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Special Crash Investigations: On-Site Guardrail End Terminal Crash Investigation; Vehicle: 1998 Ford Ranger; Location: Missouri; Crash Date: August 2018

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Dynamic Science, Inc.	DS18023

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Dynamic Science, Inc. 26141 Marguerite Parkway, Suite C Mission Viejo, CA 92692	**11. Contract or Grant No.** 693JJ918C000012

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15. Supplementary Notes

Each crash represents a unique sequence of events, and 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.

16. Abstract

This report documents the on-site crash investigation of a 1998 Ford Ranger that struck a sequential kinking terminal (SKT) guardrail end terminal. The investigation was conducted on behalf of the FHWA. This single-vehicle crash occurred at night in August 2018 in Missouri on a divided two-lane State highway. The Ford, driven by a belted 31-year-old female, was occupied by an unbelted 34-year-old male front row passenger. The Ford departed the roadway on the left edge and struck the SKT end terminal on the left shoulder. The vehicle then crossed over two lanes to the right, departed the roadway on the right edge, and struck a guardrail face on the right shoulder. The Ford came to rest facing west on the right shoulder. The driver of the Ford was not injured or transported. The front row passenger sustained a minor severity injury. He was transported to a local hospital and then transferred to another hospital, where he was treated for an unknown duration.

17. Key Words	18. Distribution Statement
guardrail end terminal, injury	The document is available to the public from the National Technical Information Service, www.ntis.gov.

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Background

This report documents the on-site crash investigation of a 1998 Ford Ranger (Figure 1) that struck a sequential kinking terminal (SKT) guardrail end terminal. The investigation was intended to determine what role the guardrail may have played in causing or mitigating injuries to the vehicle occupants. The investigation was initiated by a Missouri highway department engineer who notified the Federal Highway Administration (FHWA) of the crash. The investigation was conducted on behalf of FHWA. After reviewing the case and determining the SKT guardrail end terminal qualified and that the case was of interest, FHWA forwarded the notification with scene images to the Special Crash Investigations (SCI) group of the National Highway Traffic Safety Administration with instructions to deploy the SCI team. SCI assigned the case to Dynamic Science, Inc., in August 2018. The SCI team completed inspections of the vehicle and crash site in September 2018.

Figure 1. The 1998 Ford Ranger

Figure 2. SKT field side looking south

This single-vehicle crash occurred at night in August 2018 in Missouri. The crash site was a divided two-lane State highway. The Ford, driven eastbound by a belted 31-year-old female, was occupied by an unbelted 34-year-old male front row passenger.

The Ford departed the roadway on the left edge and struck the SKT end terminal on the left shoulder (Figure 2). The vehicle then crossed over two lanes to the right, departed the roadway on the right edge, and struck a guardrail face on the right shoulder. The Ford came to rest facing west on the right shoulder. The driver of the Ford was not injured or transported. The front row passenger sustained a minor severity injury. He was transported to a local hospital and then transferred to another hospital where he was treated for an unknown duration. The Ford was towed due to damage.

Summary

Crash Site

The crash site was a divided eastbound State highway. The roadway included two concrete eastbound lanes, each measuring 3.6 m (12.7 ft), separated by a dashed white painted stripe and bordered by a solid yellow painted fog line on the left and a solid white painted fog line on the right (Figure 3). The roadway was configured with a paved concrete shoulder on the left measuring 1.0 m (3.0 ft) in width and a paved concrete shoulder on the right measuring 3.1 m (9.2 ft) in width. The left shoulder was configured with two types of rumble strips. Milled-in 13 cm (5.0 in) grooves, cut 1 cm (7/16 in) deep and spaced 30 cm (12.0 in) apart, were present on the yellow-painted fog line. Intermittent traverse rumble strips measuring 40 cm (16.0 in) in width and spaced 8.6 m (28.2 ft) apart were offset 15 cm (6.0 in) left of the fog line. A metal post and steel guardrail configured with an SKT end terminal was located 1.3 m (4.3 ft) left of the left fog line (Figure 4, see Guardrail End Terminal Discussion of this report.). The roadway curved right at a radius measuring 630.0 m (2,067.0 ft) at the left fog line with a level slope measured at 15.0 m (50.0 ft) in advance of the end terminal. The super-elevation at that point was positive 6.6 percent. The roadway straightened at the SKT and continued straight for 25.0 m (82.0 ft) before curving back to the right. At Post 1, the roadway slope was level and the super-elevation was positive 5.7 percent.

