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ON-SITE ROLLOVER INVESTIGATION

CASE NUMBER - IN08035
LOCATION - ILLINOIS
VEHICLE - 2008 HYUNDAI SANTA FE LIMITED
CRASH DATE - August 2008

Submitted:

June 4, 2009

Contract Number: DTNH22-07-C-00044

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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 report covers an On-Site Rollover Investigation that involved a 2008 Hyundai Santa Fe Limited, which rolled over on the roadway following a right side impact with a 2006 Jeep Liberty Sport. The focus of this on-site investigation was the Hyundai's rollover. The Hyundai was occupied by a restrained 53-year-old female driver and a restrained 31-year-old female front right passenger. The driver was traveling east on a 3-lane, divided, city street approaching an intersection. The Jeep was traveling northwest and entered the intersection where the front impacted the Hyundai's right quarter panel. The impact was sufficient to deploy the Hyundai's right side curtain air bag and right front seat back-mounted side impact air bag. The impact caused the Hyundai to rotate clockwise and it rolled over, left side leading, two quarter turns onto its top. The Hyundai's driver and front right passenger sustained minor injuries and were transported by ambulance to a hospital where they were treated in the emergency room and released.			
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IN08035

The focus of this on-site investigation was the rollover of a 2008 Hyundai Sante Fe Limited (**Figure 1**). This investigation was brought to the National Highway Traffic Safety Administration's attention on October 3, 2008 by the sampling activities of the National Automotive Sampling System. The crash involved a 2008 Hyundai Santa Fe Limited, which rolled over on the roadway following a right side impact with a 2006 Jeep Liberty Sport. The crash occurred in August, 2008, at 1545 hours, in Illinois and was investigated by the applicable city police department. This contractor inspected the crash scene and Hyundai on October 16 and 17, 2008. The Jeep had been repaired and was not inspected. The Hyundai's driver was interviewed on November 11, 2008. This report is based on the police crash report, scene and Hyundai inspections, driver interview, occupant medical records, occupant kinematic principles, and this contractor's evaluation of the evidence.

Figure 1: The damaged 2008 Hyundai Santa Fe Limited

CRASH CIRCUMSTANCES

Crash Environment: The trafficway on which the Hyundai was traveling was a 3-lane, divided, city street, traversing in an east west direction. The Hyundai was traveling east approaching a four-leg intersection. The east roadway had one through lane, a left turn lane, and was divided from the west roadway by a raised concrete median 2 m (6.7 ft) in width. The through lane was 3.9 m (12.8 ft) in width and the left turn lane was 3 m (9.8 ft) in width. The roadway pavement markings consisted of a solid white outside edge line, a solid white lane line, white left turn arrows, a solid yellow median edge line, and a solid white stop bar at the intersection. The trafficway on which the Jeep was traveling was a 3-lane, divided, city street, traversing in a northwesterly and southeasterly direction. The Jeep was traveling northwest approaching the intersection. The northwest roadway had one through lane, a left turn lane, a right turn channel, and was divided from the southeast roadway by a raised concrete median 1.3 m (4.3 ft) in width. The through lane was 3.9 m (12.8 ft) in width and the left turn lane was 3.5 m (11.5 ft) in width. Both trafficways were bordered by bituminous shoulders 1.1 m (3.6 ft) in width. The intersection was controlled by three-phase traffic signals and the speed limit for both vehicles was 64 km/h (40 mph). At the time of the crash the light condition was daylight, the atmospheric condition was clear, and the roadway pavement was dry, level, concrete. Traffic density was moderate and the site of the crash was suburban commercial. See the Crash Diagram on page 10 of this report.

Pre-Crash: The Hyundai was occupied by a restrained 53-year-old female driver and a restrained 31-year-old female front right passenger. The driver stated during the interview that she was traveling east approaching the intersection at approximately 64-72 km/h (40-45 mph) and intended to continue east through the intersection (**Figure 2**). The Jeep was occupied by a restrained 26-

year-old female driver, and she intended to continue northwest through the intersection (**Figure 3**). The Hyundai's driver did not recall if she attempted any actions to avoid the crash, which occurred within the intersection. A witness told police that the traffic signal was in the red phase for the Hyundai.

