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Special Crash Investigations On-Site ET-Plus Guardrail End Treatment Crash Investigation Vehicle: 1996 Toyota Camry Location: Missouri Crash Date: March 2016

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

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

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

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16. Abstract This report documents the impact to an ET-Plus guardrail end treatment by a 1996 Toyota Camry. At the time of the crash, the Toyota was operated by a belted 39-year-old male driver and was traveling westbound on a limited access roadway. The crash occurred when the vehicle drifted right from its travel lane and departed the right roadway edge, where its front plane struck the guardrail end treatment. During the crash, the end terminal and guardrail were displaced and deformed. Two kinks formed in the guardrail, and the guardrail penetrated the Toyota's interior in two locations. Due to a lack of significant injuries, there likely was no direct occupant contact with the guardrail associated with those penetrations. The Toyota rotated counterclockwise and came to rest in the roadside. The male driver exited the Toyota unassisted and was transported to a local hospital, where he was held overnight and released within 24 hours of the crash.			
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VEHICLE: 1996 TOYOTA CAMRY
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CRASH DATE: MARCH 2016

BACKGROUND

This report documents the impact to an ET-Plus guardrail end treatment by a 1996 Toyota Camry (**Figure 1**). At the time of the crash, the Toyota was operated by a belted 39-year-old male driver and was traveling westbound on a limited access roadway. The crash occurred when the vehicle drifted right from its travel lane and departed the right roadway edge, where its front plane struck the guardrail end treatment. During the crash, the end terminal and guardrail were displaced and deformed. Two kinks formed in the guardrail, and the guardrail penetrated into the Toyota's interior in two locations. Due to a lack of significant injuries, there likely was no direct occupant contact with the guardrail associated with those penetrations. The Toyota rotated counterclockwise and came to rest in the roadside. The male driver exited the Toyota unassisted and was transported to a local hospital, where he was held overnight and released within 24 hours of the crash.

Figure 1: East-facing view of the Toyota and guardrail following the crash (*on-scene image obtained from an online news source*).

The crash was identified by the Missouri Department of Transportation (MoDOT), 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 during March of 2016. 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 with MoDOT and the investigating law enforcement agency. The on-site investigation occurred during March of 2016, and consisted of the inspection of the crash site, including the ET-Plus guardrail system and the damage it sustained during the crash. The Toyota was also inspected and its exterior damage, interior damage, occupant contact, manual restraint systems, and supplemental restraint systems were documented. Due to its age, the Toyota was not equipped with an event data recorder (EDR).

CRASH SUMMARY

Crash Site

The crash occurred on the westbound portion of a limited-access roadway during daylight hours in March 2016. According to the National Weather Service, conditions in the locale at the time of the crash included sunny skies with a temperature of 16 °C (61 °F), 22 percent relative humidity, and 24 km/h (15 mph) westerly winds. The physical environment of the roadway was documented during the SCI crash site inspection using a Nikon Nivo 5.M+ total station mapping system. In the area of the crash, the westbound portion consisted of two 3.6 m (11.8 ft) wide travel lanes. They were delineated by a single dashed-white line, with a single solid-white fog line and a single solid-yellow median line. The right travel lane was supported by a 3.1 m (10.2 ft) wide north shoulder, while the left travel lane was supported by a 2.1 m (6.9 ft) wide south shoulder. Both shoulders contained rumble strips adjacent to the respective travel lanes. Surfaces consisted of concrete shoulders and asphalt travel lanes.

The westbound portion of the roadway was divided from the eastbound portion by an 8.6 m (28.2 ft) wide depressed grass swale. In the center aspect of the swale and parallel to the roadways was a standard cable barrier guardrail system. For the Toyota's travel trajectory in the area of the crash, the roadway was straight and progressed on an approximate 3 percent downgrade toward an underpass. Speed was regulated by a posted limit of 97 km/h (60 mph).

For the roadway's approach to the underpass, a guardrail provided protection from the underpass embankment and the large-diameter concrete bridge pilings. The guardrail was located adjacent to the north shoulder of the roadway and began approximately 65 m (213 ft) east of the underpass. It consisted of W-beam guardrail with steel I-beam posts, and was installed with an ET-Plus end treatment system (see ET-Plus End Treatment and Guardrail section of this report). **Figure 2** depicts the Toyota's travel trajectory on the limited-access roadway toward the underpass and guardrail system. A crash diagram is included at the end of this technical report.

Figure 2: View of the Toyota's westbound pre-crash travel trajectory on the limited access roadway.

Pre-Crash

The 39-year-old male operated the Toyota westbound in the right lane of the limited-access roadway. He used the vehicle's 3-point lap and shoulder safety belt for manual restraint. Shortly after passing an exit lane and ramp, the driver allowed the Toyota to begin to drift right from its

travel lane. The SCI Investigator was unable to locate the driver for an interview. As a result, the cause of the vehicle's drift and the driver's state of attentiveness remain unknown.

The Toyota drifted to the right and crossed over the right fog line and rumble strip, entering the right shoulder. It traversed across the shoulder and its right front tire departed the right roadway edge. There was no evidence at the crash site to suggest any avoidance action by the driver prior to the crash. The vehicle's roadside departure aligned the right aspect of the Toyota's front plane with the Trinity ET-Plus end terminal of the guardrail. It approached the end terminal in a tracking attitude. Based on the physical evidence at the scene, the angle of approach was estimated to be 5 degrees.

Crash

Based on the damage sustained by both the guardrail system and the vehicle, as well as the distance traveled by the Toyota from impact to final rest, the estimated speed of the Toyota at impact was approximately 113 km/h (70 mph). Crash forces resulted in the deployment of the Toyota's frontal air bag system. The vehicle's front plane/right aspect engaged the impactor face (Event #1) and its momentum displaced the energy absorbing end terminal downstream. A tire mark from the Toyota's left front tire located in the shoulder adjacent to Posts 1 and 2 evidenced the initial impact. The Toyota maintained its forward momentum as it displaced the end terminal along the guardrail, and sheared multiple wooden support posts of the end treatment system. The offset force of the impact and subsequent engagement induced a clockwise rotation to the Toyota, evidenced by an arcing left rear tire mark located on the roadway's west shoulder adjacent to Posts 5, 6, and 7.