The right shoulder was configured with intermittent traverse rumble strips measuring 40 cm (16.0 in) in width and spaced 8.6 m (28.2 ft) apart that were offset 30 cm (12.0 in) right of the fog line. A metal post and steel guardrail configured with an ET2000 end terminal was located 3.4 m (11.0 ft) right of the right fog line. The posted speed limit was 105 km/h (65 mph). Conditions at the time of the crash were dark, partly cloudy, and wet. Temperature was 19.4 degrees C (67 degrees F), humidity was 97 percent, and the winds were calm. A crash diagram is included at the end of this report.

Figure 3. Crash site looking east

Figure 4. SKT traffic side looking north

Pre-Crash

The Ford was traveling eastbound in the second lane from the right at an unknown speed. The driver stated to the police that she had thought an exit was ahead. The vehicle departed the roadway on the left edge and, upon realizing no exit was present, the driver steered right as an

avoidance maneuver. The driver stated that the vehicle "swerved" in response to her steering input and suggested the rear tires may have lost traction.

Crash

The crash included two events. Initially, the front left bumper corner struck the SKT end terminal in a nose/extruder hit end-on configuration, displacing the end terminal and three posts (Event 1). The impact caused the Ford to rotate counterclockwise, and the vehicle's front plane contacted the steel guardrail face in a side swiping configuration, depositing paint and scrape marks on the W-beam over a distance of 9.0 m (29.5 ft) beginning at Post 3 and ending at Post 6. The Ford was then displaced or steered to the right, crossing both lanes and departing the roadway on the right edge before the vehicle's front plane struck the steel guardrail face on the right shoulder (Event 2) in a mid-section hit redirection configuration. The vehicle deposited a tire mark measuring 28 cm (11.0 in) in length ending near the point of impact (POI). The Ford came to rest facing west on the right shoulder in the area of the second impact.

The SKT end terminal was a yielding object, precluding a reconstruction. To provide comparative information, the WinSMASH program with the barrier algorithm was used to calculate a total delta V of 19 km/h (12 mph), longitudinal delta V of -19 km/h (-12 mph), lateral delta V of 0 km/h, and a barrier equivalent speed of 19 km/h (12 mph).

Post-Crash

The driver of the Ford exited the vehicle in an unknown manner. She was not injured or transported. According to his medical records, the front passenger exited under his own power. He sustained a police-reported "B" (non-incapacitating) severity injury, which was later determined to be a left parietal scalp avulsion. He was transported by ambulance to a local hospital, and then transferred to another hospital for treatment of an unknown duration. The Ford was towed due to damage.

Guardrail End Terminal Discussion

The SKT end terminal (Figure 5) guardrail was configured with a steel anchor cable system, steel ground strut, steel W-beams, steel posts, and composite offset blocks. The SKT was a 4-inch (10 cm) extruder-type end terminal. The rectangular impact face measured 51 cm (20.0 in) in width and 49 cm (19.5 in) in height. The guide chute exit height measured 48 cm (19.0 in). The guardrail was configured with a steel ground strut measuring 175 cm (69.0 in) in length located between Post 1and Post 2, an anchor cable attached to Post 1, and an anchor bracket attached to the W-beam between Post 1 and Post 2. All posts for this guardrail were of steel construction.

Figure 5. SKT guardrail, left shoulder looking east

Post 1 was a tubular configuration measuring 15 cm (6.0 in) square. Steel I-beams measuring 15 cm (6.0 in) high and 10 cm (4.0 in) wide were used for Posts 2 to 12. Posts 3 to 12 were assembled with composite offset blocks measuring 10 x 20 x 36 cm (4.0 x 8.0 x 14.0 in). Spacing between posts averaged 1.9 m (6.2 ft) with the exception that Post 10 was 0.9 m (3.0 ft) from Post 9. The posts were located lateral to the roadway at an average distance of 1.3 m (4.3 ft). The height of the W-beam measured from top to ground was 79 cm (31.0 in).

