

Use of Human Factor Analysis and Classification System (HFACS) Framework for Assessing Tower Crane Safety in Construction Sites

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Abstract

Crane related accidents in construction have been consistently high and have been a major cause of concern to the regulating agencies. High profile crane fatalities during the recent years have led Occupational Safety and Health Administration (OSHA) to promulgate stricter regulations regarding various aspects of crane safety, including crane operators' and other personnel's certification, and manufacturing of cranes. Although this promulgation may have addressed some of the safety issues directly related to tangible causal factors of crane accidents, very little has been done to understand the underlying causal factors contributing to trigger an accident. Behind the obvious cause of an accident event lie a multitude of latent causes whose culmination leads to accidents. Accidents invariably happen when these latent causes are overlooked, or their combined effects contributing to accidents are not well understood. There are no such frameworks present that analyze the sources of accident factors to their root and underlying causes. Human Factor Analysis and Classification System (HFACS) is a highly effective tool that has been successfully used in the aviation sector to identify the latent and contributory factors that lead to an aircraft accident. In this research study, an attempt has been made to apply this framework in the construction industry using a case of a crane accident in a construction site. It is found that the framework is applicable in analyzing construction accidents, and the contributory factors leading to the crane accident discussed in the paper can be traced back to the roots originating in the organization and the supervisory level.

Keywords

Mobile tower crane, HFACS, Human factor, Safety, Construction

1. Introduction

Use of cranes in construction, especially in high rise construction, has been inevitable to achieve productivity increase and efficiency. Hundreds of tower cranes silhouetting the city's horizon are the common sights in cities enjoying high economic growth. However, with the increasing dependence on cranes for construction operations has also brought about inherent hazards primarily because of the large quantities of energy involved and the human-crane-environment interactions required. Because of this, there is a high potential for damage to occur to people and equipment. Despite the remarkable effort by

regulating agencies such as OSHA to bring about stricter rules in the wake of five high-profile crane accidents that killed 15 people in 2008, accident rates related to crane operations are still high. The proportion of fatalities and injuries that are crane related is difficult to accurately deduce but it has been reported that approximately 30-50 crane fatalities occur in the construction industry per year in the US, with there being a total of approximately 70 crane fatalities across all industries per year (BLS, 2008). This constitutes approximately 25-33% of all construction casualties (MacCollum, 1993).

The safety performance of any crane operation activity is affected by a plethora of varied human, technical, environmental, and organizational factors. Although the apparent cause of any construction accident is generally attributed to a single trigger, very often either due to human error or due to technical fault, it is often the case that the accidents are the result of many latent factors and sub-factors contributing together to trigger an accident. Most models of the incidence of occupational accidents in the construction industry are composed of multiple factors. Although statistical techniques can be used to infer cause-and-effect relationships among these factors, the large number of factors involved and the complexity of the relationships among each other make it difficult for managers to identify potential hazards in construction projects to develop effective safety procedures (Cheng et. al, 2010). Statistical trends in the more recent past indicate that additional research and knowledge are needed about the causation and the preventive measures so that safety professionals can give counsel on how these injuries and fatalities can be further reduced (Manuele, 2008). While there have been research efforts in the past to identify factors affecting safety on construction sites with tower cranes (Shapira and Beny, 2009; Shepherd et al., 2000) and their weightings (Shapira and Simcha, 2009), there is a paucity of analytical methods for analyzing and interpreting the various system risk factors that contribute to the cause of an accident. In a study undertaken by Shapira et al. (2009) to list and weight factors affecting site safety due to tower-crane operation, it was found that Human Factor was the most influential with a weightage of 0.388, followed by Safety Management (0.305), Project Conditions (0.213), and Environment (0.095). While most of the effort to date in the construction industry is directed towards finding a technical fault in the system, there is a lack of study or there is an absence of a framework directed towards analyzing the human related errors causing an accident. Such framework should not only focus at the worker level or the operator level to find the errors leading to an accident, but should encompass all the hierarchy levels of the organization. Human Factor Analysis and Classification System (HFACS) has proved to be a very effective framework for the aviation sector to identify the latent and contributory causes of an air-traffic accident. There is a need for a similar framework in the construction industry too.

