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**Special Crash Investigations:
On-Site Guardrail End Terminal
Crash Investigation;
Vehicle: 2012 Hyundai Sonata;
Location: Missouri;
Crash Date: June 2018**

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16. Abstract This report documents the crash investigation of a 2012 Hyundai Sonata with an ET2000 guardrail end terminal. The investigation was conducted on behalf of FHWA. This single-vehicle crash occurred in the morning on a divided east/west U.S. highway in Missouri in June 2018. The Hyundai was being driven westbound by a belted 57-year-old male. There were no other occupants in the vehicle. The driver told the police he saw a deer enter the roadway ahead, causing him to swerve and depart the right side of the roadway. The Hyundai's front plane struck the ET2000 guardrail end terminal and came to rest on the field side of the guardrail. The guardrail sustained 11.4 m (37.3 ft) of damage including extrusion of the W-beam. The driver was transported by ambulance to a local hospital, where he was treated and released. The Hyundai sustained minor severity damage to the front plane and was towed due to damage.			
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Special Crash Investigations
On-Site Guardrail End Terminal Crash Investigation
Case Number: DS18017
Vehicle: 2012 Hyundai Sonata
Location: Missouri
Crash Date: June 2018

BACKGROUND

This report documents the crash investigation of a 2012 Hyundai Sonata into an ET2000 guardrail end terminal. The investigation was conducted on behalf of FHWA. The investigation was initiated by a Missouri highway department that notified the Federal Highway Administration (FHWA) of the crash. After reviewing the case and determining the ET2000 guardrail end terminal qualified and the case was of interest, the FHWA forwarded the notification with on-scene images to the Special Crash Investigations (SCI) group of the National Highway Traffic Safety Administration, requesting it deploy the SCI team. SCI assigned the case to Dynamic Science, Inc. in June 2018. The SCI team completed inspections of the vehicle and crash site in July 2018. State highway department personnel were present and provided a lane closure for the scene inspection and field support for the scene and vehicle inspections.



Figure 1. The 2012 Hyundai Sonata.

This single-vehicle crash occurred in the morning on a divided, east/west, U.S. highway in Missouri in June 2018. The Hyundai was being driven westbound by a belted 57-year-old male. There were no other occupants in the vehicle. The driver told the police he saw a deer enter the roadway ahead, causing him to steer abruptly right and depart the right side of the roadway. The Hyundai's front plane struck the ET2000 guardrail end terminal and came to rest on the field side of the guardrail. The Hyundai (**Figure 1**) sustained minor severity damage to the front plane and was towed due to damage to a police lot. The guardrail sustained 11.4 m (37.3 ft) of damage including extrusion of the W-beam (**Figure 2**). SCI obtained the police report indicating the driver sustained "B" non-incapacitating (evident, non-disabling) injuries and a complaint of back pain, and was transported by ambulance to a local hospital. The Hyundai was configured with an air bag control module (ACM) with Event Data Recorder (EDR) capability supported by the Global Information Technology (GIT) EDR data retrieval



Figure 2. Guardrail ET2000 and extruded W-beam.

tool. Permission to remove the EDR from the vehicle and send it to NHTSA to conduct a bench top download was not obtained prior to the inspection and the EDR data was not imaged.

SUMMARY

Crash Site

The crash site was a divided, east/west, U.S. highway. The westbound roadway included a left shoulder bordered by a solid yellow painted stripe, two westbound lanes measuring 3.6 m (11.8 ft) each in width and separated by a dashed white painted stripe, and a right shoulder measuring 3.1 m bordered by a solid white painted fog line and configured with intermittent patches of rumble strip. On the right shoulder, a wood and steel guardrail configured with an ET2000 end terminal was located 3.5 m (11.5 ft) right of the right fog line (**Figure 3**). The roadway was straight with a positive 0.8 percent slope and negative 2.5 percent super-elevation at 45.7 m (150.0 ft) east of the end terminal. The posted speed limit was 96 km/h (60 mph). Conditions at the time of the crash were daylight, cloudy, and wet. A crash diagram is included at the end of this report.