At impact from the Ford to the end terminal, the SKT was displaced approximately 3.1 m (10.2 ft) rearward along the W-beam with a section of W-beam measuring 2.9 m (9.6 ft) in length extruding to the field side. Posts 1 to 3 were damaged. Post 1 was pulled away from the bolts connecting it to the ground strut and came to rest on the field side. The leading end of the anchor cable remained attached to Post 1, and the trailing edge was pulled away from the W-beam. Post 2 remained bolted to the ground strut but was flattened to the ground. Post 3 was leaning slightly away from an upright orientation but remained grounded. The composite offset block was loosened from both the post and the W-beam. The damage to Post 3 appeared to have been caused by the extruded W-beam which remained in contact with the post after the crash. The SKT rotated slightly counterclockwise along its longitudinal axis, causing the W-beam to twist in a likewise direction ending at Post 4. The SKT channel and welds did not exhibit any fracturing or deformation caused by the impact or extrusion. The impact face sustained minor damage at the lower aspect and on the reflective sheeting. There were no kinks present.

The vehicle was displaced to the traffic side of the guardrail and traveled in a southeast trajectory, crossing over and departing the roadway on the right edge before impacting the

guardrail face on the right shoulder (Figure 6). Distance from POI1 to POI2 measured 31.0 m (101.7 ft). The guardrail was 71 cm (28.0 in) in height. Direct damage included a dent and scrape marks in the W-beam measuring 40 cm (16.0 in) in width. Two lengths of W-beam on either side of the impact were kinked, and two posts were tilted toward the field side of the impact.

Figure 6. Second guardrail impact, right shoulder

The complete In-Service End Treatment Evaluation Data Collection Forms for the SKT are included in this report as Appendix A.

1998 Ford Ranger

Description

The 1998 Ford Ranger was a 2-door, single cab light truck identified by the Vehicle Identification Number 1FTYR10C9WUxxxxxx manufactured in March 1998, and the odometer reading was 547,157 km (339,988 mi). The vehicle manufacturer recommended size P225/70R14 tires with a recommended pressure of 35 psi (241 kPa) for the front and rear. The Ford was equipped with Kenda Klever A/P tires size LT235/75R15 manufactured in 2014 on the left front, right rear, and right front positions, and a Michelin X size P235/75R15 (TIN unknown) on the left rear. The left rear tire was damaged, including a hole of approximately 20 percent of the outer sidewall.

The Ford was configured with one row of seating for two occupants. The front row was equipped with bucket seats and integral head restraints. The seat cushion seat track settings were unknown. A fold-down center console with storage compartment separated the seats.

Exterior Damage

The Ford sustained minor severity damage to the front (Figure 7), left, and back planes during the crash. The left plane struck the SKT guardrail end terminal face tearing away sheet metal aft of the B-pillar and displacing the rear tailgate, the front plane struck the guardrail face, and the back bumper appeared to have snagged on either the SKT or a post, fracturing and displacing the bumper. Direct damage to the front plane began at the front left bumper corner and extended 30 cm (11.8 in) to the right. The Field L extended from bumper corner to bumper corner and measured 147 cm (57.9 in). The steel bumper was used to obtain 17 crush measurements in 10.0 cm (3.9 in) increments, and the Nikon Total Station and the Faro Blitz program computed crush measurement in six increments as follows: C_1 = 12 cm (4.7 in), C_2 = 8 cm (3.1 in), C_3 = 8 cm (3.1 in), C_4 = 6 cm (2.4 in), C_5 = 5 cm (2.0 in), and C_6 = 0. Direct and induced damage measuring 459 cm (180.7 in) continued down the left side, the more severe damage located aft of the B- pillar. The cargo bed sheet metal was torn away, the left rear wheel was bent, and the tire was torn and holed. The Collision Deformation Classification for the Ford in Event 1 was 12FLEE9.

Figure 7. Front plane damage, the 1998 Ford Ranger

The Ford sustained minor severity overlapping damage to the front plane in Event 2. Direct damage began at the left front bumper corner and extended 127 cm (50.0 in) to the right. The Field L extended from bumper corner to bumper corner, and the estimated CDC for the Ford in Event 2 was 11FDEW1.

Interior Damage

The Ford's interior sustained minor severity damage caused by impact forces and occupant contacts. The doors remained closed and operational; the side windows and backlight were undamaged. No integrity loss or intrusions were documented. The driver likely contacted the steering wheel rim, which was canted forward on the left side 5 cm (2.0 in). The front row passenger likely contacted the rear-view mirror and windshield. The mirror was displaced from the windshield, which revealed fractures in a spider web pattern at the upper aspect.

