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Forensic Engineering Analysis of Fatal Overhead Crane Accident

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Abstract

This paper outlines the forensic procedure and techniques used in the reconstruction and safety assessment of a fatal overhead crane accident. The decedent (a subcontractor) was working as a pipe fitter at a manufacturing plant. At the time of the accident, the decedent had climbed up onto an overhead crane rail to move existing pipework when the crane struck and killed him. This paper presents the application of various techniques/methodologies to reconstruct the complex accident, including 3D HD scanning, drone video imaging, and 3D modeling/principles of photogrammetry to understand how the incident occurred and provide visualizations of the construction project. Safety analysis was conducted by analyzing crane maintenance and operation as well as the duties/responsibilities of the different employers and comparing industrial standards and practices such as OSHA, ANSI, and safety principles.

Keywords

Overhead crane, 3D high-definition scanning, drone video imaging technology, 3D modeling, visualization, safety, OSHA, ANSI, safety, forensic engineering

Introduction

In 2012, the decedent was working as a pipe fitter with laborers from other contractors in the installation of new and large manufacturing equipment at a paper mill plant in Virginia.

On the day of the accident, one of the contracted companies asked the construction manager for pipework to be relocated so the scaffolding could be installed. The construction manager, who was contracted by the plant owner to supervise the new installation of the equipment, directed the decedent's employer (another contractor involved with the construction project) to relocate the pipework. A cross-beam attached to a structural column was interfering with the relocation of the pipework. The cross-beam, which was located approximately 36 ft above the main floor of the plant, was adjacent to one of the travel tracks/rails of an overhead bridge crane (**Figure 1**). The cross-beam needed to be removed for the pipework to be relocated (**Figure 2**). On the same day, another contractor was operating the crane to move around other equipment/materials in the plant.

As the overhead crane was being operated, the decedent was in the process of removing the cross-beam. As the crane was traveling down the plant on the track/rails, it apparently struck the decedent and dragged him in between the crane and the column that the cross-beam was attached to, crushing him in the process. Witnesses to the accident started yelling at the crane operator to stop the crane. The operator momentarily stopped the crane by

Figure 1
Accident location. Cross-beam to be removed pointed out with a green arrow. Overhead crane in the background pointed out with a blue arrow. Overhead crane rail pointed out with a red arrow.

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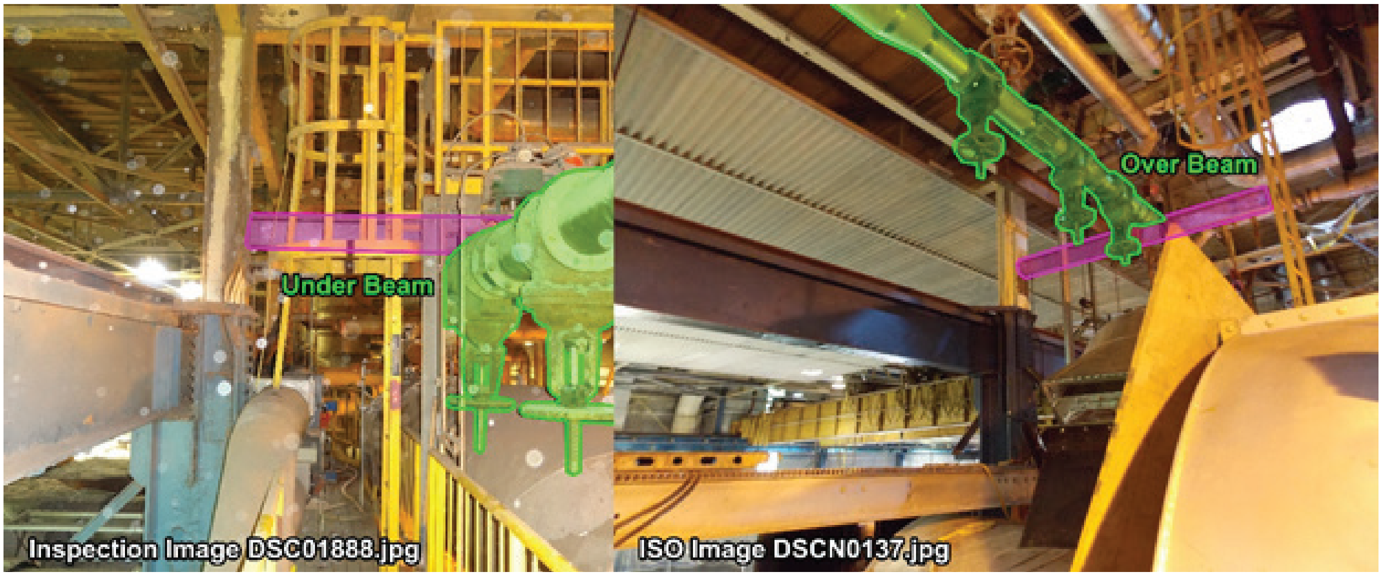

