Journal of the National Academy of Forensic Engineers®

http://www.nafe.org

ISSN: 2379-3252

Vol. 37 No. 1 December 2020

Forensic Engineering Analysis of Projectile Thrown from Phantom Vehicle

By Richard M. Ziernicki, PhD, PE (NAFE 308F), William H. Pierce, PE (NAFE 846C), and Angelos G. Leiloglou, M Arch., (NAFE 956C)

Abstract

This paper presents a case study involving an 8-lb "projectile" piece of concrete thrown from a phantom vehicle into the windshield of a semi-tractor truck, subsequently striking the driver's (plaintiff's) head. A witness told the investigating officer that the phantom vehicle was a white-rear dump truck similar to the trucks he'd seen coming in and out of a construction entrance at a nearby park. However, no follow-up investigation was conducted by investigative officers. The lead author was retained by the plaintiff's attorney to follow up and investigate the witness' observation of the phantom white-rear dump truck in an attempt to identify the probable source of the concrete projectile, locate the phantom vehicle, reconstruct the incident, and determine the probable cause of the incident. Several forensic engineering techniques were used during the forensic engineering investigation, including evidence analysis, photography, high-definition scanning, photogrammetry, evaluation of the accident timeline, physical testing, case study analysis, projectile analysis, and application of the process of elimination methodology. Through the forensic engineering analysis, the probable source of the projectile concrete was identified, the white-rear dump truck and driver were identified, the accident was reconstructed, and the probable cause of the accident was determined.

Keywords

Phantom vehicle, photogrammetry, projectile analysis, high-definition scanning, point cloud, windshield damage, forensic engineering

Introduction

The plaintiff was driving a semi-tractor truck, hauling a load of various manufactured steel product on a flatbed trailer, and traveling southbound on a county road in a rural, rocky area. According to the police report, an 8-lb piece of concrete came off the load of an oncoming, phantom northbound white rear-dump truck, and unexpectedly went through the plaintiff's windshield, striking him in the head. The plaintiff lost control of the semi, and it drifted off the right side of the roadway, struck an electrical pole, and continued traveling to the southwest through an empty field prior to coming to rest. The chain of events, as depicted by the police report, is shown in **Figure 1**. The phantom white rear-dump truck did not stop after the collision.

There was one reported witness to the accident. The witness was initially standing by his shed, approximately 300 ft to the east of the county road. The witness described hearing a thumping sound from a phantom white rear-dump truck he saw traveling northbound on the county road.

After hearing the thumping sound and looking up at the phantom white rear-dump truck for two seconds, the witness continued walking into the shed. Shortly thereafter, lights in the shed went out, the witness looked out the window, and he saw the power pole falling. The witness stated that approximately seven to 10 seconds had elapsed from initially seeing the northbound phantom white rear-dump truck until the power went out. After witnessing the electrical pole falling through his shed window, the witness observed the plaintiff's truck traveling southwest into the field. He got into his truck, and drove to the plaintiff across the street.

When the witness opened the truck's driver-side door, the 8-lb piece of concrete (concrete projectile) that struck the plaintiff fell out of the truck. The witness told investigating officers that he had observed several white dump trucks going into and out of a construction entrance of a park approximately a half-mile to the south of the accident site.

Richard M. Ziernicki, PhD, PE, 7185 S. Tucson Way, Centennial, CO 80112, 303-925-1900, rziernicki@knottlab.com
DOI: 10.51501/jotnafe.v37i1.118

The witness suggested to an investigating officer that there was similar concrete to the concrete projectile used on the construction entrance's vehicle tracking pad — and that the projectile may have been picked up by a white rear-dump truck's dual tires while leaving the construction site. However, the investigating officers ceased any further investigation to the origin of the concrete.

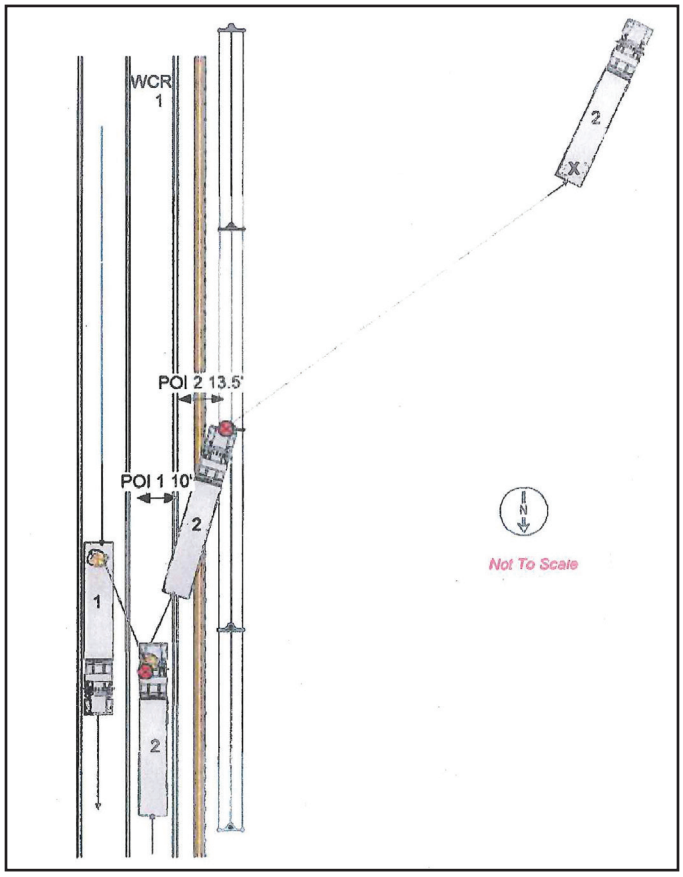

Figure 1
Police diagram of the accident (north facing down). Northbound vehicle one is the phantom semi, and southbound vehicle two is the plaintiff's semi.