Figure 3. Crash site, looking west.

Pre-Crash

The Hyundai was traveling westbound in the first lane from the right at a driver-estimated speed of 89 km/h (55 mph). The driver saw a deer enter the roadway ahead and in response he abruptly steered right to avoid the animal, causing him to depart the right side of the roadway. The crash site revealed no evidence of pre-impact braking or wheel lockup. Given the vehicle speed, wet roadway conditions, and abrupt steering input, the vehicle was likely not tracking at the time of departure.



Figure 4. Area of impact, guardrail Post 1.

Crash

The crash included two events. Initially, the front plane of the Hyundai struck the ET2000 end terminal head-on (Event 1) (**Figure 4**). The end terminal yielded, the first six posts were damaged, and a section of metal W-beam measuring 4.3 m (14.1 ft) long extruded through the terminal chute. One or more unknown components of the damaged guardrail struck the left plane in a sideswiping configuration, beginning at the left A-pillar and ending at the left C-pillar (Event 2). The Hyundai rotated 30 degrees clockwise and was displaced right to the field side of the guardrail where it traveled in a northwest trajectory depositing a left tire track measuring 19.4 m (63.6 ft) on the descending roadside having a slope measuring negative 1.4 percent. The vehicle came to rest facing northwest 25.9 m (85.0 ft) from the first impact. During the crash, the driver's frontal, seat-mounted, and inflatable curtain (IC) air bags deployed and his seat belt pretensioner actuated.

For the Hyundai in Event 1, the barrier algorithm of the WinSMASH program calculated a barrier equivalent speed (BES) of 24 km/h (15 mph). The barrier calculation type precluded a reconstruction. Event 2 was a sideswipe impact precluding a WinSMASH calculation.

Post-Crash

The police were notified two minutes after the crash and arrived in 14 minutes. The driver exited the vehicle with assistance from medical responders and was transported by ambulance to a local hospital. The Hyundai was towed due to damage to a police lot and placed on hold.

GUARDRAIL END TERMINAL DISCUSSION

The guardrail was configured with an ET2000 end terminal (**Figure 5**), steel W-beam, wood posts configured with wood offset blocks, and steel posts configured with wood offset blocks. The ET2000 was a 5-inch extruder-type end terminal configured with a rectangular impact face measuring 51 cm (20.0 in) wide x 52 cm (20.5 in) high. The guide chute exit height measured 39 cm (15.3 in). The guardrail was configured with a steel ground strut measuring 205 cm (80.7 in) long located between Posts 1 and 2, an anchor cable attached to Post 1, and an anchor bracket attached to the W-beam between Posts 1 and 2. The wooden guardrail posts 1 to 5 measured 14 x 19 cm (5.5 x 7.5 in) and posts 6 and 7 measured 15 x 20 cm (6.0 x 8.0 in). The steel posts 8 to 12 measured 15 x 10 cm (6.0 x 4.0 in). Posts 3 to 12 were assembled with offset wood blocks measuring 15 x 20 x 36 cm (6.0 x 8.0 x 14.0 in). Spacing averaged 1.9 m (6.2 ft) for Posts 1–12 and W-beam height measured top to ground was 65 cm (25.5 in).



Figure 5. ET2000 end terminal.

At impact with the impact head, the ET2000 end terminal was displaced to the field side and a section of W-beam measuring 4.3 m (14.0 ft) long extruded on the field side. The ET2000 did not exhibit any damage or deformation caused by the impact or extrusion. Posts 1, 2, 3, and 5 were sheared off at ground level and post 4 was uprooted. An additional length of non-extruded W-beam measuring 7.1 m (23.3 ft) was damaged, including three rail kinks at posts 4, 6, and 7. The anchor bracket and cable were displaced to the ground and the ground strut remained in place on the remnants of posts 1 and 2.