As the guardrail was deformed and displaced, it began to kink in multiple locations. The first kink was located approximately 6.6 m (21.5 ft) downstream from Post 1, between Post 4 and Post 5. As the guardrail deformed and the vehicle rotated clockwise, this kink enabled the guardrail to override the left front fender of the Toyota. The guardrail penetrated through the windshield and engaged the windshield header of the vehicle (Event #2), the corresponding forces of which sheared the guardrail at the kink and separated the Toyota's entire roof structure. A second kink developed approximately 13 m (42.7 ft) downstream of Post 1, between Posts 7 and 8. This kink engaged the left plane of the rotating Toyota (Event #3) and penetrated into the vehicle at the beltline adjacent to the left C-pillar. Impact forces reversed the Toyota's clockwise rotation, and the vehicle began to rapidly rotate counterclockwise as it maintained its momentum and continued through the roadside. After passing

Figure 3: East-facing view of the crash site, the deformed guardrail, and vehicle tire marks, visible from a nearby overpass at the time of the SCI inspection.

behind the guardrail, the Toyota completed 270-degrees of counterclockwise rotation through the soil surface of the roadside. The Toyota's trajectory through the roadside was evidenced by tire marks (**Figure 3**) through the grass and soil surface.

The Toyota slid to momentary rest on the sloped roadside facing north, and then tracked forward approximately 3 m (9.8 ft) to final rest. Its final rest position was located 43.4 m (142.4 ft) west of the initial guardrail impact and 7.7 m (25.3 ft) north of the roadway edge. The total length of its counterclockwise rotation was 30.5 m (100.1 ft). During the crash, the Toyota engaged and deformed 15.4 m (50.6 ft) of the W-beam guardrail.

Post-Crash

Local law enforcement, fire department, and emergency medical services (EMS) personnel responded to the crash scene. The driver exited the Toyota without assistance prior to their arrival. He was then transported by ambulance to a local hospital for the evaluation and treatment of his injuries. The driver was released from the hospital within 24 hours of the crash. The Toyota was recovered from the crash scene by a local service and towed to a local yard, where it was held on impound by the investigating law enforcement agency.

ET-PLUS END TREATMENT AND GUARDRAIL

The ET-Plus System End Terminal was an energy absorbing end treatment that terminated the 70.5 cm (27.75 in) high W-beam guardrail. The ET-Plus system end terminal was a tangent system manufactured by Trinity Highway Products. The manufacturer's literature and installation manuals can be found at www.highwayguardrail.com/products/etplus.html. The end terminal was designed to be displaced along the W-beam and absorb impact force by crushing and flattening the W-beam during its movement. The flattened and deformed beam was projected out of the impact head toward the field (off-traffic) side.

Figure 4: Image depicting an exemplar ET-Plus installation located near the crash site.

The involved system's installation was a seven-post configuration over a distance of 11.4 m (37.5 ft). It consisted of a 13 cm (5 in) version of the ET-Plus rail flattening head assembly, sections of standard W-beam guardrail, foundation tubes at Posts 1 and 2 with a ground strut, a tension cable from Post 1 to the W-beam guardrail between Posts 1 and 2, and seven standard wood posts at Post locations 1-7. An anchor plate and lag screw held the ET-Plus head assembly at Post 1, while the W-beam guardrail at Post 1 was free-floating. The guardrail itself was supported by a carriage bolt at Post 2, with a wooden block-out and carriage bolt providing support at Posts 3-7. At Post 8, the guardrail system transitioned from the end treatment into standard guardrail, with steel posts, composite block-outs, and carriage bolts.

Figure 4 depicts a similar ET-Plus installation that was located approximately 1.6 km (1.0 mi) east of the crash site and used for exemplar purposes.

During the crash, the Toyota struck the impact-face of the end terminal (originally located at Post 1) and displaced it westward along the W-beam. This flattened the guardrail, and it curled on the field side of the impact head. Approximately 4.9 m (16.1 ft) of flattened W-beam extruded from the impact head. This corresponded to the approximate location of Post 4, evidenced by the presence of the carriage bolt hole/slot for Post 4 in the exit chute of the end terminal's impact head. Based on the SCI inspection, it was determined that a kink developed in the W-beam between Post 4 and Post 5 ahead of the impact head as it was displaced along the rail. This kink allowed the W-beam guardrail to override the left front fender and hood of the Toyota. The W-beam penetrated through the Toyota's windshield, contacted the top instrument panel and steering wheel, and then engaged the windshield header of the vehicle. This sheared the roof from the Toyota and severed the W-beam guardrail. No occupant contact occurred during this penetration of the guardrail. The severed section of guardrail, which included the end terminal impact head, was projected along the Toyota's crash trajectory. It struck the W-beam guardrail between Post 12 and Post 15, deformed Post 15, and came to final rest in the roadside (**Figure 5**).

Figure 5: West-facing view of the ET-Plus end terminal impact head and deformed W-beam guardrail in their displaced position following the crash.

Figure 6: West-facing view of the deformed guardrail at the time of the SCI inspection.

A second kink developed in the W-beam guardrail as it continued to be deformed by the Toyota during the crash. This second kink occurred between Posts 8 and 9. The kinked W-beam engaged the left plane of the Toyota in the area of its left rear door and penetrated into the occupant compartment adjacent to the left C-pillar at the beltline. This induced rapid counterclockwise rotation to the Toyota. No occupant contact occurred during this penetration of the guardrail. The section of guardrail between the initial kink (between Posts 4 and 5) leading up to Post 9 was displaced into the area of protection by the Toyota. At the time of the SCI inspection, this 8.9 m (29.2 ft) length of W-beam extended from Post 9 at an approximate 30-degree angle in the direction of the Toyota's crash trajectory (**Figure 6**). The ET-Plus guardrail was inspected post-crash and documented by the SCI Investigator through a combination of

measurements and photographs. A diagram depicting the deformed guardrail is included on **Page 17**. The completed FHWA Guardrail Forms are included at the end of this report as **APPENDIX A**.

The height of the W-beam was 69 cm (27.0 in), measured at an undamaged section between Post 13 and Post 14. Dimensions of the impact-face of the end terminal measured 39 x 71 cm (15.5 x 28.0 in), width x height. The extruder head's length was 50 cm (19.7 in) and the guide chute's length was 92 cm (36.2 in), producing a total overall length for the ET-Plus end terminal device of 142 cm (55.9 in). The width of the guide chute (**Figure 7**) was 12.5 cm (4.9 in).

