167590------), equipped with a 2.4-liter, L-4 gasoline engine and a 4 speed automatic transmission. The front row was equipped with bucket seats with folding backs, adjustable head restraints, lap-and-shoulder

safety belts, driver and front right passenger dual stage frontal air bags, driver's knee air bag, front seat-mounted side impact air bags, and side impact IC air bags that provided protection for the front and second row outboard occupants. The second row was equipped with a bench seat with folding backs, lap-and-shoulder safety belts, adjustable head restraints, and Lower Anchors and Tethers for Children (LATCH) in the outboard seating positions. The driver estimated the vehicle's mileage was approximately 40,234 kilometers (25,000 miles). The vehicle's specified wheelbase was 270 cm (106.3 in).

Figure 6: Damage to the Scion from the rollover

CASE VEHICLE DAMAGE

Exterior Damage Event 1: The Scion sustained front plane damage during the impact with the culvert. The direct damage began at the front right bumper corner and extended 23 cm (9.1 in) to the left on the front bumper fascia. The bumper fascia was displaced off the vehicle during the crash. The crush measurements were taken on the bumper reinforcing bar and the residual maximum crush was 5 cm (2 in) occurring at C_6. The table below presents the crush on the front plane.

Units	Event	Direct Damage		Field L	C_1	C_2	C_3	C_4	C_5	C_6	Direct	Field L
		Width CDC	Max Crush								±D	±D
cm	1	23	5	115	2	3	4	4	4	5	59	0
in		9.1	2.0	45.3	0.8	1.2	1.6	1.6	1.6	2.0	23.2	0.0

Damage Classification Event 1: The Collision Deformation Classification (CDC) for the culvert impact was 12FRLE1 (0 degrees). The damage algorithm of the WinSMASH program calculated the total Delta V as 14 km/h (8.7 mph). The longitudinal and lateral velocity changes were -14 km/h (-8.7 mph) and 0 km/h, respectively.

Exterior Damage Event 2: The Scion also sustained right front wheel damage from the impact with the culvert. The sidewall of the tire was cut and the wheel rim was dented (**Figure 4**). The impact displaced the right front wheel rearward 12 cm (4.7 in).

Damage Classification Event 2: The CDC for the right front wheel impact was 12FRWN3. The WinSMASH program could not be used to calculate a Delta V for this impact since wheel impacts are out of scope for the program. The severity of the damage on the wheel was moderate based on the displacement of the wheel and the damage on the rim.

Figure 7: The maximum vertical crush to the roof of the Scion

Exterior Damage Event 3: Both side planes and the top plane of the Scion were damaged during the rollover. The damage on the left side plane began 49 cm (19.3 in) forward of the left front axle and extended 110 cm (43.3 in) rearward along the left fender, hood, and A-pillar. The damage resumed 68 cm (26.8 in) forward of the left rear axle and extended 140 cm (55.1 in) rearward along the roof side rail, C-pillar, and quarter panel. The damage on the right side plane began 323 cm (127.2 in) forward of the right rear axle and extended 87 cm (34.3 in) rearward along the right fender. The damage resumed 70 cm (27.6 in) forward of the right rear axle and extended 102 cm (40.2 in) rearward along the right roof side rail, C-pillar, and quarter panel. The damage on the top plane resided on the hood, the right roof side rail, the tops of the C-pillars, and the back hatch. The maximum vertical crush (**Figure 7**) was 5 cm (2 in). It was located at the right center portion of the roof, 99 cm (39 in) forward of the right rear axle. The maximum lateral crush was 5 cm (2 in) and was located on the right roof rail, 92 cm (36 in) forward of the right rear axle. The roof, hood, and both quarter panels sustained induced damage.

Damage Classification Event 3: The CDC for the rollover was 00TDDO2. The WinSMASH program could not be used to calculate a Delta V for this event since rollovers are out of scope for the program. Based on the extent of the roof crush, the severity of the damage was minor.

The vehicle manufacturer's recommended tire size was P215/45R17 and the vehicle was equipped with the recommended size tires. The Scion's tire data are presented in the table below.

