TRANSPORTATION SCIENCES
CRASH DATA RESEARCH CENTER

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VERIDIAN ON-SITE SIDE IMPACT OCCUPANT PROTECTION INVESTIGATION
SCI TECHNICAL SUMMARY REPORT

SCI/NASS COMBO CASE NO. - 98-03-063A

SUBJECT VEHICLE - 1998 BMW 528i

LOCATION - STATE OF NEW YORK

CRASH DATE - SEPTEMBER 1998

Contract No. DTNH22-94-D-07058

Prepared for:

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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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16. *Abstract* This on-site investigation focused on the performance of the side impact occupant protection system in a 1998 BMW 528i. The BMW was occupied by an unrestrained 26-year-old male driver and a 46-year-old male front right passenger who was restrained by the manual 3-point lap and shoulder belt. The driver of the BMW relinquished control of the vehicle on the outboard lane of a divided state highway. The vehicle departed the right roadside and struck a guardrail which resulted in the separation of the right front wheel assembly. The BMW was redirected across the travel lanes in a counterclockwise (CCW) rotation. The BMW departed the left roadside in a CCW yaw and initiated a rollover onto the grassy median with the right side leading. The BMW appeared to have rolled six quarter-turns. During the rollover, the unrestrained driver was ejected across the opposing travel lanes onto the grassy shoulder where he came to rest and expired. He sustained a cerebral laceration, cerebral subarachnoid hemorrhage, multiple skull fractures, a minor liver laceration, facial abrasions, contusions, and lacerations, a large left chest abrasion, a left abdomen abrasion, abrasions on the left forearm and dorsal aspects of both hands, anteromedial abrasions on the right calf and left thigh, and multiple left knee lacerations. The rollover was sufficient to deploy the right front passenger's side air bag and the front right passenger's Head Protection System (HPS). The front right passenger loaded the front right passenger's side air bag and HPS during the initial right side impact with the ground. He loaded the deflated front right passenger's side air bag and HPS during the fifth quarter-turn. He loaded right side interior components and sustained a right eyelid contusion, a right rib cage contusion, a cervical spine strain (whiplash) and a right shoulder sprain. The BMW struck the guardrail on the opposite side of the median while it was upside down, and came to rest facing north adjacent to the guardrail. The front right passenger was transported to a local trauma center and admitted for treatment. He was released two days following the crash..			
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BACKGROUND

This on-site investigation focused on the performance of the side impact occupant protection system in a 1998 BMW 528i **(Figure 1)**. The BMW was occupied by an unrestrained 26-year-old male driver and a 46-year-old male front right passenger who was restrained by the manual 3-point lap and shoulder belt. The driver of the BMW relinquished control of the vehicle on the outboard lane of a divided state highway. The vehicle departed the right roadside and struck a guardrail which resulted in the separation of the right front wheel assembly. The BMW was redirected across the travel lanes in a counterclockwise (CCW) rotation. The BMW departed the left roadside in a CCW yaw and initiated a rollover onto the grassy median with the right side leading. The BMW appeared to have rolled six quarter-turns. During the rollover, the unrestrained driver was ejected across the opposing travel lanes onto the grassy shoulder where he came to rest and expired. He sustained a cerebral laceration, cerebral subarachnoid hemorrhage, multiple skull fractures, a minor liver laceration, facial abrasions, contusions, and lacerations, a large left chest abrasion, a left abdomen abrasion, abrasions on the left forearm and dorsal aspects of both hands, anteromedial abrasions on the right calf and left thigh, and multiple left knee lacerations. The rollover was sufficient to deploy the right front passenger's side air bag and the front right passenger's Head Protection System (HPS). The front right passenger loaded the front right passenger's side air bag and HPS during the initial right side impact with the ground. He loaded the deflated front right passenger's side air bag and HPS during the fifth quarter-turn. He loaded right side interior components and sustained a right eyelid contusion, a right rib cage contusion, a cervical spine strain (whiplash) and a right shoulder sprain. The BMW struck the guardrail on the opposite side of the median while it was upside down, and came to rest facing north adjacent to the guardrail. The front right passenger was transported to a local trauma center and admitted for treatment. He was released two days following the crash.

Figure 1. Damaged 1998 BMW 528i

This crash was initially identified and sampled as NASS CDS case 98-03-063A. The NASS researcher notified the Zone Center of the case due to the deployment of the side impact air bag system. The notification was subsequently forwarded to NHTSA and an on-site investigation was assigned to the Veridian SCI team.