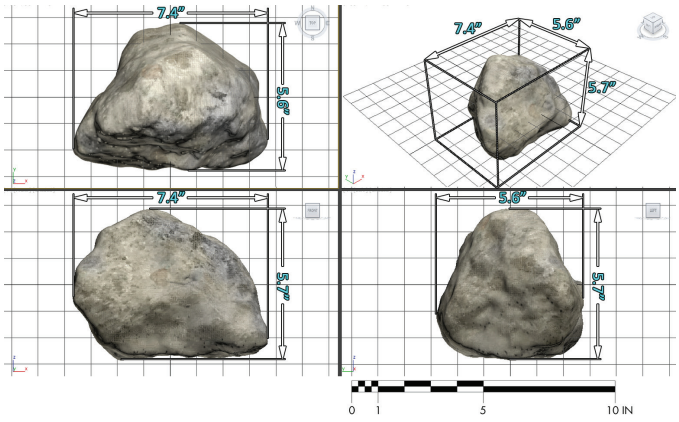

Figure 2
General envelope of the concrete projectile based on HD scans.

Suspected Truck Involved

The plaintiff's counsel identified that there was an active landscaping project at the park identified by the witness at the time of the incident. Through the discovery process, the plaintiff's counsel discovered that there were two white dump trucks traveling to and from the park, delivering loads of compost on the day of the incident. One of the dump trucks was a white side-dump truck; the other was a white rear-dump truck. The white rear-dump truck generally matched the witness' description of the truck heard making the thumping sound prior to the incident.

Engineering Analysis

The lead author was retained by the plaintiff's attorney to follow up and investigate the witness' observation of the phantom white rear-dump truck in an attempt to identify the probable source of the projectile, identify the phantom vehicle, reconstruct the incident, and determine the probable cause of the incident.

Concrete Projectile

The concrete projectile was documented using photography and high-definition (HD) 3D scanning. Six HD scans were taken around the entire surface of the concrete projectile. A virtual model of the concrete with textures was created with a high degree of engineering precision from the HD scans and photographs[1]. **Figure 2** shows the virtual model generated from the HD scans and the general envelope (or overall dimensions) of the concrete. The concrete was, at its widest extents, 7.4 in. by 5.6 in. by 5.7 in. and weighed approximately 8 lb.

Generally, the concrete is elongated and prismatic. One side had soil embedded in several spots (**Figure 3**).

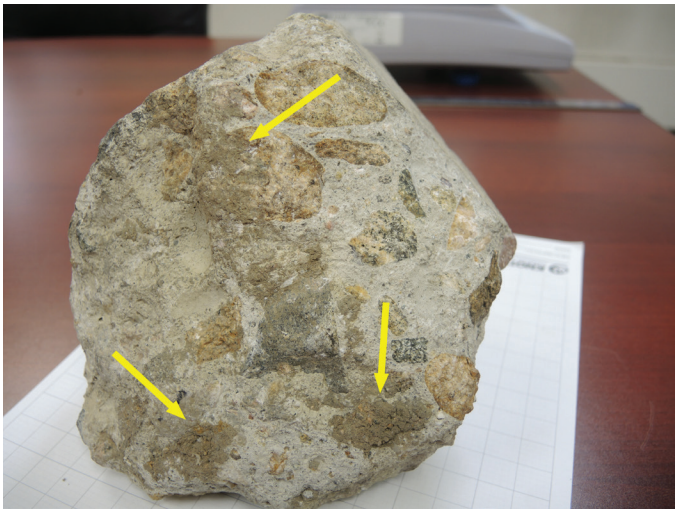

Figure 3
Soil embedded on the face of the projectile concrete.

The presence of soil on only one of the concrete's faces is evidence that the face had initially been resting on soil, and a force was applied on the projectile to embed the soil onto the surface of the concrete. Black residue was also observed on two sides of the concrete. The black residue was primarily found on the two faces that formed a wedge shape opposite of the soil (**Figure 4**).

During inspection of the concrete, a sample of the black material was taken from a section with a heavier concentration of the material. The sample was sent for material identification testing.

A digital microscopy image of the black material is shown in **Figure 5**. The lab analyst visually observed "black material, semi-translucent crystal, and fibers." The lab determined the black material likely contained styrene butadiene rubber, which is a typical elastomer used in the manufacture of tires[2]. The lab also determined that the fibrous material displayed chemical similarities with a compost sample, which was the same type of compost delivered to the park by the two dump trucks on the day of the incident. Therefore, the lab testing showed that there was material that had chemical similarities to tires, and the compost that had been delivered on the day of the incident to the park via dump trucks. A geometric analysis was performed.

Photogrammetry Analysis of Recycled Concrete on Vehicle Tracking Pad

The suspected source of concrete was the construction entrance at a nearby park described by the witness.

Figure 4
Black material observed primarily on two faces of concrete projectile opposite of soil (yellow arrow points to general side of embedded soil).

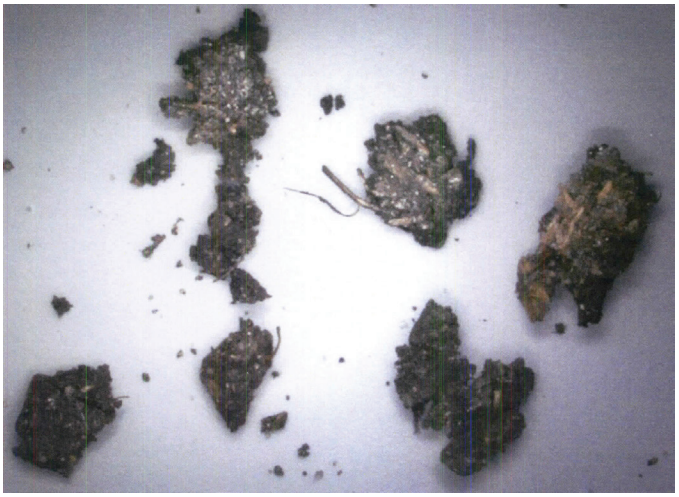

Figure 5
Digital microscopy of the material.

The construction entrance had a vehicle tracking pad comprised of 3-in. aggregate. Next to the vehicle tracking pad was the stabilized staging area, consisting of much larger recycled concrete. **Figures 6** and **7** are photographs of the vehicle tracking pad (VTC) and stabilized staging area (SSA) approximately two weeks before the incident.

The photographs show that, in general, the recycled concrete in the SSA is larger than the material installed on the VTC. However, the photographs also show that recycled concrete from the stabilized staging area overlapped a large portion of the VTC. Therefore, as trucks entered and exited the site, they would have likely run over the larger pieces of recycled concrete from the stabilized staging area that overlapped the VTC.