Figure 2: Approach of the Hyundai eastbound into the intersection

Figure 3: Approach of the Jeep northwestboud into the intersection

Crash: The front of the Jeep impacted the right rear side of the Hyundai (**Figure 4**, event 1). The impact engaged the rear portion of the Hyundai's right rear door as well as the right rear wheel and quarter panel. The direction of force was within the 1 clock sector and the impact force was sufficient to trigger deployment of the Hyundai's right side curtain air bag and the front right seat back-mounted side impact air bag. The impact caused the Hyundai to rotate clockwise and it traveled into the east leg of the intersection. The vehicle was equipped with Electronic Stability Control (ESC), but the impact induced significant rotation such that the driver was unable to regain control. As the vehicle rotated, it rolled over (event 2) with the left side leading, two quarter turns (**Figures 5** and **6**) and came to final rest on its top on the eastbound lane heading west (**Figure 7**). The Jeep continued through the intersection and came to final rest on the northeast corner of the intersection heading north.

Post-Crash: The police and emergency medical service were notified and responded to the crash scene. The Hyundai's driver and front right passenger were transported by ambulance to a hospital. The driver of the Jeep refused medical assistance and was not transported. Both vehicles were towed from the scene due to damage.

Figure 4: Damage to the right quarter panel, right rear wheel and right rear door from impact with the front of the Jeep

ROLLOVER DISCUSSION

The Hyundai's rollover mitigation features consisted of ESC. It was not equipped with a rollover side curtain air bag system. The NHTSA has given the vehicle a four star rollover rating on a five star scale and a Static Stability Factor of

1.22[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 this vehicle's specific chance of rollover was given as 17%. 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 rollover. A higher SSF indicates a more stable vehicle. Most passenger vehicles have an SSF of 1.30 to 1.50[2]. This vehicle model also did not tip 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).

Figure 5: Damage to the Hyundai's left side plane from the rollover (outlined in yellow tape)

Figure 6: Damage to the top plane from the rollover; arrows on roof show direction of formation of abrasions on plastic of luggage rack

In this crash, the Hyundai's initial right side plane impact with the Jeep induced a clockwise rotation. The impact induced significant rotation and caused the opposing force on the left side wheels to build as it rotated. The force on the left side wheels was sufficient to induce a roll moment and the vehicle rolled over, left side leading, two quarter turns across a distance of approximately 8 m (26.2 ft). The vehicle came to final rest on its top.

Figure 7: View west in eastbound lane; arrow shows area where the Hyundai came to final rest

CASE VEHICLE

The 2008 Hyundai Santa Fe Limited was a front wheel drive, 4-door sport utility vehicle (VIN: 5NMSH13EX8H------) equipped with a 3.3L, V6 engine, 4-wheel anti-lock brakes, traction control, ESC, and a tire pressure monitoring system. The front row was equipped with bucket seats with active head restraints, lap-and-shoulder belts with adjustable upper anchors, dual stage driver and front right passenger frontal air bags, seat back-mounted side impact air bags, and side impact curtain air bags, which provided head protection for the front and second row outboard seating positions. The second row was equipped with a split bench seat with folding backs, adjustable head restraints, and lap-and-

1 www.safercar.gov, 5/29/09

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

shoulder belts in all three seating positions. The second row was also equipped with Lower Anchors and Tethers for Children (LATCH) in the outboard seating positions. The mileage at the time of the inspection could not be determined because the vehicle was equipped with an electronic odometer and was without power. The driver estimated that the vehicle's mileage was approximately 6,437 kilometers (4,000 miles). The vehicle's specified wheelbase was 270 cm (106.3 in).

CASE VEHICLE DAMAGE

Exterior Damage: The Hyundai's impact with the Jeep involved the right side plane. The right rear door, right rear wheel, right quarter panel, and right side of the back bumper cover were all directly damaged. The direct damage began 64 cm (25.2 in) forward of the right rear axle and extended 152 cm (59.8 in) rearward on the right side. The crush measurements were taken at the mid-door level, and the maximum crush was 18 cm (7.1 in) occurring at C_2. There was no change to the right or left side wheelbase, and the induced damage involved the right rear door, right quarter panel, and back bumper cover. The vehicle's right side crush profile is shown in the table below.