Figure 2
Photographs comparing the location of the pipework and cross-beam after the pipework was relocated (left) and before the pipework was relocated (right). Cross-beam is highlighted in pink; pipework is highlighted in green.

letting go of the controls and was intending to reverse the crane away from the decedent. However, he inadvertently moved the crane forward again instead, further crushing the decedent, who later succumbed to his injuries.

The Virginia Occupational Safety and Health Administration (VOSH) investigated the accident, had the crane tested, and determined that it had too much "drift" after the brakes were applied. The VOSH official determined that based on the testing of the crane's brake system, it should have been taken out of service, and cited the crane/plant owner for operating a crane with a defective brake system. Furthermore, the official found that the parts to fix the brakes were in the plant for some time before the accident, but the plant owner decided to not fix the brakes. The official also found the crane's alarm, which sounds during movement of the crane, was difficult to hear and was ineffective.

In addition, the VOSH official found that the operator was not trained on the crane in question at the time of the accident and was not authorized to operate the crane. Therefore, the crane operator's employer was cited for allowing the operator to operate the crane. The VOSH official also cited the crane operator's employer for failing to properly inspect, notice the brakes were defective, and take the crane out of service for the brake problems.

The plaintiff was the estate of the decedent, and the defendants included the owners of the plant/crane, construction manager, crane operator, and his employer. The purpose of the forensic investigation was to determine whether or not the plaintiff had any contributory negligence in the accident. Virginia law recognizes the pure contributory negligence rule, "which says that a damaged party cannot recover any damages if it is even 1% at fault[1]".

The defendants made claims that the decedent should not have been where he was at the time when he was struck by the crane, that he should have heard and seen the crane coming, and/or that he should have stopped his work and locked out/tagged out the crane from operating before beginning his work.

Methodologies used for this forensic engineering analysis included:

1. Using 3D HD scanning, drone video imaging, analysis of accident scene photographs and 3D modeling of the plant to reconstruct the position of equipment at the time of the incident.

2. Determining the impact location based on physical evidence.

3. Conducting a line-of-sight study to determine whether or not the crane operator could have seen the decedent prior to the accident.

4. Evaluating the maintenance and operation of the crane and the duties/responsibilities of the different contractors by comparing industrial standards

and practices such as from Occupational Safety and Health Administration (OSHA), American National Standards Institute (ANSI), and safety principles.

Reconstructing the Renovation Project in the Plant

It was the manufacturing plant's policy, the crane's operator manual, and the ANSI B30.2 safety standard, "Overhead and Gantry Cranes," that the crane operator must keep the crane's travel track/rails clear of all personnel[2]. The ANSI standard states:

2-3.3.4 Before the lift. Crane Operators shall verify that no worker is on or adjacent to the crane before closing the main switch (Crane Disconnect).

The overhead crane in question was controlled with a remote pendant that extends down from the crane (**Figure 3**) and allows the operator to control the crane from the floor of the plant (also referred to as a "floor-operated" crane). Since the pendant is directly connected to the crane, the operator is required to walk with the crane as the crane is traveling inside the plant. At the same time, the decedent was working 36 ft above the floor.

