CAUSE ANALYSIS OF U.S. CRANE-RELATED ACCIDENTS

By

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To my beloved parents and supporting sister

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As one of the most noticeable objects on construction sites and a symbol of modern construction operations, cranes possess the capacity of lifting heavy loads and maneuvering the loads over long spans. When properly located on a site, cranes can strategically lift and lower loads to virtually any desired location on a construction site. Unfortunately, when large numbers of cranes have been dispatched to a construction site, the hazard exposure also increases for construction workers who work with, around or under these cranes.

The recent rash of crane accidents across the United States, and even internationally, has raised the public's awareness of the potential hazards posed by crane use in the construction industry. Many of these crane accidents resulted in fatalities that were investigated by the Occupational Safety and Health Administration (OSHA). This study examined those crane-related fatalities that occurred in the period from 2000 to 2009. During these years, more than 12% of the construction worker fatalities were related to or involved crane operations. Several accidents resulted in multiple fatalities of construction workers.

The more important aspect of these crane-related fatalities is that they were totally preventable if proper safety precautions had been taken and workers are properly equipped with knowledge of hazard self perception. Under pressure from the government and the general public, OSHA decided to replace the long-standing crane safety regulations (CFR Subpart N) with a newly-drafted crane and derrick rule that takes into consideration modern construction site scenarios and newly-introduced building techniques and equipment.

This objective of this study was to examine the descriptions of crane accidents to identify the direct causes and contributing factors of these accidents. A secondary objective was to evaluate the effectiveness of the newly-proposed OSHA crane and derrick rules that aim to minimize the hazard exposure of construction workers. Lastly, this research was undertaken to help develop specific best practices concerning crane operations.

CHAPTER 1
INTRODUCTION

Problem Statement

Every worker who goes to work in the morning deserves to go home safely at night. This statement was made by a mother who lost his son in a crane disassembly accident in February 2009. Her son, who worked as a disassembly worker, had no place to tie off when he was standing on a crawler crane. After the operator started to move the crane, the worker lost his balance and was pulled into the cable rigging and was killed immediately.

As a long-standing problem of construction companies and administrative agencies, the construction industry has a disproportionately large number of injuries and fatalities in comparison to other industrial sectors. Across the United States, construction ranks as the most dangerous industry. The number of construction-related worker fatalities was 816 in 2009, representing almost 20% of all work-related fatalities, according to federal statistics. One of the major causes of fatalities during construction involves unsafe lifting operations that utilize of cranes, which accounts to about 12% of all the construction worker fatalities.

In 1971, OSHA was established and started to specify standards that need to be followed in order to reduce the number of work-related injuries and fatalities. Code of Federal Regulations Title 29, Part 1926 was enacted to specifically address safe operations involving construction activities. Despite these rules and regulations, there are unusually high numbers of construction worker injuries and fatalities. The recent rash of crane accidents across the United States, and even internationally, has heightened the public's awareness of the potential hazards posed by crane operations in the construction industry.

Under the pressure of public's demand of a more stringent crane and derrick safety standards, OSHA released a new standard, addressing the use of cranes and derricks in construction and replacing a decades-old standard. This new standard was aiming to address key hazards related to crane operations on construction worksites, including electrocution, crushed by parts of the equipment, struck-by the equipment/load, and falls.

An examination of the OSHA fatality data from 2000 to 2009 revealed that most of crane-related accidents were preventable if proper safety precautions had been taken and proper techniques had been implemented. Most construction companies have specific safety initiatives and injury-free work-place programs in place, but the threat of crane-related accidents continues to be a concern in the construction industry. This study will examine the major causes and factors that lead to crane-related accidents on construction sites and also explore the best practices concerning specific crane operations.

Scope of the Study

The subject of this study applies to power-operated construction equipment, that is used to hoist, lower and horizontally move suspended loads This includes articulating cranes; crawler cranes; floating cranes; cranes on barges; locomotive cranes; mobile cranes; tower cranes, derricks and other machines when configured to hoist, lower and horizontally move a suspended load.