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	152	18	152	14	18	16	9	0	0	-151	-151
in		59.8	7.1	59.8	5.5	7.1	6.3	3.5	0.0	0.0	-59.4	-59.4

The Hyundai's rollover involved the left side plane and the top plane (**Figures 5** and **6**). The left fender, left front wheel, left front door, left side view mirror, left rear door, left quarter panel, left roof side rail, all the left side pillars, hood, windshield, windshield header, roof, and right and left luggage racks were directly damaged. The direct damage on the left side plane began 72 cm (28.3 in) rear of the left rear axle and extended 376 cm (148 in) forward on the left side. The direct damage on the top plane began 123 cm (48.4 in) forward of the left rear axle and involved the full width of the roof [110 cm (43.3 in)], the upper portion of the windshield, and a 124 x 56 cm (48.8 x 22 in) area at the front of the hood (**Figure 6**). The maximum vertical crush to the roof structure was 4 cm (1.6 in) and occurred to the windshield header (**Figure 8**). It was located 12 cm (4.7 in) left of the center of the right A-pillar. There was no lateral displacement of either roof side rail or A-pillar. Induced damage from the rollover involved the left side plane, windshield, hood, and roof.

Figure 8: Vertical crush to windshield header

Damage Classification: The Collision Deformation Classifications for the Hyundai were **01-RZEW-2** (**30** degrees) for the impact with the Jeep (event 1) and **00-TYDO-2** for the rollover (event 2). The Missing Vehicle algorithm of the WinSMASH program calculated the Hyundai's total Delta V for the right side impact (event 1) as 13 km/h (8.1 mph). The longitudinal and lateral velocity changes were -11 km/h (-6.8 mph) and -6 km/h (-3.7 mph), respectively. The results were based only on the Hyundai's crush profile because the Jeep was not inspected, and should be considered a borderline reconstruction of the Hyundai's Delta V. The WinSMASH program could not be used for the rollover event because rollover's are out of scope for the program. The severity of the rollover was minor based on the extent of the roof crush.

The manufacturer's recommended tire size was P235/60R18 and the vehicle was equipped with tires of this size. The Hyundai's tire data are shown in the table below.

Tire	*Measured Pressure*		*Vehicle Manufacturer's Recommended Cold Pressure*		*Tread Depth*		*Damage*	*Restricted*	*Deflated*
	kPa	psi	kPa	psi	milli-meters	32nd of an inch			
LF	228	33	207	30	6	7	None to tire, but abrasions on rim	No	No
LR	221	32	207	30	7	9	None	No	No
RR*	Unk.	Unk	207	30	7	9	Sidewall cracked	No	No
RF	221	32	207	30	6	7	None	No	No

(*The right rear tire's valve stem was broken and the tire pressure measurement could not be taken.)

Vehicle Interior: Inspection of the Hyundai's interior revealed a crack on the left side of the center console, probably due to contact by the driver's lower right leg. There was also a scuff mark on the left side of the center console arm rest, probably due to contact by the driver's right hip. A blood smear was also found on the roof console. This was probably related to a laceration on the driver's right hand, which she reported sustaining as she crawled out of the vehicle following the crash. There was no other discernable evidence of occupant contact and no evidence of deformation of the steering wheel or compression of the energy absorbing steering column.

All of the vehicle's doors remained closed and operational and all of the window glazing was either closed or fixed. The windshield remained in place and was cracked by impact forces during the rollover. The remaining window glazing was undamaged.

The Hyundai sustained 11 intrusions into the front row and one intrusion in the cargo area. The front row intrusions all occurred on the vertical axis and involved the windshield header, roof, windshield, right roof side rail, right A-pillar and the roof console. The most severe intrusion into the driver's occupant space involved the windshield, which intruded 7 cm (2.8 in). The most

severe intrusion into the front right passenger's occupant space also involved the windshield, which intruded 13 cm (5.1 in). The windshield header and right A-pillar also intruded 4 cm and 3 cm (1.6 in and 1.2 in), respectively into the front right occupant space. The right side panel rear of the C-pillar intruded laterally 3 cm (1.2 in) into the vehicle's cargo space.