Figure 6
Photograph of vehicle tracking pad (VTC) and stabilized staging area (SSA) at the park taken by city inspectors, approximately two weeks prior to incident. Yellow arrow shows material in concrete washout area; blue arrow shows material on VTC.

Figure 7
Photograph of concrete washout/SSA and VTC taken by city inspectors on April 22, 2014, approximately two weeks prior to incident. Yellow arrow shows material in concrete washout area; blue arrow shows material on VTC.

The process of photogrammetry was applied to the photographs of the VTC and SSA[3,4,5,6,7]. First, the make, model, and general properties of the camera used to capture the photographs were obtained from each of the image's metadata. After identifying the camera, an exemplar camera was purchased and calibrated. The calibration process was used to correct the digital photographs for lens distortion.

After lens distortion was corrected, control points seen in both photographs and reference points from HD scanning of the park's construction entrance were input into photogrammetry software (**Figures 8** and **9**). Through the photogrammetry process, virtual cameras were created, matching the properties, location, and orientation of the cameras that captured each of the VTC photographs. After solving for the virtual cameras, the modeled virtual concrete projectile was placed within the virtual scene through the perspective of each virtual camera, essentially overlaying the modeled concrete projectile (to-scale) within the photographs over two of the pieces of recycled concrete installed on the VTC prior to the incident.

The virtual concrete projectile overlaid (to-scale) on the photographs is shown in **Figures 10** and **11**. The Figures show that concrete projectile was similar in both size and shape to the recycled concrete installed on the VTC prior to the incident.

Inspection of the Park

During the park inspection, the previous construction entrance was documented using photography and HD scanning. Seven high-definition scans were taken near the entrance. **Figure 12** shows the HD scan of the park.

The construction project had long been completed prior to the inspection, and the vehicle tracking pad was no longer in place. The recycled concrete that had been spread over the VTC during the construction project had been removed prior to the inspection, and most of the inspection area was covered in grass (**Figure 13**).

Near the entrance, there were some protruding sections of recycled concrete embedded within the soil. Our firm observed one piece of recycled concrete above soil level. The aggregates observed on the surface of the recycled concrete sample were of various colors. The authors visually compared the aggregate within the sample piece of recycled concrete and the aggregate within the projectile concrete using inspection photographs. **Figure 14** shows that the aggregate found on the sample's surface was visually similar to the aggregate found on the concrete projectile's surface. Therefore, the recycled concrete found at the accident site had visual similarities to the concrete projectile.

Figure 8
Control points between the two photographs and reference points used to solve for the cameras.

Figure 9
Control points between the two photographs and reference points used to solve for the cameras with the point cloud of the scene.

Figure 10
Projectile concrete overlay (to-scale) on photograph.

Figure 11
Projectile concrete overlay (to-scale) on photograph.

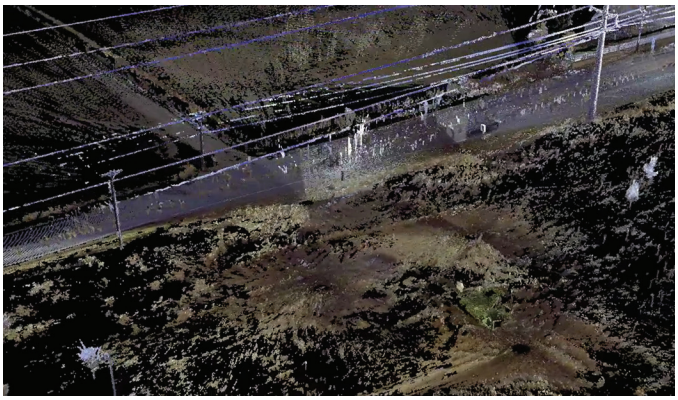

Figure 12
High-definition scanning of the park.

Figure 13
The area where VTC was previously installed is shown here. The circle represents general area that sample concrete was collected during inspection.

Concrete Projectile Fit in Dual Tires

The defendant's dump trailer was documented using photography and HD scanning. At the time of the inspection, for demonstration purposes, a concrete of similar size and shape to the projectile concrete that was obtained at the park was embedded in the trailer's rear left set of dual tires to show that the concrete fit very well in the set of dual tires (**Figure 15**).

Geometrical analysis with a virtual model of the trailer tires and concrete projectile was done to determine how the projectile concrete would have fit within the set of dual tires, matching the areas where the black material was observed on the concrete with where the concrete made contact with the tires (**Figure 16** and **Figure 17**). The analysis also showed how the concrete would have been pressed fit into the set of dual tires (**Figure 18**).

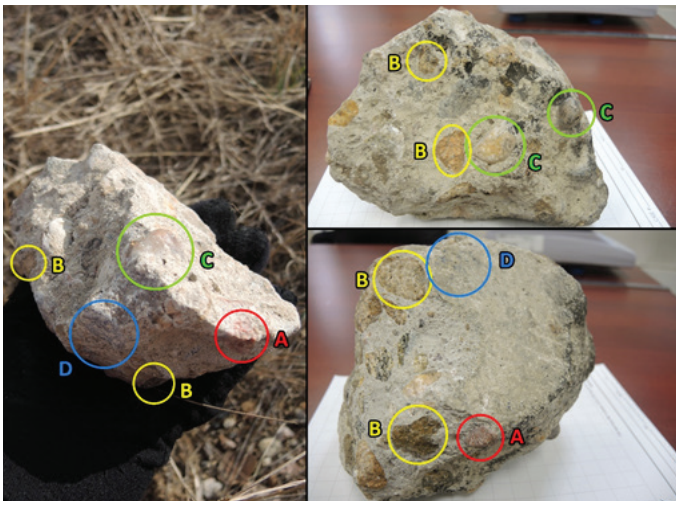

Figure 14
Visual similarities between sample recycled concrete found during inspection (left) and the concrete projectile (right). Colored circles identify areas of visual similarity.

Figure 15
Concrete of similar size and shape as projectile concrete obtained from the park embedded within the defendant trailer rear left set of dual tires.

Concrete Projectile Trajectory Through Windshield

The truck's windshield was severely damaged during the incident. The damage was concentrated near the upper-left most corner of the windshield (**Figure 19**). The damage to the windshield included a hole that was consistent with a spheroid-like object striking and penetrating the windshield. The shape of the hole was generally consistent with the shape of the piece of concrete projectile that fell out of the cab when the witness opened the cab door.