Because of the strong lifting capacity of cranes, the long span and special assembly/disassembly configurations, workers that operate cranes or work around them could have quite high level of hazard exposure. Some fatal accidents occurred when workers merely walked under the crane. Based on the review of previous research conducted by Beavers and his colleagues (2006), the leading direct causes of crane-related accidents include:

- Failure of boom/cable (Struck or Fall)
- Crane tip over
- Electrocution
- Struck by load (other than boom/cable)
- Worker falls
- Crushed during assembly/disassembly
- Struck by boom/cab/counterweight

This study will first analyze the major direct causes and contributing factors that lead to crane-related accident during construction activities. This will be done by examining OSHA fatality investigation data, then attempt to explore best practices that address typical accident scenarios during crane operations to ensure worker's safety. Also, the most hazardous scenarios identified in this research will be used to compare with the newly-proposed requirements in OSHA's new crane and derrick rule, to critically examine the projected effectiveness of this new safety standard.

Objectives of this Study

- Analyze the direct causes and the contributing factors of crane-related accidents to identify the most typical accident scenarios on construction sites. An attempt will be made to identify trends or patterns of the causation of crane-related accidents;

- Compare the most significant safety hazards in crane operations with the new requirements in OSHA crane and derrick safety rule, to determine the effectiveness of the newly-proposed rule;

- Propose crane operation procedures (best practices) concerning specific operations that will minimize worker's hazard exposure.

CHAPTER 2
LITERATURE REVIEW

Overview

Along with the development of new building technologies, there is an increased need for heavy lifting capabilities to install pre-cast components and various types of building materials. This is especially true for high-rise projects where crane operations are a vital part of the construction process. With heavy lifting capabilities and long spans that can reach remote areas on construction sites, many cranes have been specifically designed to address these needs. This has been made possible with the introduction of high-strength steel in the 1950s (Shapiro and Shapiro, 1988).

There are two basic configurations of construction cranes, mobile cranes and tower cranes. Mobile boom cranes range in size from small, highly mobile cherry pickers, with lift capacities of 15 to 80 tons, to larger models with lifting capacities of up to 1,000 tons and total boom lengths up to 600 ft. (National Safety Council, 1992).

Compared with mobile cranes, tower cranes have their own advantages. They can be located internal or external to a building, may or may not feature a climbing section in their support structure that allows elevation gain as the building under construction increases in height, and they may have a fixed horizontal boom with a trolley-mounted hoist, or a moveable, variably angled-above-horizontal boom with a rigged tip (Shapiro and Shapiro, 1988).

The construction industry in North America has traditionally embraced a mobile-crane culture (Shapira and Glascock, 1996) with the number of mobile cranes in the United States being far greater than the number of tower cranes. Unlike the tower crane, which is essentially a stationary machine, the mobile crane is a self-propelled mobile machine, capable of moving freely on the jobsite or between jobsites.

Although mobile cranes have dominated the North American market, a cultural change appears to be taking place toward a greater use of tower cranes on building projects. Ideal for dense urban environments that have a small footprint, they are available in a growing diversity of sizes and configurations (Shapira et al., 2007).

Construction Industry Statistics

Construction fatalities in the U.S. represent approximately 16% of all workplace fatalities (BLS, 1997). The risk of a U.S. construction laborer being fatally injured at work in any one year is greater than 1:3000 (Shepherd et al., 2000). In 2001, the construction industry had the third highest fatality rate among the nine major economic sectors with 13.3 fatalities per 100,000 workers; exceeded only by agriculture and mining (Department of Labor 2003).

In the United States, construction ranks as the most dangerous industry, representing about 20% of all work-related fatalities. During the year of 2009, the number of fatally-injured workers in the construction industry was 816, far outweighing the total fatality numbers of industries that came in 2nd and 3rd place (Natural Resources and Mining, Manufacturing).

As an integral part of most construction projects, cranes, when properly operated, contribute substantially to the efficient progress of work. However, cranes also have the potential of causing enormous loss of life and property. One of the major causes of fatalities during construction is in the use of cranes or derricks during lifting operations (Beavers et al., 2006). Given the size and power of available cranes, the potential for the loss of property and life with operations utilizing cranes without proper planning and safety procedures is tremendous (Neitzel et al., 2001).

Cranes are normally operated by an operating engineer working with a rigger (who rigs and guides loads) and possibly a signalperson (who guides loads) (Neitzel et al., 2001). The level of safety consciousness and knowledge of safety operations for these operators is critical to ensure the well-being of the entire procedure. In addition, the risk of loss is not limited only to those directly involved in construction operations, as evidenced by several recent crane accidents in which pedestrians were killed. These include accidents involving truck-mounted cranes that visit the site frequently to deliver materials. These cranes are usually operated by the truck's driver, who may not be adequately trained on proper crane operations (Neitzel et al., 2001).

