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NHTSA

DOT HS 812 820

November 2019

Special Crash Investigations On-Site Guardrail End Terminal Crash Investigation Vehicle: 2013 Toyota Avalon Location: California Crash Date: May 2017

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9. Performing Organization Name and Address Dynamic Science, Inc. 26141 Marguerite Parkway, Suite C Mission Viejo, CA 92692	10. Work Unit No. (TRAIS)
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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 vehicle(s) 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 crash investigation of a 2013 Toyota Avalon that struck a guardrail configured with a FLared Energy Absorbing Terminal (FLEAT) end terminal and the fatal injuries sustained by the driver. This single-vehicle crash occurred during afternoon hours on an interstate highway in the state of California during May 2017. The Toyota was being driven southbound by an 81-year-old male. For unknown reasons, the Toyota traveled off the right edge of the roadway and struck the FLEAT end terminal. The vehicle then struck a metal sign pole, which was followed by a secondary guardrail impact and a vehicle fire which quickly spread to the occupant compartment. The Toyota sustained contact damage to the front, right and left planes, and fire-related damage to all planes. The fire prevented removal of the driver from the vehicle by those who stopped to help. The driver sustained burn injuries and other fatal injuries of an unknown nature.

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

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Special Crash Investigations
On-Site Guardrail End Terminal Crash Investigation
Case Number: DS17009
Vehicle: 2013 Toyota Avalon
Location: California
Crash Date: May 2017

BACKGROUND

This report documents the crash investigation of a 2013 Toyota Avalon (**Figure 1**) that struck a guardrail configured with a FLared Energy Absorbing Terminal (FLEAT) end terminal (**Figure 2**) and the fatal injuries sustained by the driver. This case was initiated by a California transportation agency that notified the Federal Highway Administration (FHWA) of the crash. After reviewing the case and determining the FLEAT guardrail end terminal qualified and the case was of interest, the FHWA forwarded the notification along with the police report and on-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 June 2017.

Figure 1. 2013 Toyota Avalon.

Figure 2. FLEAT guardrail end terminal struck by 2013 Toyota Avalon (Caltrans [California Department of Transportation] photo).

For unknown reasons, the Toyota traveled off the right edge of a southbound interstate highway and struck the guardrail end terminal. The first impact was followed by an impact with a sign pole, a second guardrail impact and a vehicle fire that spread to the occupant compartment of the Toyota. The fire prevented extrication of the driver by those who stopped to help and he sustained fatal injuries of an unknown nature. The investigation was intended to determine the dynamics of interaction between the guardrail and the vehicle, and what role the guardrail may have played in causing the driver's injuries. The scene, vehicle and guardrail inspections were completed in June 2017. A police officer was present during the vehicle inspection. The Toyota was supported by the Bosch Crash Data Retrieval (CDR) system but the vehicle's event data recorder (EDR) was not imaged. Fire damage prevented on-site imaging of EDR. It was located under the center console, which had melted, fallen, and hardened around the EDR module, making it inaccessible.

This single-vehicle crash occurred during daylight on an interstate highway in California during May 2017. The Toyota was being driven southbound by an 81-year-old male. No other occupants were in the vehicle. For unknown reasons, the Toyota traveled off the right edge of the southbound roadway and struck the FLEAT end terminal. The guardrail sustained 6.5 m (21.3 ft) of damage to the W-beam, including an extruded length measuring 4.8 m (15.7 ft). The vehicle then struck a metal sign pole, which was followed by a secondary guardrail impact and a fire that quickly spread to the occupant compartment. The Toyota sustained contact damage to the front, right, and left planes, and fire-related damage to all planes. The driver sustained fatal injuries of an unknown nature. The Toyota was towed due to damage and placed on a police evidence hold.