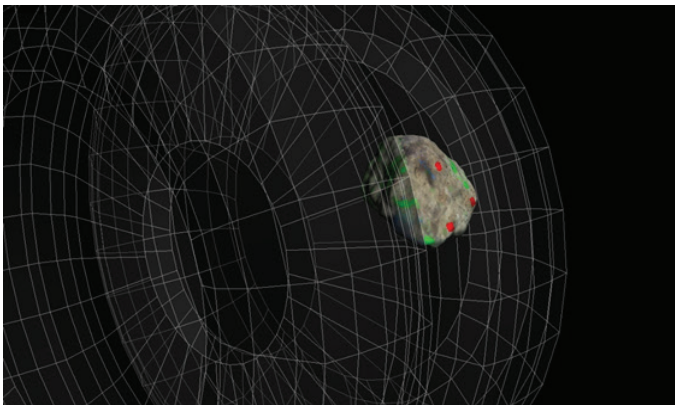

Figure 16
Graphic showing a scaled model of the concrete wedged in scaled dual tires. (Green marks = locations of black material embedded; red marks = locations of soil.)

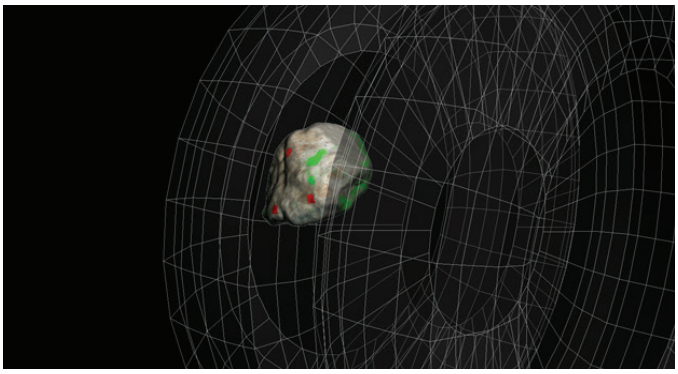

Figure 17
Graphic showing a scaled model of the concrete wedged in scaled dual tires from the other side. (Green marks = locations of black material embedded; red marks = locations of soil.)

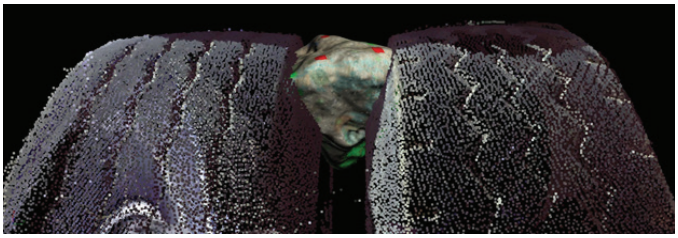

Figure 18
Visualization of the projectile concrete press-fit in HD scan of the dual tires.

There also were concrete fragments found on the rear cab wall (**Figure 20**), and the rear cab wall was dented, consistent with the concrete striking the rear cab wall after striking the windshield and the plaintiff.

The plaintiff's truck was documented approximately two years after the damage had been repaired. During the inspection, the truck was documented using photography and HD scanning. **Figure 21** is the point cloud of the truck.

The HD scans and the process of photogrammetry were used to determine where the concrete entered the windshield, the approximate location of the plaintiff's head, and the location that the concrete hit the rear wall of the cab. As an example, **Figure 22** shows the point cloud of the truck overlaid on the scene image as a result of the photogrammetry process.

After identifying the location of the hole in the windshield, approximate seating location of the plaintiff, and the location of the dent in the rear of the cab, the trajectory of the concrete projectile through the windshield was determined (**Figure 23**). The projectile entered the windshield at a height of approximately 96.6 in. The trajectory shows that the projectile entered from the left (driver's)

Figure 19
Damage to windshield consistent with projectile concrete impact (scene photograph).

Figure 20
Concrete fragments along panel behind driver's seat.

Figure 21
Point cloud of the truck.

Figure 22
Application of photogrammetry to scene photographs using HD scans to determine windshield damage location.

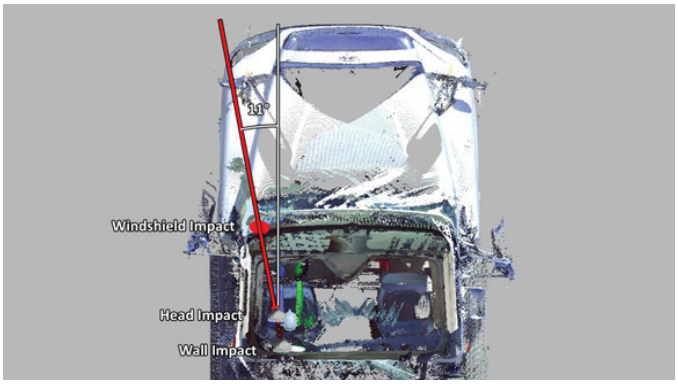

Figure 23
Trajectory of the projectile concrete through the cab top view.

side and traveled both rearward and right relative to the truck. This lateral (left-to-right) trajectory is consistent with the projectile originating in the northbound lane of the county line road, in contrast to coming from the southbound lane of the county line road from a leading vehicle.

As further validation that the concrete had originated in the northbound lane, physical evidence was identified that supported the concrete lateral trajectory angle through the windshield.

The windshield damage pattern and entry hole form a diagonal oval that extends from the left, upward to the right. The oval has a length to width ratio of 1.78 to 1 (**Figure 24**), which is a higher ratio than concrete projectile's length to width ratio. Therefore, the oval in the windshield is elongated compared to the shape of the concrete projectile. The angle, size, and shape of the oval provide insight to the direction that the projectile entered the windshield.

For example, in a shooting reconstruction[8,9,10,11], the lateral component of a bullet projectile's trajectory through a laminated windshield is given by the orientation of an elongated oval formed by the cylindrical bullet in the windshield (**Figure 24**)[12, 13]. The angle of the oval's long axis relative to the windshield's vertical axis is consistent with the lateral component of the projectile bullet's entry velocity. An example of measuring this angle is shown in **Figure 25**.

The example in **Figure 24** shows a windshield from the interior of the vehicle. The bullet hole forms an elongated oval shape. The protractor is aligned with the base parallel to the plane of the front of the vehicle. The angle of the long axis of the elongated oval is approximately 17 degrees to the right, which is consistent with the projectile bullet traveling at a lateral angle of 17 degrees from left to right (**Figure 27**).