2. Literature Review

Congressional Research Service (CRS) Report gives an overview of crane safety in the United States since the OSHA Cranes, Derricks, Hoists, Elevators and Escalators safety standard 29 CFR 1926 Subpart N went into effect in 1971 (Levine, 2008). The OSHA safety standards were minimally revised in 1988 and 1993, leaving them “virtually unchanged” since 1971. OSHA appointed the Crane and Derrick Negotiated Rulemaking Advisory Committee (C-DAC) in 2003. In 2004, the committee voted for an extensive revision of the standard with an emphasis on crane operator certification. OSHA’s Advisory Committee on Construction Safety and Health (ACCSH) approved the draft in October, 2006 (Levine, 2008). The newly drafted OSHA regulations on Crane and Derricks have focused significantly on the technical aspect of crane operation. One should be reminded here that most of the causes of crane accidents originate not in the material or the technical components of the equipment/instrument but originate from human related errors that span across the organization. Therefore, a different approach to analyze the causes of accidents is required to reach at the root cause of such accidents.

The Human Factors Analysis and Classification System (HFACS) identifies the human causes of an accident and provides a tool to assist in the investigation process and target training and prevention efforts (Wiegmann and Shappell, 2001) . It was developed by Dr. Scott Shappell and Dr. Doug Wiegmann, Civil Aviation Medical Institute and University of Illinois at Urbana-Campaign, USA, respectively, in response to a trend that showed some form of human error was a primary causal factor in 80% of all flight accidents in the Navy and Marine Corps. HFACS is based on the "Swiss Cheese" model of human error first presented by Reason (1990), which looks at four levels of active errors and latent failures, including unsafe acts, preconditions for unsafe acts, unsafe supervision, and organizational influences as shown in Figure 1. It is a comprehensive human error framework that folded Reason's ideas into the applied setting, defining 19 causal categories within four levels of human failure.