Tire	*Measured Pressure*		*Vehicle Manufacturer's Recommended Cold Tire Pressure*		*Tread Depth*		*Damage*	*Restricted*	*Deflated*
	kPa	psi	kPa	psi	milli-meters	32nd of an inch			
LF	Flat	Flat	221	32	5	6	None	No	Yes
LR	207	30	200	29	5	6	None	No	No
RR	Flat	Flat	200	29	5	6	None	No	Yes
RF	Flat	Flat	221	32	5	6	Cut Sidewall	Yes	Yes

Vehicle Interior: The inspection of the Scion's interior revealed a scuff on the left roof side rail, probably from contact by the driver's head. There was no deformation of the steering wheel or compression of the energy absorbing steering column.

Both doors remained closed and operational. Prior to the crash, all of the window glazings were either closed or fixed. The windshield was in place and cracked from impact forces and had partially collapsed from weathering. The roof glazing, right front glazing, and backlight glazing were disintegrated due to impact forces.

There were two intrusions of the passenger compartment. The roof intruded vertically 5 cm (2 in) in the front right passenger area and 6 cm (2.4 in) at the second row right passenger area.

ROLLOVER DISCUSSION

The Scion was not equipped with Electronic Stability Control (ESC) or a rollover sensing system. The NHTSA has given the vehicle a four star rollover rating on a five star scale and a Static Stability Factor of 1.38[1]. A four star rating indicates that the vehicle has a 10%-20% chance of a rollover when involved in a single vehicle crash and the chance of rollover for this vehicle was rated at 11%. The Static Stability Factor (SSF) is a calculation based on the vehicle's track width and height of its center of gravity. The result of the calculation is a measure of a vehicle's resistence to a rollover. A higher SSF indicates a more stable vehicle. The majority of passenger vehicles have an SSF of 1.30 to 1.50[2]. This vehicle model also did not tip-up in the dynamic steering maneuver test in which the test vehicle is put through a fish-hook shaped steering maneuver (i.e., hard left and hard right steer) at a speed of between 56 km/h-80km/h (35-50 mph).

The rollover of the Scion was initiated by the frontal plane impact with the culvert, which caused the vehicle to vault and rotate clockwise. As the vehicle rotated, it rolled over with the left side leading. The vehicle was airborne a distance of approximately 12 m (39 ft) traversing across a residential driveway and touching down in a residential yard where it rolled over across a positive 5% grass covered grade. The vehicle rolled over 8 quarter turns and traversed a total distance of 34 m (112 ft) from the impact with the culvert to its final rest position. At final rest, the vehicle was on its wheels heading south.

EVENT DATA RECORDER

The Scion's EDR was imaged via direct connection to the air bag control module using the manufacturer's readout tool and version 1.4.1.0 of the readout tool software. The EDR recorded data for a frontal event. The driver's belt switch status was reported as "Belted." The driver's seat position was reported as "RW," which is understood to mean rearward. The deployment time for the driver's frontal air bag was reported as 22 ms. The deployment stage was reported as "Hi," which is understood to indicate a stage 2 deployment. The vehicle manufacturer's readout tool documentation indicated that pre-crash data was not applicable for this vehicle. In the imaged

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[1] www.safercar.gov,9/16/10

[2] "Trends in the Static Stability Factor of Passenger Cars, Light Trucks, and Vans", NHTSA Technical Report, DOT HS 809 868, June 2005

pre-crash data graph, the EDR reported zeros for speed and engine rpm, and the accelerator and brake were reported as "Off." The EDR reported 150 ms of velocity change data, which is presented in the table below. A column was added to convert mph to km/h.

ms	Vel Chg (mph)	Vel Chg (km/h	ms	Vel Chg (mph)	Vel Chg (km/h)	ms	Vel Chg (mph)	Vel Chg (km/h)
10	0.4	0.6	60	7.8	12.6	110	8.2	13.2
20	1.4	2.3	70	8.6	13.9	120	8.4	13.5
30	1.6	2.6	80	8.4	13.5	130	8.7	14.0
40	3.1	5.0	90	8.5	13.7	140	8.8	14.2
50	5.2	8.4	100	8.2	13.2	150	8.7	14.0

AUTOMATIC RESTRAINT SYSTEM

The Scion was equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system that consisted of dual-stage driver and front right passenger frontal air bags, a driver knee air bag, driver seat position sensor, and a front right passenger weight sensor. The manufacturer has certified that the vehicle is compliant to the Advanced Air Bag portion of the Federal Motor Vehicle Safety Standard (FMVSS) No. 208. The driver's frontal air bag and knee air bag deployed in this crash. The front satellite impact sensors were located on the left and right radiator supports.

