U.S. Department
of Transportation
National Highway
Traffic Safety
Administration

NHTSA

DOT HS 812 651

November 2018

Special Crash Investigations On-Site SKT Guardrail End Terminal Crash Investigation Vehicle: 2010 Hyundai Elantra Location: Pennsylvania Crash Date: May 2017

DISCLAIMER

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no responsibility for the contents or use thereof.

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the National Highway Traffic Safety Administration.

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

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

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

Suggested APA Format Citation:

Crash Research & Analysis, Inc. (2018, November). *Special Crash Investigations On-Site SKT Guardrail End Terminal Crash Investigation; Vehicle: 2010 Hyundai Elantra; Location: Pennsylvania; Crash Date: May 2017* (Report No. DOT 812 651). Washington, DC: National Highway Traffic Safety Administration.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. DOT HS 812 651	*2. Government Accession No.*	*3. Recipient's Catalog No.*
4. Title and Subtitle Special Crash Investigations On-Site SKT Guardrail End Terminal Crash Investigation; Vehicle: 2010 Hyundai Elantra; Location: Pennsylvania; Crash Date: May 2017		*5. Report Date*: November 2018 *6. Performing Organization Code*
7. Author Crash Research & Analysis, Inc.		*8. Performing Organization Report No.* CR17014
9. Performing Organization Name and Address Crash Research & Analysis, Inc. P.O. Box 302 Elma, NY 14059		*10. Work Unit No.* *11. Contract or Grant No.* DTNH22-12-C-00269
12. Sponsoring Agency Name and Address National Highway Traffic Safety Administration 1200 New Jersey Avenue SE. Washington, D.C. 20590		*13. Type of Report and Period Covered* Crash Date: May 2017 *14. Sponsoring Agency Code*

15. Supplementary Note
An investigation of the SKT guardrail end treatment struck by a 2010 Hyundai Elantra.

16. Abstract
This report documents the on-site investigation of a sequential kinking terminal (SKT) guardrail end terminal struck by a 2010 Hyundai Elantra during a left roadway departure. The Hyundai was operated by a 26-year-old unbelted female who was completely ejected through the right front door window opening during the crash and sustained fatal injuries. The prolonged impact sequence involved two areas of the vehicle's right plane. The right-side impact air bag system consisted of front seat-mounted and inflatable curtain air bags which deployed during the second interaction.

The Hyundai was traveling northbound in the left lane on a limited-access, divided, two-lane roadway. While negotiating a right curve, the Hyundai departed the left road edge and struck a delineator. A trailing witness reported that the driver of the Hyundai swerved to the right and then over-corrected back to the left resulting in a counter-clockwise yaw. The Hyundai departed the left road edge and its right plane struck the guardrail end treatment. The driver was completely ejected through the right front door window opening onto the grass median. As the vehicle displaced the end-treatment northward, the rear aspect of the right plane engaged the deformed guardrail causing the vehicle to reverse its rotation to clockwise. This engagement deployed the Hyundai's right-side impact air bag systems. The Hyundai rotated into the grass median and partially overrode the ejected driver as it came to rest facing in a southerly direction. The responding rescue personnel found the driver to be unresponsive underneath the right front portion of the vehicle. She was pronounced deceased at the crash site.

17. Key Words end treatment end terminal guardrail unbelted ejection		*18. Distribution Statement* Document is available to the public from the National Technical Information Service, www.ntis.gov	
19. Security Classif. (of this report) Unclassified	*20. Security Classif. (of this page)* Unclassified	*21. No. of Pages* 28	*22. Price*

TABLE OF CONTENTS

SPECIAL CRASH INVESTIGATIONS
CASE NO.: CR17014
ON-SITE SKT GUARDRAIL END TERMINAL CRASH INVESTIGATION
VEHICLE: 2010 HYUNDAI ELANTRA
LOCATION: PENNSYLVANIA
CRASH DATE: MAY 2017

BACKGROUND

This report documents the on-site investigation of a sequential kinking terminal (SKT) guardrail end terminal struck by a 2010 Hyundai Elantra **(Figure 1)** operated by a 26-year-old unbelted female. The driver was completely ejected through the right front door window opening during the crash and sustained fatal injuries. The prolonged impact sequence involved two areas of the vehicle's right plane. The right-side impact air bag system consisted of front seat-mounted and inflatable curtain (IC) air bags that deployed during the second interaction. The crash was identified by the Pennsylvania Department of Transportation (PENNDOT), which submitted notification to the Federal Highway Administration (FHWA). The FHWA determined that the crash type and guardrail end treatment met the criteria for further research and subsequently forwarded the notification to the Crash Investigation Division (CID) of the National Highway Traffic Safety Administration in June 2017. 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 gained cooperation with PENNDOT, and conducted the on-site scene investigation in June 2017. The Hyundai was inspected in July 2017 due to a delay in obtaining cooperation to conduct an inspection.

Figure 1: On-scene police image of the damaged end treatment and the final rest position of the Hyundai.

The Hyundai was traveling northbound in the left lane on a limited-access, divided, two-lane roadway. While negotiating a right curve, the Hyundai departed the left road edge and struck a delineator. A trailing witness reported that the driver of the Hyundai swerved to the right and then over-corrected back to the left resulting in a counter-clockwise yaw. The Hyundai departed the left road edge and its right plane struck the guardrail end treatment. The driver was completely ejected through the right front door window opening onto the grass median. As the vehicle displaced the end-treatment northward, the rear aspect of the right plane engaged the deformed guardrail, causing the vehicle to reverse its rotation to clockwise. This engagement deployed the Hyundai's right-side impact air bag systems. The Hyundai rotated into the grass

median and partially overrode the ejected driver as it came to rest facing in a southerly direction. The responding rescue personnel found the driver to be unresponsive underneath the right front portion of the vehicle. She was pronounced deceased at the crash site.