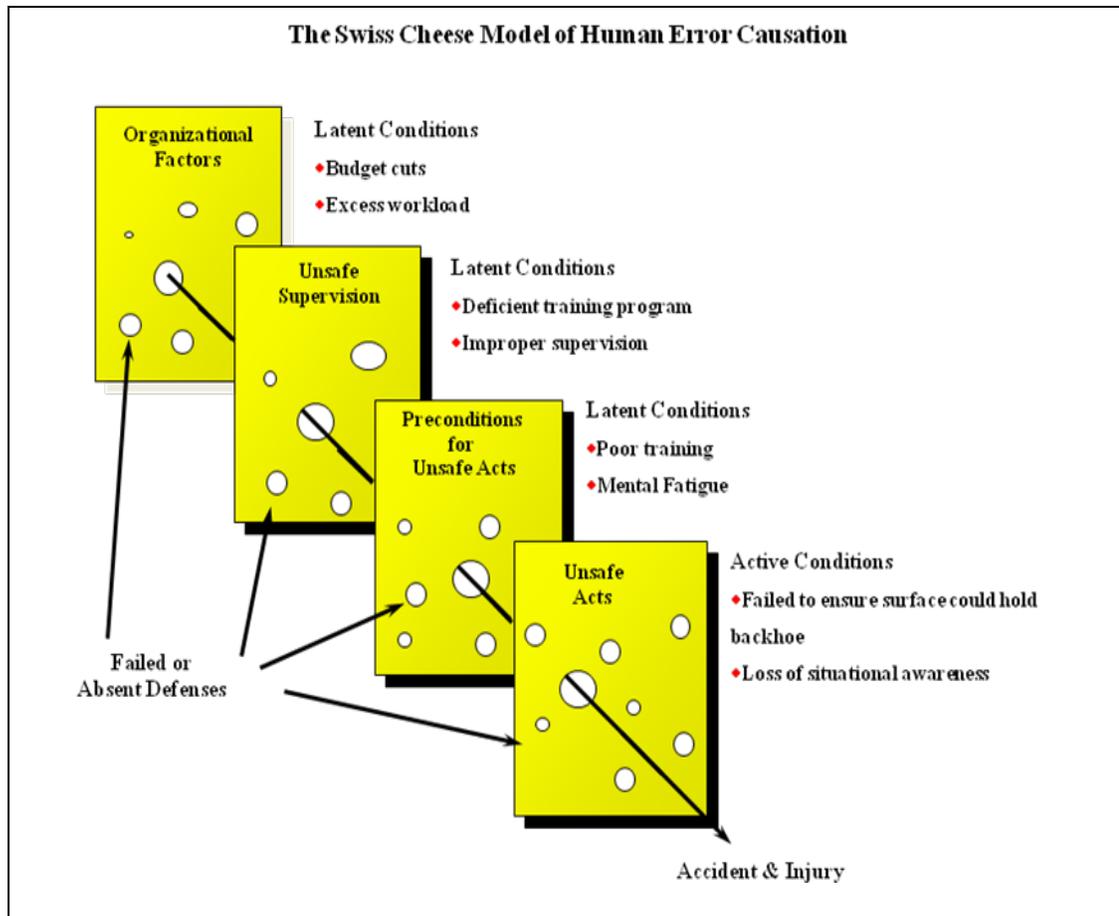


Figure 1: The “Swiss cheese” Model of Accident Causation (Reason, 1990)

3. Research Purpose

Although OSHA has promulgated stricter regulations on crane operations considering the fact that there are so many crane related fatalities over the recent years, it seems that human factor related to crane accidents has not been given due importance it deserves as can be inferred from the recent changes in OSHA regulation regarding cranes. Most of the clauses revised in 29 CFR 1926 OSHA Construction Industry Regulations are related to accident causes other than human factors such as mechanical, operational, environmental, etc. This inadequacy of attention to the human factor of accident causation

could partly be attributed to a lack of understanding of the role of human error in crane related accident analysis. This problem is aggravated by the fact that construction accidents may not necessarily be caused by a single human variable. Behind the obvious cause of accident trigger lie multitude of latent causes whose culmination leads to accidents. Accidents invariably happen when these latent causes are overlooked or their combined effects contributing to accidents are not well understood. There are no such tools to comprehensively classify crane accidents due to human error and to assess the combined effect of all the causal factors contributing to an accident. Given this scenario, it is essential to look into the causes of human error in crane accidents in greater detail, more appropriately with the help of an established human error classification framework, and then assess the collective influence of these factors that trigger an accident. The aim of this research is to see if the well-established frameworks for analyzing accidents due to human error, such as the Human Factor Analysis and Classification System (HFACS), which is widely being used in the aviation sector and other industries, can be applied to analyze accidents in the construction industry.

4. Research Methodology and Approach

HFACS taxonomy has proved very useful for understanding human errors in commercial aviation. The HFACS framework, based on Reason's model of latent and active failures (Reason, 1990) provides a comprehensive framework to investigate the organization at multiple socio-hierarchical levels. The same framework will be utilized in this study to look at the human errors which occur across multiple levels within construction organizations. The proposed research uses the HFACS framework by applying it to a case study of a mobile crane accident. The case study is obtained from NIOSH Fatality Assessment and Control Evaluation (FACE) Program (<http://www.cdc.gov/niosh/face/>) that intends to provide interested users with access to the full text of hundreds of fatality investigation reports. In this study, only a single case of mobile crane accident has been analyzed. However, it is the intention of the authors to identify the relationships between the factors of the HFACS taxonomy by analyzing a sufficiently large number of crane accidents in the future. By doing so, it will be possible to use the HFACS framework as a predictive tool.

4.1 Case Study Summary: Worker Dies When Tower Crane and Water Tower Crash to the Ground (NIOSH FACE Program: Case No.: 00IA031 Report Date: January 2001)

A 29-year-old worker for a water tank company was killed when the partially assembled water tower he was working on was struck by a falling portable tower crane. The man was part of a three-man crew that reconditions and relocates used water towers, this one intended for a small rural Iowa community. An independent crane company was hired to erect supports for the water tower and lift the tank into its final position. This company erected its portable tower crane adjacent to the new foundations for the water tower, as close as possible. After hoisting the tank and while swinging it into position, with just a few feet to go, the rear crane outrigger facing the water tower slipped between cribbing timbers and sank into the ground. The entire tower crane fell towards the water tower, smashing everything in its path. The victim was sitting on a horizontal strut of the water tower base (see Figure 2), approximately 80 feet in the air, preparing to adjust and tighten bracing rods once the tank was in position. Two other workers were injured. Among them one was the member of the tank crew, who was positioned inside the ladder cage for the water tower, and the other one was the operator of the crane, who was sitting inside the control box of the crane 120 feet above the ground. Photo in Figure 2 was taken by a newspaper reporter a few minutes before the crane fell.