The vehicle was also equipped with front seat-mounted side impact air bags and roof side rail-mounted side impact IC air bags. The vehicle's side impact sensors were located in the doors and lower C-pillars. The left IC air bag deployed in this crash.

The driver's frontal air bag was located within the steering wheel hub and the module cover was a three flap configuration constructed of pliable vinyl. The top flap was 13 cm (5.1 in) in width and 8 cm (3.1 in) in height. Each bottom flap was 7 cm (2.8 in) in width and 6 cm (2.4 in) in height. The module cover flaps opened at the designated tear points and were undamaged. The deployed air bag was 62 cm (24.4 in) in diameter and had two tethers and two vent ports. The vents were vertical slits located on the back of the air bag at the 1 and 11 o'clock positions. They were 5 cm (2 in) in length. Inspection of the deployed air bag revealed two very light scuffs on the front of the air bag that appeared to be facial make-up. There was no damage to the air bag.

The driver's knee air bag was located within the lower instrument panel. The module cover was constructed of pliable vinyl and had two flaps. Each flap was 25 cm (9.8 in) in width and 3.5 cm (1.4 in) in height. The deployed air bag was 56 cm (22 in) in width and 26 cm (10.2 in) in height. The top and bottom fabric was connected by a 3 cm (1.2 in) tether that ran the length of the air bag. Inspection of the air bag revealed blood transfers on the upper left portion of the air bag from contact by the driver's left knee.

The front passenger frontal air bag was located at the mid instrument panel level. This air bag did not deploy as a result of the crash.

The Scion's side impact IC air bags were located along the roof side rails inside the headliner and extended from the top of the A-pillar to the C-pillar. The deployed left IC air bag was 150 cm (59 in) in width, 33 cm (13.4 in) in height. The bottom edge of the IC air bag extended 6 cm (2.4 in) below the beltline. The air bag was tethered to the A-pillar with a 27 cm (10.6 in) nylon cord. The space between the front of the air bag and the A-pillar was 25 cm (9.8 in) at the approximate center of the air bag. Inspection of the IC air bag revealed a fluid transfer, possibly blood located 35 cm (13.8 in) aft of the front of the air bag and 7 cm (2.8 in) above the bottom of the air bag. There was no discernable occupant contact scuff marks on the IC air bag. The air bag sustained no damage.

The driver and front right passenger seat-mounted side impact air bag were located in the outboard sides of the front seat backs. Neither of these air bags deployed as a result of the crash.

MANUAL RESTRAINT SYSTEM

The Scion was equipped with lap-and-shoulder safety belts in the front and second rows. The driver's safety belt was equipped with continuous loop belt webbing, a fixed upper anchor, retractor mounted pretensioner, sliding latch plate, and an Emergency Locking Retractor (ELR). The front right safety belt was similarly equipped but had a switchable ELR/Automatic Locking Retractor (ALR). The second row safety belts were equipped the same as the front right safety belt.

The inspection of the driver's safety belt assembly revealed historical usage scratches on the latch plate. Load marks were present on the latch plate belt guide and on the belt webbing. The load marks on the belt webbing were 22 cm (8.7 in) in length and began 106 cm (41.7 in) above the stop button. The retractor was not jammed and functioned normally. While the pretensioner probably actuated, this could not be confirmed. Based on the load mark evidence on the safety belt, the driver was restrained during the crash. This was consistent with the safety belt switch data reported by the vehicle's EDR and the driver's SCI interview statement.

CASE VEHICLE DRIVER KINEMATICS

Based on the SCI interview, the driver of the Scion [21-year-old female, 180 cm (71 in) and 68 kg (150 lbs)] had both hands on the steering wheel and was leaning forward in her seat for better visibility during the rain storm. The seat track was located 4 cm (1.6 in) forward of the rear position and the seat back was slightly reclined. The tilt steering column was located between the full up and center positions. The driver was not wearing any corrective lenses.