The on-site investigation focused on the documentation of the SKT guardrail system and the damage it sustained during the crash. The physical environment of the roadway and the guardrail were also documented using the Nikon total station. A complete inspection of the Hyundai was conducted including measurement of the structural deformation and intrusion, identification of occupant contact points and the ejection portal, and an assessment of the manual and supplemental restraint systems. The Hyundai was not equipped with an event data recorder (EDR) due to its date of manufacture; therefore, crash data was not available for reconstruction purposes.

CRASH SUMMARY

Crash Site

The crash occurred on a divided interstate roadway during daylight hours. At the time of the crash, the National Weather Service reported the conditions as clear with a temperature of 28.9ºC (84 ºF), humidity at 94 percent and south-southwest winds at 10.0 km/h (16.1 mph). All road and off-road surfaces were dry. The interstate's crash site vicinity consisted of two lanes in each of the north and southbound travel directions separated by a depressed grass median. The posted speed limit was 89 km/h (55 mph). An exit ramp was located to the east of the northbound lanes. A painted gore area separated the exit ramp from the through lanes. The left northbound lane measured 3.7 m (12.1 ft) in width. The right northbound lane was 3.5 m (11.5 ft) wide. Lane delineations consisted of a solid white east lane line, a broken center line separating the two northbound lanes, and a solid yellow west edge line. Both travel lanes were3.7 m (12 ft) in width and were bordered by paved shoulders. All travel lane and shoulder surfaces were asphalt. The east shoulder consisted of the wide gore area. The west shoulder was 1.1 m (3.6 ft) wide. A tactile warning strip (rumble strip) was cut into the surface of the west shoulder. **Figure 2** is an overall northbound view of the crash site.

Figure 2: Northbound trajectory view of the Hyundai's approach to the crash site.

The northbound lanes curved to the right with a radius of curvature of 995 m (3,264 ft). There was a positive 3.5 percent grade to the north leading into the crash site. The super-elevation at the initial point of impact with the guardrail end treatment was +10 percent. The grass median that sloped downward to a common drainage ditch between the north and southbound travel

lanes was 15.2 m (50.0 ft) in width. The base of the median was 1.6 m (5.2 ft) below the elevation of the road. A W-beam guardrail and the STK end treatment was located adjacent to the edge of pavement and protected the northbound traffic from a ravine located to the north of the crash site. A crash diagram is included at the end of this technical report.

Pre-Crash

The Hyundai was traveling in a northerly direction in the left lane of the divided interstate roadway at a police and witness-estimated speed of 105 km/h (65 mph). While negotiating the right curve, the Hyundai drifted to the left, traversed the rumble strips and the west shoulder and departed the road onto the grass median. Left side tires marks began on the grass roadside 116 m (380.6 ft) south of the impending guardrail impact. The front plane/left aspect of the Hyundai struck and overrode a delineator post (Event 1) that was located immediately west of the west shoulder edge.

The driver responded to the road departure by initiating a clockwise steering input in an attempt to regain the left northbound travel lane. The Hyundai initiated a clockwise yaw on the median evidenced by the diverging left side tire marks as the vehicle traveled 45.3 m (142.7 ft) along the roadside. The Hyundai reentered the left travel lane and crossed into the right northbound lane as the driver counter-steered to the left. This counterclockwise steering input transitioned the Hyundai's yaw from clockwise to counterclockwise. The vehicle traversed the left lane and the west shoulder as it rotated approximately 30 degrees counterclockwise of its intended northbound heading. Tire marks from the right front, left front and left rear axle positions were present on the left lane and west shoulder. The left rear mark measured 12.6 m (41.3 ft) in length. The angle of the road side departure was approximately 20 degrees. The Hyundai's counterclockwise yaw tire marks are depicted in **Figure 3**. Over the course of its 116 m (380.6 ft) off road and yawing trajectory the Hyundai slowed by road friction to an estimated 72 km/h (45 mph) as it approached the end terminal.

Figure 3: North-facing view of the Hyundai's yaw tire marks as it departs the left travel lane toward the guardrail impact.

Crash

The Hyundai rotated counterclockwise to a broadside attitude and right front door of the Hyundai struck the SKT end treatment (Event 2). The direction of the impact force was in the 3 o'clock sector. The force of the impact disintegrated the right front door glazing and crushed the door of the Hyundai inward. The door latch pulled through the B-pillar due to a stress overload, which allowed the right front door to override the front right seat cushion. The unbelted driver of the

Hyundai responded to the lateral impact force and was ejected through the window opening of the right front door into the median approximately 14 m (46 ft) northwest of the end treatment impact.

The end terminal was displaced northward along the W-beam during the initial contact evidenced by the extrusion of 2.4 m (8.0 ft) of guardrail. As the vehicle continued on its northwesterly trajectory and right plane of the vehicle fully engaged the deforming guardrail, additional damage occurred at the right B-pillar and sill from the subsequent post contact. The end terminal impact, located at the vehicle's CG, neutralized the vehicle CCW rotation.

The right plane/back aspect of the Hyundai engaged the guardrail at the (relatively) stiffer structures of the right rear wheel assembly (Event 3). This engagement resulted in the deployment of the right front seat-mounted and IC air bags. The guardrail deformed by bending at the Post 3 location into a V-shaped pattern due to the angularity of the engagement **(Figure 4)**. This lateral impact force located aft of the Hyundai's center of gravity reversed the vehicle's rotation from counterclockwise to clockwise as it separated from the guardrail. The Hyundai rotated approximately 270 degrees as it traveled down the embankment into the median. As the Hyundai came to rest, the front right undercarriage partially overrode the ejected driver. At final rest, the Hyundai was facing south in the center of the depressed median 15.4 m (50.5 ft) from the end terminal impact.

Figure 4: North-facing view of the SKT end terminal and deformed guardrail system.

Post-Crash

The Hyundai came to rest in the median facing with the vehicle's right front undercarriage partially on top of the ejected driver. The police, fire, and emergency medical services (EMS) personnel responded to the scene. EMS and firefighters evaluated the condition of the driver and determined she was deceased. They removed the driver from under the Hyundai and she was transported to the medical examiner's facility for autopsy. The Hyundai was towed from the scene of the crash and transferred to a regional insurance vehicle salvage facility where it was inspected for this investigation.