The vehicle was displaced to the field side of the guardrail and traveled in a northwest trajectory to final rest on the roadside. The complete FHWA Guardrail Form is included in this report as **Appendix A**.

2012 HYUNDAI SONATA

Description

The 2012 Hyundai Sonata was a 4-door, full-size sedan identified in the police report and confirmed at the time of inspection using the Vehicle Identification Number

5NPEB4AC0CHxxxxxx. The vehicle was manufactured in July 2011. The odometer was electronic, and the mileage was unknown due to the absence of power. The vehicle manufacturer recommended size P205/65R16 tires with a recommended pressure of 33 psi (225 kPa) for the front and rear. The Hyundai was equipped with Uniroyal Tiger Paw tires of the recommended size manufactured in 01/2016 on the front and Goodyear Assurance tires of the recommended size manufactured in 12/2014 on the rear.

The Hyundai was configured with two rows of seating for five occupants. The front row was equipped with bucket seats and adjustable head restraints. The second row was equipped with a bench seat, folding back, and adjustable head restraints.

Exterior Damage

The Hyundai sustained minor severity damage to the front (**Figure 6**), left, and top planes during the crash. The front plane sustained direct and induced damage at head-on impact with the ET2000 guardrail end terminal. The left plane was damaged on the left front fender, left front door, and left rear door at impact with undetermined guardrail components in a secondary sideswipe configuration. The top plane was damaged at the hood, which sustained induced damage in the first impact. Direct damage to the bumper fascia began 13 cm (5.1 in) left of the front right bumper corner and extended 155 cm (61.0 in) to the left. The Field L extended from bumper corner to bumper corner and measured 170 cm (66.9 in). The bumper fascia was displaced, and the backing bar was used to obtain crush measurements. Sixteen measurements in 10.0 cm (3.9 in) increments were taken at bumper level by the Nikon Total Station and the Faro Blitz program computed crush measurement in six increments as follows: $C_1 = 0$ cm, $C_2 = 2$ cm (0.8 in), $C_3 = 7$ cm (2.8 in), $C_4 = 17$ cm (6.7 in), $C_5 = 15$ cm (5.9 in), and $C_6 = 9$ cm (3.5 in). The observed principal direction of force was 0 degree, and the collision deformation classification (CDC) for the Hyundai was 12FDEW1.



Figure 6. Front plane crush measurements, the 2012 Hyundai Sonata.



Figure 7. Left plane damage, the 2012 Hyundai Sonata.

The Hyundai sustained minor severity damage to the left plane in a secondary impact with unknown components of the guardrail (**Figure 7**). The left front fender sustained induced damage, the trim at sill level was displaced, and both tires were flat and the wheel covers were bent. Direct damage began at the left A-pillar 45 cm (17.7 in) aft of the left front axle, extended 215 cm (84.6 in) rearward and ended at the left C-pillar. This was a side swipe damage configuration with an observed PDOF of 350 degrees and the CDC was 12LYES1.

Interior Damage

The Hyundai's interior sustained minor severity damage caused by the impact forces, air bag deployments, and driver contacts. No glazing was damaged and all doors remained closed and operational. No intrusions were documented. Three air bags were deployed and the driver's seat belt pretensioner was actuated. Evidence of driver loading was documented on the seat belt assembly.

Manual Restraint Systems

The Hyundai was equipped with driver and front passenger lap and shoulder seat belts. The driver's belt was equipped with continuous loop belt webbing, a sliding latch plate, an emergency locking retractor, and an adjustable upper anchor that was adjusted to the full-up position. The front row seat belts were equipped with retractor-mounted pretensioners configured with load limiters. According to the vehicle owners' manual, the pretensioners were intended to actuate in frontal impacts meeting a severity threshold and side impacts in which a side air bag deploys. The driver was belted at the time of the crash. His seat belt webbing was unspooled and locked by the actuated belt pretensioner. The belt assembly revealed evidence of driver loading in the form of scuff marks on the plastic trim of the latch plate and on the webbing at 44 cm (17.3 in) above the stop button.