This shooting reconstruction method was applied to the physical evidence in the subject incident. The entry oval in the windshield is substantially longer than the longest dimension of the concrete projectile (similar to a cylindrical bullet forming an elongated oval when shot at an angle), and the elongated oval distinctly forms an angle from the left upward to the right (**Figure 24**). Like the example shown in **Figure 26**, this elongated oval shape and angle is consistent with the concrete projectile entering the cab with a lateral velocity component from the left to right side of the cab.

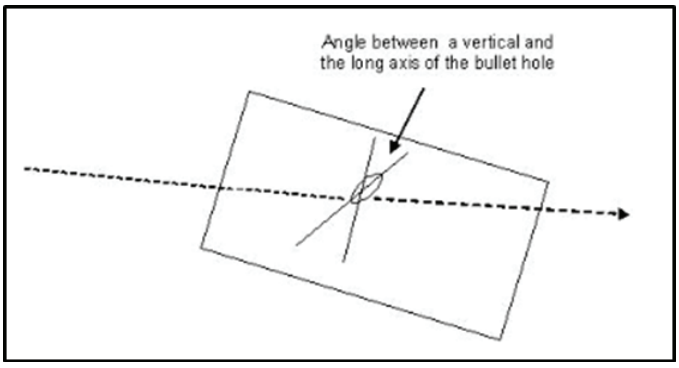

Figure 25
Projectile bullet hole produced in a windshield.
The angle of the oval indicates direction bullet is shot.
Graphic courtesy of Consolidated Consultant Co.

Figure 24
Elongated oval-shaped opening in windshield from
left to upper right. Oval length to width ratio is 1.78 to 1.

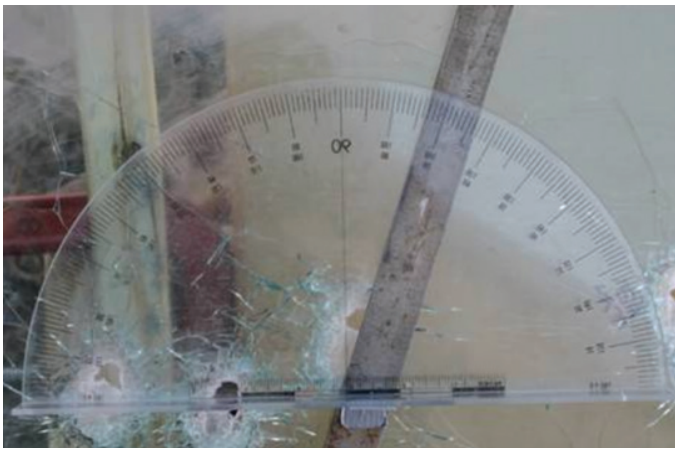

Figure 26
Example of measurement to determine lateral angle.
Graphic courtesy of Consolidated Consultant Co.

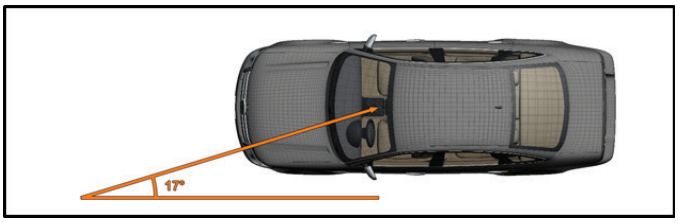

Figure 27
Example of bullet lateral angle through windshield of 17 degrees.
Demonstrative graphic created by the authors.

Defendant Driver Timeline Inconsistencies

According to the defendant driver's deposition testimony, he saw the truck in the field as he was driving northbound on the county line road to the park delivering his first load of compost. Therefore, the defendant driver claimed that the accident occurred prior to his arrival at the park. After dumping his first load of compost, he then drove back southbound on the county line road past the accident site a second time. For the defendant driver's observations to be true, he would have had to have made both observations after 8:45 a.m., when the accident occurred, but before 8:58 a.m., when the county line road was shut down near the accident site as observed by the responding trooper and as recorded in dispatch records. Therefore, the defendant driver had only 13 minutes to do the following:

- Drive southbound approximately 1 minute from the incident scene to the park.
- Wait for the other side-dump truck driver, who, according to the testimony, was finishing dumping a load of compost, to finish dumping the load and drive away from the compost pile.
- Back up to the compost pile, and then dump the load of compost.
- Get out of his truck and check to be sure the load was fully dumped.
- Make a left turn onto northbound county line road and drive approximately 1 minute past the accident scene again.

According to both drivers and the defendant landscaping company's manager, the process of both drivers dumping their loads would have taken substantially longer than 13 minutes. Therefore, the county line road would have likely been closed by the time the defendant driver had approached the scene traveling northbound from the park. From the simple timeline analysis, it is highly improbable that the defendant driver saw the truck in the field as he was driving southbound on the county line road to deliver his first load of compost for the day.

Concrete Drop Testing

Investigating officers first attributed the concrete from falling off the load of a dump truck. Both static and dynamic testing were conducted to test the hypothesis that the concrete could have fallen off the load of the dump truck from a height of approximately 8 ft and rebounded vertically upward back up to 8 ft into the windshield of the truck. Static testing of concrete dropped from a height of 8 ft showed very minimal rebound. Defense experts conducted dynamic testing in which 22 exemplar pieces of concrete were dropped from a height of 8 ft from a moving vehicle traveling approximately 40 mph. The dynamic testing clearly showed that the concrete would only rebound approximately 2 to 3 ft — far lower than the rebounding to the height of 8 ft. Therefore, the static and dynamic testing were evidence that the concrete had not fallen off the load of a dump truck as initially suspected by investigating officers.

Methodology — How the Concrete Projectile Was Thrown into Plaintiff's Windshield

Several hypothetical scenarios were identified to explain how the concrete projectile was thrown into the plaintiff's windshield. The scientific method of deductive reasoning and the process of elimination (inferential reasoning) to eliminate hypotheses that were unreasonable or impossible was used. After eliminating hypothetical scenarios, there was only one scenario that was possible. Based on the process of elimination, the probable scenario was determined.

1. First, the hypothetical of a projectile thrown by a pedestrian was explored. There were no overpasses of which the concrete could be thrown from into moving traffic. Further, there was no suspicious activity of someone throwing rocks into traffic, despite typical busy traffic on the county line road.