The first seven posts, all of which were all wood, were sheared approximately at ground level. Further damage was sustained by steel posts at post locations 8, 9, and 15. The SCI Investigator examined all remnants of posts, which were strewn in the roadside in the crash trajectory of the Toyota. A reconstruction was performed to match each post to its original location for examination purposes. **Figure 8** depicts sheared Post 2, replaced and resting on its base during

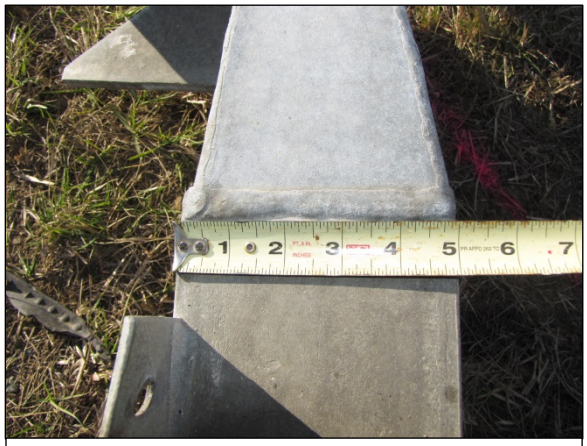


Figure 7: Measurement of the guide chute width of the ET-Plus end terminal device at the time of the SCI crash site inspection.

Figure 8: View of damaged Post 2 (repositioned for documentation during SCI reconstruction) and other sheared posts at the crash site.

inspection. Other sheared posts can be seen in the background. The W-beam guardrail sustained damage from Post 1 to Post 10, with a total damaged length of 15.4 m (50.5 ft). A separation in the guardrail had occurred between Post 4 and Post 5.

Post 1 was a 14 x 19 cm (5.5 x 7.5 in) pressure-treated wood beam that was embedded into the ground inside a steel sleeve. The top surface of the sleeve was approximately 9 cm (3.5 in) above ground level. A bolt 4 cm (1.5 in) above ground level and perpendicular to the roadway secured the post in the sleeve. A hole was drilled through the center of the post parallel to the roadway to weaken the post. Post 2 was also a 14 x 19 cm (5.5 x 7.5 in) pressure-treated wood beam embedded into the ground inside a steel sleeve. Similar to Post 1, the post was secured in the sleeve by a bolt perpendicular to the roadway. At the time of inspection, this bolt was located at

ground level. The top of the sleeve was 4 cm (1.5 in) above ground level. Like Post 1, Post 2 also had a weakening hole drilled through it parallel to the roadway.

Figure 9: Displaced ground angle strut.

A ground angle strut was originally installed between Posts 1 and 2 on the field side. This strut tensioned the system and was bolted to the side of the steel post sleeves. During the crash, the angle strut was sheared from its mounting location and displaced along the Toyota's crash trajectory. **Figure 9** depicts a view of the traffic-side of the separated ground angle strut at the time of the SCI crash site inspection. As positioned in the image, the right aspect of the strut was attached to the field side of the Post 1 sleeve.

Posts 3-7 were common 15 x 20 cm (6 x 8 in) pressure-treated wood beam posts that supported the W-beam with wood block-outs and carriage bolts. During the crash, the bolt head at each of these posts pulled through the W-beam by deforming the hanger slot in the rail. All five of the posts were sheared at or below ground level in the area of their respective weakening holes. The weakening holes were all originally aligned parallel to the roadway.

Figure 10: View of deformed Post 8 and Post 9 at the time of the SCI crash site inspection.

Post 8 marked the transition from the end treatment to the standard guardrail barrier. From Post 8 onward, all posts were nominal 10 x 15 cm (4 x 6 in) steel I-beams and the W-beam was supported by 19 cm (7.5 in) composite block-outs with carriage bolts. Post 8 was deflected approximately 60-degrees in the direction of the Toyota's crash trajectory, and rotated approximately 45-degrees counterclockwise. The composite block-out remained attached to the post with the carriage bolt, which had pulled through the hanger slot in the guardrail. It was apparent that the Toyota had directly engaged Post 8 during the crash. **Figure 10** depicts deformed Posts 8 and 9, as well as the location of the displaced angle strut and several of the displaced and sheared wooden posts. Post 9 remained in a vertical position. The block-out remained attached to the face of the post, though the carriage bolt had pulled through the hanger slot in the guardrail. Although it did not appear to be deflected by the crash, it was rotated approximately 10-degrees clockwise. There was no visible direct contact to Post 9 from the Toyota. At Post 10, the guardrail was separated from the post

due to induced deflection of the W-beam. Although the carriage bolt had pulled through the hanger slot in the guardrail, Post 10 itself appeared undamaged. There was no visible deflection or contact to Post 10.

Post 11 was the apparent end of damage relative to the impact of the Toyota with the end treatment and W-beam guardrail system. The W-beam guardrail remained supported by the steel post, composite block-out, and carriage bolt. There was no visible deflection or contact to the guardrail or post relative to the crash at Post 11.

Although damage to the guardrail from the Toyota's impact and engagement ended at Post 11, a second area of damage to the guardrail system was identified. This included direct contact and minor deformation to the top aspect of the W-beam near the Post 12 location, direct contact and deformation to the top half of the W-beam between Post 14 and Post 15, and direct contact and deflection of the composite block-out at Post 15. This damage was attributed to a secondary impact by the displaced and separated end terminal and guardrail, subsequent to the initial impact with the Toyota.

1996 TOYOTA CAMRY

Description

The 1996 Toyota Camry (**Figure 11**) was a 5-passenger sedan that was identified by the VIN 4T1BG12K5TUxxxxxx. It was manufactured in November 1995. The vehicle's odometer reading at the time of the SCI inspection was 421,987 km (262,210 mi). The body was configured on a 262 cm (103.1 in) wheelbase with front-wheel drive. It was powered by a 2.2 liter, inline 4-cylinder gasoline engine that was linked to a 4-speed automatic transmission, with a center console-mounted shifter.

Figure 11: Front right oblique view of the Toyota.

The Toyota's gross vehicle weight rating was placarded at 1,882 kg (4,150 lb). Front and rear gross axle weight ratings were both 1,089 kg (2,400 lb). The vehicle's curb weight was 1,365 kg (3,009 lb). There was no placarding of recommended tire size/pressure. Manufacturer literature indicated that the original equipment was P195/70R14. At the time of the SCI vehicle inspection, the Toyota was equipped with size P185/70R14 tires at both front positions and size P185/65R14 tires at both rear positions. Specific tire data measured at the time of the SCI inspection were as follows:

	Manufacturer/ Model	Tire Identification Number (TIN)	Measured Tread Depth	Restriction	Damage
LF	Insignia SE200	W5RW E20 1611	2 mm (3/32 in)	No	None
LR	Auto Grip P308	KWA2 4012	3 mm (4/32 in)	No	None
RR	Auto Grip P308	KWA2 4212	2 mm (3/32 in)	No	None
RF	Kendal Kenetica	ZYJ9 4NA	0 mm (0/32 in)	No	None

The interior of the Toyota was configured with two rows for the seating of up to five occupants (2/3). The front seats were bucket seats with manual seat track and seat back recline adjustments, and were equipped with adjustable head restraints. At the time of the SCI inspection, the driver's seat was adjusted to its full-rear track position, with the seatback slightly reclined and the adjustable head restraint fully-down. The second row consisted of a three-passenger bench seat with integral head restraints at the outboard positions. Manual restraint systems in the Toyota consisted of 3-point lap and shoulder safety belts for the four outboard seat positions, with a lap belt and locking latch plate at the second row center position. Both front safety belts were adjustable at their respective D-ring locations. Supplemental restraints consisted of driver and passenger frontal air bags.