Figure 2: Picture of Water Tower Taken a Few Minutes Before the Incident

4.2 Applying HFACS Framework to the Case Study

The HFACS classification system has four hierarchical levels. The hierarchical levels in the HFACS model are:

- i) Organizational influences
- ii) Unsafe supervision
- iii) Preconditions for unsafe acts
- iv) Unsafe acts of operators.

The model assumes that each level above influences the level below it. As shown in Table 1, within each level there are numerous specific types of contributing safety factors. HFACS framework is used to analyze the causal factors (both direct and latent) for the case study summarized above and discussed in detail in the appendix.

Table 1: HFACS Factor/Sub-factor

	HFACS Level	HFACS Factor	HFACS Sub-factor	Applicable to the Case Study
Level 4	Organizational Influence	Organizational process		
		Resource management		√
		Organizational climate		
Level 3	Unsafe Supervision	Inadequate supervision		
		Supervisory violation		
		Planned inappropriate operations		
		Failure to correct problem		√
Level 2	Preconditions for Unsafe Acts	Environmental factors	Physical environment	√
			Technological environment	
		Conditions of operators	Adverse mental states	
			Adverse physiological	
			Physical/mental limitations	
		Personal factors	Crew Resource Management	√
Personal readiness				
Level 1	Unsafe Acts	Errors	Decision errors	
			Skill-based errors	
			Perceptual errors	
		Violation	Routine	√
			Exceptional	

HFACS Level 4: Organizational Influences

Although the investigative accident report does not point to any obvious organization level flaws, most of the accidents like this one are the result of the contributory effects of factors which are latent in the upper level of the HFACS hierarchy. Generally, the most elusive of latent failures revolve around issues that are related to single or a combination of resource management, organizational climate and, organizational process. The water tank company had only three employees. The two workers were positioned in the water tower and the third was giving instructions to these two men from the ground. In the case of these mobile tower cranes, it is very important that the crane set-ups should be closely observed during lifting operations to detect instability caused by changing load and ground conditions. However, in this case, there was no one monitoring these situations. So, it points to the lack of staffing to carry out this relatively risky job. Had there been someone to monitor the ground situation at the tower crane base during the trial lift, the accident could have been prevented.

HFACS Level 3: Unsafe Supervision

In addition to the causal factors associated with the operator, the causal chain of events can be traced back up the supervisory chain of command. As such, the HFACS framework identifies four categories of unsafe supervision: inadequate supervision, supervisory violation, planned inappropriate operations, and failure to correct problem. This case is a clear example of how

failing to correct a recurrent problem will lead to a disaster situation like this. It has been mentioned in the report that the crane company had a fatal accident three years ago while carrying out a similar job. In that case the same type of mobile tower crane was used. Timbers under the outriggers were placed on a recently backfilled soil adjacent to the new windmill foundation, and the timbers sank into the loose soil, causing the tower crane to fall with its hoisted load. The case discussed here follows a similar pattern of accident causation. So, there clearly seems to be a lack of precaution taken from the supervisory level to ensure that the same mistakes were not repeated.

HFACS Level 2: Preconditions for Unsafe Acts

Unsafe acts of operator/worker are invariably attributed to the cause of most of the crane accidents. However, there are always underlying causes of those unsafe acts that can be traced to the preconditions that foster them. The *Preconditions for Unsafe Acts* level is divided into three categories - environmental factors, condition of operators, and personnel factors - and these two categories are then divided into subcategories. Environmental factors refer to the physical and technological factors that affect practices, conditions and actions of individual and result in human error or an unsafe situation. Condition of operators refer to the adverse mental state, adverse physiological state, and physical/mental limitations factors that affect practices, conditions or actions of individuals and result in human error or an unsafe situation. Personnel factors refer to the crew resource management and personal readiness factors that affect practices, conditions or actions of individuals, and result in human error or an unsafe situation. In this case study, physical environment of the accident site can be clearly linked to the precondition responsible for the unsafe act. The soil in which one of the outriggers of the mobile tower crane rested was a backfilled soil which was very unstable and had a very low load bearing capacity. There were not enough provisions made for the base of the tower crane to rest on a stable ground. So, the condition of the site did contribute to a very large extent on the cause of the accident. Another possible precondition for the unsafe act is the crew resource management. From the part of the tank company, there were not enough people to carry out the job safely. There was no one in particular observing the crane set-up during lifting operations to detect instability caused by changing load and ground conditions.