SUMMARY

Crash Site

This single-vehicle crash occurred during the nighttime hours on the eastbound lanes of a divided urban expressway. The roadway was illuminated by luminaires that were positioned in the center median. At the time of the crash the weather was clear and the asphalt roadway was dry. The roadway consisted of three travel lanes in each direction separated by a grassy median barrier which had a 20 degree upward slope toward the westbound lanes. The eastbound lanes were configured with a W-beam guardrail and 10 cm (4") curb on the outboard aspect. The westbound lanes were configured with a double W-beam guardrail on the inboard aspect. The roadway had a slight curve to the left and there were no traffic controls present at the crash site. The posted speed limit for the urban expressway was 80 km/h (50 mph). The scene schematic is included as **Figure 11** of this report.

Pre-Crash

The 26-year-old male driver of the BMW was presumed to have been seated in an upright posture with the seat track adjusted between the mid-track and full-rear positions. The driver was operating the BMW in the outboard eastbound lane of the divided state highway. For unknown reasons, the driver relinquished control of the vehicle and failed to negotiate a left curve. The BMW departed the right side of the roadway in a tracking mode **(Figure 2)**.

Figure 2. Eastbound approach for the BMW and area of initial guardrail impact

Crash

The front right aspect of the BMW impacted the outboard guardrail as the vehicle departed the roadway. Paint transfers were noted on the guardrail from the BMW's contact. The guardrail impact snagged the right front tire/wheel assembly which resulted in complete separation of the suspension components. The BMW was redirected by the guardrail and traveled across the three eastbound travel lanes in a CCW yaw. The BMW initiated a rollover onto the grassy median with the right side leading **(Figure 3)**. The damage to the vehicle suggested a longitudinal component in the rollover event. The vehicle appeared to have rolled a total of six quarter-turns. The right front side air bag and right side HPS deployed as a result of the rollover event. It impacted the inboard guardrail for westbound traffic on the opposite side of the median during the fifth quarter turn. The BMW struck the guardrail with the right side area on the fifth quarter turn and with the hood/top aspect on the sixth quarter turn. The unrestrained driver was fully ejected through the windshield and was thrown across the opposing travel lanes and came to rest on a grassy area adjacent to the shoulder. The BMW came to rest on the median adjacent to the opposing guardrail, upside down and facing north.

Figure 3. View of median and rollover trajectory

Post-Crash

The ejected driver was found by first responders lying on the opposing grassy shoulder and was fatally injured. The front right passenger was removed from the vehicle by rescue personnel and transported by ambulance to a local trauma center and admitted for two days.

VEHICLE DATA - 1998 BMW 528i

The 1998 BMW 528i was identified by the Vehicle Identification Number (VIN): WBADD6323WB (production sequence omitted). The BMW was equipped with a 2.8 liter, 6-cylinder engine, a four-speed adaptive automatic transmission, front and rear wheel disc brakes with anti-lock, engine-speed-sensitive variable-assist power steering, All-Season Traction with Cornering Brake Control, interlocking door anchoring system, a crash sensor that automatically turns on hazard lights, interior lights, and unlocks doors, dual-state frontal air bags, side impact air bags, and side impact HPS. The BMW also had power windows, power locks, power mirrors, and a tilt/telescoping steering wheel which was found in the mid positions. The BMW was also equipped with alloy wheels with Michelin Energy MXV4 225/60R15 tires.

The seating in the BMW 528i was configured with front bucket seats with 10-way power adjustments and adjustable head restraints. The driver's head restraint was in the full-down position and the front right passenger's head restraint was raised 3 cm (1") above the seat back. The rear seating positions were configured with a bench seat with adjustable head restraints for each position and a forward folding center armrest.

VEHICLE DAMAGE

Exterior Damage - *1998 BMW 528i*

The BMW 528i sustained moderate damage as a result of the initial guardrail impact **(Figure 4)**. The bumper fascia was completely separated from the vehicle and the upper radiator support was separated on the right side. The leading edge of the right front fender was crushed rearward and displaced upward. The right front suspension was fractured and the strut, wheel, and control arm were separated. Longitudinal abrasions were present on the rear right aspect of the hood. The right front fender and door sustained longitudinal abrasions with black and yellow transfers which began 74.9 cm (29.5") forward of the rear edge of the right front door and extended 80.0 cm (31.5") rearward. The SCI-revised Collision Deformation Classification for the initial right side guardrail impact was 12-FREE-9.