SUMMARY

Crash Site

The crash site was the southbound lanes of a four-lane divided interstate highway in California (**Figure 3**). The asphalt roadway was straight, level and dry. The four travel lanes were separated by dashed white lines. The roadway was bordered on the right by a white fog line, a concrete shoulder, and a metal W-beam guardrail. It was bordered on the left by a yellow fog line, a concrete shoulder, a grass-covered median and a metal W-beam guardrail. The posted speed limit was 105 km/h (65 mph). Conditions were daylight and the weather at the nearest reporting station was 23.9 degrees C (75.0 degrees F), 53 percent humidity, 16 km (10 miles) visibility and calm winds. Crash diagrams are included at the end of this report.

Figure 3. Crash site, southbound approach.

Figure 4. FLEAT end terminal impact face.

Pre-Crash

The Toyota was traveling southbound in the third lane from the right at an estimated minimum speed of 92.0 km/h (57.1 mph).[1] For unknown reasons, the vehicle crossed over two lanes to the right and departed the roadway on the right edge at a shallow angle trajectory and traveled onto the paved shoulder.

Crash

The Toyota's front plane struck the FLEAT guardrail end terminal (**Figure 4**) in a head-on configuration (Event 1). The barrier algorithm of the WinSMASH program calculated a barrier equivalent speed (BES) of 17 km/h (11 mph). The vehicle initiated a post-impact

[1] See Appendix B: Impact Speed Calculations.

counterclockwise rotation while continuing to travel southbound on the field side of the guardrail. After traveling 23.8 m (78.0 ft) from the first impact with the guardrail, the Toyota's right plane struck a large metal sign pole in an angled configuration (Event 2). The pole was a non-breakaway design and had a diameter measuring 46 cm (18.0 in) at the base. It supported a cantilevered highway sign identifying an exit ramp. Direct damage to the pole consisted of scrape marks beginning at ground level and extending 132 cm (52.0 in) upward. The pole remained upright following the crash. The barrier algorithm of the WinSMASH program calculated a barrier equivalent speed (BES) of 25 km/h (16 mph).

Figure 5. Crash site, looking south at Toyota's final rest position (police photo).

Following the pole impact, the Toyota rotated clockwise and the rearward aspect of its left plane struck the back side of the guardrail W- beam (Event 3). This was a minor impact. Direct damage and crush were unknown. The Toyota came to rest facing southwest near the pole and guardrail (**Figure 5**). Total distance traveled from the first impact to final rest measured 29.0 m (95.0 ft). At some point during or soon after the crash the vehicle caught fire which spread to the occupant compartment (Event 4).

Post-Crash

Witness statements in the police report indicated that, following the crash, the vehicle immediately caught fire. Witness 1 saw the crash, stopped, and called 911. Witness 2 saw the fire, stopped, and broke out the driver's window attempting to remove the driver from the vehicle but could not do so due to the spreading fire. Witness 3 saw the fire, stopped, and attempted unsuccessfully to put out the fire using his fire extinguisher. He then attempted to cut the driver's seat belt but was unsuccessful because the growing fire forced him to retreat from the vehicle. The driver's level of consciousness during these rescue attempts was unknown. The driver remained inside the vehicle until fire departments arrived and extinguished the fire. The driver sustained fatal injuries including major thermal injuries, was declared deceased on-scene, and was transported to the coroner's office. The Toyota was towed due to damage on orders of the police and placed on an evidence hold. It was later released.

Figure 6. FLEAT end terminal and extruded W-beam.

GUARDRAIL END TERMINAL DISCUSSION

The guardrail end terminal in this crash was a FLared Energy Absorbing Terminal (FLEAT) extruder-type end terminal. The rectangular impact face measured 52 x 35 cm (20.5 x 14.0 in) and the guide chute exit measured 48 cm (19.0 in) in height. The FLEAT was configured with a metal ground strut measuring 170 cm (67.0 in) in length 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 measured 15 x 20 cm (6.0 x 8.0 in) and were assembled with composite offset blocks measuring 13 x 18 cm (5.0 x 7.0 in). Post spacing measured 190 cm (75.0 in) and W-beam height measured top to ground was 81 cm (32.0 in). At impact with the guardrail, a section of W-beam measuring 4.8 m (15.7 ft) in length (**Figure 6**) extruded on the traffic side of the guardrail. The total damaged length of W-beam measured 6.5 m (21.3 ft). The guardrail impact head, anchor cable and bracket were displaced. The first three wooden posts were fractured through (**Figure 7**) and the first five wooden posts were replaced. The guardrail kinked in two places, beginning at post 4 and ending at the post 5 (**Figure 8**). It appeared from the damage to the W-beam that it ceased to extrude through the FLEAT head at the area of the first kink. A strait section of W-beam measuring 4.1 m (13.5 ft) was replaced at the area of the second guardrail impact.