Supplemental Restraint Systems

The Hyundai's supplemental restraint systems included a control module, driver's and passenger's frontal air bags, front row seat-mounted side-impact air bags, front and second row side impact IC air bags, and seat belt pretensioners. At impact with the guardrail end terminal, the driver's frontal, seat-mounted, and IC air bags deployed and his seat belt pretensioner actuated. The air bags all deployed normally and exhibited no evidence of damage or driver loading.

NHTSA Recalls and Investigations

A search last queried in December 2020 using the Hyundai's VIN revealed one unrepaired recall. On February 27, 2018, NHTSA Recall Number 18V137000 (Manufacturer Recall Number 174) was issued. In summary, the manufacturer recalled the vehicles because in the event of a crash, the ACU may short-circuit and prevent the frontal air bags, side air bags, and seat belt pretensioners from deploying.

2012 HYUNDAI SONATA DRIVER

Driver Demographics

Age/sex:	57 years/male
Height:	185 cm (73 in)
Weight:	136 kg (300 lb)
Eyewear:	Unknown
Seat type:	Bucket with adjustable head restraint
Seat track position:	Middle to full rear track
Manual restraint usage:	Lap and shoulder seat belt
Usage source:	Vehicle inspection
Air bags:	Frontal, seat-mounted side-impact, and IC air bags deployed

Alcohol/drug data:	None reported
Egress from vehicle:	Assisted through left side door
Transport from scene:	Ambulance to a local hospital
Type of medical treatment:	Treated and released

