TRANSPORTATION SCIENCES
CRASH RESEARCH SECTION

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CALSPAN ON-SITE VEHICLE ROLLOVER INVESTIGATION
CALSPAN CASE NO. CA98-041
VEHICLE: 1998 MERCEDES-BENZ ML 320
LOCATION: ALABAMA
CRASH DATE: JULY, 1998

Contract No.
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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.

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BACKGROUND

This on-site investigation involved a 1998 Mercedes-Benz ML320 sport utility vehicle that was involved in a rollover crash **(Figure 1)**. The primary focus of the investigation was to identify the rollover initiation type and assess the performance of the vehicle in the rollover sequence. The Mercedes initially impacted the rear of a semi-trailer prior to the driver applying a counterclockwise steering input which directed the vehicle onto the grass median. She subsequently applied a rapid clockwise (CW) steering input which induced a CW yaw. As the vehicle reentered the asphalt road surface, the left front alloy wheel gouged the pavement which tripped the sport utility vehicle into a side-over-side lateral roll to the left. The Mercedes completed 10 quarter rolls prior to coming to rest on its roof approximately 61 m (200') from the trip point. The female driver was properly restrained by the manual belt system. She sustained a right hand laceration with tendon transection and was treated at a local hospital and released. The right front door mounted side impact air bag deployed during the rollover event.

Figure 1. On-scene photograph of the Mercedes-Benz at final rest

The local NASS team leader at PSU 48 initially identified the crash from a newspaper photograph. She obtained the Police Crash Report (PCR) and forwarded the notification to NHTSA on July 28. The crash was subsequently assigned to Calspan's Special Crash Investigation Team on the 28th and an on-site investigation was conducted on July 29-30.

SUMMARY

Crash Site

The crash occurred on an urban four lane divided arterial **(Figure 2)** during daylight hours in a posted 80 km/h (50 mph) speed zone. In the vicinity of the rollover, the asphalt travel lanes curved to the right with a radius of curvature of 762 m (2500') and a 3 percent negative grade relative to the ML320's direction of travel. The inboard travel lane was bordered by a 0.8 (2'8") asphalt shoulder with a mountable curb bordering the inboard edge of the shoulder. The grass median was 6.3 m (20'8") in width with a W-beam guardrail median barrier. The outboard shoulder was 2.5 m (8'3") in width. The conditions were police reported as overcast and dry.

Figure 2. Overall view of the crash site.

Pre-Crash

The 40 year old female driver of the Mercedes-Benz ML320 was traveling in an easterly direction on the inboard travel lane of the arterial roadway. She was traversing a bridge that was straight with a slight negative grade at an estimated speed of 100 km/h (60 mph). A tractor/semi-trailer combination unit was traveling on the outboard travel lane of the arterial and initiated a lane change maneuver onto the inboard lane. The driver of the unit stated to the investigating officer that he checked his rear view mirrors and noted the approaching Mercedes-Benz, however, he determined that he had sufficient distance to safely complete the lane change maneuver. The driver of the Mercedes stated that the tractor-trailer combination initiated the maneuver directly ahead of her path of travel which resulted in her initiating avoidance actions. Both driver's denied contact between the vehicles.

Crash

Evidence on the Mercedes-Benz indicated that the front left area of the ML320 impacted the rear of the semi-trailer. The evidence consisted of black rubber transfers on the front bumper fascia, inboard aspect of the left head lamp lens, and the left hood face of the Mercedes. Although the tractor/semi-trailer unit was not inspected, the transfers were consistent with impact against the rear splash shield and tires of the semi-trailer. In addition, a narrow vertically oriented yellow paint transfer was noted to the right aspect of the hood face. This yellow transfer probably resulted from minor contact against the underride guard of the semi-trailer.

The driver of the ML320 applied a counterclockwise (CCW) steering input in response to the lane change maneuver by the driver of the tractor/semi-trailer. The steering input redirected the ML320 onto the inboard shoulder immediately east of the bridge. The left side tires of the Mercedes traversed the asphalt shoulder and entered the grass median prior to the beginning of the mountable curb. The physical evidence at the crash scene indicated the driver of the ML320 applied a rapid clockwise (CW) steering input as the vehicle entered the median. As a result of the rapid CW steering input, and probable application of the ABS braking system, the ML320 initiated a CW yaw. The yaw was evidenced by the arcing left side tire marks on the grass median surface **(Figure 3)**. There was no indication of right side tire marks on the asphalt or grass surfaces.