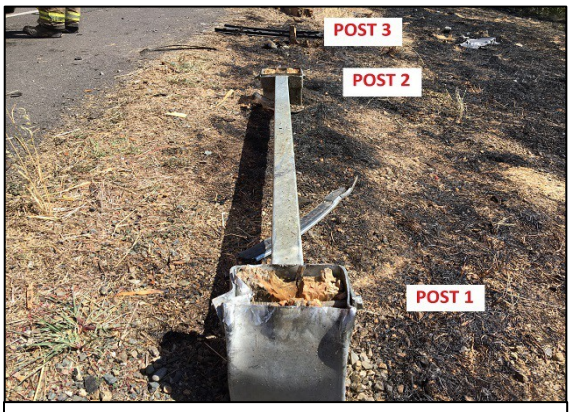


Figure 7. On-scene image, fractured posts 1-3 (police department photo).

Figure 8. On-scene image, kinks in W-beam at posts 4-5 (police department photo).

2013 TOYOTA AVALON

Description

The 2013 Toyota Avalon was a 4-door sedan that was identified in the police report as a 2013 Toyota Camry. A search using the license plate revealed the Vehicle Identification Number 4T1BK1EB2DUxxxxxx. The odometer was burned, precluding an odometer reading. The manufacturer recommended P215/55/R17 tires for front and rear. The vehicle's tires were burned and unidentifiable except for the front right position, which was an unknown Sumitomo model having a Tire Identification Number (TIN) that indicated a manufacture date of April 2016.

The Toyota was configured with seating for five occupants. The front row was equipped with bucket seats and adjustable head restraints. The seats were destroyed in the fire and adjustment settings for the driver's seat track and headrest were unknown.

Exterior Damage

The Toyota sustained minor severity front plane damage from the impact with the guardrail end terminal (**Figure 9**). The front bumper fascia was displaced from the vehicle and not available for inspection; the bumper backing bar was used to measure crush. The direct damage began 29 cm (11.4 in) right of the front left bumper corner and extended 32 cm (12.5 in) to the right. The Field L extended from bumper corner to bumper corner. Maximum crush was located 64 cm (25.2 in) right of the left front bumper corner. Thirteen measurements 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 = 1 cm (1.6 in), C_3 = 9 cm (3.1 in), C_4 = 9 cm (3.5 in), C_5 = 2 cm (1.6 in), C_6 = 1 cm (0.4 in). The principal direction of force was 0 degrees. The Collision Deformation Classification (CDC) for the Toyota in Event 1was 12FCEN1.

Figure 9. Front plane crush measurement, 2013 Toyota Avalon.

The vehicle sustained moderate severity right plane damage from the impact with the metal pole (**Figure 10**). Direct damage began 192 cm (75.6 in) aft of the front axle and extended 60 cm (23.6 in) forward. The Field L began 10 cm (3.9 in) aft of the rear axle and extended 244 cm (96.1 in) forward. Maximum crush was located 160 cm (63.0 in) aft of the left front axle. Twenty-four measurements were taken at sill level by the Nikon Total Station and the Faro Blitz program computed crush measurement in six increments as follows: C_1 = 4 cm (1.6 in), C_2 = 14 cm (5.5 in), C_3 = 22 cm (8.7 in), C_4 = 21 cm (8.3 in), C_5 = 20 cm (7.9 in), C_6 = 7 cm (2.8 in). The principal direction of force was 60 degrees. The CDC for the Toyota in Event 2 was 02RPAW3.