Figure 4. View of front right damage to the BMW 528i

The BMW 528i sustained severe damage as a result of the rollover **(Figure 5)**. Laterally oriented abrasions were present on the left half of the hood. The left aspect of the hood was displaced 29.2 cm (11.5") to the right. Longitudinal abrasions were present on the full width of the roof, both side rails, and on the rear aspect of the sun roof. The maximum vertical crush on the left roof side rail measured 12.1 cm (4.8") and the maximum crush on the right roof side rail measured 3.8 cm (1.5"). Grass was embedded into the left side rail. The full width of the trunk lid was abraded fore and aft, crushed forward and shifted laterally to the left. Longitudinal abrasions and lateral crush were also noted on the right rear quarter panel, upper right C-pillar, and right rear door which began 71.1 cm (28.0") forward of the right rear axle. The combined direct and induced damage along the right rear side aspect measured 137.2 cm (54.0") and extended rearward to the right rear corner. Six crush measurements were taken along the right rear quarter panel and were as follows: C1 = 25.4 cm (10.0"), C2 = 25.4 cm (10.0"), C3 = 12.7 cm (5.0"), C4 = 15.2 cm (6.0"), C5 = 5.1 cm (2.0"), C6 = 0.0 cm. Grass was present in the left rear quarter panel and diagonally oriented abrasions were present on the left rear door and left rear quarter panel. The left front fender also sustained diagonally oriented abrasions and was crushed downward approximately 13 cm (5") and laterally to the right approximately 8 cm (3"). The SCI-revised CDC for the rollover event was 00-TDDO-4.

Figure 5. View of right side rollover damage

The damage associated with the impact to the median guardrail was moderate. Direct damage was noted on the right upper A-pillar which appeared to be a result of contact with the median guardrail **(Figure 6)**. The direct contact damage began 50.8 cm (20") forward of the right B-pillar and measured 23.5 cm (9.3") in length. The maximum crush on the right A-pillar measured 5.1 cm (2.0"). A second impact was located on the roof side rail. The direct damage on the right side rail began 12.7 cm (5.0") forward of the right B-pillar and measured 29.2 cm (11.5") in length. The SCI-revised CDC for the impact to the median guardrail was 00-RDAN-2.

Figure 6. Damage to the right A-pillar and roof side rail

The left front wheel did not sustain damage. The left rear wheel sustained faint superficial abrasions and the right rear wheel was abraded circumferentially around the outer bead. The left rear tire bead separated from the wheel and both rear tires were deflated.

Interior Damage - *1998 BMW 528i*

Interior damage to the 1998 BMW 528i was severe and attributed to passenger compartment intrusion and passenger compartment integrity loss **(Figure 7)**. Integrity was lost through the windshield, roof glazing, side glazing, backlight, and the left rear door. The windshield laminate was torn along the middle and lower aspects of the right A-pillar. The laminate was split across the windshield header with the bond intact, split along the entire left A-pillar, and split 20.3 cm (8.0") along the base at the left A-pillar. The tempered glazing of the sunroof, backlight, and side doors disintegrated as a result of the crash. The left rear door opened and the trunk latch released during the crash.

Figure 7. Interior view showing windshield integrity loss

Intrusions were documented and were as follows:

Position	Intruded Component	Intruded Value	Direction
11	Left A-pillar	5 cm (2")	Vertical
11	Left B-pillar	11 cm (4")	Lateral
11	Roof	4 cm (2")	Vertical
11	Roof side rail	2 cm (1")	Lateral
13	Right A-pillar	5 cm (2")	Lateral
13	Roof side rail	6 cm (2")	Lateral
13	Roof	8 cm (3")	Vertical
21	Roof	18 cm (7")	Vertical
21	Backlight header	18 cm (7")	Vertical
21	Left C-pillar	26 cm (10")	Lateral
21	Left side rail	13 cm (5")	Vertical
22	Backlight header	15 cm (6")	Vertical
22	Roof	10 cm (4")	Vertical
23	Backlight header	8 cm (3")	Vertical
23	Roof	5 cm (2")	Vertical

Contact evidence from the driver was present in the BMW **(Figure 8)**. The rear view mirror was separated from the mounting point and exhibited body fluid (blood) on the right aspect and hair at the mirror mount. The probable driver ejection path from the vehicle resulted in the 3 cm (1") forward deformation of the upper half of the steering wheel rim, a fracture of the left turn signal arm from the column, left knee contact evidenced by scuff marks on the left aspect of the knee bolster that were located 51 cm (20") left of center and 28 cm (11") below the top aspect, a body fluid (blood) stain on the left side of the bolster, and a possible contact with the left door side impact air bag cover, which was bowed outward.