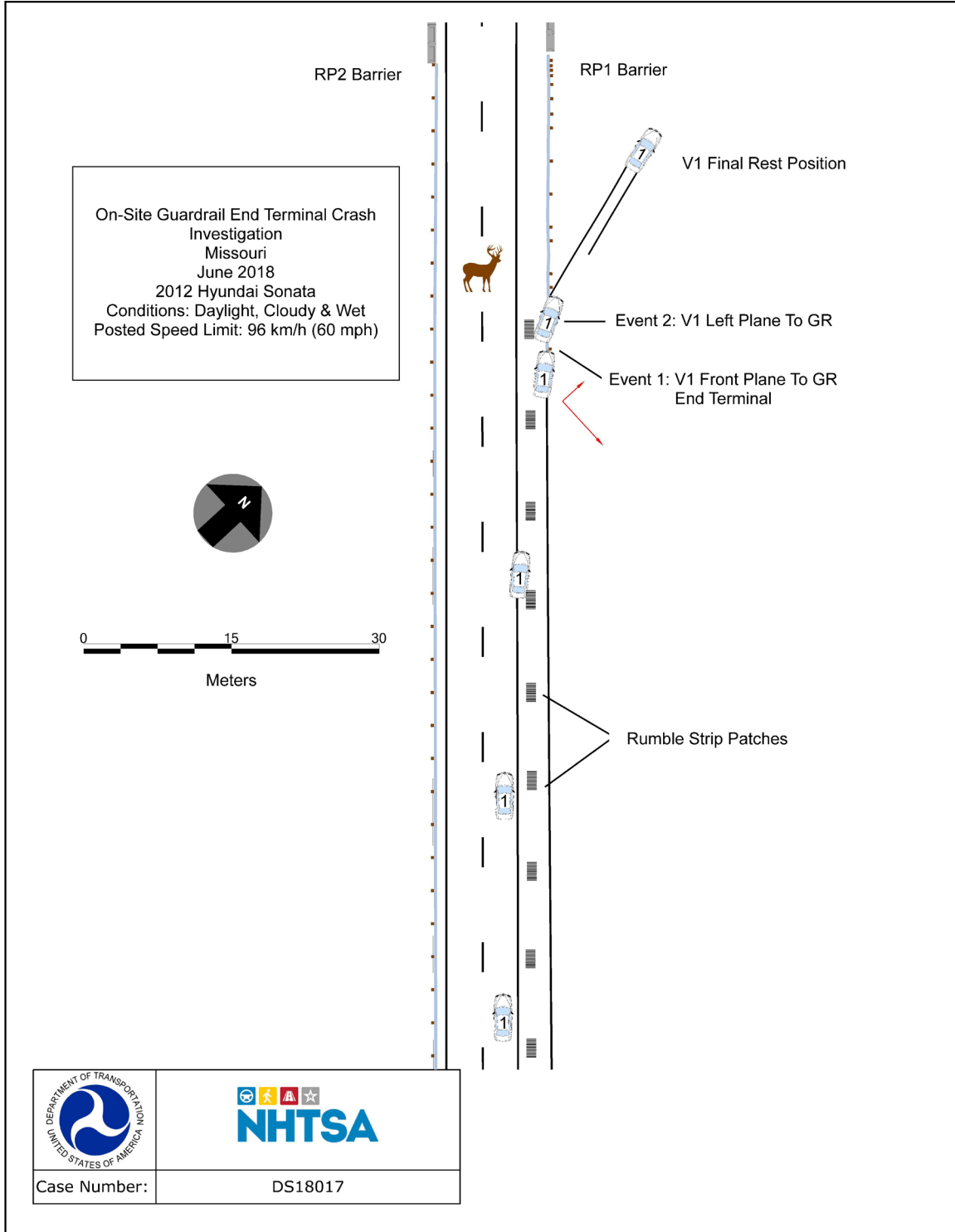
Driver Injuries

The driver complained of back pain and reported an unsubstantiated loss of consciousness. Based on his EMS and emergency department medical records, the driver had no codeable injuries.

Driver Kinematics

The belted 57-year-old male driver was seated in an unknown posture and actively steering the vehicle. He reportedly saw a deer enter the roadway ahead, causing him to steer right in avoidance and depart the roadway. At impact with the ET2000 end terminal, the driver was displaced forward in response to the direction of force. The driver's frontal, seat-mounted, and IC air bags deployed and his seat belt pretensioner actuated. The driver loaded the seat belt with his chest and the frontal air bag with his face, head, and chest. The vehicle was displaced to the right and traveled a short distance on the field side of the guardrail. The driver remained held in his seated position by the seat belt until the vehicle came to rest on the roadside and he was assisted from the vehicle by responders. He was transported by ambulance to a local hospital, where it was determined he was uninjured and he was subsequently released.

CRASH DIAGRAM



APPENDIX A: Federal Highway Administration Guardrail Form

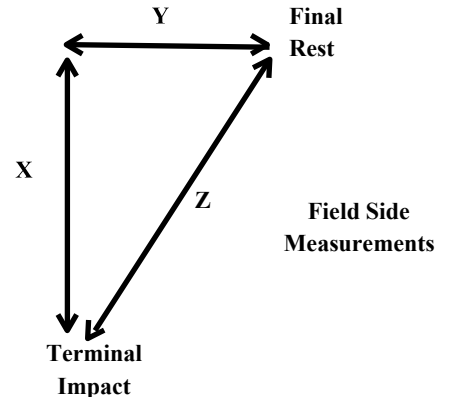
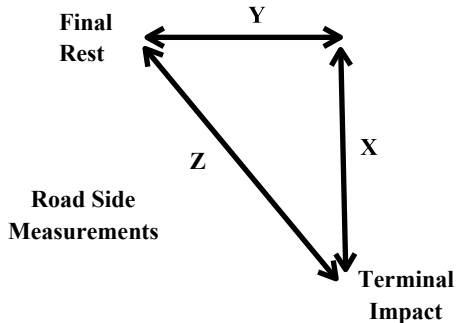
Case No.: DS18017