HFACS Level 1: Unsafe Acts

The Unsafe Acts level is divided into two categories - errors and violations - and these two categories are then divided into subcategories. Errors are unintentional behaviors, while violations are a willful disregard of the rules and regulations. The tower crane company responsible for hoisting the water tank had in the past encountered an accident while performing a very similar job. There were no precautions taken in order to avoid a similar overturning situation caused due to unstable soil. Subpart-N of OSHA clearly mentions that "A visual inspection of the crane or derrick, rigging, personnel platform, and the crane or derrick base support or ground shall be conducted by a competent person immediately after the trail lift to determine whether the testing has exposed any defect or produced any adverse effect upon any component or structure." [§1926.550 (g) 5(iv)]. This was obviously not performed in this case. This indicates that the company clearly violated the OSHA regulations. Not only is this an isolated case of violation, but this is a case of repeated violation by the tower crane company.

5. Conclusion and Recommendation

HFACS framework, which was conceptualized based on Reason's "Swiss Cheese" Model of Human Error, has proved very useful for analyzing air traffic related accidents. With the success of this framework in identifying both obvious and latent causes in air traffic accidents, there have been efforts to apply the same framework to other industrial accidents and the outcomes have been quite satisfactory. The effort in this study was to use the same framework in construction operations, specifically applied to crane operations. With the use of this framework, it was possible to identify factors related to human error from an actual crane related accident in construction. In most accident analysis in construction operations, the cause of the accident is usually attributed to the unsafe act of the operator or the worker. Though, it is true that these accidents can be directly related to the operator/worker error, these errors or faults can be traced back to the contributory factors of the supervisors and upper level management. By identifying the real cause of the accident in the way described using a case study in this research, it is then possible to take preventive actions not only at the worker or operator level but also at the upper hierarchy of the organization.

As shown in the case study, the real cause of the accident may not necessarily be at the operator/worker level. There are many latent causes that contribute to the final trigger that leads to an accident. These contributory causes have been traced up to originate in the supervisory level and partly in the organization level. For example, had the water tank company allocated one more staff to oversee the crane setup and the ground condition during the trial lift up operation, necessary preventive measures would have been taken before the actual hoisting operation.

Although a single case of the crane accident has been presented here, the HFACS framework can be used to analyze a pattern of accidents that have occurred over the years in construction industry that involve crane operation. Cases reported and maintained by FACE program of NIOSH can be a good starting point to conduct such analysis.

HFACS framework alone, however, does not qualitatively or quantitatively address the causal relationships between these factors at the same level and at the different levels. In order to establish connections and quantify the relationships between causal factors in this study, a large repository of hard data (accident reports) and experts' belief will be required to assess safety using predictive tools such as Bayesian Belief Network (BBN). BBN provides a probabilistic framework to address and quantify the causal relationships under uncertainty, and has been successfully used in various industrial settings to assess the likelihood of accidents.

It would be useful if the HFACS framework, initially conceived and designed to study the causes behind the air traffic accidents in the military, is modified for the purpose of investigating construction accidents. Air traffic policy makers have learnt a lot from their past mistakes by using such a framework and they have come up with policies to effectively reduce the number of such accidents. With a good accident reporting system in place in construction and with the use of such highly effective accident causation theories such as the one adopted by the aviation sector, it would be possible to reduce the large number of casualties that we have been experiencing in construction industry since a long time.

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Appendix: Case Study (NIOSH FACE Program: Case No.: 00IA031 Report Date: January 2001)

Introduction of the case study

In July 2000, a mobile tower crane fell into an adjacent water tower, causing the death of a 29-year-old man working for a tank company that specializes in the relocation of used water towers. The Iowa FACE program became aware of the incident the next day from local news media and began an immediate investigation. A site visit was planned that same afternoon, and photographs were taken of the construction site, the crane that fell, and the smashed water tower. One investigator conducted this site visit and also returned a week later to make detailed measurements after the crane had been removed from the site. Other information was gathered from newspapers, interviews with the company erecting the water tower, a national internet forum on crane accidents, and other crane companies using this same type of mobile crane. An operator's manual was also obtained. Additional photographs were obtained from reporters who were at the scene immediately prior to and during the incident.