Figure 8. View of driver contacts

The front right passenger contacted the left upper corner of the glove box evidenced by a diagonal scuff located 27 cm (11") right of center and 23 cm (9") below the top of the instrument panel. He also contacted the right interior door panel evidenced by a diagonal scuff on the pull handle, a black scuff on the bottom aspect of the door speaker cover, and vertical scuffs on the wood trim of the right front door panel.

MANUAL RESTRAINT SYSTEM - 1998 BMW 528i

Manual 3-point lap and shoulder belts were available for all of the seating positions. Both frontal seat belts were configured with sliding latch plates, dual mode locking retractors, buckle pretensioners, and adjustable D-rings located in the mid-positions. The lower anchorages for the seat belt webbing were attached to the seat frames. The buckle pretensioners did not fire in the crash.

The driver's seat belt was not used in the crash, and exhibited several faint wear marks on the latch plate suggestive of very infrequent usage.

The front right passenger's seat belt exhibited faint routine wear marks on the latch plate suggestive of infrequent usage. Heavy load marks were present on the inside surface of the webbing **(Figure 9)**. The latch plate stop button was located 42.5 cm (16.3") above the seat track mount. Black vinyl transfers from the latch plate were located 35.5 cm (14.0") above the stop button and extended upward 7.6 cm (3.0") along the full width of the belt webbing. The bottom side of the webbing was heavily abraded in a slight diagonal pattern with fragments of vinyl collected on the latch plate. Creases in the webbing were present 22.8 cm (9.0") above the lower anchorage and extended 20.3 cm (8.0") upward. White stress marks from occupant loading were present on the inside aspect of the webbing 20.3 cm (8.0") above the stop button, and white stretch marks were present 43.2 cm (17.0") above the stop button. There were no D-ring loading marks or transfers.

Figure 9. View of front right seat belt showing loading evidence

FRONTAL AIR BAG SYSTEM - 1998 BMW 528i

The BMW 528i was equipped with dual-stage frontal air bags for the driver and front right passenger positions. The frontal air bag system did not deploy as a result of the crash. The driver's air bag was housed in the center of the steering wheel with H-configuration module cover flaps. The front right passenger's air bag was located in a mid-mount module on the right instrument panel. The cover flap measured 33.3 cm (13.1") in width and 19.1 cm (7.5") in height.

SIDE IMPACT OCCUPANT PROTECTION SYSTEM - 1998 BMW 528i

The 1998 BMW 528i was equipped with a side impact occupant protection system that included driver's and front right passenger's side torso air bags and driver's and front right passenger's HPS. The front right passenger's side air bag and the right side HPS deployed as a result of the rollover event.

Figure 10. View of deployed front right passenger's side air bag and HPS

The right front passenger's side air bag deployed from the right front door-mounted module that was located above the right front passenger's arm rest. The leather door panel was hinged at the bottom aspect and measured 29.2 cm (11.5") in length on the top aspect, 19.1 cm (7.5") on the in length along the bottom aspect, and 14.0 cm (5.5") in height. The identification sticker on the inside aspect of the cover flap read: "BMW 8212806, >PUR+PA<2". The front right passenger's side air bag measured 44.5 cm (17.5") in width and 26.7 cm (10.5") in height. Tether stitching was present on the inboard center aspect of the air bag in a longitudinal configuration. The stitching measured 29.1 cm (11.5") long, and curled in a downward 5 cm (2") diameter semi-circle fashion on the rear aspect of the air bag face. There was no contact evidence on the surface of the air bag.

The HPS was positioned diagonally across the right front passenger's position at the time of deployment, and extended rearward from the lower right A-pillar at an upward angle to the right roof rails. The nylon tubes were reinforced with Kevlar and were covered with a nylon mesh webbing. A clear plastic membrane cover was present around the HPS which had partially torn due to the deployment. A warning label was affixed to the clear plastic cover regarding the replacement of the deployed HPS. The diameter of the tube measured 12.7 cm (5.0") and the length measured 104.1 cm (41.0"). The tube was tethered by a reinforced rear external strap which measured 33.0 cm (13.0") in length and 2.5 cm (1.0") in width. A lead tube that measured 17.8 cm (7.0") in length was attached to the forward aspect of the HPS and was connected to the inflator that was located in the A-pillar. There were no identifiable contacts to the HPS.