AUTOMATIC RESTRAINT SYSTEM

The Hyundai was equipped with a Certified Advanced 208-Compliant (CAC) frontal air bag system. 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 system consisted of dual stage driver and front right passenger frontal air bags, driver seat position sensor, an occupant weight sensor for the front right passenger seating position, seat belt buckle switch sensors, and retractor mounted pretensioners. Neither of the front air bags deployed in this crash.

Figure 9: The Hyundai's front right seat back-mounted side impact air bag

The Hyundai's side impact air bag system consisted of front seat back-mounted side impact air bags and roof side rail-mounted side impact curtain air bags. Based on the Holmatro "Rescuer's Guide to Vehicle Safety Systems," the vehicle's side impact sensors were located on each side of the vehicle within the lower B and C-pillars. The inflation cylinders for the side curtain air bags were located within the D-pillars. The right side curtain air bag and front right seat back mounted side impact air bag deployed as a result of the Jeep's impact to the vehicle's right side.

Figure 10: The front portion of the Hyundai's right side curtain air bag

The front right seat back-mounted side-impact air bag was located within the front right outer seat back. It was oval-shaped and was 31 cm (12.2 in) in width and 40 cm (15.7 in) in height (**Figure 9**). It was not equipped with tethers or vent ports. No damage or discernable occupant contact evidence was found on the air bag.

Figure 11: Back portion of the Hyundai's right side curtain air bag

The right side curtain air bag (**Figures 10** and **11**) was housed within the right roof side rail.

It was 186 cm (73 in) in width and 42 cm (16.5 in) in height. It was not equipped with any visible vent ports. A triangular shaped fabric, 20 cm (7.9 in) wide, connected the side curtain air bag to a nylon tether rope that was anchored to the A-pillar. This tether rope was 24 cm (9.4 in) long and 2 cm (0.8 in) wide. It had been cut in two and the cut was located 8 cm (3 in) from the A-pillar. The gap between the triangular shaped fabric and the window frame at the belt line was 16 cm (6.3 in) and 10 cm (3.9 in) above the rope tether. The back of the side curtain air bag was attached to the C-pillar by a tether that was 11 cm (4.3 in) long and 2 cm (0.8 in) wide. There was no damage or discernable occupant contact located on the side curtain air bag. The left side impact curtain air bag and seat back-mounted side impact air bag did not deploy in this crash.

MANUAL RESTRAINT SYSTEM

The Hyundai was equipped with lap-and-shoulder belts for all five seating positions. The driver's seat belt consisted of continuous loop belt webbing, an Emergency Locking Retractor (ELR), sliding latch plate, and an adjustable upper anchor that was in the full down position. The front right seat belt was equipped with a switchable ELR/Automatic Locking Retractor (ALR), sliding latch plate, and adjustable upper anchor that was located in the middle position. The front row seat belts were equipped with retractor-mounted pretensioners. The belt webbing spooled freely in and out of both retractors indicating the pretensioners probably did not actuate in this crash. The second row seat belts consisted of continuous loop belt webbing, switchable ELR/ALRs, sliding latch plates and fixed upper anchors.

The inspection of the driver's and front right passenger's seat belt systems revealed no evidence of loading, but historical usage scratch marks were present on both latch plates. While there was no evidence of loading on the seat belts, both the driver and front right passenger sustained seat belt related contusions, which confirmed the driver's interview statement that both were restrained at the time of the crash. The remaining seat positions were unoccupied.

CASE VEHICLE DRIVER KINEMATICS

The driver [53-year-old, female; 165 in and 85 kg (65 in, 187 lbs)] was seated in an upright posture with her back against the seat back. Her right foot was on the accelerator pedal, left foot on the floor, and both hands on the steering wheel. The seat track was located between the forward and middle positions and the seat back was slightly reclined. The tilt steering column was located in the full down position. The driver was wearing sunglasses.

The Hyundai's impact with the Jeep displaced the driver forward and to the right opposite the Hyundai's 1 o'clock direction of force. Her lower right leg loaded and cracked the center console and her right hip loaded and scuffed the center console arm rest; however, the driver sustained no injuries due to these contacts. Occupant kinematic principles indicate that the driver would have been displaced to the left and toward to the roof as the Hyundai rotated clockwise and rolled over to the left and onto its top. The driver sustained contusions on each hip from loading the seat belt and a neck strain due to impact force. She remained restrained in her seat position and exited the vehicle with the assistance of a passerby. She sustained a laceration on her right hand from windshield glass fragments as she was crawling out of the vehicle.