The employer was a small company specializing in the reconditioning and relocation of used water tanks and water towers. The company had been in business part-time for six years, and full-time for the past 15 months. The company had three employees, all three having multiple combined years of experience working with and moving water tanks. Two workers were positioned on the water tower itself, while the owner gave verbal instruction from the ground.

The company had a written safety program, and all three men had gone through safety training for this type of work. Due to the complexity of the work and the unique circumstances of every job, specific written safety instructions were not possible. However, safety was routinely discussed each day on the job. Workers were aware of the risks and wore proper fall-protective equipment, including safety harnesses and shock-absorbing lanyards. The victim had seven year's experience working with water tanks and two year's experience with this tank company. This was the first fatal accident for this tank company.

The crane company, however, had a fatal accident three years ago while erecting a windmill generator on top of a 140-foot column. In that case the same type of mobile tower crane was used. Timbers under the outriggers were placed on recently backfilled soil adjacent to the new windmill foundation, and the timbers sank into the loose soil, causing the tower crane to fall with its hoisted load.

Investigation

The tank company was contracted to dismantle, relocate, and reassemble a water tower, which had been used at a public facility. The reconditioned water tower was to be the water supply for a small rural community, population 250. The total height of the water tower was 127 feet. The water tank had a capacity of 50,000 gallons, was 22 feet in diameter, 23 feet tall, and had an empty weight of 28,000 lbs. Tank company employees considered this a small job, having worked on much larger municipal water tanks in the past.

Two months prior to this accident, a local contractor excavated the area to a depth of 18 feet and structurally filled this area to a depth of 7 feet, all according to engineering specifications received from an engineering firm that specializes in water tower construction. Structural fill dirt, which was trucked in for this, was described as gray brown lean clay trace silt. This fill was compacted to 98 % of maximum, and later tested and certified (at 7 feet below grade), by an

independent engineering firm as suitable for a load bearing capacity of 2000 psf. (pounds per square foot). This was the level where the foundations for the water tower were poured. The next 6 feet of soil was backfilled and compacted to 95 % of maximum, which was never tested, but would likely still retain the 2000 psf. rating. The final 6-12 inches of topsoil was composed of black dirt, which had been scraped off the area prior to excavation. This top soil had no certified bearing load, for it was not compacted, but was simply to allow grass to grow in the area. The mobile crane trailer had difficulty maneuvering in this black dirt and required assistance from the excavation contractor on site. The exposed sections of the four concrete foundations for the tower were 24 feet, 10 inches apart. The four legs of the water tower were bolted to these concrete pads, and horizontal struts and tightening rods were in place to keep the supports square.

The last major construction procedure was to lift the reconditioned water tank onto the legs of the water tower. The in-state crane company was using a portable telescopic-type tower crane with a capacity of 30 tons. It had a platform height of 140 feet with a 50-foot boom, giving the entire crane a height of approximately 188 feet. The last crane from this manufacturer was made in 1980; therefore, this crane was at least 20 years old. It is described as more complicated than other cranes; however, it is well suited to set up and use quickly in urban settings.

The water tank was initially unloaded about 100 feet from the water tower. The crane therefore, was first erected at a suitable location to move the water tank into the proper position for the final lift, adjacent to the water tower legs. During this move, the capacity and reach of the crane was tested by "booming down" or "walking the load", i.e., extending the swing radius to 30 feet, 6 feet farther than would be required for the final lift, which required a swing radius of approximately 24 feet. The tank was kept just off the ground for the test lift in case of overloading. At this time the crane had no difficulty moving the empty tank; therefore, the water tank was placed adjacent to the water tower and the portable crane was moved into position for the final lift the next day. The crane was not tested by "booming down" at this final location prior to the lift.