As the right side of the vehicle traveled into the ditch, the driver braced on the steering wheel with both hands. The impact with the culvert displaced the driver forward. She loaded the safety belt, which caused a contusion on her left shoulder and left hip. Her face and both forearms loaded the deployed frontal air bag and her knees loaded the deployed knee air bag. The contact

with the frontal air bag caused contusions on her nose and both eyes. She also sustained abrasions and contusions on both forearms and elbows. Both knees were contused from loading the knee air bag. As the vehicle rotated clockwise and rolled over left side leading, she was redirected to the left and toward the roof. The driver's head contacted the left roof side rail during the rollover, which caused a contusion on her left forehead at the hairline. Her left scapula sustained an abrasion when it contacted the left front window sill. Her left thigh contacted the left front door, which contused the thigh. The driver also sustained a contusion on the top of her right foot and abrasions over both ankles from contacting the foot controls and the lower left instrument panel, respectively. The driver remained restrained in her seat position throughout the crash and exited the vehicle without assistance through the left front door.

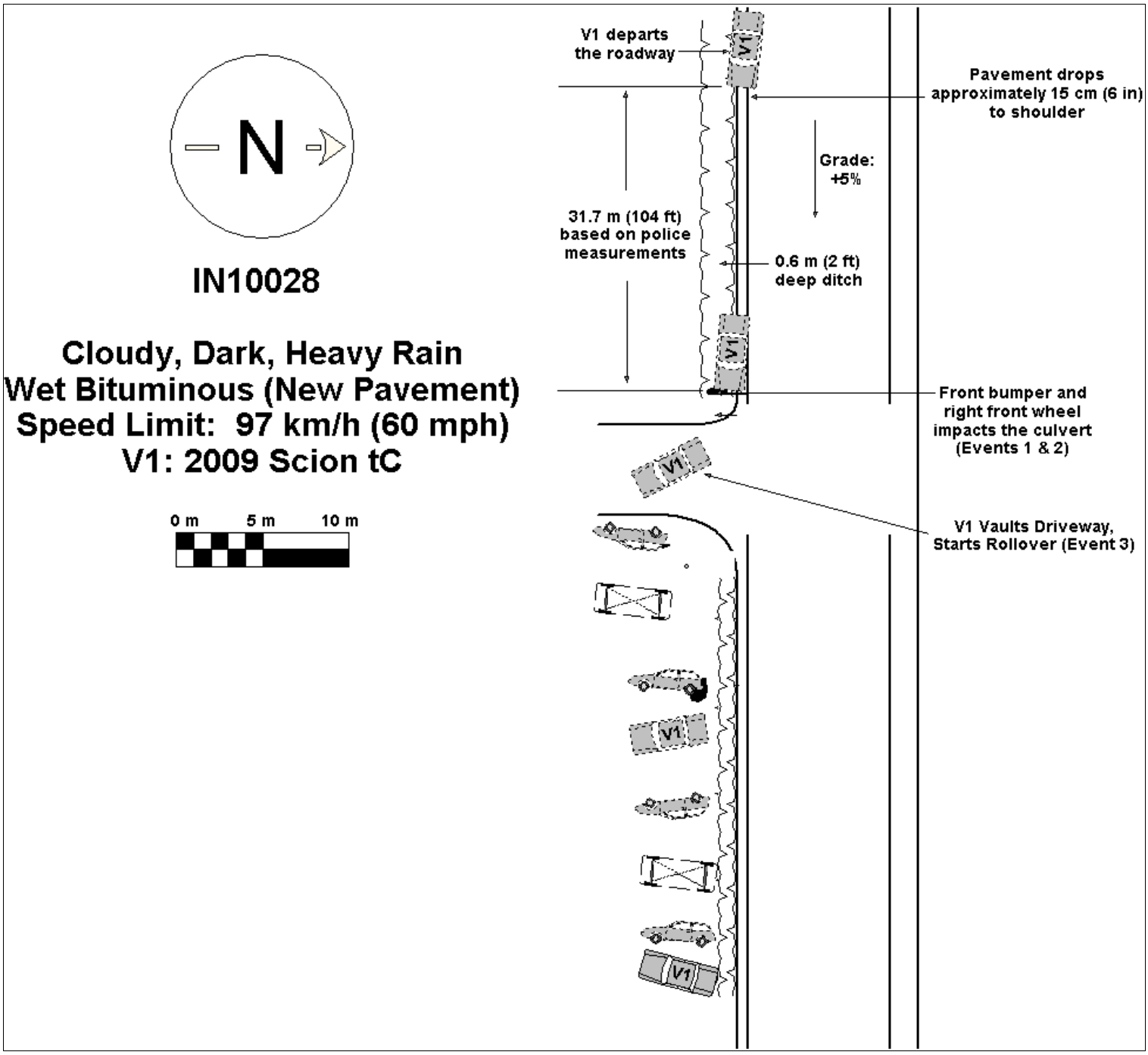
CASE VEHICLE DRIVER INJURIES

The driver was transported by ambulance to a local hospital where she was treated in the emergency room and released. She had no follow-up visits to a medical facility. The driver missed five days of work due to the crash. The table below presents the driver's injuries and injury sources.

Injury Number	Injury Description (including Aspect)	NASS Injury Code & AIS 2005	Injury Source	Source Confidence	Source of Injury Data
1	Contusion (bump) left forehead, at hairline	minor 210402.1,7	Roof, left front side rail	Certain	Emergency room records
2	Contusion (bruising) nose and swelling left facial region with deviation nasal septum	minor 210402.1,4 210402.1,1 210402.1,2	Air bag, driver's	Certain	Emergency room records
3 4	Contusions periorbital, not further specified				Interviewee (same person)