Figure 3. Left side yaw marks on the grass median.

The left side tire marks of the Mercedes-Benz ML320 identified the trajectory of the vehicle. The left rear tire mark was 29.3 m (96.0') in length which terminated at the mid point of the grass median at the on-set of the lateral rollover. The left front tire mark was 26.8 m (88.0') in length which arced back onto the asphalt surface of the roadway. The left front tire of the vehicle traversed the top surface of the mountable curb and contacted the asphalt shoulder surface **(Figure 4)**. The high coefficient of friction surface acting on the laterally skidding tire surface resulted in the

Figure 4. Left front tire traverses curb and re-enters paved surface.

sidewall of the tire partially folding under the alloy wheel. The outer aspect of the alloy wheel tire bead contacted and gouged the asphalt surface. The gouge from the left front wheel was 0.8 m (2'9") in length and 12.7 cm (5.0") in width with a maximum depth of approximately 2.5 cm (1.0"). Refer to **Figures 5 and 6**. Fragments of the removed asphalt compound were embedded into the outer aspect of the wheel **(Figure 7)**. It should be noted, however, that the left front tire did not air out and remained inflated to a post-crash measured pressure of 30 psi.

Figure 5. Left front wheel gouge in the asphalt shoulder.

Figure 6.. Close-up view of the wheel gouge.

Figure 7. Asphalt embedded into the bead of the left front alloy wheel.

As a result of the wheel gouging the asphalt shoulder surface, the ML320 was tripped into a lateral side-over-side rollover, leading with its left side. At the on-set of the rollover, the ML320 had rotated approximately 40 degrees in a clockwise direction over the longitudinal distance of 29.3 m (96.0'). As the vehicle initiated the lateral rollover, the left front wheel continued to mark on the asphalt surface. An aluminum transfer extended 0.3 m (1.0') beyond the gouge created by the left front wheel **(Figure 6)**. The left rear quarter panel area of the vehicle gouged the grass median on the first quarter role. The large gouge mark (area where the grass had been removed by the vehicle) on the median was located 2.4-5.5.m (8.0-18.0') past the termination point of the left rear tire mark. The overall width of the median gouge was approximately 1.1 m (3'6").

The first gouge on the asphalt road surface from left side contact was located 4.8 m (15'9") north of the trip point adjacent to the inboard yellow edge line. The Mercedes-Benz continued to roll on a lateral trajectory, completing 10 quarter rolls before coming to rest on its roof approximately 61 m (200') north of the trip point. The quarter turns were identified by fifteen (15) gouge marks in the asphalt road surface over the longitudinal trajectory of the vehicle. Final rest was identified by a oil fluid spill in the outboard northbound travel lane. At rest, the vehicle was on its roof facing in a northerly direction diagonal to the travel lanes. The Crash Schematic is attached as **Figure 14**.

Post-Crash

The driver was properly restrained by the manual 3-point lap and shoulder belt system and remained in the vehicle during the multiple rollover event. At rest, she was suspended by the belt system within the driver's compartment of the vehicle. The driver was assisted from the vehicle by rescue personnel and transported to a local hospital where she was treated for a hand injury and released. The Mercedes-Benz was up-righted onto its wheels and towed from the scene to a storage facility.

VEHICLE DATA

The Mercedes-Benz ML320 was originally purchased by the driver and her husband in April, 1998. The 40 year old female driver was the primary driver of the vehicle, therefore her usage accounted for the majority of the 7,111 km (4,419 miles) that were recorded on the vehicle's odometer. The ML320 was manufactured on 4/98 and identified by vehicle identification number 4JGAB54E1WA (production number deleted).

The drive train consisted of a 3.2 liter gasoline engine coupled to an electronically controlled 5-speed automatic transmission with full-time 4-wheel drive and an electronic traction system. The vehicle's braking system consisted of 4-wheel power-assisted disc brakes with 4-wheel anti-lock (ABS). The vehicle was a body-on-frame configuration with four doors and a rear liftgate. The vehicle was equipped with Dunlop Grand Trek P255/65R16 mud and snow rated tires that were mounted on 5-spoke OEM aluminum alloy wheels.

The interior of the Mercedes-Benz was configured as a five passenger vehicle with front bucket seats and a folding rear spilt-bench seat. The reclining front seat backs were equipped with adjustable head restraints. The left front head restraint was adjusted to the full up position vehicle the right front restraint was in the full down position. It was unknown if the right head restraint was adjusted to this position or was displaced downward by the intrusion of the roof. The vehicle was equipped with power front bucket seats, power door locks and windows, a power sunroof, and a tilt steering wheel.