SKT GUARDRAIL END TREATMENT

The SKT end terminal was an energy absorbing end treatment used to terminate W-beam guardrail systems (**Figure 5**). The SKT installation was 15 m (50 ft) in length and consisted of an SKT end terminal, two hinged posts at post locations 1 and 2, an anchor cable, and five standard steel posts at post locations 3 to 7 that supported the W-beam with a composite block-out and carriage bolt. Splices in the W-beam were located at Post 3, Post 5, and Post 7. The SKT installation was manufactured by Road Systems, Inc., and met the requirements for NCHRP 350 Test Level 3. The manufacturer's literature and installation manuals can be found at: http://roadsystems.com/skt.html.

Figure 5: Image depicting an exemplar SKT installation.

Figure 6: Southeast-facing image depicting the struck end terminal and the extruded W-beam.

The struck guardrail was a tangent system installed adjacent to the left shoulder of the interstate. The height of the W-beam measured 75 cm (29.5 in) in an undamaged section of the beam between Post 6 and 7. The Hyundai struck the impact face of the end terminal (**Figure 6**) originally located at Post 1. The impact face measured 51 x 51 cm (20.0 x 20.0 in). There was no discernable direct contact damage to impact face. The force of the impact displaced the end terminal to the north and extruded 2.4 m (8 ft) of the W-beam. The extruded W-beam curled to the field side, away from the road.

Posts 1 to 4 of the installation were damaged during the crash along with a total length of 3.8 m (22.4 ft) of W-beam. Damage to the installation required replacement of the W-beam to the splice at Post 5. 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 box-beam that was attached via a hinge bolt to the lower post section that was embedded into the ground. The hinged bolt was (correctly) positioned on the upstream side of the post. 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 box-beam separated from the lower section and was displaced to the north. The cable anchor, originally attached between Post 1 and the W-beam, separated during the impact and was also displaced onto the road side.

Post 2 consisted of two I-beam elements that were connected by a hinge bolt located approximately at ground level. This hinge bolt was correctly positioned on the downstream side of the post. The foundation post was embedded into the ground. The hinged upper section of Post 2 rotated 90 degrees to the east during the crash. At this post, the W-beam was originally bolted to an open slot in the upper aspect of the I-beam flange. The bolt released (slid) from the slot as the I-beam rotated to the east.

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 at Post 3 and 4 pulled through the W-beam by deformation of the slot in the rail. The composite block-outs remained attached to the posts and the bolts were deformed. Posts 3 and 4 deformed by bending at ground level in the direction of the Hyundai's travel. Post 3 was bent/rotated approximately 80 degrees and Post 4 was bent approximately 10 degrees. There was no deformation at Post 5 and beyond.

As the impact developed, the right plane of the Hyundai engaged the (road) side of the end terminal due to the angularity of the impact. The lateral component of the impact force caused the W-beam to bend at Post 3 and Post 4. The W-beam bent into a V-shape pattern (**Figure7**). Post-crash, the end terminal was located 6.8 m (22.3 ft) north of Post 1 through a combination of its extruded displacement and the bending of the W-beam.

Figure 7: East facing side view depicting the location of the displaced end terminal.

2010 HYUNDAI ELANTRA

Description

The Hyundai Elantra, 4-door sedan (**Figure 8**), was identified by Vehicle Identification Number: KMHDU4AD0AUxxxxxx and was manufactured in March 2010. The vehicle was designed with unibody construction on a 265 cm (104.3 in) wheelbase chassis and had a curb weight of 1,246 kg (2,247 lb). The powertrain consisted of a transverse-mounted, 2.0-liter gasoline engine linked to a 4-speed automatic transmission with front-wheel drive. Standard features included 4-wheel power-assisted disc brakes with ABS, power-assisted rack-and-pinion steering and traction

control. The gross vehicle weight rating (GVWR) was 1,755 kg (3,869 lb) with specific gross axle weight ratings of 1,010 kg (2,227 lb) front and 950 kg (2,094 lb) rear. The vehicle manufacturer recommended tire size was P195/65R15 with cold tire pressures of 220 kPa (32 PSI) for both axle positions. At the time of the crash, the Hyundai was equipped with Firestone Champion Fuel Fighter all-season tires of the recommended size mounted on original equipment manufacturer steel wheels. The specific tire data at the time of the SCI inspection was as follows:

Figure 8: Right side view of the Hyundai.

Position	Tire Identification Number	Measured Tread	Restricted	Damage
LF	W2AE CF1 0716	5 mm (3/32 in)	No	None
LR	W2C6 A1C 5113	4 mm (5/32 in)	No	None
RR	W2C6 A1C 5113	4 mm (5/32 in)	No	Wheel deformed, tire flat
RF	Unknown	4 mm (5/32 in)	No	None, tire flat

The interior of the Hyundai was configured for seating of five occupants (2/3) with front row bucket seats and a forward folding, split-back second row bench seat. The front row bucket seats were manually adjusted with adjustable head restraints, both 4 cm (1.5 in) above the seat backs. At the time of the SCI inspection, the driver's seat track was in the full-forward position with the seat back reclined 40 degrees aft of vertical. All three second row seat backs were adjusted to the full-down positions. Safety systems consisted of manual 3-point continuous loop seat belts for the five designated seat positions with front row retractor pretensioners and adjustable D-rings. Supplemental safety systems consisted of Certified Advanced 208-Compliant front air bags, front seat-mounted and roof side rail-mounted IC air bags for side impact.

Exterior Damage

The left aspect of the front plane and headlamp assembly struck a steel delineator post (Event 1) that was located immediately west of the west shoulder. The impact fractured the plastic lens of the headlamp and scuffed the bumper fascia. There was no residual crush associated with this event. The collision deformation classification (CDC) assigned to this impact was 12FLEE1.