The projectile concrete had material similar to tire rubber, which is more consistent with interaction with a tire than with a pedestrian, and fibrous material consistent with compost delivered to the park on the day of the incident. There wasn't any compost observed in scene photographs to suggest the concrete had originated near the incident scene. The lack of reported suspicious activity in the area despite heavy traffic, lack of overhead pedestrian

bridges, and presence of material consistent with rubber and compost on the concrete did not support a pedestrian throwing the projectile concrete at the plaintiff's vehicle. Therefore, the hypothesis that a pedestrian threw the concrete projectile toward the plaintiff's vehicle was eliminated.

2. The hypothesis that the concrete was thrown from a phantom southbound vehicle leading the truck was next. This hypothetical was rejected as the source of the concrete projectile due to the following:

- The horizontal trajectory of the concrete from the windshield to the plaintiff and to the rear of the truck's cab. This lateral (left-to-right) trajectory was consistent with the concrete projectile originating in the northbound lane (**Figure 23**). Therefore, the horizontal trajectory of the projectile concrete through the windshield showed the projectile did not come from the southbound lane, but rather the northbound land.

- The size, shape, and orientation of the hole in the plaintiff's windshield is further evidence that provides validation of the horizontal trajectory analysis. Consistent with the trajectory analysis, the size, shape, and orientation of the hole in the windshield showed that the concrete originated in the northbound lane of travel and was thrown west into the plaintiff's southbound lane of travel.

Therefore, the horizontal trajectory analysis, which was validated by analysis of the size, shape, and orientation of the hole in the plaintiff's windshield was consistent with the projectile thrown from a northbound vehicle.

3. The engineers analyzed whether the concrete was imbedded between dual tires of the defendant's semi prior to ejection toward the plaintiff's head. While the space between non-deflected dual tires is smaller than the general dimensions of the concrete, the flexibility of the tires allows tire to deflect and wrap around the concrete. Evidence of this deflection, in the form of black residue, surrounded opposing wedged faces of the projectile. Lab testing confirmed the black material contained a typical elastomer used in the manufacture of tires. Therefore, the concrete had physical evidence imbedded on its surface consistent with tire rubber. Further, the black material consistent with tire rubber on two opposing wedged faces was geometrically consistent with the concrete wedged between a set of dual tires.

4. The scenario in which the projectile fell off the load of a northbound truck was evaluated. There were multiple reasons that this scenario was improbable:

a. Visual testing of the concrete showed black material consistent with tire rubber (and inconsistent with asphalt) on two opposing wedged faces of the concrete. The presence of the black material was evidence that the concrete projectile had been wedged between a set of dual tires rather than being loaded on a northbound truck.

b. The static and dynamic exemplar concrete drop testing demonstrated that the concrete could not have fallen off the load of a dump truck and rebounded 8 ft into the southbound truck's windshield.

Methodology — Determining the Source of the Concrete Projectile

After determining the path in which the concrete projectile was thrown into the plaintiff's windshield, the probable source of the projectile concrete was determined. There was substantial scientific evidence linking the projectile to the park:

1. In the days preceding the incident as well as the day of the incident, compost had been delivered and dumped at the park by the defendant's dump truck drivers. Independent of any witness testimony, a fibrous material with similar physical and chemical characteristics as the compost was found embedded within the sample of material collected from the projectile concrete.

2. Independent of any witness testimony, the projectile was of similar size and shape as recycled concrete identified in photographs at the park on or near the VTC, as determined through the scientifically validated photogrammetry process.

3. Independent of any witness testimony, aggregate within a piece of concrete found at the park was visually similar to the aggregate in the projectile concrete.

Based on the above evidence, it was concluded that the projectile concrete had come from the VTC at the park.

Methodology for Determining How the Projectile Concrete was Transported

There were two defendant dump trucks traveling to and from the park on the day of the incident: a white rear-dump truck and a white side-dump truck. There were no other dump trucks reported at the park on the day of the incident.

The witness described a white rear-dump truck traveling northbound on the county line road making a thumping noise immediately prior to the incident. There was only one white rear-dump truck operating on the day of the incident. Therefore, through simple deduction, the projectile had likely been transported from the park via the white rear-dump truck.

Photographs taken of the VTC show relatively larger-sized pieces of recycled concrete (similar in size and shape as the projectile) on the VTC's left side closest to the SSA. Therefore, it is likely that the concrete projectile was embedded within a left set of the defendant's white rear-dump truck.

The driver of the white rear-dump truck alleged during his deposition that as he was initially traveling southbound on the county line road toward the park to drop his load, he saw the southbound truck in the field. After this point in time, he testified that he had driven to the park, waited for another dump truck to dump a load, dumped his load, and traveled northbound back past the accident scene a second time. The driver's testimony was considered. However, there was the significant time discrepancy in his testimony that contradicted officer testimony and dispatch records, which showed the road had been closed only 13 minutes after the incident. In comparison, it would have taken an estimated 30 to 45 minutes for the driver of the dump truck to pass the scene again traveling northbound. Therefore, the dump truck driver's testimony was inconsistent with the road closure timing.

Simulations, Visualizations, and Event Timing

Scientific visualizations were created showing the motion of the white rear-dump truck leaving the park and traveling northbound on the county line road, the concrete ejecting from the dual tires into the southbound truck's windshield, and the truck going off road.

The vertical launch angle of the concrete projectile was not known. For visualization purposes, it was assumed that the projectile was ejected rearward from the rear dual tires at approximately 45 degrees and at the tangential velocity of the tire (40 mph). Shortly after launching, the concrete projectile struck the mud flap, causing rapid forward acceleration of the projectile. During the inspection of the truck, the geometry of the mud flaps relative to the rear dual tires and mud flap weights were documented.

A conservation of rotational momentum analysis was conducted to calculate the speed loss of the projectile after interacting with the mud flap. To simplify the conservation of momentum analysis, the mud flap was assumed to be a solid rectangular prism connected with a frictionless pin connection. After impact, the delta-v of the projectile in the longitudinal direction was calculated as approximately 20 mph. An assumption was made that the mud flap decreased the vertical angle by approximately one-half.

The analysis of the concrete projectile being released due to centrifugal force, then impacting the mud flap, losing some energy, continuing rearward and finally striking the windshield of southbound semi, was performed. In other words the concrete hits the flap, loses energy, and continues in the same southbound (rearward) direction.