How the Crane-Related Accidents Happened?

There are a large number of safety devices and procedures designed to reduce the potential for crane accidents. Despite this, the number of injuries and fatalities associated with crane operations remains high. Shepherd and his colleagues (2000) examined descriptive taxonomy of 525 U.S. crane fatalities and found crane fatalities are not `freak occurrences'; as they are both predictable and preventable, i.e., the massive loss of human life is unnecessary.

To classify fatality cases, seven mutually exclusive proximal causes of crane-related fatalities and their own contributing factors were proposed by Beavers and his colleagues (2006). These include the following:

- Failure of boom/cable (Struck or Fall)
- Crane tip over
- Electrocution
- Struck by load (other than boom/cable)

- Worker falls
- Crushed during assembly/disassembly
- Struck by boom/cab/counterweight

Based on that research, most of the fatalities studied appear to be due to carelessness or inattention, such as working too close to energized power lines, improper rigging, or lifting loads that exceeded the weight capacities of the cranes. It is not known to what extent “carelessness or inattention” resulted from management pressures to get jobs done quickly or the lack of quality training for workers, supervisors, and “competent persons”.

For the 119 victim occupations identified, only 12 were crane operators, leaving 107 victims (90%) who were riggers, laborers, ironworkers, carpenters, etc. It appears to this researcher that there is a systemic problem in the construction industry: lack of training of those who are often required to work in and around crane lifting operations (Beavers et al., 2006).

In a study that focused on major factors affecting safety in tower-crane environments, Shapira and Lyachin (2009) identified 21 major factors affecting safety in tower-crane environments and categorized them in 4 major groups: project condition related, environment-related, human-related and safety management related (shown in Table 2-1). Among those affecting factors, “Operator proficiency” is the factor that scored the highest degree of Influence. Site safety management, company safety management, blind lifts maintenance management, operator character, signal person experience, and winds were assessed by the experts as “highly affecting” tower-crane-related safety on construction sites. As the newest finding, Vivian and Fung (2011) took the Hong Kong construction industry as an example, and concluded that factors affecting the safety in tower crane operations include: negligence or misjudgment of participants in tower crane operations, inadequate training, subcontracting practices in tower crane operations, and pressure from deadlines.

Some contractors have improper provisions for safe systems of crane operations . Crew members also may have insufficient knowledge of the code of practice which also contributes to the occurrence of accidents.

OSHA Standard Requirements for Crane Operations

Construction worker injuries have broad and adverse impacts, which include the personal suffering of the injured workers, construction delays and productivity losses incurred by the construction contractors, higher insurance premiums that result from costly injuries and possible liability suits for all parties involved in the project (Hinze and Russell, 1995).

The Occupational Safety and Health Administration (OSHA) was established to enforce the general duty clause and the construction safety standards promulgated for the workplace. Considering the pressure from the public and the government, the Occupational Safety and Health Act of 1970 authorized the U.S. Department of Labor to ensure that better safety practices are carried out in places of employment.

In the Code of Federal Regulations Title 29, Part 1926, that pertains to the construction industry, the requirements for crane operations are addressed in three subparts: Subpart N (Cranes, Derricks, Hoists, Elevators, and Conveyors), Subpart O (Motor Vehicles, Mechanized Equipment), and Subpart R (Steel Erection). The requirements enacted in the 1970 version regulation generally stipulated the standard crane procedures for Material and Personnel Hoists, Lifting Operations Under Overhead Power lines, and Hoisting and Rigging during Steel Erection.

Overhead Power Lines (1926.600)

According to Part 1926--Safety and Health Regulations for Construction in Code of Federal Regulation (OSHA, 2010), when the equipment that works in the vicinity of power lines or energized transmitters is parked, the parking brake shall be set. Equipment parked on inclines shall have the wheels chocked and the parking brake set. Exceptions are provided where electrical distribution and transmission lines have been de-energized and visibly grounded at the point of work or where insulating barriers, not a part of or an attachment to the equipment or machinery, have been erected to prevent physical contact with the lines.