The right plane of the Hyundai struck the SKT end terminal of the guardrail system (Event 2). The direct contact damage from the face of the end terminal was located on the mid-aspect of the right front door and involved distinct creases in the door panel that extended vertically 53 cm (20.75 in) and 46 cm (18.0 in) horizontally (**Figure 9**) and matched the dimensions of the end terminal. The vertical crease was located 90 cm (35.3 in) aft of the right front axle location. As

the Hyundai struck the guardrail, the door crushed laterally (inward) resulting in separation of the door latch striker from the B-pillar (**Figure 10**). The B-pillar also displaced laterally and was torn at the sill over a length of 23 cm (9 in). The sill of the Hyundai below the right B-pillar struck guardrail Post 2, crushing the component approximately 5 cm (2 in). The crush profile for the damage pattern was documented at the mid door level resulting in the following profile: C1 = 3 cm (1.2 in), C2 = 8 cm (3.1 in), C3 = 20 cm (7.9 in), C4 = 17 cm (6.7 in), C5 = 10 cm (3.9 in), C6 = 2 cm (0.8 in). The maximum lateral displacement of the door measured 39 cm (15.2 in). The CDC attributed to this damage was 03RPEW4.

Figure 9: Direct contact damage on the right front door panel from the head of the SKT end treatment.

Figure 10: Deformation to the right front door of the Hyundai from the impact end terminal.

The Event 3 impact involved the back aspect of the right plane. The direct contact damage began on the quarter-panel 227 cm (89.5 in) aft of the right front axle and extended 116 cm (45.5 in) to the rear bumper corner (**Figure 11**). Included in the damaged region was the right rear tire wheel assembly and suspension. This axle position was displaced forward 8 cm (3.2 in) and the steel wheel was deformed at the bead which aired out the tire. The impact energy was transferred into the axle location and deformed the assembly laterally to the left. The crush profile documented along this damage plane accounting for free space was as follows: C1=17 cm (6.7 in), C2 = 36 cm (14.2 in), C3 = 29 cm (11.4 in), C4 = 23 cm (9.1 in), C5 = 6 cm (2.4 in), C6 = 2 cm (0.8 in). The CDC for this event was 03RBEW4. The barrier equivalent speed of this damage profile calculated by the WinSMASH program was 17 km/h/ (10 mph). The reconstruction of the crash was considered borderline due to the yielding properties of the impact configuration and the magnitude of the barrier equivalent speed was to be low based on SCI field experience.

Figure 11: Right lateral image of the Hyundai depicting the Event 3 damage.

Event Data Recorder

The 2010 model year Hyundai was not equipped with an event data recorder (EDR). Data descriptive of this crash sequence was not available. EDR-supported Hyundai vehicles began production with the 2012 model year with data imaging capable through a scan tool manufactured by Global Information Technology.

Interior Damage

The occupant compartment of the Hyundai sustained damage from exterior deformation that resulted in multiple intrusions of the occupant space and damage associated with occupant contact. Maximum intrusion was 43 cm (16.75 in) of lateral displacement of the aft aspect of the right front door (**Figure 12**) as it overrode the front right seat cushion due to the striker separation from the B-pillar. The deformation of the door separated the interior door panel. The lower right B-pillar intruded laterally 20 cm (8 in) into the front row right occupant space. Additional intrusions of this area included 8 cm (3 in) of lateral displacement of the sill and 34 cm (13.5 in) of window frame intrusion. The second-row right seat position was reduced in size by 10 cm (4 in) of lateral intrusion of the forward aspect of the right rear door panel and 5 cm (2 in) of longitudinal displacement of the front row right seat back.

Figure 12: Lateral interior image of the Hyundai depicting the door intrusion

The Hyundai was equipped with an AS1 laminated windshield, AS2 door and backlight glazing. The vehicle was not equipped with a roof window. Pre-crash, all four operable door windows were closed. During the crash, the laminated windshield fractured without holing or bond separation and the right front door glazing disintegrated due to door deformation. All left side door glazing, the backlight and the right rear door glazing remained closed and intact.

The unbelted driver moved laterally across the interior of the Hyundai prior to ejection. Her left lower leg and foot swiped or scuffed the lower left instrument panel knee bolster to the left of the steering column **(Figure 13)**. The scuff mark was directional, originating from the lower aspect and translating up and right with respect to the interior of the Hyundai. The driver's right thigh contacted and displaced the console-mounted automatic shifter lever to the right **(Figure 14)**. The driver's continued lateral movement to the right in the vehicle resulted in a complete ejection through the right front door window opening. No contact evidence on the window frame or door panel was observed (e.g., hair, tissue, fibers).

Figure 13: Left leg/foot scuff to the lower instrument panel/knee bolster.

Figure 14: Console-mounted shifter deflected right from driver right thigh contact.

Manual Restraint Systems

The manual restraint systems in the Hyundai consisted of continuous loop 3-point lap and shoulder seat belts with sliding latch plates. The front row systems were configured with adjustable D-rings. The driver's D-ring was adjusted to the full-down position while the front row right was adjusted to the full-up position. The driver's seat belt retracted onto an emergency locking retractor (ELR). All other seat belt systems in the Hyundai retracted into ELR/automatic locking retractors. Both front row retractors were equipped with pretensioners that were linked to the frontal air bag system. The air bag system was not commanded to deploy therefore the pretensioners did not actuate in this crash.

At the time of the SCI inspection, the driver's seat belt was retracted and stowed against the B-pillar. An inspection of the seat belt system identified subtle historical wear marks on the latch plate with minimal edge wear on the seat belt webbing. There was no crash/occupant induced loading evidence on the seat belt system to support usage at the time of the crash. The driver was not restrained by the 3-point lap and shoulder seat belt at the time of the crash.