The analysis was done using conservation of momentum and considered the following: weight of the mud flap, geometry of the mud flap, mud flap moment of inertia (rectangular thin plate), the semi's velocity (wheel rotational angle), ejection angle and position of the mud flap in reference to the rolling wheel, and the resultant ejection height and velocity.

These calculations were not intended to be part of this paper, the author's focus was rather on other innovating technologies, such as high-definition 3D scanning, 3D modeling, simulation, and animation.

A velocity vector diagram was created. The concrete projectile had a rearward velocity component resulting from the initial tangential rearward launch and interaction with the mud flap. The concrete projectile also had an initial forward translational movement, consistent with the speed of the truck (40 mph). Combined, the exit speed of the projectile was approximately 34 mph forward (northbound direction). Based on the lateral trajectory of the concrete projectile, as determined from the physical evidence, the longitudinal and lateral velocities were determined (**Figure 28**).

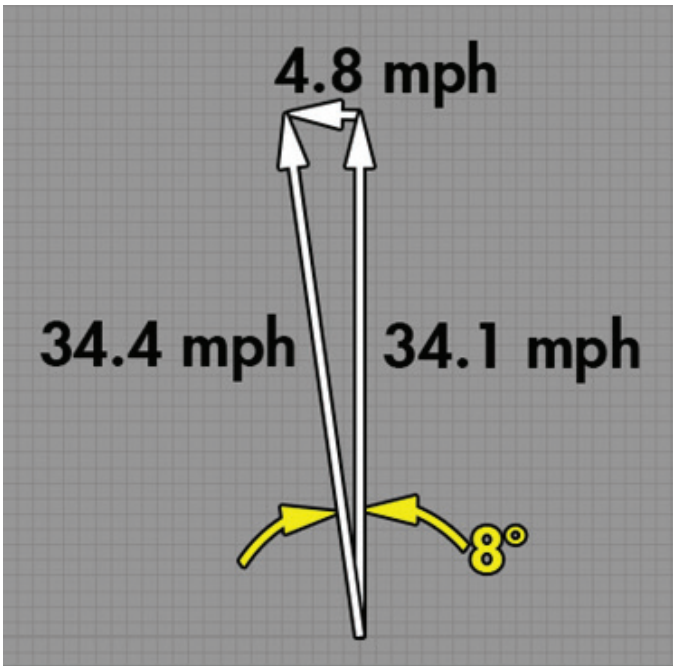

Figure 28
Forward trajectory of the concrete projectile after interaction with the mud flap.

The closing speed of the projectile and the southbound truck, assumed traveling the posted speed limit of 45 mph, was calculated as approximately 79 mph (**Figure 29**). After determining the concrete projectile's trajectory and motion, the motion of the both trucks were simulated in PC-Crash[14].

After calculating the trajectory of the concrete projectile and simulating the motions of both vehicles, scientific visualizations were created. One of the scientific visualizations included showing the trajectory of concrete projectile ejecting from the northbound dump truck and striking the windshield of the southbound truck (**Figure 30**).

A photorealistic scientific visualization showing the northbound dump truck picking up the concrete projectile, driving northbound, the ejection of the concrete projectile into the windshield of the southbound truck, and the southbound truck traveling off the roadway into the field to the west of the roadway was also created using aerial imagery and scene photographs (**Figure 31**).

A scientific visualization was created, showing the field of view of the witness (**Figure 32**). The scientific visualization showed that approximately 11 seconds after the witness first observed the northbound white rear-dump truck making a thumping sound, the southbound

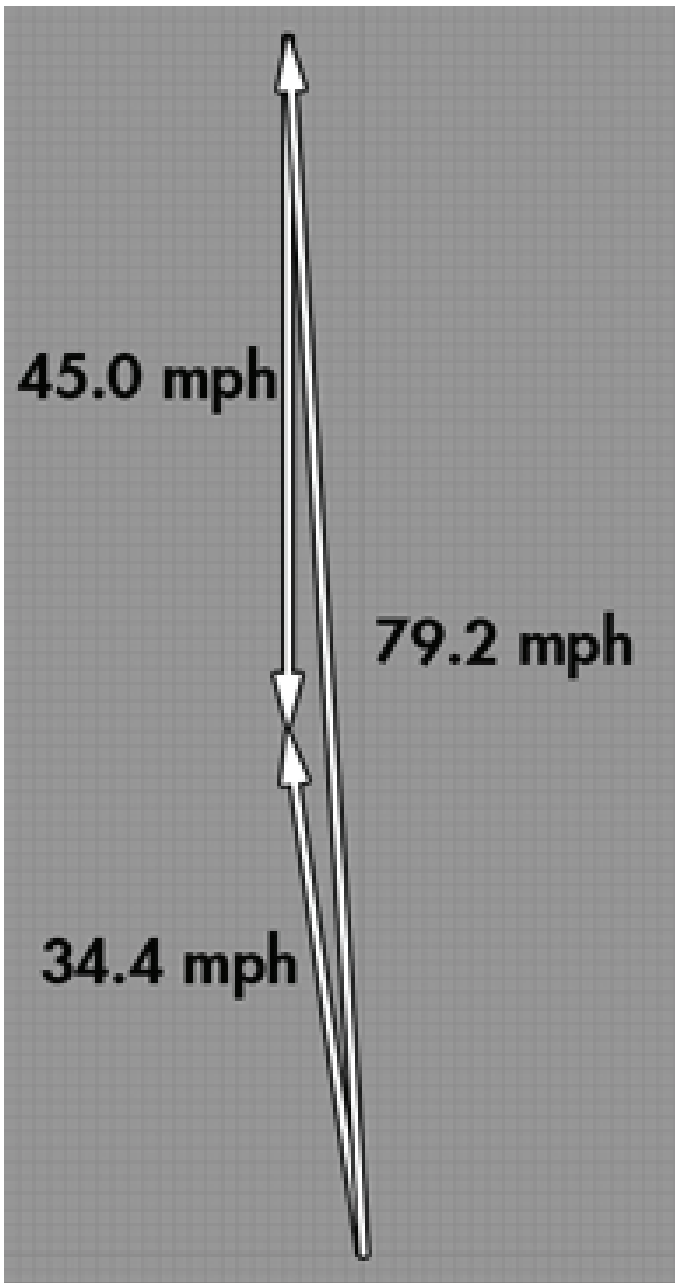

Figure 29
Concrete projectile's closing speed relative to the truck.