The occupant safety systems were comprised of both manual and automatic restraint systems. The manual belt systems consisted of continuous loop 3-point lap and shoulder belts for the four outboard seated positions. The front belt systems were equipped with adjustable upper anchorages (D-rings) and lower attachment points affixed to the seat cushion frames. The left front D-ring was adjusted to the full up position while the right D-ring was adjusted one notch above the full down position. The belt systems were equipped with dual mode locking tractors that were incorporated into the respective pillar. The center rear seat position was equipped with a lap belt system. Although this seat position was not occupied at the time of the crash, the lap belt webbing was cut by rescue personnel during the removal of the driver at the crash scene.

The automatic safety systems consisted of frontal air bags and door mounted side impact air bags for the driver and right passenger positions. The right side impact air bag deployed during the rollover crash. In addition to the frontal air bags, the Supplemental Restraint System (SRS) utilized emergency tensioning retractors (ETR) in the front belt systems. The ETRs consist of a pyrotechnic cylinder that spools-up the slack of the shoulder belt webbing at the activation of the frontal air bag system. In this rollover crash, the ETRs did not deploy due to the non-deployment of the frontal air bag system.

VEHICLE DAMAGE

Exterior

The frontal damage that resulted from the initial impact sequence with the tractor-trailer combination was rated as minor. A black rubber transfer that probably resulted from impact against the left rear splash shield of the semi-trailer was noted to the bumper fascia and the hood face of the ML320. The damage was subsequently masked by the subsequent rollover, however, there was no residual crush at bumper level. Two separate

rubber transfers were noted at the leading edge of the bumper fascia. The outboard transfer was located 66-74.3 cm (26-29.25") left and center while the more prominent inboard transfer was located 21.3-49.5 cm (8.4-19.5") left of center. An additional transfer was located on the inboard aspect of the left headlamp lens.

The black transfer extended onto the hood face of the Mercedes-Benz **(Figure 8)**. The transfer began 6.4 cm (2.5") right of center and extended 41.3 cm (16.25") left of center. At the mid point of the transfer, it extended 29.2 cm (11.5") vertically onto the apex of the hood face. The transfer bordered the sheetmetal at the left surround for the plastic grille assembly which was fractured during the crash. An additional yellow paint transfer was noted to the vertical aspect of the right hood face. The transfer probably resulted from contact with a marking on the rear of the struck semi-trailer. The Collision Deformation Classification (CDC) was for this initial impact was 12FYEW-1.

Figure 8. Frontal damage

The subsequent rollover resulted in severe damage to the roof area of the vehicle with direct contact and residual crush resulting to all body panels with the exception of the rear liftgate door **(Figure 9)**. The initial contact (first quarter roll) involved the left side of the vehicle against the grass/dirt median and the asphalt road surface. The left rear quarter panel was dented with dirt embedded into the trim panel at the rear quarter window from the median contact. The fuel filler door was separated, however, the fuel cap remained intact and there was no fuel leakage. The left rear door was crushed to a depth of 2.5 cm (1.0") at the mid forward third area of the panel. Faint abrasions were present on the door surface, rub strip, and the window frame was crushed and abraded. The left rear door handle was fractured from the door and found on the median at the crash scene. The left front door was abraded superficially on the rub strip with several abrasions located on the door panel below the rub strip. The rear view mirror was fractured and compressed into the door panel which crushed the mid aspect of the door to a depth of 2.5 cm (1.0"). The left front door window frame was heavily abraded and crushed in a downward direction. Vertically oriented abrasions were noted to the left front fender at the forward aspect and at the wheel opening. The left side surface of the front bumper fascia was abraded from contact against the asphalt road surface.

Figure 9. Left front three-quarter view of the rollover damage.

The right side of the ML320 sustained minor damage that consisted of isolated dents to the doors and quarter panel. There was no direct contact damage to the right rear quarter panel. The right side rear view mirror mounting bracket fractured from ground contact during the rollover sequence.