Exterior Damage

The Toyota sustained impact damage to its front, left, and top planes, consistent with the events of the crash. Direct contact damage on the front plane from the initial impact with the ET-Plus end terminal impact head began 4 cm (1.6 in) right of center and extended 36 cm (14.0 in) to the right. This damage was evidenced by vertically-oriented impressions and crush that mirrored the profile of the impact head. The front bumper cover was fractured and separated during the impact. Longitudinal deformation was sustained by the bumper beam, radiator support, hood, and engine compartment components. The right front headlight assembly was disintegrated, and the hood was deformed. **Figure 12** depicts an overhead view of the Toyota's front plane and the damage associative to the initial impact with the ET-Plus end terminal impact head.

Figure 12: Overhead view of the Toyota depicting the frontal deformation.

Figure 13: Front plane view of the 1996 Toyota Camry.

A residual crush profile was documented by the SCI Investigator using a Nikon Nivo 5.M+ total station mapping system. Due to the separation of the bumper beam (**Figure 13**), the crush profile was measured along both the lower radiator support and leading edge of the hood. However, the magnitude of the hood crush was not sufficient to warrant an averaged profile, and the hood measurements were dropped. The Field-L width measured 118 cm (46.5 in) across the front plane.

The documented residual crush profile produced the following resultant measurements: C1 = 5 cm (2.0 in), C2 = 11 cm (4.3 in), C3 = 22 cm (8.7 in), C4 = 41 cm (16.1 in), C5 = 38 cm (15.0 in), and C6 = 19 cm (7.5 in). Maximum crush measured 60 cm (23.6 in), observed between the C4 and C5 measurement locations. The collision deformation classification (CDC) assigned to the damage pattern was 12FZEN2. This crash type was outside of the WinSMASH program's scope for analysis due to the yielding property of the impact. A borderline reconstruction of the crash severity (delta-V) was calculated using Barrier algorithm of the WinSMASH model. The calculated barrier equivalent speed (BES) was 37 km/h (23 mph). Based on SCI expertise, the estimated vehicle velocity change (delta-V) of the impact was 24-32 km/h (15-20 mph).

The second impact event consisted of engagement of the guardrail kink between Posts 4 and 5 with the Toyota that resulted in separation of the Toyota's entire roof structure. Induced lateral deformation of the left A-pillar, left B-pillar, and left roof side rail accompanied the damage pattern. Direct contact damage began on the upper aspect of the left front fender, extended onto the hood, penetrated into the occupant compartment adjacent to the left A-pillar, and extended vertically to the windshield header. No specific measurements could be obtained to accurately document the damage profile. The CDC assigned to the damage was 00LYHW6. This impact was outside of the scope of the WinSMASH program; no representative or comparison value could be calculated. The estimated delta-V was of moderate-severity. **Figure 14** depicts the Toyota with the separated roof repositioned on the damaged vehicle.

Figure 14: Overhead view of the Toyota with the separated roof repositioned for documentation purposes.

Figure 15: View of the Event 3 area of damage to the Toyota's left plane.

The third event involved the engagement of a secondary kink in the guardrail, located between Posts 8 and 9, with the left plane of the Toyota. Direct contact damage began near the center aspect of the left rear door and continued at beltline level to the left C-pillar. In this area, the upper aspect of the left rear door and the left upper C-pillar were deformed toward the interior of the vehicle. **Figure 15** depicts the area of the Event 3 damage pattern. The guardrail penetrated the interior through the left rear glazing opening and contacted the upper aspect of the second row left seatback.

No specific measurements could be obtained to accurately document the Event 3 damage profile. The CDC assigned to the damage was 00LZHN3. This impact was also outside of the scope of the WinSMASH program; no representative or comparison delta-V value could be calculated. The severity of this impact was also rated as moderate.

Event Data Recorder

The 1996 Toyota Camry was not equipped with an EDR. Therefore, no crash data was available.

Interior Damage

The interior of the Toyota sustained damage that consisted of air bag deployment, penetration of the guardrail into the occupant compartment in multiple locations, and corresponding lateral and vertical intrusion of left plane components. The areas of penetration included the windshield, roof, and left rear door areas.

The first guardrail penetration resulted when the W-beam kinked between Posts 4 and 5 during the initial stages of the crash sequence. The kink occurred in advance of the ET-Plus impact head as it was displaced along the guardrail. The kink overrode the left aspect of the Toyota's hood and penetrated into the vehicle's interior through the base of the windshield, adjacent to the left A-pillar. The guardrail then contacted the top of the left instrument panel, deforming the foam and polymer surface (**Figure 16**). It also contacted the top of the steering wheel rim and the top of the deployed driver's frontal air bag, which resulted in a cut, abrasions, and rearward deformation of the steering wheel rim, as well as an abrasion to the driver's air bag. **Figure 17** depicts the damage to the top of the steering wheel rim from the penetrating guardrail.

Figure 18: Forward-looking view of the Toyota's headliner as viewed from the second row right position.

Figure 19: Intrusion of the Toyota's left B-pillar and left roof side rail induced by the engagement of the kinked guardrail with the roof structure.

The penetrating guardrail continued vertically and engaged the windshield header and roof structure of the Toyota. This resulted in lateral deformation to the left upper pillars and left roof side rail, and separated the entire roof structure. Direct contact damage associated with the second event extended from the left plane across the vehicle's centerline, above the front row right seat position.

Intrusions into the Toyota's interior that were related to the first guardrail kink and pentration included 20 cm (8.0 in) lateral intrusion of the left roof side rail and 21 cm (8.2 in) lateral intrusion of the left B-pillar. Significant penetration and damage was visible to the separated roof's headliner (**Figure 18**). Also associated with the first kink and roof separation were the 22 cm (8.5 in) vertical intrusion of the left B-pillar and 24 cm (9.5 in) vertical intrusion of the left roof side rail (**Figure 19**).