The driver was transported by ambulance to a hospital where she was treated in the emergency room and released. She received no follow-up treatment and lost five work days as a result of the crash. The table below shows the driver's injuries and injury sources.

Injury Number	Injury Description (including Aspect)	NASS Injury Code & AIS 90	Injury Source	Source Confidence	Source of Injury Data
1	Strain, acute cervical	minor 640278.1,6	Noncontact injury: impact forces	Probable	Emergency room records
2 3	Contusions {bruises}, 2.5 cm (1 in) diameter, on both hips	minor 590402.1,1 590402.1,2	Lap portion of safety belt system	Certain	Interviewee (same person)
	Laceration right hand[3], not further specified	Not coded			Emergency room records

CASE VEHICLE FRONT ROW RIGHT PASSENGER KINEMATICS

The Hyundai's front row right passenger [31-year-old, female; 168 cm and 95 kg (66 in, 210 lbs] was seated in an upright posture with her back against the seat back and both feet on the floor. The seat track was adjusted to between the middle and full rear positions and the seat back was slightly reclined. The passenger was wearing sunglasses and was holding a small package.

The Hyundai's impact with the Jeep displaced the front row right passenger forward and to the right opposite the 1 o'clock direction of principal force. While there was no discernable evidence of occupant contact on the side curtain air bag or seat back-mounted side impact air bag, occupant kinematics principles indicate that the passenger's head probably loaded the deployed right side curtain air bag and her right torso probably loaded the deployed front right seat back-mounted side impact air bag. Occupant kinematic principles also indicate that the passenger was displaced to the left and toward to the roof as the Hyundai rotated clockwise and rolled over to the left and onto its top. The passenger sustained a contusion across her abdomen due to loading the seat belt and an abrasion on her right elbow, probably from loading the seat back-mounted side impact air bag. She also sustained an abrasion on the left lower left, probably from loading the console. She remained restrained in her seat position and exited the vehicle without assistance.

CASE VEHICLE FRONT ROW RIGHT PASSENGER INJURIES

The front row right passenger was transported by ambulance to a hospital where she was treated in the emergency room and released. She received one follow-up visit to her personal physician and lost five work days as a result of the crash. The table below shows the passenger's injuries and injury sources.

[3] According to the driver's interview, she cut her hand as she was crawling out of the vehicle.