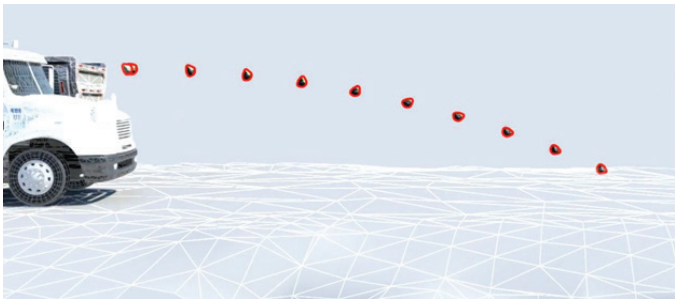

Figure 30
Still frame from scientific visualization showing trajectory of the concrete projectile.

Figure 31
Still frame from photorealistic scientific visualization of accident.

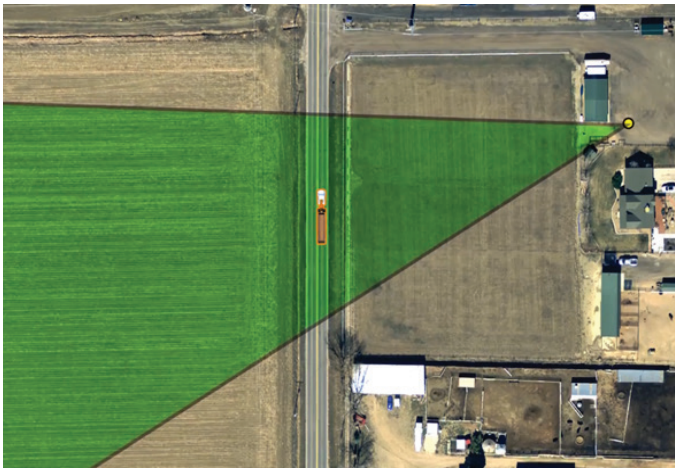

Figure 32
Scientific visualization showing the field of view of the witness.

truck struck the utility pole and knocked out the power to the witness' residence. The reconstructed timing is generally in-line with the witness' estimated time of seven to 10 seconds between him first observing the northbound white rear-dump truck and his power going out. Therefore, the witness's timing of the events is consistent with the projectile ejected from a set of the northbound white rear-dump truck's dual tires.

Conclusion

Based on the forensic engineering analysis presented in this paper, it was concluded that the concrete projectile had originated from the vehicle tracking pad at the park. The white-rear dump truck observed by the witness was confirmed to be a white-rear dump truck that had delivered a load to the park prior to the accident. While the white-rear dump truck was at the park, the concrete projectile became imbedded within the truck's left rearmost dual tires. After the white-rear dump truck left the park, it drove north on the county road. As it was driving, the concrete imbedded within the dual tires made a thumping sound heard by the witness. The concrete ejected from the dual tires of the northbound white-rear dump truck and struck the southbound truck and plaintiff. As a result of the collision, the plaintiff last control of the truck, and the truck drifted west into the ditch, striking a utility pole and knocking out the power to the witness' residence. The truck traveled approximately 470 ft, coming to rest in the field to the west of the roadway.

References

1. L. Wasser, "The Basics of LiDAR – Light Detection and Ranging – Remote Sensing," National Science Foundation [Online]. Available: https://www.neonscience.org/lidar-basics [Accessed: October 28, 2020].

2. Omnexus: The material selection platform, "Styrene-Butadiene Rubber: Complete Technical Guide on SBR and its Features" [Online]. Available: https://omnexus.specialchem.com/selection-guide/styrene-butadiene-rubber-sbr-guide# [Accessed: October 15, 2020].

3. K. Breen and C. Anderson, "The Application of Photogrammetry to Accident Reconstruction," SAE Technical Paper Series, 1986, Paper No. 861422.

4. M. Callahan, B. LeBlanc, R. Vreeland, and G. Bretting, "Close-Range Photogrammetry with Laser Scan Point Clouds," SAE Technical Paper Series, 2012, Paper No. 2012-01-0607.

5. C. Coleman, D. Tandy, J. Colborn, and N. Ault, "Applying Camera Matching Methods to Laser Scanned Three Dimensional Scene Data with Comparisons to Other Methods." SAE Technical Paper Series, 2015, Paper No. 2015-01-1416.

6. S. Fenton and R. Kerr, "Accident Scene Diagramming Using New Photogrammetric Technique," SAE Technical Paper Series, 1997, Paper No. 970944.

7. R. Ziernicki and D. Danaher, "Forensic Engineering Use of Computer Animations and Graphics." Journal of the National Academy of Forensic Engineers, Vol. 23, No. 2, pp. 1-9. Dec. 2006.

8. R. Ziernicki and A. Leloglou, "Newest Technologies Utilized in the Reconstruction of an Officer

Involved Shooting Incident." Journal of the National Academy of Forensic Engineers. (In Print).

9. R. Ziernicki, W. Pierce, and A. Leiloglou, "Forensic Engineering Usage of Surveillance Video in Accident Reconstruction." Journal of the National Academy of Forensic Engineers, Vol. 31, No. 2, Dec., pp. 9-19, 2014.

10. F. Devernay and O. Faugeras, "Straight Lines Have to be Straight: Automatic Calibration and Removal of Distortion from Scenes of Structured Environments," Machine Vision and Applications. Vol. 13. No. 1, 2001.

11. D. Danaher and R. Ziernicki. "Forensic Engineering Evaluation of Physical Evidence in Accident Reconstruction," Journal of the National Academy of Forensic Engineers, Vol. 24, No. 2, Dec., pp. 1-10, 2007.

12. E. Hueske, Practical Analysis and Reconstruction of Shooting Incidents. Florida: CRC Press, 2006.

13. Consolidated Forensic Experts, "Lateral Angle Determination for Bullet Holes in Windshields," 2016 [Online]. Available:http://www.expertwitnessnews.com/lateral-angle-determination-bullet-holes-windshields/ [Accessed 2017 July 5].

14. "PC-Crash (Version 11)," MacInnis Engineering Associates Ltd. [Online] Available: http://www.pc-crash.com/.