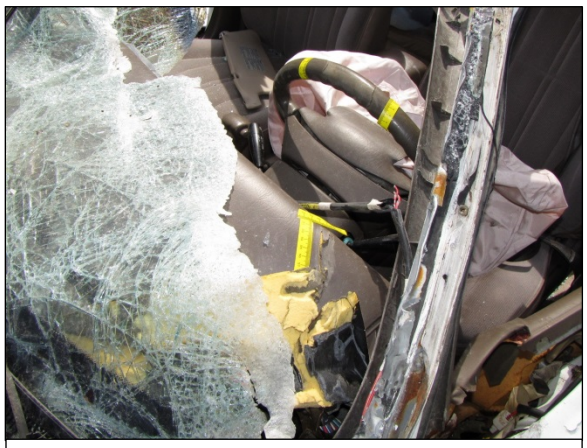


Figure 16: Penetration damage to the windshield, instrument panel, and steering wheel rim from the guardrail associated with Event 2.

Figure 17: Damage to the steering wheel rim that resulted from contact with the guardrail as it penetrated into the Toyota's interior.

The second kink in the guardrail, which developed between Posts 8 and 9, penetrated into the second row left position of the Toyota's interior at the top aspect of the left rear door, adjacent to the left C-pillar. Corresponding intrusions included the 20 cm (8.0 in) lateral intrusion of the left rear door's rear upper quadrant, 15 cm (6.0 in) lateral intrusion of the upper C-pillar, and 38 cm (15.0 in) vertical intrusion of the upper C-pillar.

Manual Restraint Systems

The Toyota Camry was equipped with 3-point lap and shoulder safety belts for the four outboard seat positions. The second row center position was equipped with a lap belt and locking latch plate. Each front safety belt system consisted of continuous-loop webbing, a sliding latch plate, and an adjustable D-ring. At the time of the SCI vehicle inspection, the driver's D-ring was adjusted fully upward and the front right D-ring was adjusted fully downward. The driver's safety belt webbing retracted onto an emergency locking retractor (ELR), while the front right system used a switchable automatic locking retractor (ALR)/ELR.

Inspection of the driver's safety belt system found the webbing extended from the retractor. It was locked in position due to deformation to the B-pillar and corresponding engagement of the ELR. There was historical wear to the latch plate and webbing, though no significant loading evidence was identified. It should be noted that significant loading evidence would not be expected in a crash of these circumstances due to the relatively low to moderate severity of the impact's delta-V and its distribution of force over an extended time period.

Figure 20 depicts the driver's safety belt system. The SCI Investigator did identify several areas of blood droplets on the webbing, as well as on the latch plate. Based on the post-crash condition of the safety belt system and the driver's status, the SCI Investigator determined that the driver was restrained by the manual safety belt system at the time of the crash.

Figure 20: Toyota driver's lap and shoulder safety belt system at the time of the SCI vehicle inspection.

Supplemental Restraint Systems

The Toyota was equipped with dual-stage frontal air bags for both the driver and front row right occupant positions. During the guardrail end terminal impact, both air bags deployed from their respective modules. The driver's air bag module was located in the center hub of the steering wheel rim, while the front right occupant's was located in the top of the right instrument panel.

The driver's air bag deployed from the module without damage or occupant contact to the module cover flaps. Nomenclature located on the air bag between its two vent ports included "45165-06010," "0001491," T181," and "091195." Aside from manufacturer part numbers, the nomenclature indicated that the air bag was manufactured on September 11, 1995. A small scuff/abrasion was located on the forward-facing aspect of the air bag above the vent ports, at the 12 o'clock position (**Figure 21**).

Figure 21: Abrasion to the top of the Toyota's driver air bag from contact with the intruded guardrail.

Figure 23: View of the deployed front right air bag in the Toyota at the time of the SCI inspection.

This abrasion was in alignment with the gouge on the top of the steering wheel, and was determined to have resulted from contact with the intruding guardrail during the crash sequence. On the air bag's face, there were a few droplets of blood at the upper aspect (**Figure 22**).

The front right air bag also deployed from its module without damage to the air bag or its cover flaps. The large air bag was vented on each side near its upper aspect. Inspection of the front right air bag was unremarkable. **Figure 23** depicts the large deployed air bag in its deflated state. There was no occupant contact from the restrained driver to the front right air bag.

1996 TOYOTA CAMRY OCCUPANT DATA

Driver Demographics

Age/Sex:	39 years/male
Height:	180 cm (71 in)
Weight:	68 kg (150 lb)
Eyewear:	None
Seat Type:	Forward-facing bucket seat with adjustable head restraint
Seat Track Position:	Rearmost
Manual Restraint Usage:	3-point lap and shoulder safety belt system
Usage Source:	Vehicle inspection
Air Bags:	Frontal air bag, deployed

Alcohol/Drug Involvement:	Unknown
Egress From Vehicle:	Exited vehicle under own power
Transport From Scene:	Ambulance to a local hospital
Type of Medical Treatment:	Held overnight and released within 24 hours of the crash

Driver Injuries

Injury No.	Injury	AIS 2015	Involved Physical Component (IPC)	IPC Confidence Level
1	Concussion with brief loss of consciousness, NFS	161002.2	Left B-pillar	Probable
2	10x10 cm avulsion to left parietal region	110802.1	Left B-pillar	Probable
3	7 cm straight linear laceration to the left head	110602.1	Left B-pillar	Probable
4	Abrasions to both hands on dorsal surface	710202.1	Left instrument panel	Probable

Source – EMS and hospital records

Driver Kinematics

The 39-year-old male was seated in the driver's seat of the Toyota. Based on the observations of the SCI inspection, the driver used the available 3-point lap and shoulder safety belt system for manual restraint. While the driver operated the Toyota westbound on the limited-access roadway, it began to drift right from the travel lane.

The Toyota departed the roadway and struck the guardrail without evidence of avoidance action by the driver. At impact with the ET-Plus end terminal impact head and guardrail system, crash forces resulted in the deployment of the Toyota's driver frontal air bag. The driver initiated a forward trajectory in response to the 12 o'clock direction of the impact forces. His use of the manual restraint system prevented his unrestricted movement in the vehicle's interior.

As the vehicle struck the guardrail, it began a clockwise rotation. The guardrail kinked between Posts 4 and 5, was directed over the left front fender onto the hood of the Toyota, and penetrated through the windshield and into the vehicle's interior. The guardrail contacted the top aspect of the left instrument panel, top of the steering wheel rim, and the top of the deployed driver's frontal air bag. It continued its vertical trajectory and engaged the windshield header of the Toyota. Associated forces resulted in induced displacement of the left upper A-pillar, left upper B-pillar, and left roof side rail to the right. Subsequently, the entire roof structure became separated from the vehicle.