Supplemental Restraint Systems

The Hyundai was equipped with six air bags consisting of the Certified Advanced 208-complaint frontal air bags for the driver and front row right occupant position, front seat-mounted side impact air bags and the roof side rail-mounted side impact air bags. The air bag system was controlled by an air bag control module ACM that was mounted to the center tunnel of the vehicle. The frontal air bag system consisted of dual-stage air bags, seat track positioning sensors, seat belt buckle switches, a front row right occupant presence sensor and front row retractor pretensioners. The driver air bag did not deploy and the retractor pretensioner did not actuate as the system was not commanded to deploy in this right-side impact crash.

The right seat-mounted and IC air bags deployed (**Figure 15**) as a result of the Event 3 impact with the guardrail system. The seat-mounted air bag deployed through the right-side seat back stitching. The air bag was 48 cm (19.0 in) in height and extended 30 cm (12.0 in) forward. There was no damage or occupant contact to this air bag. The right IC air bag deployed from the juncture of the roof side rail and the headliner. The IC air bag was tethered to the right A-pillar via a 15 cm (6.0 in) tether that remained intact. There was no sail panel to fill the void of the right A-pillar. The rectangular air bag measured 152 cm (60 in) in length and provided coverage for both occupant rows. At the mid-point of the front row, the vertical height of the IC air bag was 38 cm (15.0 in). At the same location of the second row, the IC air bag was 36 cm (14.0 in) in height. The IC air bag was not damaged and there was no occupant contact evidence. The intrusion of the right front door window frame displaced the IC air bag inward with respect to the interior of the vehicle. The inflation of the IC air bag was not altered, and the supplemental restraint system still offered crash protection and ejection mitigation.

Figure 15: Right interior view of the Hyundai depicting the deployed air bags.

Based on the SCI vehicle inspection and the circumstances of the crash, the driver was ejected prior to the deployment of the right IC air bag. Observations of the interior inspection revealed the separation of the door striker plate from the B-pillar and the presence of numerous sharp edges that would have abraded or cut the seat-mounted side impact air bag had it deployed during the initial right door engagement (Event 2) with the end terminal. Secondary, the driver was cleanly ejected through the right front door window opening as all other glazing remained intact and all doors remained closed. The right front door opened but intruded into the front row right position. The 21 cm (8.4 in) wide opening gap at the B-pillar was absent any physical evidence of occupant contact and was too small for the driver to fit through. Had the IC air bag deployed during Event 2, her ejection path would have been mitigated by the inflated IC air bag. There was no physical evidence of any contact to the IC air bag, which indicated that it deployed as a result of Event 3, after the driver's ejection had occurred.

2010 HYUNDAI ELANTRA OCCUPANT

Driver Demographics

Age/Sex:	26 years/female
Height:	155 cm (61 in)
Weight:	91 kg (200 lb)
Eyewear:	None
Seat Type:	Forward-facing bucket seat with adjustable head restraint
Seat Track Position:	Forward to mid-track (estimated based on demographics)
Manual Restraint Usage:	None, 3-point lap and shoulder belt was available
Usage Source:	Vehicle inspection/complete ejection
Air Bags:	Driver's frontal, front seat-mounted, and IC air bags available; (right side impact air bags deployed)
Alcohol/Drug Involvement:	None
Egress From Vehicle:	Complete ejection
Transport From Scene:	Coroner, deceased at scene
Type of Medical Treatment:	None (autopsy)

Driver Injuries

Inj. No.	Injury	AIS 2015	Involved Physical Component	IPC Confidence Level
1	Left and right unci and hippocampus are slightly herniated	140202.5	Ground	Probable
2	Disarticulation of the atlanto-occipital articulation	650208.3	Ground	Probable
3	Compression of chest	410099.1	Vehicle undercarriage	Probable
4	Compression of abdomen	510099.1	Vehicle undercarriage	Probable
5	Multiple subpleural petechiae	442999.9	Vehicle undercarriage	Possible
6	Multiple left face contusions	210402.1	Ground	Probable
7	Multiple left face abrasions	210202.1	Ground	Probable
8	Multiple right shoulder contusions	710402.1	Ground	Probable
9	Multiple right shoulder abrasions	710202.1	Ground	Probable
10	Multiple left shoulder contusions	710402.1	Ground	Probable
11	Multiple left shoulder abrasions	710202.1	Ground	Probable
12	Multiple torso contusions	410402.1	Vehicle undercarriage	Possible
13	Multiple torso abrasions	410202.1	Vehicle undercarriage	Possible
14	Multiple contusions of the right extremity	710402.1	Ground	Probable
15	Multiple abrasions of the extremities	710202.1	Ground	Probable
16	Multiple contusions of the left extremity	710402.1	Ground	Probable
17	Multiple abrasions of the right extremity	710202.1	Ground	Probable

Source – Coroner's report (complete autopsy)

Driver Kinematics

The driver of the Hyundai was seated in a presumed forward-to-mid seat track position based on her demographics. The driver's seat position had been altered at the time of the SCI inspection as it was found full-forward with the seat back reclined 40 degrees aft of vertical. She was not restrained by the manual seat belt system as the belt system did not yield evidence of occupant loading and the fact that the driver was completely ejected during the crash.

The Event 1 impact with the delineator did not displace the driver from her seated position or cause injury. As the Hyundai rotated counterclockwise, the driver was minimally displaced to her right by the centrifugal force of the rotation. At impact with the end treatment system of the guardrail (Event 2), the driver continued to move to her right in response to the lateral (3 o'clock) impact force. The AS2 window glazing was disintegrated by the impact and door deformation.

As the driver moved right, her left lower leg scuffed the lower instrument panel/knee bolster left of the steering column. Her right thigh contacted and displaced the console mounted shifter to the right. Her head and upper body began to travel through the right front window frame. The driver was completely ejected through the window opening **(Figure 16)** onto the median. The front right door lost integrity as the striker plate separated from the B-pillar, allowing the door to intrude and override the right front seat cushion.

Figure 16: Right front door window opening was the ejection portal for the unbelted driver.