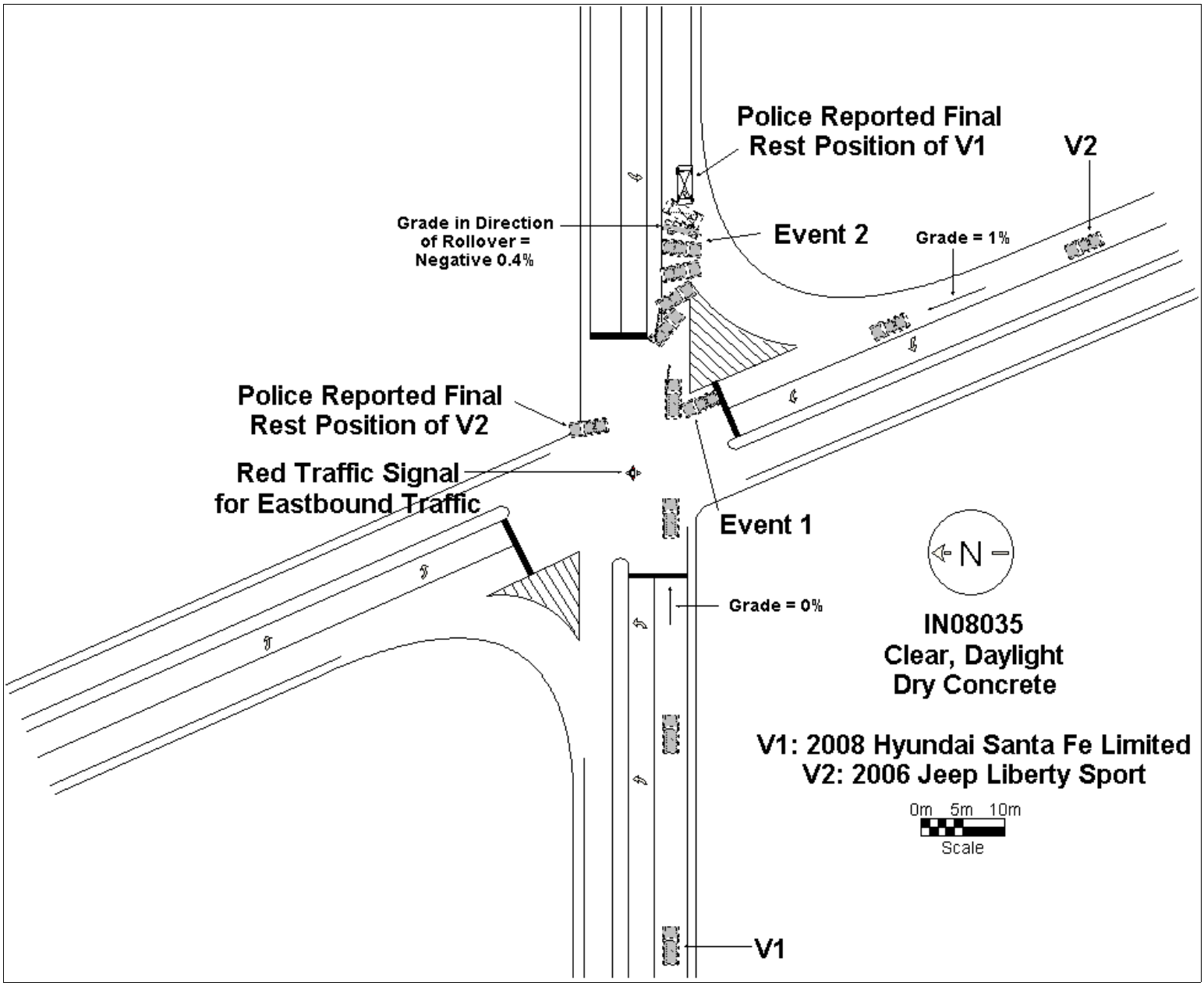
Injury Number	Injury Description (including Aspect)	NASS Injury Code & AIS 90	Injury Source	Source Confidence	Source of Injury Data
1	Abrasions right elbow, not further specified	minor 790202.1,1	Air bag, front right passenger's side impact	Probable	Emergency room records
2	Abrasions left lower leg, not further specified	minor 890202.1,2	Interior, center console, first row	Probable	Emergency room records
3	Contusion {bruise} across abdomen, not further specified	minor 590402.1,8	Lap portion of safety belt system	Certain	Interviewee (same person)
4	Contusions, not further specified	minor 990400.1,9	Unknown injury source	Unknown	Emergency room records

OTHER VEHICLE

The 2006 Jeep Liberty Sport was a 4-wheel drive, 4-door sport utility vehicle (VIN: J4GL48K26W------) equipped with a 3.7L, V6 engine. The Jeep was also equipped with dual stage driver and front right passenger frontal air bags and was certified by the manufacturer to be compliant to the advanced air bag portion of the Federal Motor Vehicle Safety Standard (FMVSS) No 208. According to the police crash report, the driver's frontal air bag deployed as a result of the impact with the Hyundai.

The Missing Vehicle algorithm of the WinSMASH program calculated the Jeep's total Delta V for the front impact (event 1) as 13.0 km/h (8.1 mph). The longitudinal and lateral velocity changes were -11 km/h (-6.8 mph) and 7 km/h (4.4 mph), respectively. The results were based only on the Hyundai's crush profile and should be considered a borderline reconstruction of the Jeep's Delta V.

Other Vehicle's Driver: The Jeep's driver (26-year-old, female) was restrained by the lap-and-shoulder belt and sustained a B (non-incapacitating) injury.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V2
Grade in Direction
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Negative 0.4%
Event 2
Grade = 1%
Police Reported Final
Rest Position of V2
Red Traffic Signal
for Eastbound Traffic
Event 1
N
Grade = 0%
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Clear, Daylight
Dry Concrete
V1: 2008 Hyundai Santa Fe Limited
V2: 2006 Jeep Liberty Sport
0m 5m 10m
Scale
V1