Manual Restraint Systems

The Ford 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 (ELR), and an adjustable upper anchor that was adjusted to the full-down position. The police report stated that the driver was belted at the time of the crash. No physical evidence of loading was documented on the seat belt.

The front passenger's lap and shoulder seat belt was equipped with continuous loop belt webbing, a sliding latch plate, an ELR/automatic locking retractor (ALR), and an adjustable upper anchor that was adjusted to the full-down position. The police report stated that the occupant was unbelted at the time of the crash. No physical evidence of loading was documented on the seat belt. His kinematics and injury confirm an unbelted status.

Supplemental Restraint Systems

The Ford's supplemental restraint systems (SRS) included driver's and passenger's frontal air bags. No air bags deployed in this crash.

NHTSA Recalls and Investigations

A search last queried in March 2021 using the Ford's year, make, and model revealed no open recalls.

1998 Ford Ranger Occupants

Driver Demographics

Age/sex:	31 years old/female
Height:	Unknown
Weight:	Unknown
Eyewear:	Unknown
Seat type:	Bucket with integral head restraint
Seat track position:	Unknown
Manual restraint usage:	Lap and shoulder seat belt
Usage source:	Vehicle inspection
Air bags:	Frontal air bag not deployed
Alcohol/drug data:	Unknown
Egress from vehicle:	Unknown
Transport from scene:	None
Type of medical treatment:	None

Driver Injuries

According to the police report, the driver was not injured or transported.

Driver Kinematics

The belted 31-year-old female driver was seated in an unknown posture and operating the vehicle at an unknown speed. At impact with the SKT end terminal, the driver was displaced forward in response to the direction of force. The ELR engaged the seat belt, holding the driver in her seated position. She presumably loaded the belt with her chest, but no physical evidence of loading was present on the seat belt components. Her torso possibly contacted the steering wheel, bending the left aspect forward 5 cm (2.0 in). The vehicle initiated a counterclockwise rotation while being displaced to the right, and the driver remained in her seated position. At impact with the second guardrail, the driver was again displaced forward in response to the direction of force and was held in her seated position by the seat belt, where she remained until the vehicle came to rest. She exited the vehicle in an unknown manner and was reported by the police to be not injured or transported.

Front Row Right Occupant Demographics

Age/sex:	34 years old/male
Height:	Unknown
Weight:	Unknown
Eyewear:	Unknown
Seat type:	Bucket with integral head restraint
Seat track position:	Unknown
Manual restraint usage:	Lap and shoulder seat belt not used
Usage source:	Vehicle inspection
Air bags:	Frontal air bag not deployed
Egress from vehicle:	Exited without assistance

Transport from scene: Ambulance to hospital
Type of medical treatment: Transferred to another hospital, admitted for unknown duration