OCCUPANT DEMOGRAPHICS - 1998 BMW 528i

Driver

Age/Sex:	26-year-old male
Height:	183 cm (72")
Weight:	95 kg (209 lb)
Seat Track Position:	Between mid-track and full-rear positions
Manual Restraint Use:	Unrestrained
Usage Source:	Vehicle inspection, ejection
Eyewear:	None
Type of Medical Treatment:	Transported by ambulance to a local hospital and pronounced dead on arrival

Driver Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Mechanism
Cerebrum laceration: dura lacerated in area of fracture in frontal region	Severe (140688.4,9)	Ground
Cerebral subarachnoid hemorrhage over both cerebral hemispheres	Serious (140684.3,1) Serious (140684.3,2)	Ground
Comminuted vault fracture: depressed fracture underlying forehead laceration	Serious (150404.3,5)	Ground
Basilar skull fracture (NFS): fracture lines extend into floor right and left anterior fossae and floor left middle fossa	Serious (150200.3,8)	Ground
Shallow liver lacerations, minor: anterior and posterior surfaces extending up to 3 mm in depth	Moderate (541822.2,1)	Ground
Scalp contusion with extensive galeal hemorrhage	Minor (190402.1,0)	Ground
Left cheek and jaw area abrasions	Minor (290202.1,2)	Ground
Left forehead abrasions	Minor (290202.1,7)	Ground
Abrasion on the right jaw area	Minor (290202.1,8)	Ground
Facial contusions	Minor (290402.1,0)	Ground

Injury	Injury Severity (AIS 90/Update 98)	Injury Mechanism
10 cm (4") laceration extending from above medial right eyebrow across forehead into hairline	Minor (290600.1,7)	Ground
6 cm (2") laceration on the right jaw area	Minor (290602.1,8)	Ground
Large left chest abrasion	Minor (490202.1,2)	Ground
Left upper abdomen abrasion	Minor (590202.1,2)	Ground
Abrasions on the left forearm and dorsal aspects of both hands	Minor (790202.1,3)	Ground
Anteromedial abrasions on the right calf and left thigh	Minor (890202.1,3)	Ground
Multiple left knee lacerations measuring up to 4 cm (2")	Minor (890602.1,2)	Ground

Injury source: Autopsy report

Driver Kinematics

The 26-year-old male driver of the BMW 528i was seated in an upright posture with the seat track adjusted between the mid-track and full-rear positions. The driver was unrestrained. At impact with the guardrail, he initiated a forward trajectory. He was redirected laterally to the right as the vehicle was redirected by the guardrail in a CCW yaw. The unrestrained driver was redirected around the vehicle interior as it initiated the rollover. During the fifth quarter-turn, the out-of-position driver loaded the steering column and the knee bolster, evidenced by the forward deformation of the steering wheel rim, scuff marks and the fracture of the turn signal arm. He was ejected through the windshield, thrown across all three opposing travel lanes, and came to rest on a grassy area adjacent to the shoulder. The ejection and impact with the ground resulted in fatal injuries. He sustained a cerebrum laceration, cerebral subarachnoid hemorrhage over both cerebral hemispheres, a comminuted vault fracture, a basilar skull fracture, shallow liver lacerations, a scalp contusion with extensive galeal hemorrhage, left cheek and jaw area abrasions, left forehead abrasions, an abrasion on the right jaw area, facial contusions, a 10 cm (4") laceration extending from above medial right eyebrow across the forehead into the hairline, a 6 cm (2") laceration on the right jaw area, a large left chest abrasion, a left upper abdomen abrasion, abrasions on the left forearm and dorsal aspects of both hands, anteromedial abrasions on the right calf and left thigh, and multiple left knee lacerations measuring up to 4 cm (2"). He was transported to a local hospital and pronounced dead on arrival.