The top surface of the roof and hood sustained severe damage during the rollover **(Figure 10)**. The direct contact damage on the roof extended

Figure 10. Right side view of the rollover damage.

across the full width of the vehicle onto the top aspect of all four door window frames. The direct abrasive damage extended longitudinally from the windshield header to the top hinge points of the liftgate. The OEM roof rack was crushed downward to the roof panel. Crush profiles were documented both longitudinally along the roof side rails and laterally across the header area. The crush profiles were documented vertically from the beltline of the ML320 and compared to an undamaged exemplar vehicle. The results are listed in **Table 1.**

Table 1
Roof Crush Profiles

Location	Length	C1	C2	C3	C4	C5	C6
Header	120.7 cm (47.5")	19.1 cm (7.5")	17.1 cm (6.75")	18.4 cm (7.25")	20.3 cm (8.0")	21.6 cm (8.5")	22.5 cm (8.9")
Left Roof Side Rail	215.9 cm (85.5")	0 cm	7.7 cm (2.75")	8.9 cm (3.5")	15.2 cm (6.0")	16.5 cm (6.5")	17.1 cm (6.75")
Right Roof Side Rail	210.8 cm (83.0")	0 cm	3.8 cm (1.5")	10.2 cm (4.0")	18.4 cm (7.25")	26.7 cm (10.5")	22.9 cm (9.0")

The hood was displaced laterally right during the rollover sequence. The left corner of the hood was displaced laterally 66.0 cm (26.0"). The face and top surface of the hood was abraded from contact with the asphalt road surface which probably deformed the hood and separated the hood latch resulting in the lateral displacement.

The upper aspects of the window frames of all four doors were crushed in a downward direction which restricted the operational status of the doors. The left front door was operational, however, additional force was required to open and close the damaged door. The remaining right front and rear side doors were jammed closed. The rear liftgate door was abraded on the top surface, however, the door remained operational and served as the area of egress for the driver.

The windshield was completely cracked as a result of roof/header deformation. At the time of the SCI inspection which occurred two weeks following the crash, the plastic laminant was torn along the full length of the header and both upper A-pillars. As a result, the windshield glazing was resting on the upper instrument panel. All side door window glazing was closed pre-crash and was shattered as a result of the side rail/window frame deformation. The quarter window in the left rear door remained intact, however, the left rear quarter window was shattered. The rear quarter windows were gasket mounted. The right quarter window gasket separated due to roof and quarter panel deformation. The glazing remain intact within the gasket. In addition to the side glazing, the tempered sunroof and backlight glazing were completely shattered by the rollover event. The CDC for the rollover event was 00-TDDO-3.

The tires and alloy wheels of the Mercedes-Benz ML320 were damaged as a result of the clockwise yaw and the subsequent tripped rollover. The outer bead area of the left front wheel was abraded circumferentially

over a 340 degree area. A 10.8 cm (4.25") length by 2.5 cm (1.0") width of asphalt was embedded into the outer bead area of the alloy wheel. This resulted from the lateral skidding of the vehicle on the asphalt at the trip point of the rollover. The CDC for this wheel contact was 11-RFWN-2. It should be noted that the left front tire was not aired out and the pressure was recorded at 30 psi. There was no damage to the right front tire or the alloy wheel.

The outer aspect of the bead area of the left rear wheel was embedded with oily asphalt. Following the inspection of the scene, it was determined that this resulted post-crash as the vehicle was up- righted and dragged to a position for towing. An oily gouge was located at the crash site which supported this transfer. The tire was completely aired out and separated from the bead, but remained on the wheel in its deflated state. The right rear alloy wheel was fractured at the bead covering an area of 38.1 cm (15.0") in length. The fractured bead was deflected 5.1 cm (2.0") inward with a large build-up of asphalt on the inner aspect of the wheel. This occurred during the rollover as the wheel impacted the asphalt road surface. In addition, the outer sidewall of the right rear tire was holed from the impact sequence. The tread depth and recorded tire pressures at the time of our inspection are identified in **Table 2**.

Table 2
Tread Depth and Tire Pressures

Tire	Tread Depth	Tire Pressure
Left Front	11/32"	30 psi
Left Rear	11/32"	0 psi (deflated)
Right Front	10/32"	30 psi
Right Rear	11/32"	0 psi (deflated)

Interior

The interior of the Mercedes-Benz ML320 sustained moderately severe damage as a result of exterior deformation and intrusion of the roof structure into all five occupant seated positions. In addition, driver contact with interior components resulted in additional, but minor interior damage.