Front Row Right Occupant Injuries

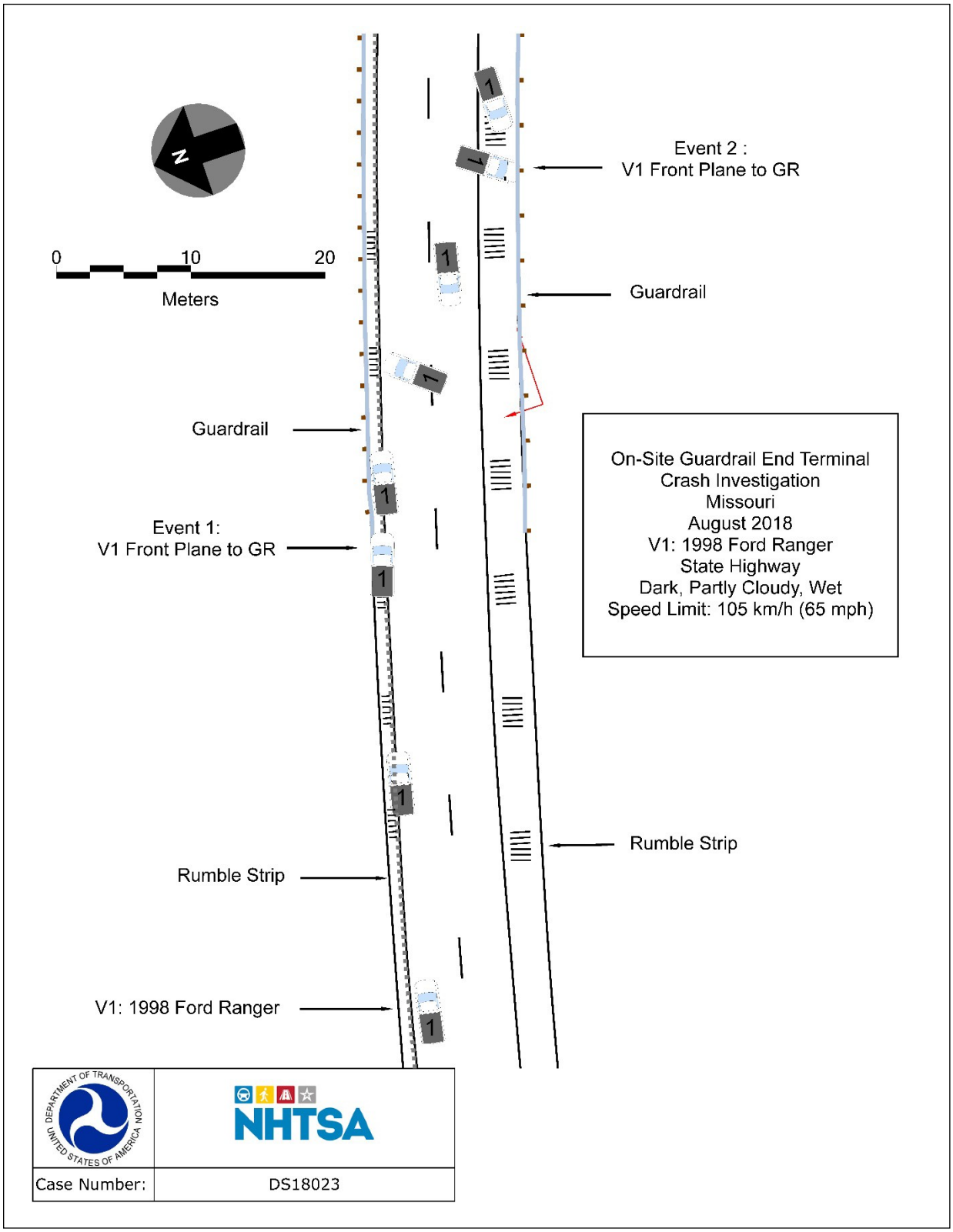
Injury No.	Injury	Injury Severity AIS 2015	Involved Physical Components (IPC)	IPC Confidence Level
1	Avulsion (2 x 4 cm) with laceration, left forehead	210802.1	Rear view mirror	Probable

Source: medical records.

Front Row Right Occupant Kinematics

The unbelted 34-year-old male occupant was seated in an unknown posture. At impact with the SKT end terminal, the occupant was displaced forward in response to the direction of force. It is likely that this occupant was displaced from his seated position with his face and head contacting the rear-view mirror and windshield, displacing the mirror and fracturing the windshield. The occupant sustained an avulsive laceration to the left forehead. The vehicle initiated a counterclockwise rotation while being displaced to the right, traversing the roadway. The occupant's kinematics during this time were not known. The vehicle's front plane struck the second guardrail, and the occupant was displaced forward in response to the direction of force, likely contacting the instrument panel. His position in the vehicle at final rest is unknown. He exited the vehicle unassisted and, while in a state of confusion and panic, began walking away from the crash site until the driver summoned him back to the vehicle. He was transported by ambulance to a local hospital and then transferred to another hospital, where he was treated for an unknown period of time.