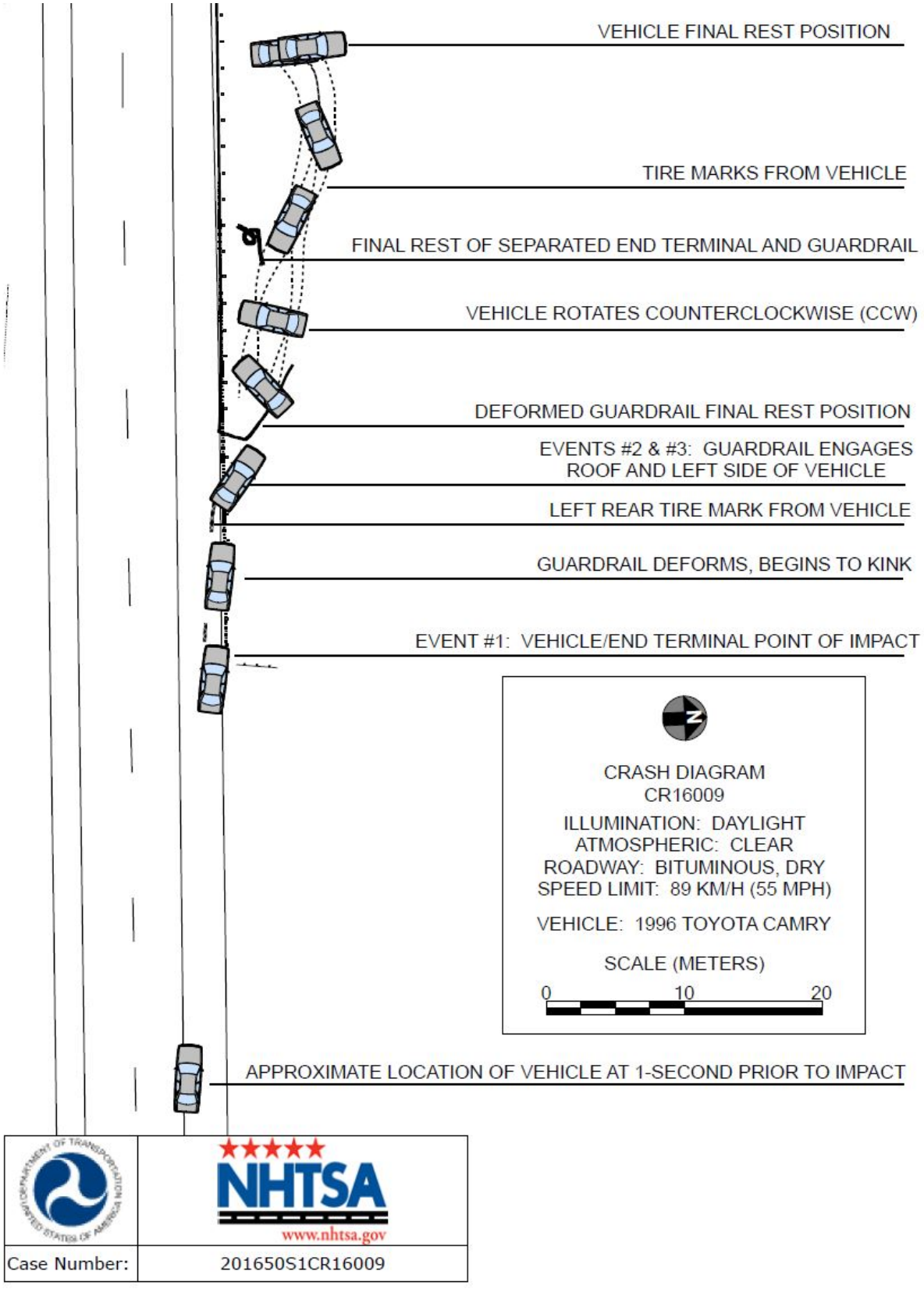
A lack of severe injury to the driver's head/face indicates that there likely was no interaction between the driver and the intruding guardrail during the crash sequence. However, during the impact sequence, the driver's head contacted the left B-pillar as it was deformed to the right and downward. This contact produced a concussion and multiple soft tissue injuries to the driver's

head. The driver remained in the area of the driver's seat position as the crash sequence progressed.

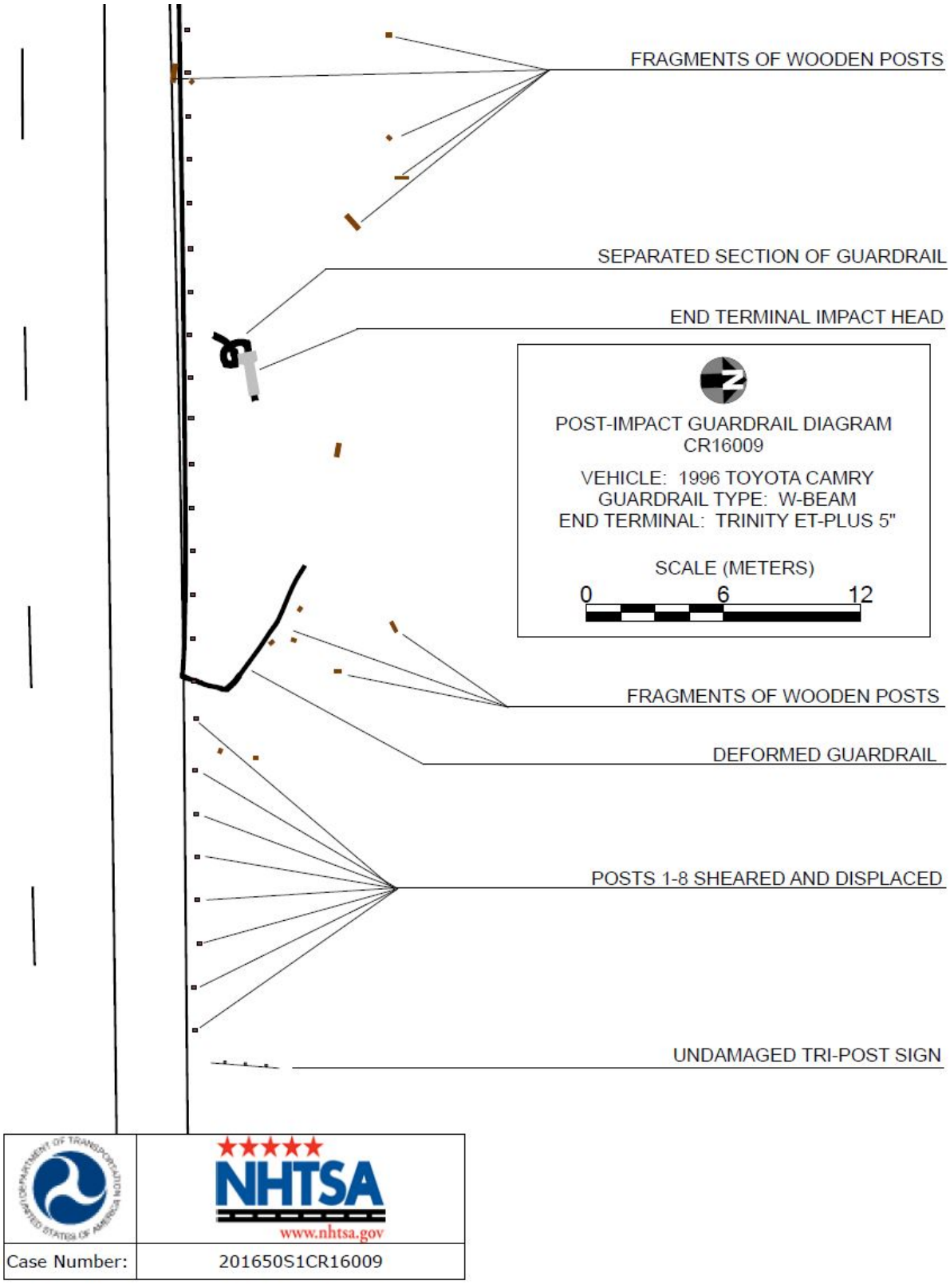
A second kink in the guardrail developed between Posts 8 and 9, which engaged the left plane of the Toyota near the C-pillar and induced rapid counterclockwise rotation to the Toyota. This induced a left lateral trajectory to the driver, and he probably contacted the left front door panel and left B-pillar with his left thigh, left flank, and head, respectively. It remains unknown if the driver sustained any injury as a result of these contacts. He maintained his leftward trajectory and remained in contact with these components as the Toyota rotated counterclockwise through the roadside.