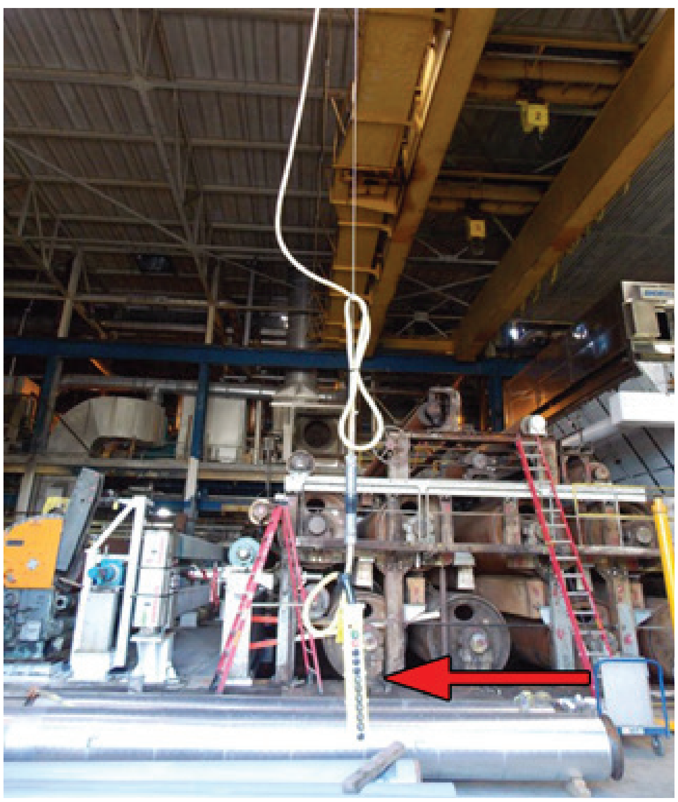

Figure 3
Provided photograph of the overhead crane and remote pendant (pendant point out with a red arrow).

In analyzing this accident, an understanding of the conditions and construction phase of the equipment in the plant at the time of the accident was necessary to determine whether the decedent was observable from the crane operator's point of view. As part of the investigation, the plant was inspected, photographed (**Figure 4**), and was scanned with a high-definition, 3D laser scanner to capture millions of points to define the geometry of the plant and all of the equipment inside the plant. The collected data points were later used to create a 3D point-cloud model of the plant. Due to the size of the plant, the various large machinery/equipment, and limited physical accessibility to various parts of the plant, an aerial drone was flown inside the plant to image and document the equipment. The aerial drone imagery provided information, views, and details that would not be easily accessible to people.

The 3D point cloud model of the plant was then put into a computer-generated virtual 3D space. Since the construction of the large equipment had already been completed at the time of the authors' inspection (years after the accident), photographs taken immediately after the accident by the VOSH official and the construction manager (**Figure 5**) were analyzed to determine which pieces of

Figure 4
Photograph taken during the inspection of the plant.

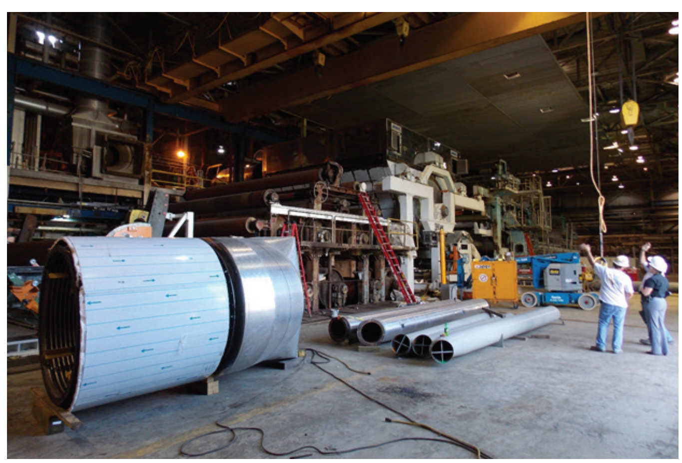

Figure 5
Provided photograph of the plant taken immediately after the accident.