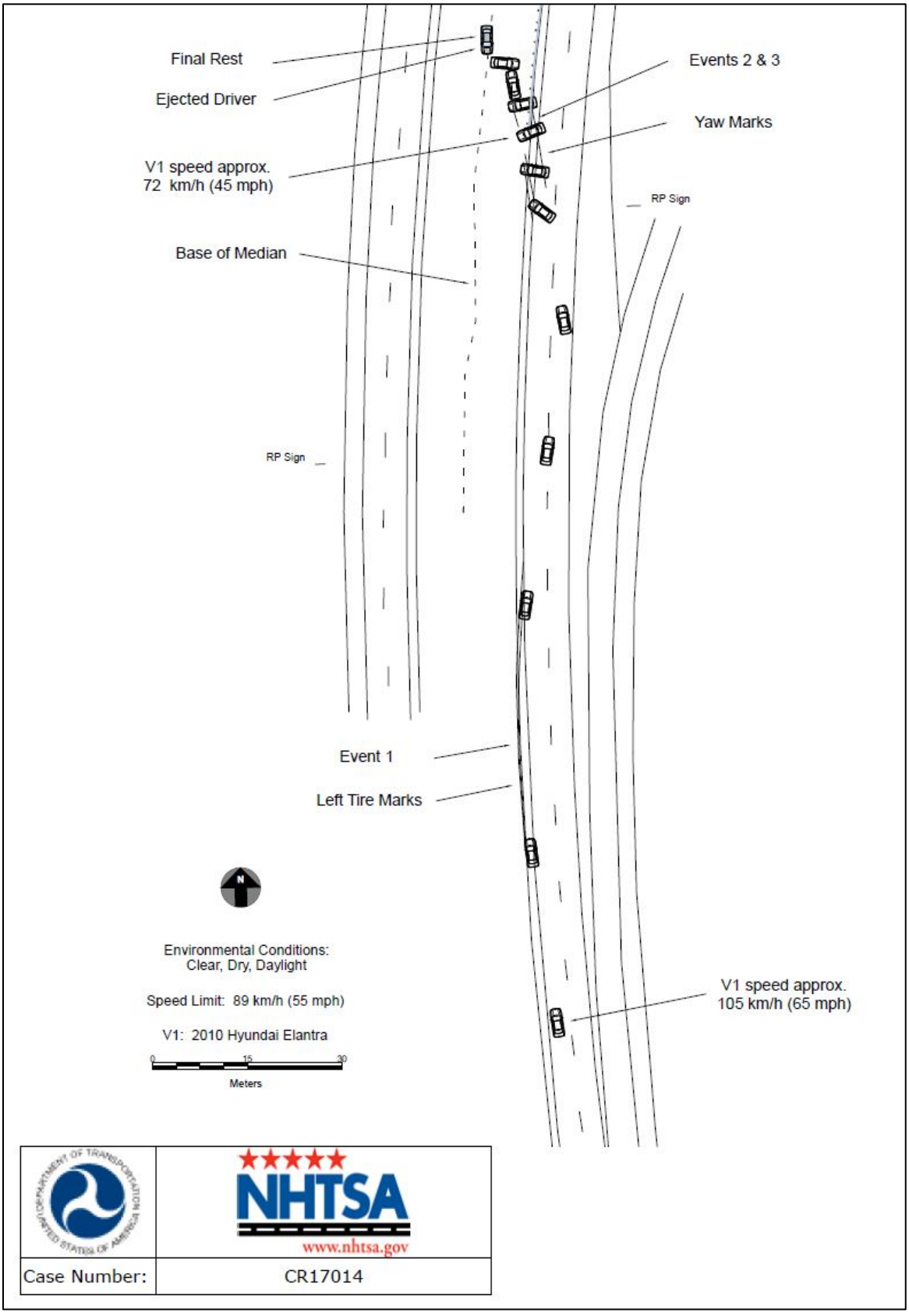
The driver struck the ground with her head and upper torso resulting in multiple abrasions and contusions of the face and shoulders. Her face/head impact with the ground compressed/flexed her structures of the neck resulting in the disarticulation of the atlanto-occiptal articulation and herniation of the left and right unci and hippocampus.

The right plane/back aspect of the Hyundai engaged the deformed guardrail system causing lateral crush of the quarter panel and deflection of the right rear axle position. This impact (Event 3) caused the deployment of the right-side impact air bag system, both seat-mounted and the IC air bags. The deployment occurred after the compete ejection of the driver from the Hyundai.