Front Right Passenger

Age/Sex:	46-year-old male
Height:	183 cm (72")
Weight:	95 kg (209 lb)
Seat Track Position:	Full-rear
Manual Restraint Use:	Manual 3-point lap and shoulder belt
Usage Source:	Vehicle inspection
Eyewear:	None
Type of Medical Treatment:	Transported by ambulance to a local hospital and admitted for two days

Front Right Passenger Injuries

Injury	Injury Severity (AIS 90/Update 98)	Injury Mechanism
Right eyelid contusion	Minor (297402.1,1)	Right side interior surface
Right rib cage contusion	Minor (450202.1,1)	Right side interior surface
Cervical spine strain (whiplash)	Minor (640278.1,6)	Impact force
Right shoulder sprain	Minor (751020.1,1)	Impact force

Injury source: Interview

Front Right Passenger Kinematics

The 46-year-old male front right passenger was seated in an upright posture with the seat track adjusted to the full-rear position. He was restrained by the manual 3-point lap and shoulder belt. The front right impact with the guardrail caused him to initiate a forward trajectory. He loaded the manual restraint, and was redirected to the right as the vehicle initiated the CCW yaw across the travel lanes. The vehicle began to roll and the door-mounted front right passenger's side air bag and right side HPS deployed as the right side of the vehicle impacted the ground. The front right passenger loaded the deployed front right passenger's side air bag with his torso and the deployed HPS with his head which mitigated contact with the roof side rail. The front right passenger's side air bag offered additional occupant protection, and the HPS protected the head from contact with environmental surfaces outside the vehicle. He stated during the interview that he sustained a cervical spine strain (whiplash) and a right shoulder sprain as a result of the impact forces during the rollover. The vehicle continued to roll and the front right passenger remained in position due to the use of the 3-point seat belt. As the BMW entered the fifth quarter turn, the front right passenger was redirected to the right a second time. By that time, the front right passenger's side air bag and HPS had substantially deflated and provided minimal protection. Although the manual restraint allowed the occupant to remain in position, he loaded the right interior door surface which resulted in a right eyelid contusion and right rib cage contusion. He was removed from the vehicle by rescue personnel and transported by ambulance to a local trauma center where he was admitted for two days.

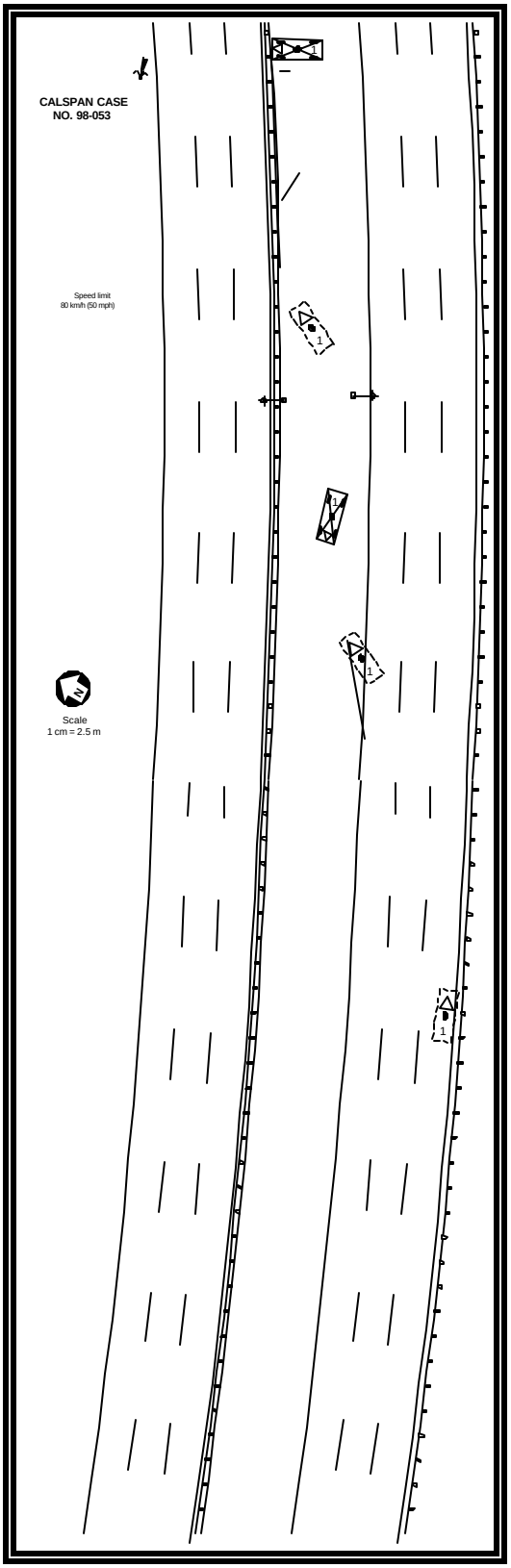

Figure 11. Scene schematic