equipment and construction were present at the time of the accident (such as certain ladders, rails, incomplete ductwork, and pipework, etc.). The equipment and materials, which did not exist at the time of the accident, were then removed from the 3D model of the plant. **Figure 6** demonstrates a 3D model of the plant during the inspection — with the pieces of equipment that did not exist or was constructed at the time of the accident highlighted in green. The photographs were also analyzed to determine which equipment and construction existed at the time of the accident but did not exist at the time of the inspection. Computer-generated 3D models of the equipment and construction were then digitally generated. The placement of the modeled equipment in the 3D virtual space was established using principles of photogrammetry, in conjunction with the 3D point cloud model as a reference[3,4,5,6,7,8]. **Figure 7** shows the added computer-generated 3D models of the equipment and construction, placed in the 3D virtual model of the plant, highlighted in red. **Figure 8** is a graphic of the 3D virtual model of the reconstructed accident scene, matching the conditions and phase of the construction at the time of the accident.

Figure 6
Computer-generated 3D virtual model of the plant at the time of inspection. Equipment and construction, which was not present at the time of the accident, is highlighted in green.

Location of the Crash

After reconstructing the accident scene, the location where the decedent was crushed was determined by analyzing evidence found in photographs and the plant's building plans. Photographs taken immediately after the accident showed evidence of blood on the support column. The location of the support beam in photographs taken immediately after the accident and during the forensic inspection were analyzed to determine the location in the building plans. Principles of photogrammetry were then used to determine the location of the decedent in the 3D virtual model of the reconstructed accident scene (**Figure 9**).

Line-of-Sight Study

After reconstructing the accident scene and determining the location where the decedent was crushed, a line-of-sight study was then performed to determine whether or not the operator would have been able to observe the decedent working near the crane's rail before and during the crane operation. The study spatially analyzed at what points in time the decedent was observable to the crane operator as he was walking with the traveling crane.

Figure 7
Computer-generated 3D models of the equipment and construction that was present at the time of the accident, highlighted in red, added into the accident scene virtual model.

Figure 8
Graphic of the computer-generated, reconstructed accident scene, matching the condition and phase of construction at the time of the accident.

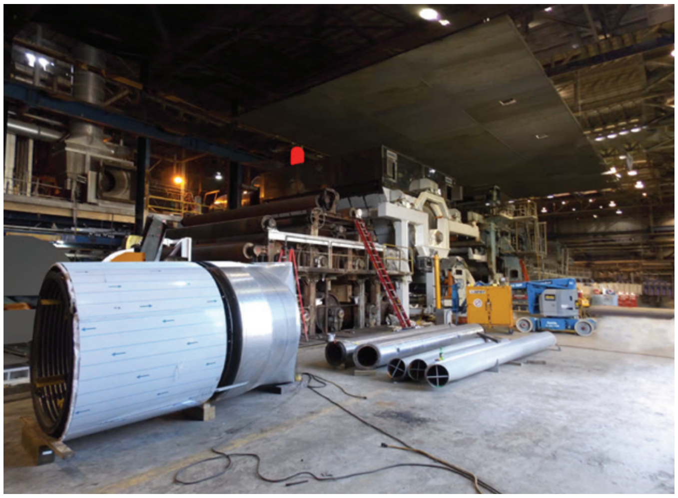

Figure 9
The location where the decedent was crushed, highlighted in red in the reconstructed accident scene.

Figure 10 demonstrates the position of the crane operator and crane, relative to the decedent at a specific point in time. From the line-of-sight study, it was determined that the crane operator would have been able to see the decedent, had the crane operator checked for personnel near the crane's travel tracks/rail before and during crane operation, as required by the ANSI B30.2 standard, the crane operator's manual, and the plant policies.

Figure 11 is a graphic of the reconstructed accident scene from the point of view of the crane operator, showing the decedent was visible to the operator before he operated the crane and for at least 21 seconds before the decedent got crushed, assuming the operator was traveling at an average walking speed. From the line-of-sight study, it was determined that had the crane operator checked for personnel near the crane's travel track/rail, he would have seen the decedent near the crane's travel track/rail,