For lines rated 50 kV or below, the minimum clearance between the lines and any part of the crane or load shall be 10 feet. For lines rated over 50 kV, the minimum clearance between the lines and any part of the crane or load shall be 10 feet plus 0.4 inch for each 1 kV over 50 kV, or twice the length of the line insulator, but never less than 10 feet. This equates to 10 feet plus a foot of additional clearance for every 30 kV over 50 kV. In transit with no load and the boom lowered, the equipment clearance shall be a minimum of 4 feet for voltages less than 50 kV, and 10 feet for voltages over 50 kV, up to and including 345 kV, and 16 feet for voltages up to and including 750 kV; A person shall be designated to observe the clearance of the equipment and give timely warning for all operations when it is difficult for the operator to maintain the desired clearance by visual means.

Cage-type boom guards, insulating links, or proximity warning devices may be used on cranes, but the use of such devices shall not alter the requirements of any other regulation of this part even if such device is required by law or regulation; Any overhead wire shall be considered to be an energized line unless and until the person owning such line or the electrical utility authorities indicate that it is not an energized line and it has been visibly grounded. Prior to working near transmitter towers where an electrical charge can be induced in the equipment or materials being handled, the transmitter shall be de-energized or tests shall be made to determine if an electrical charge is induced in the crane.

All vehicles in use shall be checked at the beginning of each shift to assure that the following parts, equipment, and accessories are in safe operating condition and free of apparent damage that could cause failure while in use: service brakes, including trailer brake connections; parking system (hand brake); emergency stopping system (brakes); tires; horn; steering mechanism; coupling devices; seat belts; operating controls; and safety devices. All defects shall be corrected before the vehicle is placed in service. These requirements also apply to equipment such as lights, reflectors, windshield wipers, defrosters, fire extinguishers, etc., where such equipment is necessary.

Rigging Equipment for Material Handling (1926.251)

According to Part 1926--Safety and Health Regulations for Construction in Code of Federal Regulation (OSHA, 2010), rigging equipment for material handling shall be inspected prior to use on each shift and as necessary during its use to ensure that it is safe. Defective rigging equipment shall be removed from service. Rigging equipment shall not be loaded in excess of its recommended safe working load.

Each day before being used, the sling and all fastenings and attachments shall be inspected for damage or defects by a competent person designated by the employer. Additional inspections shall be performed during sling use, where service conditions warrant. Damaged or defective slings shall be immediately removed from service.

Several limitations shall apply to the use of wire rope. An eye splice made in any wire rope shall have not less than three full tucks. However, this requirement shall not operate to preclude the use of another form of splice or connection which can be shown to be as efficient and which is not otherwise prohibited. Except for eye splices in the ends of wires and for endless rope slings, each wire rope used in hoisting or lowering, or in pulling loads, shall consist of one continuous piece without knot or splice. Eyes in wire rope bridles, slings, or bull wires shall not be formed by wire rope clips or knots.

Wire rope shall not be used if, in any length of eight diameters, the total number of visible broken wires exceeds 10% of the total number of wires, or if the rope shows other signs of excessive wear, corrosion, or defect.

Hoisting and Rigging During Steel Erection (1926.753)

According to Part 1926--Safety and Health Regulations for Construction in Code of Federal Regulation (OSHA, 2010), cranes being used in steel erection activities shall be visually inspected prior to each shift by a competent person. The inspection shall include the observation for deficiencies during operation. At a minimum this inspection shall include the following:

- All control mechanisms for maladjustments;
- Control and drive mechanism for excessive wear of components and contamination by lubricants, water or other foreign matter;
- Safety devices, including but not limited to boom angle indicators, boom stops, boom kick out devices, anti-two block devices, and load moment indicators where required;
- Air, hydraulic, and other pressurized lines for deterioration or leakage, particularly those which flex in normal operation;
- Hooks and latches for deformation, chemical damage, cracks, or wear;

- Wire rope revving for compliance with the hoisting equipment manufacturer's specifications;
- Electrical apparatus for malfunctioning, signs of excessive deterioration, dirt, or moisture accumulation;
- Hydraulic system for proper fluid level;
- Tires for proper inflation and condition;
- Ground conditions around the hoisting equipment for proper support, including ground settling under and around outriggers, ground water accumulation, or similar conditions; the hoisting equipment for level position; and
- The hoisting equipment for level position after each move and setup.