Maximum intrusion involved 26.7 cm (10.5") of vertical displacement of the right roof side rail at the mid point between the A- and B-pillars. **Table 3** identifies the intruding component, the location of the intrusion, the direction of the intrusion, and the magnitude of the intruding component:

Table 1

Vehicle Interior Intrusion

Intruding Component	Occupant Position	Direction	Magnitude
Left roof side rail	Left front (11)	Vertical	17.1 cm (6.75")
Left A-pillar	Left front (11)	Vertical	17.1 cm (6.75")
Windshield header	Left front (11)	Vertical	19.1 cm (7.5")
Roof	Left front (11)	Vertical	20.3 cm (8.0")
Right roof side rail	Right front (13)	Vertical	26.7 cm (10.5")
Right A-pillar	Right front (13)	Vertical	22.9 cm (9.0")
Windshield header	Right front (13)	Vertical	22.5 cm (8.9")
Roof	Right front (13)	Vertical	25.4 cm (10.0")
Roof	Left rear (21)	Vertical	15.2 cm (6.0")
Roof	Center rear (22)	Vertical	17.8 cm (7.0")
Roof	Right rear (23)	Vertical	17.8 cm (7.0")

The driver's left hip area contacted the left door panel/armrest during the rollover sequence that resulted in a 3.2 cm (1.25") separation of the panels of the interior door surface **(Figure 11)**. Although no scuff was noted to the panel, the separation was in an outward direction indicative of occupant loading. Several stands of hair were noted to the headliner over the driver's seated position. The hair strands were adhered to the fabric headliner between the sunroof and the siderail. The driver loaded the manual seat belt system during the rollover. There was no damage to the system components. Several fabric fibers were observed embedded into the shoulder belt webbing in the area of the driver's thoracic region. Numerous blood stains from the driver's right hand laceration were noted to the headliner of the vehicle that resulted post-crash as she exited the Mercedes-Benz through the rear liftgate area..

Figure 11. Driver's left hip contact to the left front door panel.

AUTOMATIC RESTRAINT SYSTEMS

The Mercedes-Benz ML320 was equipped with a frontal air bag system and a side impact air bag system for the driver and right passenger positions. The frontal air bag system was not a redesigned (depowered) system. The system consisted of a single point sensing and diagnostic control module that was mounted within

the passenger compartment of the vehicle, a steering wheel mounted driver air bag module, a mid mount front passenger air bag module, an instrument panel mounted air bag indicator lamp, and the front belt system emergency tensioning retractors. The frontal air bag system did not deploy (as designed) as a result of the minor impact sequence with the tractor/semi-trailer unit or as a result of the rollover event.

The side impact air bag system consisted of door mounted air bags for the driver and right front passenger positions. Deployment of the door mounted air bags required impact of specific magnitude to the respective side. The right side impact air bag deployed during the rollover event Although the specific time of deployment was unknown, the bag probably deployed either during the 3rd or 7th quarter roll that involved ground impact to the right side of the vehicle.

The door mounted side impact air bag **(Figure 12)** was concealed within two nearly symmetrical module cover flaps in the upper rear aspect of the front door panels. The units were identified by SRS AIRBAG molded into the lower right aspect of the upper module cover flap. The flaps were 24.1 cm (9.5") in width at the horizontal tear seam and 7.0 cm (2.75") in height. The bag membrane was constructed of a typical nylon-type fabric that was 50.9 cm (20.0") in length and 25.4 cm (10.0") in height. The bag was not vented into the passenger compartment. An internal tether limited the inward (lateral) excursion of the bag. The tether was sewn to the face of the bag with a 21.1 cm (4.75") horizontal stitch pattern located at the mid point of the bag.

Figure 12. Deployed right side impact air bag.

DRIVER DEMOGRAPHICS

Age/Sex:	40 year old female
Height/Weight:	Unknown
Manual Restraint Usage:	3-point lap and shoulder belt system
Usage Source:	Vehicle inspection/driver interview
Eyeware:	Unknown
Vehicle Familiarity:	4 months
Route Familiarity:	Frequent travel
Mode of Transport From Scene:	Ambulance
Type of Medical Treatment:	Treated at a local hospital and released

DRIVER INJURIES

Injury	Injury Severity (AIS 90)	Injury Mechanism
3-4 cm V-shaped laceration of the right index finger with partial transection of the extensor tendon	Minor (790602.1,1 740200.1,1)	Windshield (probable)
Large hematoma of the dorsal surface of the right hand	Minor (790402.1,1)	Windshield (probable)
Small laceration of the back of the left hand	Minor (790602.1,1)	Windshield (probable)
Abrasions of the right hand	Minor (790202.1,1)	Windshield (probable)
Pain of the chest and left shoulder	N/A, not AIS codeable	Shoulder belt loading