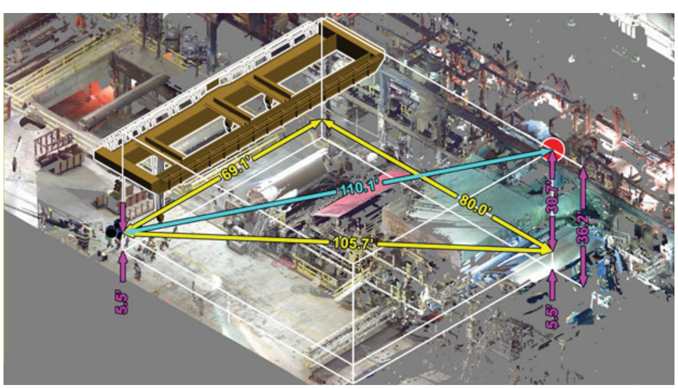

Figure 10
Graphic showing the spatial analysis for the line-of-sight study at a specific point in time. Analysis to determine where the crane operator was spatially located to the decedent.

Figure 11
Graphic showing the reconstructed accident scene from the point of view of the operator 30 seconds before the decedent got crushed. The decedent circled in green.

he would not have operated the crane until the decedent was no longer near the crane rail, and the accident would not have occurred.

Safety Analysis

A safety analysis was conducted by analyzing crane maintenance and operation practices as well as the duties/responsibilities of the different contractors and comparing industrial standards and practices such as OSHA, ANSI, and safety principles.

Improper Work Procedure/Control of Work

The construction manager was the person in charge of the construction project and was (or should have been) aware of all the work that was being done on the day of the accident.

The construction manager tasked the decedent with relocating pipework, knowing that the pipework was near the crane's path of travel and foresaw that the cross-beam that was adjacent to the path of the crane, was going to be removed for the pipework to be relocated. The construction manager also knew the crane was being operated that day. Therefore, knowing that the decedent was working near a crane that was operating that day, the construction manager should have prevented the accident from occurring by using lockout/tagout procedures to prevent the crane from being used, as required by the plant polices and the ANSI B30.2 safety standard, which states:

2-3.8.1(a) A lockout/tagout policy and procedure shall be developed, documented and implemented by the owner *or user of the overhead crane. (c) The policy shall give consideration to the following areas: (7) work to be done other than on a crane but within the path of a crane where its movement creates a hazard.*

Furthermore, there was no evidence that the decedent was aware the crane was going to be used that day — and there was no discussion from the construction manager or other contractors in pre-job "toolbox" meetings that the crane was going to be used that day.

Failing to Put Crane Out of Service

The VOSH official tested the crane after the accident, determined the crane had defective brakes, and concluded the crane should have been taken out of service. The plant/crane owner was aware of the crane's brake problems for months. Two months before the accident, the company that was hired to perform monthly inspections of the crane reported to the plant owner that its brake assembly needed to be replaced. Furthermore, the parts to fix the brake assembly were delivered and were in the plant for some time before the day of the accident. However, the plant owner decided to not put the crane out of service until the renovations work was completed — a violation of Title 29, Section 1910.179 of the *Code of Federal of Regulations* (CFR)[9], which states:

(f)(4)(vii) Brakes for stopping the motion of the trolley or bridge shall be of sufficient size to stop the trolley or bridge within a distance in feet equal to 10 percent of full load speed in feet per minute when traveling at full speed with full load.

and the ANSI B30.2 safety standard, which states:

2-1.12.4(a) A power-driven bridge shall be equipped with either a braking means or have a bridge drive frictional characteristics that will provide stopping and holding functions, under conditions where the rails are dry and free of snow and ice, as follows: (1) have torque capability to stop bridge travel within a distance in feet (meters) equal to 10% of rated load speed in ft/min (m/min) when traveling with rated load.

Furthermore, plant owners were also aware (a month before the incident) that the brake's emergency brake system (E-stop) was not working at the time of the accident. The inoperable E-stop is also a violation of section 1910.179 of the CFR, which states:

(f)(6)(iii) On all floor, remote and pulpit-operated crane bridge drives, a brake of noncoasting mechanical drive shall be provided.

And ANSI B30.2 safety standard, which states:

2-1.12.5(k) When provided an emergency brake shall stop trolley or bridge travel in accordance with the requirements of para. 2-1.12.3(a)(1) or para, 2-1.12.4(a)(1)

Had the crane been taken out of service for the defective brake systems, as required by the CFR and ANSI standard, the crane would not have been in operation — and the accident would not have occurred.