The driver rebound to the right as the Toyota slid to final rest in the roadside. He remained restrained by the manual safety belt system. Following the crash, the driver unbuckled the safety belt system, forced the driver's door open, and exited the vehicle under his own power. Following the arrival of EMS personnel, the driver was transported by ambulance to a local hospital for evaluation and treatment. He was treated and released within 24 hours of the crash.

CRASH DIAGRAM



GUARDRAIL DEFORMATION DIAGRAM



Appendix A:
Federal Highway Administration Guardrail Forms

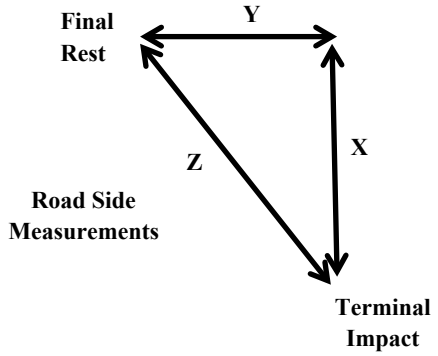
Case No.: CR16009

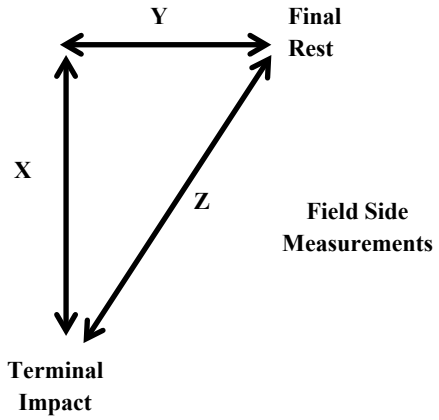
PREPOPULATED DATA (BY OTHERS)			
Date of Crash	March 2016	**Time of Crash**	Daylight hours
Case Number	CR16009	**State**	MO
Traffic Route	Limited Access	**Direction (Southbound = SB)**	WB
Ambient Conditions (at time of crash)			
Temperature (°F)	61 °F	**Lighting**	Daylight
Atmospheric	Clear		

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)	70 mph
Est. distance (straight line) from terminal impact to COM final rest position (ft.)	Z = 144.6 ft ☐Road side ☒Field Side
Est. distance (longitudinal) along guardrail from terminal impact to COM final resting location (ft.)	X = 142.4 ft
Est. distance (normal) from either 1. the white paint line; or 2. roadway/shoulder/pavement edge to COM rest position (ft.)	Y = 25.3 ft
Super elevation	☐+2% ☐-2% ☒ NONE or FLAT
Curve Radius (ft.)	N/A

KEY:

- COM - Center of Mass of Vehicle
- Distance Measurements





Case No.: CR16009

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.)					
0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	Wood	7.5 x 5.5 in	NONE	N/A	Unknown	N/A	11.09 ft	N/A	6 ft 2 in
2	Wood	7.5 x 5.5 in	NONE	N/A	Unknown	N/A	11.05 ft	N/A	6 ft 5 in

Case No.: CR16009

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type Steel Wood Other	Dim. D x W (in.) or Dia. (in.)	Type Steel Wood Composite	Dim. D x W (in.)	Yes No Unknown	Describe	Travel way	Curb	
3	Wood	7.5 x 5.5 in	Wood Fractured	Missing	Unknown	N/A	11.70 ft	N/A	6 ft 3 in
4	Wood	8 x 6 in Cavity	Wood Fractured	Missing	Unknown	N/A	11.74 ft	N/A	6 ft 2 in
5	Wood	6.8 x 6.2 in	Wood Fractured	Missing	Unknown	N/A	11.60 ft	N/A	6 ft 2 in
6	Wood	7.8 x 6.5 in	Wood	7.75 x 6 in	Yes	Upper and lower surfaces, minor scratches	11.45 ft	N/A	6 ft 4 in
7	Wood	8 x 6 in Cavity	Wood	7.75 x 6 in	Yes	Upper and lower surfaces, minor scratches	11.45 ft	N/A	6 ft 4 in
8	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.37 ft	N/A	6 ft 4 in

Case No.: CR16009

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type Steel Wood Other	Dim. D x W (in.) or Dia. (in.)	Type Steel Wood Composite	Dim. D x W (in.)	Yes No Unknown	Describe	Travel way	Curb	
9	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.37 ft	N/A	6 ft 2 in
10	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.30 ft	N/A	6 ft 3 in
11	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.22 ft	N/A	6 ft 3 in
12	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.29 ft	N/A	6 ft 3 in
13	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.30 ft	N/A	6 ft 3 in
14	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.33 ft	N/A	6 ft 4 in

Case No.: CR16009

GUARDRAIL INSTALLATION									
Post No.	Post		Block-Out		PRE-Existing Damage		Offset to post or post hole (ft.)		Spacing to next post (ft. -in.)
	Type Steel Wood Other	Dim. D x W (in.) or Dia. (in.)	Type Steel Wood Composite	Dim. D x W (in.)	Yes No Unknown	Describe	Travel way	Curb	
15	Steel	6 x 4 in	Composite	7.5 x 4 in	Yes	Upper and lower surfaces, minor scratches	11.33 ft	N/A	6 ft 3 in

Additional Comments

None.