PREPOPULATED DATA (BY OTHERS)			
Date of Crash	June 2018	TIME OF CRASH (MILITARY)	morning
Case Number	DS18017	State	Missouri
Traffic Route	(US) EM-150	Direction (Southbound = SB)	WB
Ambient Conditions (at time of crash)			
Temperature (°F)	72	Lighting	Day
Atmospheric	Cloudy		

SCENE INFORMATION	
Type of area where crash occurred	<input type="checkbox"/> Urban <input checked="" type="checkbox"/> Rural <input type="checkbox"/> Suburban
Terminal on a horizontal curve?	<input checked="" type="checkbox"/> No <input type="checkbox"/> Curve/LT <input type="checkbox"/> Curve/RT
Estimated or Reconstructed Speed at Impact (MPH)	60
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 85
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 75
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 37
Super elevation	<input type="checkbox"/> +2% <input checked="" type="checkbox"/> -2% <input type="checkbox"/> NONE or FLAT
Curve Radius (ft.)	NA

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements



Case No.: DS18017

ON-SCENE INFORMATION	
End Treatment Type	<input checked="" type="checkbox"/> Extruder <input checked="" type="checkbox"/> ET2000 <input type="checkbox"/> ET-PLUS 4in <input type="checkbox"/> ET-PLUS 5in <input type="checkbox"/> SKT <input type="checkbox"/> FLEAT <input type="checkbox"/> SOFT STOP <input type="checkbox"/> Telescope <input type="checkbox"/> X-LITE <input type="checkbox"/> X-TENSION
Curb? s	<input checked="" type="checkbox"/> No <input type="checkbox"/> AASHTO Type A <input type="checkbox"/> AASHTO Type B <input type="checkbox"/> AASHTO Type C <input type="checkbox"/> AASHTO Type D <input type="checkbox"/> AASHTO Type E <input type="checkbox"/> Yes <input type="checkbox"/> AASHTO Type F <input type="checkbox"/> AASHTO Type G <input type="checkbox"/> AASHTO Type H
Curb Height: NA	

GUARDRAIL INSTALLATION									
Post No.	Post		Offset Block		Pre-Existing Damage		Offset to Post or Post Hole (ft.-in.)		Spacing to Next Post (ft.-in.)
	Type	Dim.	Type	Dim.	Yes No Unknown	Describe	Travel Way	Curb	
	Steel Wood Other	D x W (in.) or Dia. (in.)	Steel Wood Composite	D x W (in.)					
0	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	Wood	5.5 x 7.5	NA	NA	No	-	11-3	NA	6-2
2	Wood	5.5 x 7.5	NA	NA	No	-	11-3	NA	6-4

Case No.: DS18017

Post No.	Post		Offset Block		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	Wood	5.5 x 7.5	Wood	6 x 8	No	-	11-11	NA	6-1
4	Wood	5.5 x 7.5	Wood	6 x 8	No	-	11-8	NA	6-4
5	Wood	5.5 x 7.5	Wood	6 x 8	No	-	11-6	NA	6-5
6	Wood	6 x 8	Wood	6 x 8	No	-	11-10	NA	6-2
7	Wood	6 x 8	Wood	6 x 8	No	-	11-6	NA	6-6
8	Steel	6 x 4	Wood	6 x 8	No	-	11-6	NA	6-2

Case No.: DS18017

Post No.	Post		Offset Block		Pre-Existing Damage		Offset to Post or Post Hole (ft.)		Spacing to Next Post (ft. -in.)
	Type	Dim.	Type	Dim.	Yes No Unknown	Describe	Travel Way	Curb	
	Steel Wood Other	D x W (in.) or Dia. (in.)	Steel Wood Composite	D x W (in.)					
9	Steel	6 x 4	Wood	6 x 8	No	-	11-5	NA	6-5
10	Steel	6 x 4	Wood	6 x 8	No	-	11-7	NA	6-4
11	Steel	6 x 4	Wood	6 x 8	No	-	11-8	NA	6-1
12	Steel	6 x 4	Wood	6 x 8	No	-	11-8	NA	6-3

Additional Comments:

Case No.: DS18017

EXTRUDER			
Feeder Channel Width at impact head	<input type="checkbox"/> 4inches <input checked="" type="checkbox"/> 5 inches <input type="checkbox"/> Other _____		
Guide Chute Exit Height (in.)	25		
Connection of feeder channels to head damaged?	<input checked="" type="checkbox"/> No <input type="checkbox"/> Yes	Are Welds Broken?	<input checked="" type="checkbox"/> No <input type="checkbox"/> Yes
Anchor Cable Present?	<input type="checkbox"/> No <input checked="" type="checkbox"/> Yes	Connected?	<input checked="" type="checkbox"/> No <input type="checkbox"/> Yes
Rail Extrusion?	<input type="checkbox"/> No <input checked="" type="checkbox"/> Yes	Length (ft.-in.)	14-1
Rail Extrusion Direction	<input type="checkbox"/> Traffic Side <input checked="" type="checkbox"/> Field Side		
Total Length of Rail Damaged (ft.) [total length would include extruded rail plus damaged rail downstream from head.]	37-4		

TELESCOPE			
Rail Displacement	<input type="checkbox"/> No	<input type="checkbox"/> Yes; Length: NA	No of Panels Displaced <input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6

ALL-SYSTEM PERFORMANCE			
Railkinks Downstream of Head?	<input type="checkbox"/> No	<input checked="" type="checkbox"/> Yes	No. of Kinks in Rail: 3
Was there intrusion into the Occupant Compartment by foreign object (guardrail)?	<input checked="" type="checkbox"/> No <input type="checkbox"/> Yes		
Did vehicle impact other objects after impact with terminal?	<input type="checkbox"/> No <input checked="" type="checkbox"/> Yes		
Object Contacted	Unknown guardrail components		

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	50 ft in Advance of Post 1	At Post 1	50 ft Past Post 1
Percent - %	-18.6	-1.2	-1.4
Adjacent Lane Width (ft)	11.8		
Lane Type (NAS EDS Variable: Sur. Type)	Concrete		
Shoulder Type	Concrete		
Shoulder Width (ft)	10.1		
Guardrail Height (in)	25.5		

Case No.: DS18017

VEHICLE INFORMATION	
Vehicle Type (NHTSA Input)	4-door sedan, hardtop, full size
Vehicle Identification Number (VIN)	5NPEB4AC0CHxxxxxx
Vehicle Mass (NASS var.: veh.wgt)	3,161 lbs.
Vehicle orientation upon impact	<input type="checkbox"/> Case Type 1 <input type="checkbox"/> Case Type 2 <input type="checkbox"/> Case Type 3 <input checked="" type="checkbox"/> Case Type 4 <input type="checkbox"/> Case Type 5 <input type="checkbox"/> Case Type 6 <input type="checkbox"/> Case Type 7 <input type="checkbox"/> Case Type 8 <input type="checkbox"/> Other
If "Other," describe	
Collision Deformation Classification	12FEAW1
Delta-V	-13
Occupant Compartment Penetration of rail	<input checked="" type="checkbox"/> No <input type="checkbox"/> Yes; Describe:
Quarter Turns (NASS EDS variable: Rollover)	<input type="checkbox"/> 1 <input type="checkbox"/> 2 <input type="checkbox"/> 3 <input type="checkbox"/> 4 <input type="checkbox"/> 5 <input type="checkbox"/> 6 <input type="checkbox"/> 7 <input type="checkbox"/> 8 <input type="checkbox"/> 9 <input type="checkbox"/> 10 <input type="checkbox"/> 11 <input type="checkbox"/> 12 <input type="checkbox"/> 13 <input type="checkbox"/> 14 <input type="checkbox"/> 15 <input type="checkbox"/> 16 <input type="checkbox"/> 17+
Object Precipitating Rollover, (NASS EDS variable: Rollobj)	NA
Rollover Type, Terhune Scale, (NASS EDS variable: rolintyp)	NA

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