5	Abrasion left hip, not further specified	minor 510202.1,2	Lap portion of safety belt system	Probable	Interviewee (same person)
6	Abrasion (scrape) left shoulder, not further specified	minor 710202.1,2	Torso portion of safety belt system	Certain	Emergency room records
7	Abrasion, 5.1 cm (2 in) over left scapula, not further specified	minor 710202.1,2	Left front window sill	Probable	Interviewee (same person)
8	Abrasions (scrapes), minor, bilateral elbows, not further specified	minor 710202.1,3	Air bag, driver's	Probable	EMS treatment record
9	Abrasions bilateral forearms, not further specified	minor 710202.1,3	Air bag, driver's	Probable	Emergency room records
10	Contusions (bruising) bilateral forearms, not further specified	minor 710402.1,3	Air bag, driver's	Probable	Emergency room records
11	Contusion (bruising) right knee and above, not further specified	minor 810402.1,1	Air bag, driver's knee blocker	Certain	Emergency room records

Injury Number	Injury Description (including Aspect)	NASS Injury Code & AIS 2005	Injury Source	Source Confidence	Source of Injury Data
12	Contusion (bruising) left knee, 15.2 cm (6 in)[3], not further specified	minor 810402.1,2	Air bag, driver's knee blocker	Certain	Emergency room records
13	Contusion left lateral thigh, not further specified	minor 810402.1,2	Left front door panel, forward lower quadrant	Probable	Emergency room records
14	Abrasions over both ankles, not further specified	minor 810202.1,3	Left lower instrument panel (includes knee bolster)	Probable	Emergency room records
15	Contusion (bruising) ventral (top) right foot, not further specified	minor 810402.1,1	Floor, foot controls	Probable	Emergency room records

[3] The size of the lesion was reported by the interviewee.


N
IN10028
Cloudy, Dark, Heavy Rain
Wet Bituminous (New Pavement)
Speed Limit: 97 km/h (60 mph)
V1: 2009 Scion tC
0 m
5 m
10 m
V1 departs the roadway
Pavement drops approximately 15 cm (6 in) to shoulder
Grade: +5%
31.7 m (104 ft) based on police measurements
0.6 m (2 ft) deep ditch
Front bumper and right front wheel impacts the culvert (Events 1 & 2)
V1 Vaults Driveway, Starts Rollover (Event 3)
V1