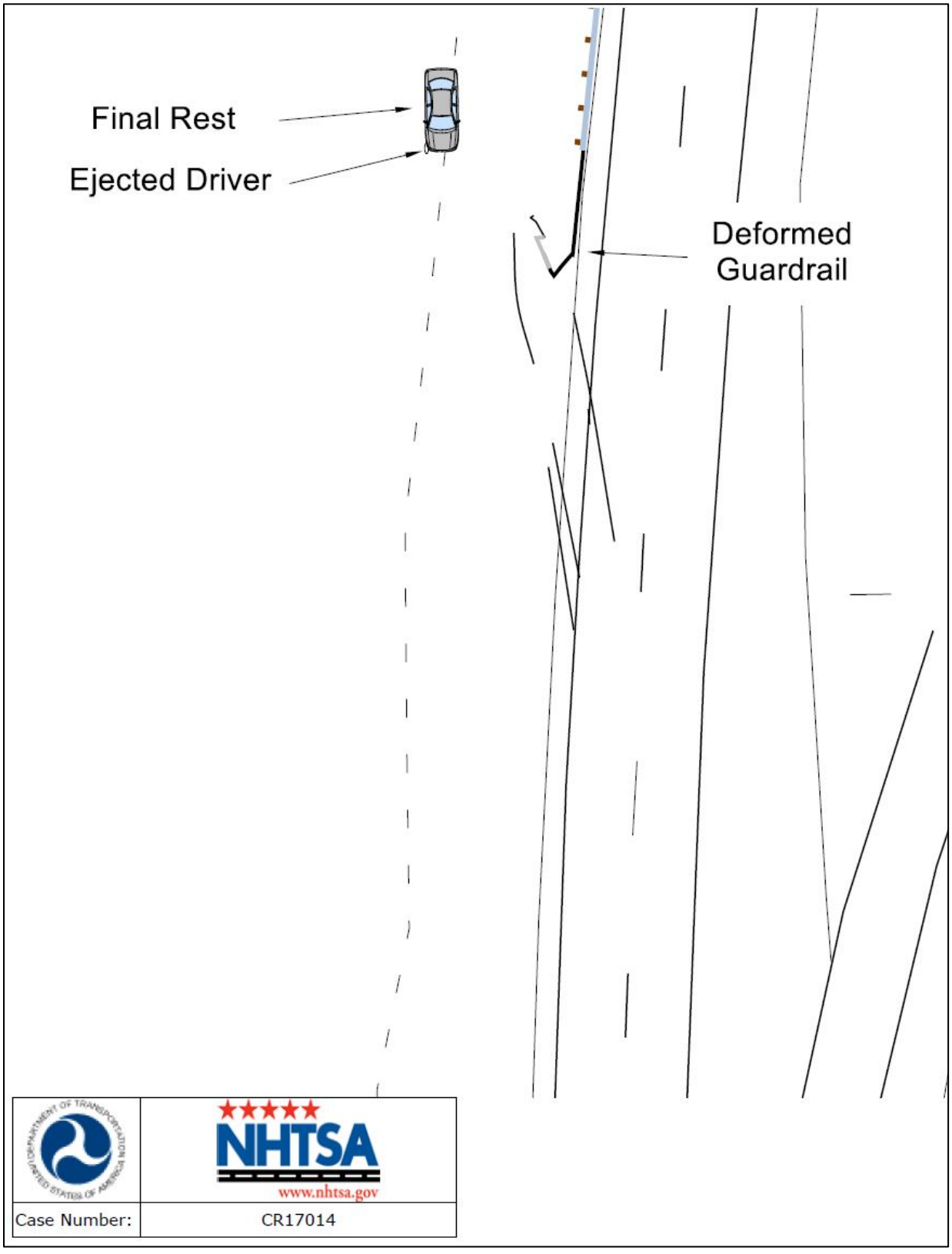
The Event 3 impact was located rearward of the vehicle's center of gravity which reversed the vehicle's counterclockwise rotation to clockwise. The Hyundai rotated down the embankment into the base of the median and partially overrode the ejected driver. At rest, the driver was lying

under the front right undercarriage of the vehicle. She sustained probable compression of the chest and abdomen with subpleural petechiae from vehicle contact. Emergency personnel arrived at the scene and determined that the driver was deceased. Her body was removed from the crash site and transported by the coroner for autopsy.

CRASH DIAGRAM



GUARDRAIL DEFORMATION DIAGRAM



APPENDIX:

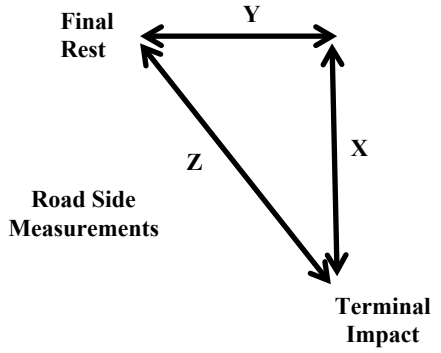
Federal Highway Administration Guardrail Forms

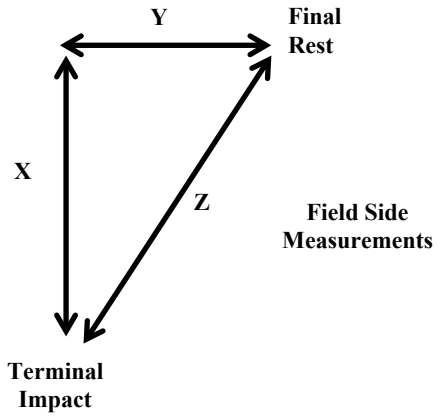
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	May 2017	**Time of Crash (Military)**	Daytime
Case Number	CR17014	**State**	PA
Traffic Route	Limited Access	**Direction (Southbound = SB)**	NB
Ambient Conditions (at time of crash)			
Temperature (°F)	84°	**Lighting**	Day
Atmospheric	Clear		

SCENE INFORMATION	
Type of area where crash occurred	❒Urban ■Rural ❒Suburban
Terminal on a horizontal curve?	❒No ❒Curve/LT ■Curve/RT
Estimated or Reconstructed Speed at Impact (mph)	Estimated 65 mph Pre-Crash ~45 mph at impact
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 51.8 ft ❒Road side ■Field Side
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 46.3 ft
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 25.9 ft
Super elevation	■>2% ❒<2% ❒NONE or FLAT
Curve Radius (ft.)	3,264 ft

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





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.)					
n/a									
1	Steel	6x 6	None	N/A	No	N/A	20.5 in	N/A	N/A
2	Steel	4 x 6 Hinged	None	N/A	No	N/A	17.5 in	N/A	6’-4”

Case No.: CR17014

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.)					
3	Steel	4 x 6	Composite	4 x 7.5 x 14	No	N/A	22 in	N/A	6’-5”
4	Steel	4 x 6	Composite	4 x 7.5 x 14	No	N/A	21 in	N/A	6’-2””
5	Steel	4 x 6	Composite	4 x 7.5 x 14	No	END OF DAMAGE	18 in	N/A	6’-3”
6	Steel	4 x 6	Composite	4 x 7.5 x 14	No	N/A	4.8		6’-4”
7	Steel	4 x 6	Composite	4 x 7.5 x 14	No	N/A	4.8		6’-3”