Figure 10. Right plane damage, 2013 Toyota Avalon.

The Toyota sustained undocumented minor damage to the rear aspect of the left plane caused by the second impact to the guardrail. The contact with the guardrail brought the vehicle to final rest.

At some time during or immediately after the crash, the Toyota sustained a fire that quickly spread to the occupant compartment. All planes of the vehicle's exterior revealed extensive thermal burn damage to the paint and sheet metal. The interior compartment was completely destroyed by the fire.

Interior Damage

The Toyota's interior sustained severe thermal damage caused by the fire and post-crash activities including efforts to extinguish the fire (**Figure 11**). The instrument panel, controls, seats, roof header, trim, restraint systems, carpet and most other non-metallic components were burned or melted. All four doors appeared to have been jammed shut and later forced open. All glazing was fractured and missing. The vehicle sustained front row lateral intrusion of the right B-pillar (20 cm [7.9 in]), right sill (20 cm [7.9 in]), and right door, rear lower quadrant (16 cm [6.3 in]). Front row longitudinal intrusion was documented at the right seat back (28 cm [11.0 in]) and right seat cushion (14 cm [5.5 in]). Second row vertical intrusion was documented at the right roof side rail (19 cm [7.5 in]).

Figure 11. Interior view, front row looking right to left, 2013 Toyota Avalon.

Manual Restraint Systems

The front row was equipped with driver and front right 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 front row seat belts were equipped with retractor-mounted seat belt pretensioners. The police report indicated the driver was belted at the time of the crash. Given the estimated longitudinal delta-V of -17 km/h (-10 mph) in the Event 1 guardrail impact, it is possible the driver's seat belt pretensioner actuated during the crash. The seat belt was destroyed during the fire and was not available for examination during the SCI inspection.

Supplemental Restraint Systems

The Toyota's supplemental restraint systems (SRSs) included a restraint control module, driver and front passenger frontal air bags, seat-mounted front row side impact air bags, and front and second row side impact inflatable curtain (IC) air bags. The SRSs in the Toyota were destroyed by thermal damage caused by the fire and their deployment status could not be determined.

Given the calculated longitudinal delta-V in the Event 1 guardrail impact, it is probable the driver's frontal air bag deployed during the crash. The police report indicated an unknown air bag deployment status. Given the calculated lateral delta -V of -22 km/h (-14 mph) in the Event 2 pole impact, it is possible the right IC air bag deployed during the crash.

NHTSA Recalls and Investigations
A search using the Toyota's VIN last queried in July 2019 revealed no safety recalls associated with this vehicle.

2013 TOYOTA AVALON OCCUPANT

Driver Demographics

Age/Sex:	81 years/male
Height:	191 cm (75 in)
Weight:	132 kg (290 lb)
Eyewear:	Unknown
Seat type:	Bucket
Seat track position:	Unknown
Manual restraint usage:	Lap and shoulder seat belt
Usage source:	Police report
Air bags:	Driver frontal air bag, seat-mounted side air bag, and IC air bag, deployment status unknown
Alcohol/drug data:	Positive for Ethanol, 0.01%
Egress from vehicle:	Removed from vehicle by responders following death
Transport from scene:	Ambulance to coroner's office
Type of medical treatment:	None

Driver Injuries

Injury No.	Injury	Injury Severity AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Burns NFS	910200.1	Fire - Event 4	Certain
2	Died of injury	099999.9	Unknown	Unknown