Case No.: CR16009

EXTRUDER			
Feeder Channel Width at impact head	☐4inches ☒5 inches ☐ Other _____		
Guide Chute Exit Height (in.)	20 in		
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.)	16 ft 1 in
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.]	16 ft 1 in of extruded rail + 5 ft 4 in within the extruder to the torn W-beam + 29 ft 1 in to kink at Post 9 = **50 ft 6 in total**		

TELESCOPE				
Rail Displacement	❒No	❒Yes Length:	No of Panels Displaced	❒1 ❒2 ❒3 ❒4 ❒5 ❒6

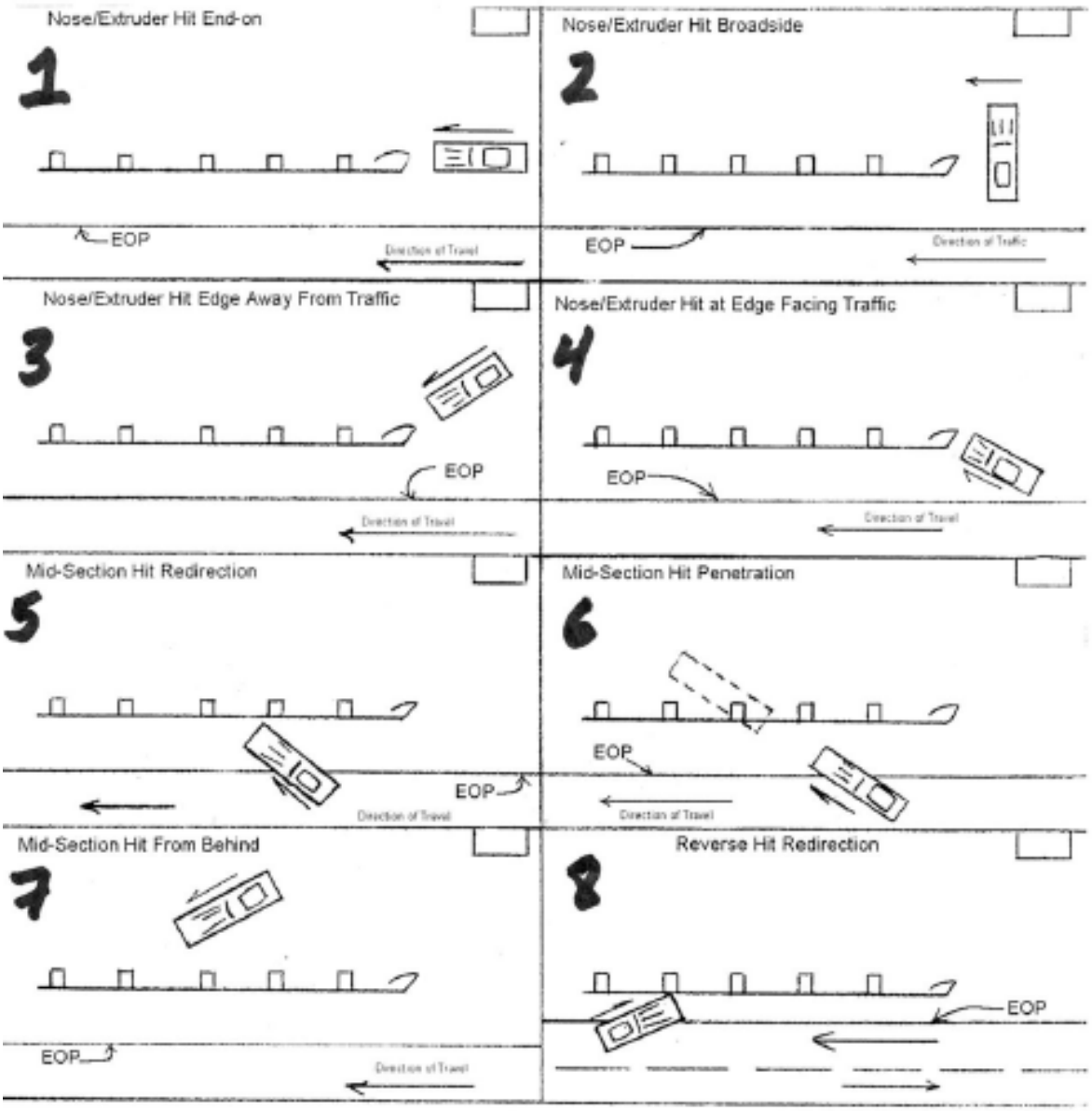
ALL-SYSTEM PERFORMANCE				
Railkinks Downstream of Head?	☐No	☒Yes	No. of Kinks in Rail:	2
Was there intrusion into the Occupant Compartment by foreign object (guardrail)?	☐No ☒Yes			
Did vehicle impact other objects after impact with terminal?	☒No ☐Yes			
Object(s) Contacted	N/A			

ALL-SYSTEM PERFORMANCE ENVIRONMENT			
SIDESLOPE	**50 ft in advance of Post 1**	**At Post 1**	**50 ft Past Post 1**
Percent - %	-3%	-5%	-8%
Adjacent Lane Width (ft)	11.8 ft		
Lane Type (NAS EDS Variable: Sur. Type)	Asphalt		
Shoulder Type	Concrete		
Shoulder Width (ft)	10.2 ft		
Guardrail Height (in)	27 in at Post 1		

Case No.: CR16009

VEHICLE INFORMATION			
Vehicle Type (NHTSA Input)	1996 Toyota Camry		
Vehicle Identification Number (VIN)	4T1BG12K5TUxxxxxx		
Vehicle Mass (NASS var.: veh.wgt)	3,009 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	N/A		
Collision Deformation Classification	12FZEN2		
Delta-V	Barrier Equivalent Speed (BES) of 23 mph (37 km/h)		
Occupant Compartment Penetration of rail	☐No	☒Yes;	Describe: Penetrated windshield at left A-pillar and struck center roof. Also struck and penetrated above LR door, adjacent to Left C-pillar
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		

Case No.: CR16009



DOT HS 812 627
October 2018

U.S. Department
of Transportation

**National Highway
Traffic Safety
Administration**

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