As mentioned, it was difficult for the semi-tractor to move the crane trailer into position because of the soft topsoil. Photographs show deep wheel tracks from the four sets of dual tires under the heavy trailer. A local farmer with 30 years of farming experience described the soil as "*hard as pavement on top, yet pure gumbo underneath*". He said the soil was very difficult to work; it drained poorly, and retained moisture more than other soils. This jobsite was flat; the ground surface was dry; the temperature was in the 90s, and there was essentially no wind that day. The tower crane was positioned at an angle to the water tower foundations, as close to the water tower as possible. This type of tower crane has four outriggers, two at the front, adjacent to the edges of the trailer, and two outriggers at its rear. The front outriggers are secured to the right and left sides of the transport trailer and have no lateral movement but are hydraulically driven downward to level the crane. The two rear hydraulic outriggers are on 9-foot extended beams, which give a center-to-center distance between these outriggers of 27 feet. These outriggers swing into position manually and then are pinned in place with a steel strut. Each beam is extended hydraulically forcing the outrigger pads downward to level the crane. Each front outrigger was set on two timbers, which were set directly on the ground. The timber dimensions were 85 inches long, 12 to 13 inches wide, and 7 inches tall. Each rear outrigger was set on three of these timbers, which also were set on the bare ground. There was no evidence of an attempt to move the 6-12 inches of topsoil in the area; all outriggers were set directly on this black dirt. The

right rear outrigger was set inside the perimeter of the new water tower, approximately 11 feet from the well opening. No plywood or steel plates were used under the timbers to distribute the load, nor were any bolts or other rigging used to secure the timbers together.

Shortly before the final lift, the water tank was raised a few feet off the ground to clean up the bottoms of the support legs. The photograph taken after the accident shows a glimpse of the outrigger and cribbing timbers that completely failed 20 minutes later. On a closer look at the photo, some details are noteworthy: (1) the ground is not level under the timbers, (2) the cribbing timber to the right has already begun to roll out from under the pad, and (3) there is a space between the right and middle timbers. The appearance of the timbers in this photo is consistent with the final position of them after the accident.

This telescopic mobile tower crane can be controlled from two locations, from an elevated cab within the tower itself at a height of 130 feet, or remotely from the ground. Both positions are equal in their ability to maneuver the crane, and the remote controls are normally used for reasons of safety. For this operation, the crane operator chose to work from the elevated cab position, apparently to more clearly see the signals from other workers located on the water tower. Two men from the tank company were positioned on the water tower itself to help "catch the iron". One was inside the ladder cage at the top of the ladder, to help with final positioning of the tank onto the water tower legs. The other man, the victim, was on a horizontal strut, preparing to position and tighten the Xbracing immediately after the tank was lowered onto the water tower. The owner of the tank company was standing on the ground giving directions to the other two men.

The water tank was raised to about 130 feet then swung over the water tower structure to align it with the base, the procedure lasting approximately 11 minutes. The tank was vertically within 3 to 4 feet of the water tower legs when the right rear outrigger on the tower crane suddenly shifted and sank down between the timbers, causing the tower to fall towards the water tower structure. The soft soil was pushed upwards, the stabilizer arm on the right outrigger snapped, and the outrigger arm swung to the rear of the trailer as the crane began falling. Witnesses report it took several seconds for the crane and tower to fall to the ground, taking nearby power lines with it.

Several people rushed to aid the three men caught in the wreckage. The crane operator was still inside the cab area, conscious, with facial wounds and other injuries. The man inside the ladder cage clung to the ladder when it fell and remained conscious, suffering only a broken ankle. The victim was unconscious and bleeding from head injuries, without a pulse or respirations. CPR was begun by a newspaper reporter and other bystanders and continued until emergency crews arrived. The victim was air-lifted to a hospital, and was pronounced dead shortly after arrival.

The investigation concluded that the tower crane fell directly in line with, and on top of, the right rear outrigger, complete failure of the ground under the right rear outrigger occurring soon after the full load was upon it. Although the top of the ground in the area was dry, deeper soil under the three timbers was wet and soft. The weight of the load squeezed this soil upward between the timbers. There was a depression approximately 18 inches deep in the ground made from the right rear dual tires of the trailer. This depression was evidently made when the outrigger failed and the complete weight of the hoisted load and the crane was momentarily transferred to the trailer before the tower fell flat to the ground.