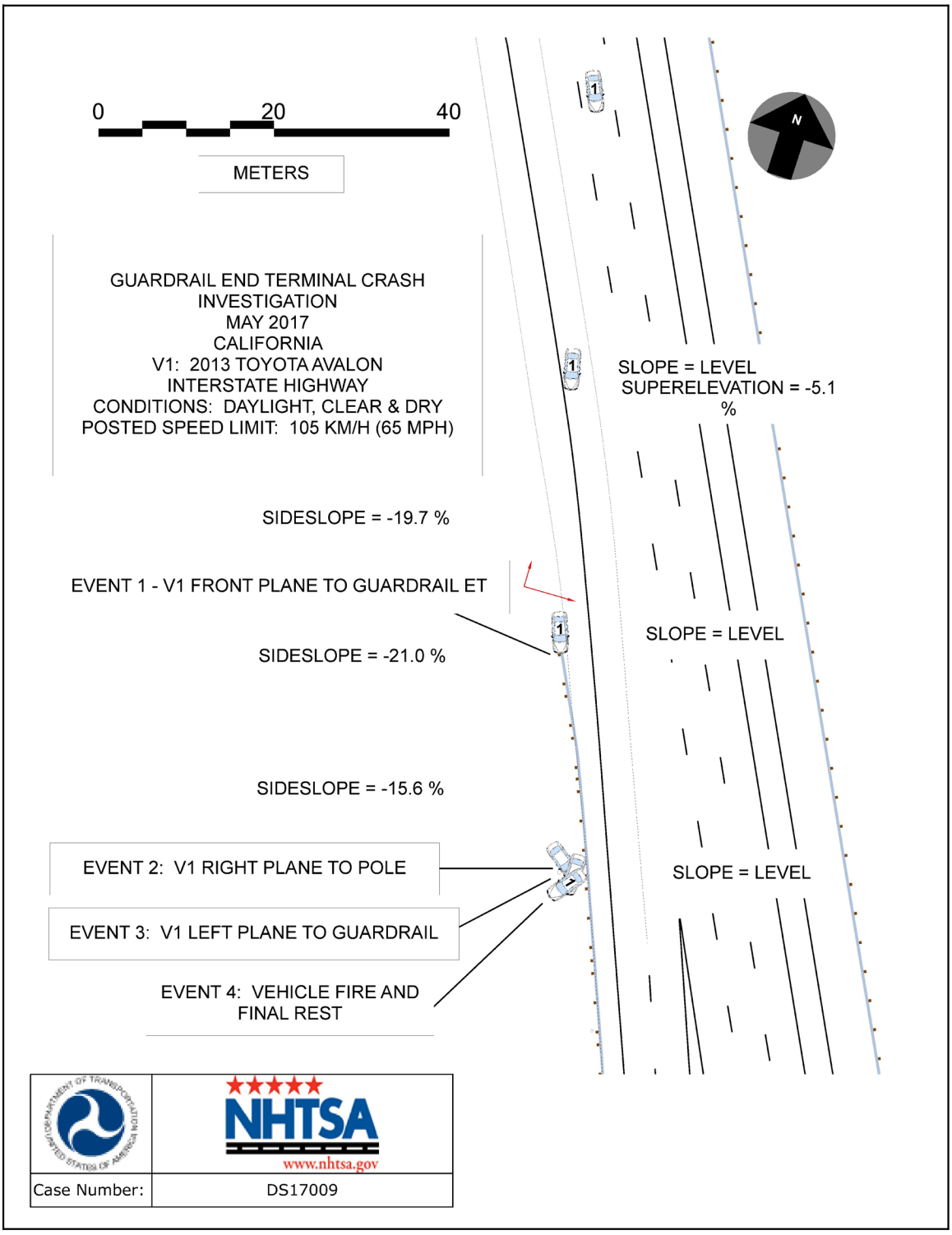
Source: Coroner's Report.