Crane Operator Responsibility

At the time of the accident, the crane operator was not trained nor was he authorized to operate the crane, as required by Section 1910.179 of the CFR, ANSI B30.2 safety standard and the plant policies. The crane operator's unfamiliarity with the crane in question is based upon the several fatal errors he made, which resulted in the death of the decedent. The errors included:

- He did not make sure the crane's track/rail was clear as required by ANSI B30.2 and the plant policy.
- He stopped the crane by letting go of the controls, instead of using the E-stop or plugging (by reversing) to more effectively stop the crane.
- After personnel yelled at him to stop the crane and move it back, he moved the crane forward, toward the decedent, instead of reversing it away from the decedent.

Furthermore, the crane operator's employer did not properly inspect the crane before using the crane as required by section 1910.179 of the CFR, which states:

(j)(2) Frequent inspection. The following items shall be inspected for defects at intervals as defined in paragraph (j)(1)(ii) of this section or as specifically indicated, including observation during operation for any defects which might appear between regular inspections. All deficiencies such as listed shall be carefully examined and determination made as to whether they constitute a safety hazard: All functional operating mechanisms for maladjustment interfering with proper operation. Daily.

Had the crane been properly inspected before the crane was operated as required by CFR, the problems with the crane's brake system would have been observed, and the crane would have been taken out of service. Had this occurred, the crane would not have been used, and the accident would not have occurred.

Decedent's Contribution

The defendants made claims that the decedent should not have been where he was at the time when he was struck by the crane. As discussed earlier, the construction manager put the decedent in a dangerous location by tasking him to work near the crane's path of travel and allowing the crane to be used at the time of the accident. Furthermore, there was no evidence that the decedent was aware the crane was going to be used that day. There was no discussion from the construction manager nor from other contractors in pre-job "toolbox" meetings that the crane was going to be used that day.

The defendants claimed that the decedent should have heard and seen the crane coming. The VOSH official found the crane's travel alarm was ineffective for the decedent to hear the approaching crane. In addition, the decedent was doing the job he was tasked to do and was not aware that the crane was going to be in operation that day.

The defendants claimed that the decedent should have locked out the crane from operating before beginning his work. However, the decedent was not a trained crane operator and had never used the crane in question. Furthermore, he was not aware that the crane was going to be used that day. In summary, the authors concluded that the decedent had no contribution to the accident.

Conclusion

The case study presents an analysis and investigation of a complex accident at a manufacturing plant that had significant changes to its conditions and construction years after the accident occurred. The case study presents techniques/methodologies to reconstruct the accident site using the following technologies and techniques:

1. Reconstruction of the accident scene

To reconstruct the accident scene, 3D high-definition laser scanning and aerial drone imagery were used to document the manufacturing plant. This data was then used to create a computer-generated 3D model of the plant. Photographs taken immediately after the accident were analyzed, and principles of photogrammetry were used to determine which equipment and construction materials did not exist at the time of the accident, so the objects could be removed from the 3D model of the plant. 3D modeling and principles of photogrammetry were then used to create a digital 3D representation of equipment and the phase of construction at the time of the accident.

2. Line-of-sight study

After the accident scene was reconstructed, a line-of-sight analysis was performed to determine that the decedent was visible to the crane operator before and during the operation of the crane.

3. Safety analysis.

A safety analysis was conducted by analyzing crane maintenance and operation practices as well as the duties/responsibilities of the different employers and comparing industrial standards and practices such as OSHA, ANSI and safety principles. Based on the analysis, it was determined the plant owner, construction manager, the crane operator and his employer all contributed to the accident and the decedent had no contribution to the accident.

In closing, the plaintiff's attorneys held three mock trials with jury focus groups. The focus group members soundly rejected the contributory negligence and lack of primary negligence and causation defenses, which helped with the mediation in the case. The focus group also found the 3D visualizations to be especially helpful as it provided a complete and accurate visual account of the accident scene and how the accident happened. One month before trial was scheduled to commence, the case ended with a non-confidential out-of-court settlement for $4.7 million. Furthermore, details of the case were published in an article for the *Virginia Lawyer Weekly*[10].

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