If any deficiency is identified, an immediate determination shall be made by the competent person as to whether the deficiency constitutes a hazard. If the deficiency is determined to constitute a hazard, the hoisting equipment shall be removed from service until the deficiency has been corrected. The operator shall be responsible for those operations under the operator's direct control. Whenever there is any doubt as to safety, the operator shall have the authority to stop and refuse to handle loads until safety has been assured.

A qualified rigger (a rigger who is also a qualified person) shall inspect the rigging prior to each shift in accordance with § 1926.251. The headache ball, hook or load shall not be used to transport personnel except as provided in paragraph (c) (4) of this section. Cranes or derricks may be used to hoist employees on a personnel platform when work under this subpart is being conducted, provided that all provisions of § 1926.1431 (except for § 1926.1431(a)) are met.

Newly-Proposed Cranes and Derricks in Construction Final Rule

Construction fatalities continue to occur in the construction industry in spite of the OSHA's comprehensive safety standards specified in Title 29, Part 1926, of the Code of

Federal Regulations (Ringen and Stafford 1996). Current OSHA crane regulations were enacted approximately 40 years ago, and have long needed updating (Peraza and Travis, 2009).

The recent rash of crane accidents across the United States, and even internationally, has raised the public's awareness of the potential hazards posed by crane use in the construction industry (Peraza and Travis, 2009). In July, 2010, OSHA released a historic new standard, addressing the use of cranes and derricks in construction and replacing a decades-old standard. The significant number of fatalities associated with the use of cranes and derricks in construction and the considerable technological advances in equipment since the publication of the old rule, issued in 1971, led the Labor Department to undertake this rulemaking.

As subpart CC of the Code of Federal Regulations Title 29, Part 1926 (Construction), this new standard will address key hazards related to cranes and derricks on construction worksites, including the four main causes of worker deaths and injury, including electrocution, crushed by parts of the equipment, struck-by the equipment/load, and falls.

The standard procedure for crane and derrick operation must be developed by a "qualified person" and must satisfy a number of specified requirements, such as providing adequate support and stability for all parts of the equipment, and positioning employees involved to minimize exposure to any unintended movement or collapse.

For crane assembly and disassembly operations, the new standard requires that the procedures used by employer must be developed by a "qualified person" and must satisfy a number of specified requirements, such as providing adequate support and stability for all parts of the equipment, and positioning employees involved to minimize exposure to any unintended movement or collapse. Also, the rule requires the work to be directed by an A/D (Assembly/Disassembly) director. The A/D director must meet the criteria for both a “competent person” and a “qualified person”. In addition, the A/D director must also address hazards associated with the operation, including 12 specified areas of concern: site and ground conditions, blocking material, proper location of blocking, verifying assist crane loads, boom and jib pick points, center of gravity, stability upon pin removal, snagging, struck by counterweights, boom hoist brake failure, loss of backward stability, and wind speed and weather.

The new standard also includes requirements concerning operator qualification and certification. To go through the certification process, the crane operators must take a written examination that includes the safe operating procedures for the particular type of equipment the applicant will be operating and technical understanding of the subject matter criteria required. Except for the written exam, a practical exam must be taken that demonstrates that the applicant has the skills needed to safely operate the equipment, the ability to properly use load chart information and recognize items required in the shift inspection .

The new standard also requires the assessment of the qualifications of the rigger and signal person. A qualified rigger is a rigger who meets the criteria for a qualified person. Employers must determine whether a person is qualified to perform specific rigging tasks. Each qualified rigger may have different credentials or experience. A qualified rigger is a person that:

- Possesses a recognized degree, certificate, or professional standing, or
- Has extensive knowledge, training, and experience, and

- Can successfully demonstrate the ability to solve problems related to rigging loads.

Since each load that requires rigging has unique properties that can range from the simple to the complex, employers must make sure the rigger can do the rigging work needed for the exact types of loads (such as structural components or unstable, unusually heavy objects) and lifts for a particular job with the equipment and rigging that will be used for that job.

For the signal person qualifications, a signal person is considered qualified if the following is demonstrated:

- Knows and understands the type of signals used at the worksite.
- Is competent in using these signals.
- Understands the operations and limitations of the equipment, including the crane dynamics involved in swinging, raising, lowering and stopping loads and in boom deflection from hoisting loads.
- Knows and understands the relevant signal person qualification requirements specified in subpart CC (1926.1419-1926.1422; 1926.1428).
- Passes an oral or written test and a practical test.