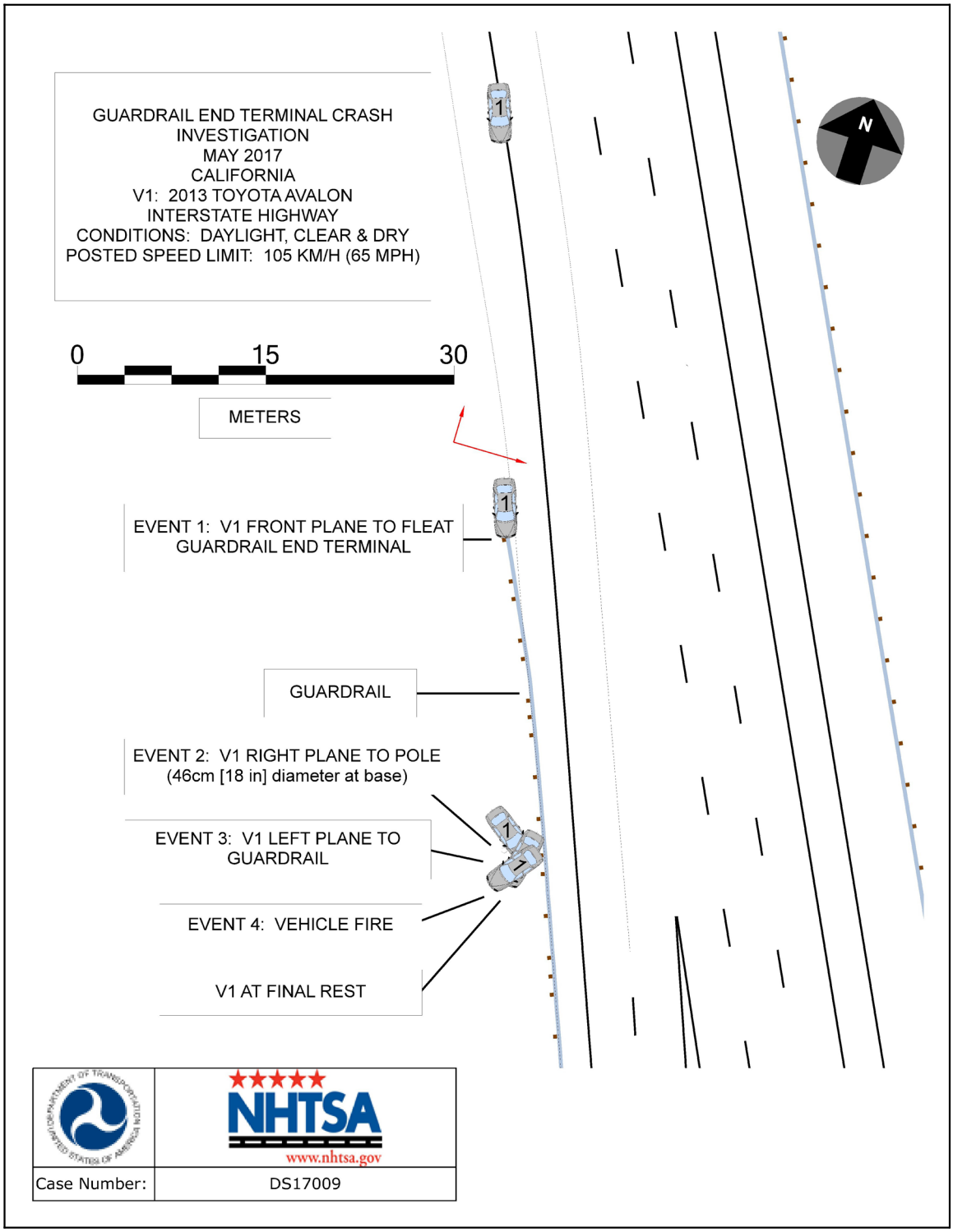
Driver Kinematics
The belted 81-year-old male driver was seated in an unknown posture. For unknown reasons, the southbound Toyota crossed over two lanes of traffic and departed the roadway on the right edge. At impact with guardrail end terminal, the driver was displaced forward loading the seat belt.

The driver's frontal air bag likely deployed and his seat belt pretensioner likely actuated. The Toyota initiated a post-impact counterclockwise rotation while continuing to travel southbound on the field side of the guardrail. The vehicle's right plane struck a large metal sign pole causing the driver to be displaced sharply right while being held in his seated position by the seat belt. His right flank and hip likely loaded the center console. The Toyota initiated a post-impact clockwise rotation around the pole and the vehicle's left rear plane struck the guardrail with minor contact. The driver was displaced back to the left and remained held in his seated position by the pretensioned seat belt. The vehicle came to rest facing south. At some point during the crash or immediately afterward the vehicle caught fire that quickly spread to the occupant

compartment. Witnesses stopped to assist the driver from the vehicle but were prevented from doing so by the fire and heat. His state of consciousness following the crash was unknown. After the fire was extinguished, the driver was declared deceased on-scene. The coroner's report stated cause of death was multiple thermal and blunt force injuries. Given the burn damage to the vehicle's interior, it was determined the driver likely sustained thermal injuries to most all body regions. No further specific injury data was available.