Crash Diagram



Appendix A: In-Service End Terminal Evaluation

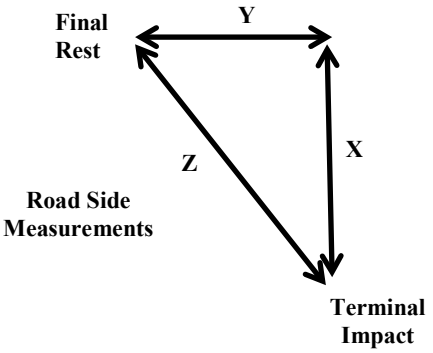
Case No.: DS18023

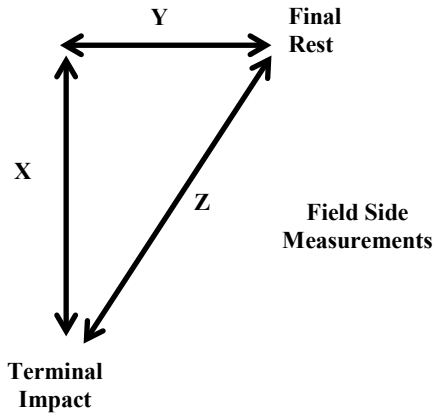
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	08/xx/2018	**Time of Crash (Military)**	Nighttime
Case Number	DS18023	**State**	Missouri
Traffic Route	US Hwy	**Direction (Southbound = SB)**	EB
Ambient Conditions (at time of crash)			
Temperature (°F)	67	**Lighting**	Dark
Atmospheric	Partly cloudy		

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)	Unknown
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 101
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 94
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 34
Super elevation	☒+2% ❒-2% ❒ NONE or FLAT
Curve Radius (ft.)	NA

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





Case No.: DS18023

ON-SCENE INFORMATION							
End Treatment Type	❒X 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: 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	Steel	6 x 6	NA	NA	No	-	4-2	NA	6-4
2	Steel	6 x 4	NA	NA	No	-	4-0	NA	6-4

Case No.: DS18023

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.)					
3	Steel	6 x 4	Composite	8 x 4	No	-	4-6	NA	6-1
4	Steel	6 x 4	Composite	8 x 4	No	-	4-5	NA	6-2
5	Steel	6 x 4	Composite	8 x 4	No	-	4-5	NA	6-3
6	Steel	6 x 4	Composite	8 x 4	No	-	4-4	NA	6-2
7	Steel	6 x 4	Composite	8 x 4	No	-	4-4	NA	6-3
8	Steel	6 x 4	Composite	8 x 4	No	-	4-4	NA	6-1

Case No.: DS18023

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.)					
9	Steel	6 x 4	Composite	8 x 4	No	-	4-5	NA	3-0
10	Steel	6 x 4	Composite	8 x 4	No	-	4-5	NA	6-1
11	Steel	6 x 4	Composite	8 x 4	No	-	4-5	NA	6-1
12	Steel	6 x 4	Composite	8 x 4	No	-	4-1	NA	6-5

Additional Comments:

Case No.: DS18023

EXTRUDER			
Feeder Channel Width at impact head	☒4inches ☐5 inches ☐Other _____		
Guide Chute Exit Height (in.)	19		
Connection of feeder channels to head damaged?	☒No ☐Yes	Are Welds Broken?	☒No ☐Yes
Anchor Cable Present?	☐No ☒Yes	Connected?	☒No ☐Yes
Rail Extrusion?	☐No ☒Yes	Length (ft.-in.)	9-7
Rail Extrusion Direction	☐Traffic Side ☒Field Side		
Total Length of Rail Damaged (ft.) [total length would include extruded rail plus damaged rail downstream from head.]	19-1		

TELESCOPE				
Rail Displacement	☐No	☐Yes; Length: NA	No of Panels Displaced	☐1 ☐2 ☐3 ☐4 ☐5 ☐6
ALL-SYSTEM PERFORMANCE				
Rail kinks Downstream of Head?	☒No	☐Yes	No. of Kinks in Rail: 0	
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	Guardrail face, followed by guardrail face opposite side of roadway			

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	-29	-24	-26
Adjacent Lane Width (ft-in)	12-8		
Lane Type (NAS EDS Variable: Sur. Type)	Concrete		
Shoulder Type	Concrete		
Shoulder Width (ft)	10.1		
Guardrail Height (in)	31		

Case No.: DS18023

VEHICLE INFORMATION		
Vehicle Type (NHTSA Input)	2-door standard cab light truck	
Vehicle Identification Number (VIN)	1FTYR10C9WUxxxxxx	
Vehicle Mass (NASS var.: veh.wgt)	3,161 lbs.	
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		
Collision Deformation Classification	12FLEE9	
Delta V	Unknown	
Occupant Compartment Penetration of rail	☒No	❒Yes; Describe:
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)	NA	
Rollover Type, Terhune Scale, (NASS EDS variable: rolintyp)	NA	

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**National Highway
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