Additional Comments

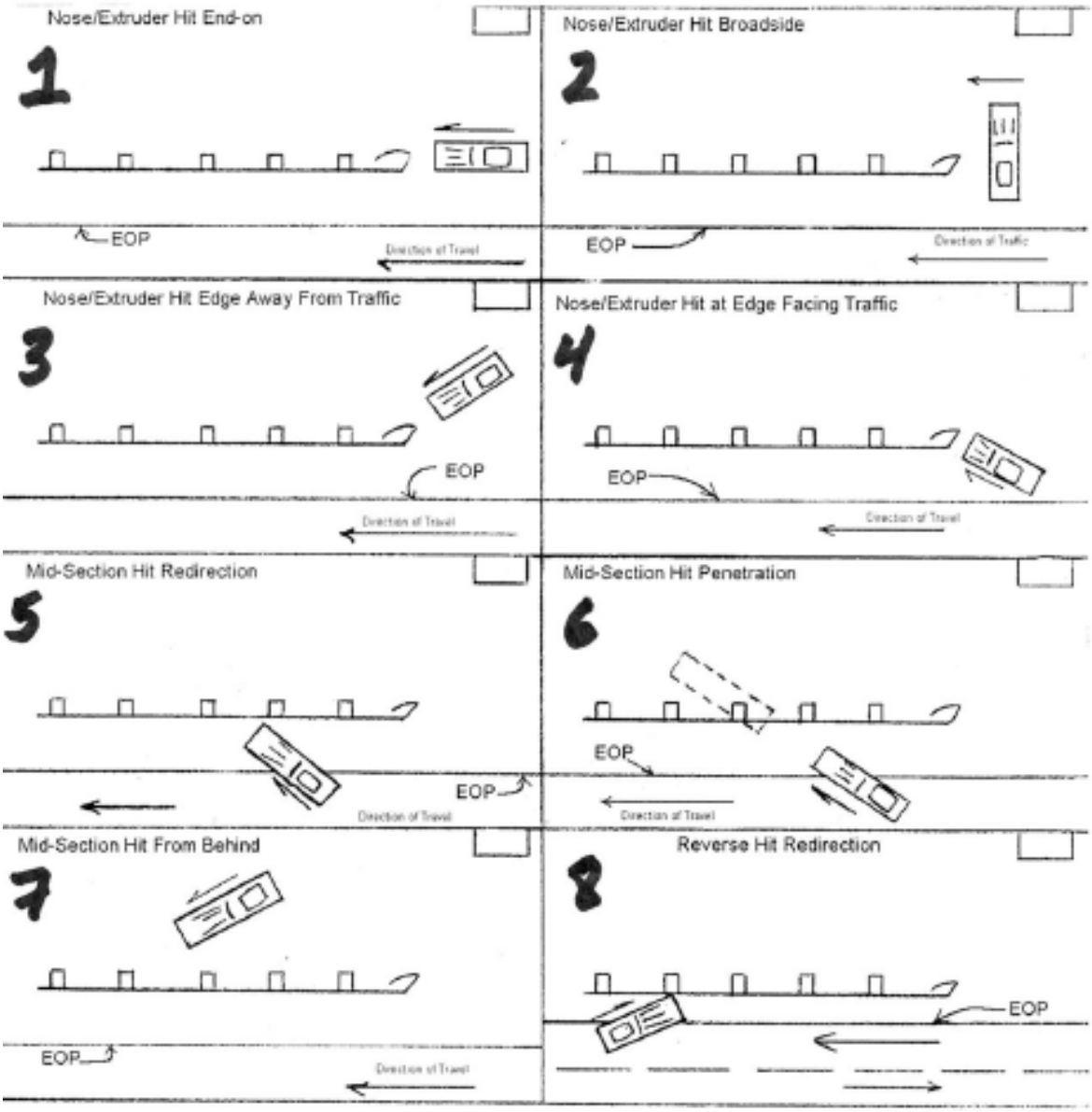
EXTRUDER			
Feeder Channel Width at impact head	❒4inches ❒5 inches ■Other		
Guide Chute Exit Height (in.)	20 inches		
Connection of feeder channels to head damaged?	■No ❒Yes	Are Welds Broken?	■No ❒Yes
Anchor Cable Present?	❒No ■Yes	Pre-crash Connected?	❒No ■Yes
Rail Extrusion?	❒No ■Yes	Length (ft. in.)	8 ft
Rail Extrusion Direction	❒Traffic Side ■Field Side ❒N/A		
Total Length of Rail Damaged (ft.) [total length would include extruded rail plus damaged rail downstream from head.]	22 ft 3 in System damaged to Post 5		

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:
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	n/a	

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	0.0%	1.0%	-7.4%
Adjacent Lane Width (ft)	12 ft-1 in		
Lane Type (NAS EDS Variable: Sur. Type)	Asphalt		
Shoulder Type	Asphalt		
Shoulder Width (ft)	3 ft – 6 in		
Guardrail Height (in)	29.5 in in undamaged section between Post 6 and 7		

VEHICLE INFORMATION		
Vehicle Type (NHTSA Input)	2010 Hyundai Elantra	
Vehicle Identification Number (VIN)	KMHDU4AD0AUxxxxxx	
Vehicle Mass (NASS var.: veh.wgt)	2,247 lb Curb Weight	
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	03RPEW4, 03RZEW4	
Delta-V	Unknown	
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)	N/A	
Rollover Type, Terhune Scale, (NASS EDS variable: rolintyp)	N/A	


Nose/Extruder Hit End-on
1
EOP
Direction of Travel
Nose/Extruder Hit Broadside
2
EOP
Direction of Traffic
Nose/Extruder Hit Edge Away From Traffic
3
EOP
Direction of Travel
Nose/Extruder Hit at Edge Facing Traffic
4
EOP
Direction of Travel
Mid-Section Hit Redirection
5
EOP
Direction of Travel
Mid-Section Hit Penetration
6
EOP
Direction of Travel
Mid-Section Hit From Behind
7
EOP
Direction of Travel
Reverse Hit Redirection
8
EOP

DOT HS 812 651
November 2018

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

13937-112318-v2