CRASH DIAGRAMS




GUARDRAIL END TERMINAL CRASH
INVESTIGATION
MAY 2017
CALIFORNIA
V1: 2013 TOYOTA AVALON
INTERSTATE HIGHWAY
CONDITIONS: DAYLIGHT, CLEAR & DRY
POSTED SPEED LIMIT: 105 KM/H (65 MPH)
0
15
30
METERS
N
1
EVENT 1: V1 FRONT PLANE TO FLEAT GUARDRAIL END TERMINAL
GUARDRAIL
EVENT 2: V1 RIGHT PLANE TO POLE (46cm [18 in] diameter at base)
EVENT 3: V1 LEFT PLANE TO GUARDRAIL
EVENT 4: VEHICLE FIRE
V1 AT FINAL REST
NHTSA
www.nhtsa.gov
Case Number:
DS17009

APPENDIX A:
In-Service End Terminal Evaluation

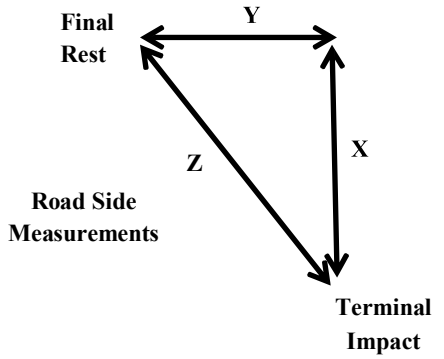
Case No.: DS17009

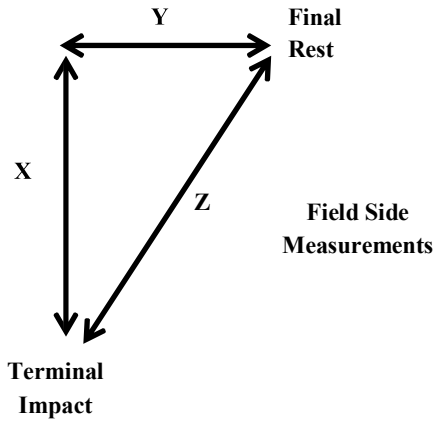
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	May 2017	**TIME OF CRASH (MILITARY)**	Afternoon
Case Number	DS17009	**State**	California
Traffic Route	I-5	**Direction (Southbound = SB)**	SB
Ambient Conditions (at time of crash)			
Temperature (°F)	75.0	**Lighting**	Daylight
Atmospheric	Clear		

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)	57
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 78.0 ft
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 78.5 ft
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	1. Y = 13.0 ft
Super elevation	❒+2% ☒-2% ❒ NONE or FLAT
Curve Radius (ft.)	N/A

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





Case No.: DS17009

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: NA							

GUARDRAIL INSTALLATION									
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.)					
0	NA	NA	NA	NA	NA	NA	NA	NA	NA
1	W	5 x 7	NA	NA	No	No	12 ft - 3 in	NA	0
2	W	5 x 7	NA	NA	No	No	11 ft - 9 in	NA	6 ft - 3 in

Case No.: DS17009

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	W	6 x 8	W	6 x 8	No	No	11 ft - 8 in	NA	6 ft - 11 in
4	W	6 x 8	W	6 x 5	No	No	11 ft - 0 in	NA	6 ft - 7 in
5	W	6 x 7	W	5 x 7	No	No	10 ft - 5 in	NA	6 ft - 9 in
6	W	6 x 7	W	6 x 7	No	No	10 ft - 0 in	NA	6 ft - 8 in
7	W	6 x 8	W	5 x 7	No	No	9 ft - 4 in	NA	6 ft - 7 in
8	W	6 x 8	W	5 x 7	No	No	9 ft - 3 in	NA	6 ft - 8 in

Additional Comments: Posts 1 through 5 were replaced.