DRIVER KINEMATICS

The driver of the 1998 Mercedes-Benz ML320 was seated in a normal driving posture with the power seat track adjusted to a rear track position. The track position was 1.3 cm (0.5") forward of the full rear position and 16.5 cm (6.5") rearward of the full forward position. The seat back was slightly reclined from the vertical position. The driver was properly restrained by the manual belt system **(Figure 13)**. Belt usage was confirmed by clothing fabric fibers that were embedded into the shoulder belt webbing, the lack of driver contact points within the vehicle, and driver statements. In addition, the driver would have probably been ejected from the vehicle, if unrestrained, during the multiple rollover event.

Figure 13. View of the driver's seat position and the manual belt system.

The initial impact with the tractor/semi-trailer combination unit resulted in minor damage to the vehicle and did not produce a sufficient velocity change to displace the driver from her pre-crash driving position. As the vehicle yawed in a clockwise direction and initiated the lateral side-over-side rollover to the left, the driver contacted the left door panel. Her loading against the door panel resulted in 3.2 cm (1.25") of separation of the panel at the rear third of the panel directly above the door armrest. There were no fabric transfers or abrasions to the contacted area. As the vehicle continued to roll and the roof intruded into the driver compartment, her head probably impacted the roof head liner directly above her seated position. Several strands of hair were noted to the headliner area above the driver's position.

During the rollover event, the driver's right hand probably contacted flying glass, the fractured windshield, or the fractured sunroof. The suspected glass contact resulted in a laceration that was located on the right hand between the 1st and 2nd digits. Although no direct contact evidence (i.e., tissue transfer/scuff marks) was found within the vehicle, blood loss from the laceration was evident on the headliner of the vehicle as the Mercedes came to rest on its roof.

The driver was assisted from the vehicle by rescue personnel and exited through the rear liftgate of the ML320. She was transported by ambulance to a local hospital where she was treated for the laceration and released.

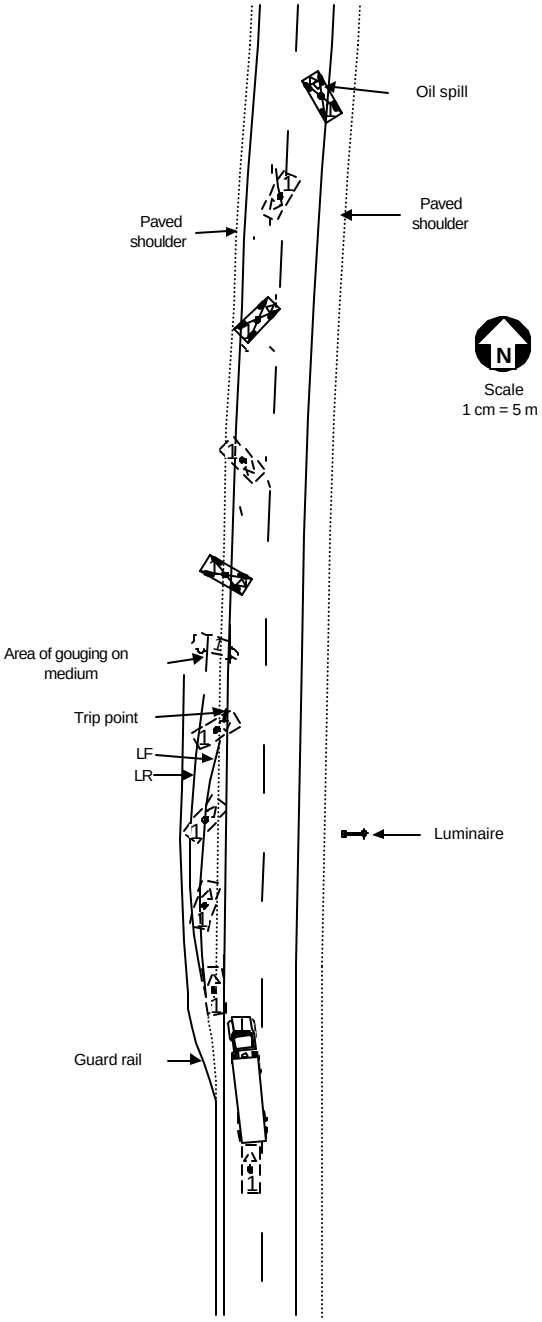

Figure 14. Crash Schematic