Case No.: DS17009

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	S	4 x 6	Comp.	4 x 7	No	No	9 ft - 0 in	NA	6 ft - 3 in
10	S	4 x 6	Comp.	4 x 7	No	No	9 ft - 1 in	NA	6 ft - 4 in
11	S	4 x 6	Comp.	4 x 7	No	No	9 ft - 0 in	NA	6 ft - 3 in
12	S	4 x 6	Comp.	4 x 7	No	No	8 ft – 11 in	NA	6 ft - 2 in
13	S	4 x 6	Comp.	4 x 7	No	No	8 ft - 11 in	NA	6 ft - 2 in

Case No.: DS17009

Post No.	Post		Offset Block		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post
14	S	4 x 6	NA	NA	No	No	8 ft - 11 in	NA	6 ft - 5 in
15	S	4 x 6	NA	NA	No	No	8 ft - 11 in	NA	6 ft - 2 in
16	S	4 x 6	Comp.	4 x 7	No	No	9 ft - 0 in	NA	6 ft - 2 in

Additional Comments:

Case No.: DS17009

EXTRUDER			
Feeder Channel Width at impact head	☐4inches ☐5 inches ☒Other _4.5 inches_____		
Guide Chute Exit Height (in.)	19.0		
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.)	15 ft – 9 in
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.]	21 ft – 4 in		

TELESCOPE				
Rail Displacement	☐No	☐Yes; Length:	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: 2
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	1. Metal pole 2. Downstream section of W-beam	

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	19.7	21.0	15.6

Case No.: DS17009

Adjacent Lane Width (ft)	12 ft - 0 in
Lane Type (NAS EDS Variable: Sur. Type)	Asphalt
Shoulder Type	Asphalt
Shoulder Width (ft)	12 ft – 7 in
Guardrail Height (in)	32 ft – 0 in

VEHICLE INFORMATION		
Vehicle Type (NHTSA Input)	2013 Toyota Avalon 4-door sedan, hardtop	
Vehicle Identification Number (VIN)	4T1BK1EB2DUxxxxxx	
Vehicle Mass (NASS var.: veh.wgt)	3,177 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	NA	
Collision Deformation Classification	12FYEN1	
Delta-V	10.5 mph	
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	

APPENDIX B:
Impact Speed Calculations

Impact Speed Calculations

Vehicle mass = 1,645 kg (1,570 kg + occupant weight 75 kg)
Amount of rail fed through terminal = 4.8 m
Terminal type: FLEAT
Departure velocity: 16.2 m/s [calculated using distance traveled to pole plus pole impact]

Post impact kinetic energy
$KE_{departing} = ½ (m) * V_d^2$
where V_d is departure velocity of impacting vehicle
$KE_{departing} = ½ (1645) * 16.2_d^2 = 215.8$ kJ

FLEAT force level (average)[1] = 63.6N
$E_{rail} = 63.6 \times 4.8 = 305.28$ kJ
Combined
$KE_c = KE_{departing} + E_{rail} = 215.8 + 305.28 = 521.08$ kJ = 521,080 joules

Velocity for the combined terminal head and vehicle
V_c = sqrt (2 x KE_c / vehicle mass + head mass)
V_c = sqrt (1042160 / 1699) = 24.7 m/s = 89.08 km/h

Initial velocity of impacting vehicle using conservation of momentum (initial velocity of impact head is 0)
$V_i = V_c$* (vehicle mass + head mass) / vehicle mass
V_i = 89.08* (1699) / 1645 = 92.0 km/h = 57.1 mph[1]

[1] Coon, B. A., & Reid, J. D. (2005). Reconstruction techniques for energy absorbing guardrail end terminals. *Accident Analysis and Prevention, 38*(1):1-13. Epub 2005 July 27. DOI: 10.1016/j.aap.2005.06.016.

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