According to OSHA, this final standard is expected to prevent 22 fatalities and 175 non-fatal injuries each year.

Table 2-1. Factors affecting safety on construction sites with tower cranes (Shapira and Lyachin, 2009)

Group	Factor	Definition
Project Condition	Obstacles and congested site	Obstacles within the crane's work envelope; crowded site
	Power lines	Overhead power lines located within the crane's work envelope
	Blind lifts	Obstruction of work (loading, unloading, travel) zone from operator view
	Overlapping cranes	Overlapping work envelopes of two or more cranes
	Sight distance and angle	Sight distance and angle from loading/unloading zones, as determined mainly by height of cab
	Cab ergonomics	Ergonomic level of operator cab for work convenience
	Length of work shift	Overtime (commonly into the Night) as an indication of operator's and ground crew's fatigue
	Multiple languages	Different languages used on site by operator and by ground crew
	Operator aids	Optional operation aids, in excess of standard aids required by safety regulations, for increased safety
	Type of load	Type of load, including rigging method
Environment	Winds	The effect of winds mainly on the lifted load but also on the crane itself
	Weather	Extreme temperatures and other weather phenomena (excluding winds)
	Visibility	Poor visibility (mainly of operator but also of others on site)
Human Factor	Operator proficiency	Experience and proficiency of crane operator
	Operator character	Behavioral patterns and mental capacity of the crane operator
	Employment source	Crane operator is on the construction company's staff or is outsourced
	Superintendent character	Behavioral patterns and mental capacity of the superintendent
	Signalperson experience	Experience of workers employed for signaling and rigging
Safety Management	Site-level management	Safety management at the site level
	Company-level management	Safety policy and management at the company level
	Maintenance management	Maintenance level of the crane and lifting accessories

CHAPTER 3
METHODOLOGY

The Bureau of Labor Statistics (BLS) reported that during the year of 2009 the construction industry (including private and public sector) had 816 cases of fatal occupational injuries. This exceeds the combined total number of the second and third highest industries on the fatal occupational injuries list (Natural Resources and Mining and Manufacturing). Hazardous crane and derrick operations were no doubt one of the major causes of construction worker fatalities.

OSHA was created through the passage of the Occupational Safety and Health Act (OSH Act in 1970). “Since then, occupational death rates in the US have been cut by 62% and injury rates have declined by 42%” (OSHA 2009). However, in spite of the Occupational Safety and Health Administration’s comprehensive safety standards specified in Title 29, Part 1926, of the Code of Federal Regulations, numerous fatal accidents continue to happen in the construction industry.

By reviewing the Code of Federal Regulations (Title 29, Part 1926), Subpart N (Cranes, Derricks, Hoists, Elevators, and Conveyors), Subpart O (Motor Vehicles, Mechanized Equipment) and Subpart R (Steel Erection) were identified as the three subparts that address crane or derrick lifting and hoisting operations.

New types of cranes or certain crane operation techniques were introduced along with the growth of the construction industry after 1971 when the original version of the crane and derrick rule became effective. The potential hazard incurred by these newly-introduced crane models and changes in building techniques might be the reason that numerous crane-related fatal accidents have occurred. Another explanation for the large number of fatal injuries that occurred in construction might be that the requirements enacted in the Code of Federal Regulations (Title 29, Part 1926) had not been fully implemented in the work place due to different understandings or lack of attention. Thus, the first stage of this research will focus on identifying the direct causes of crane-related fatalities and also the contributing factors of crane-related accidents by reviewing and categorizing fatality data obtained from OSHA's Integrated Management Information System (IMIS). Then, in the second stage, the predominant causes and factors will be examined to compare with the newly proposed OSHA crane and derrick standard. This will be done to critically examine the effectiveness of this newly-proposed crane and derrick standard. Finally, during the third stage, best practices for crane operations will be proposed based on the previously identified typical accident scenarios on construction sites to alleviate the opportunity of serious crane-related accidents, and to equip workers with adequate knowledge for self protection.

Phase 1 OSHA Fatality Data Review and Categorization

The first part of this research dealt with the categorization of the causes of the fatal accident records contained in OSHA's Integrated Management Information System. This database included records of 8042 fatalities that occurred in the inclusive years of 2000 to 2009. A text search was conducted of the narrative information available in the database. Key words such as “crane”, “derrick” and “boom” were used to locate relevant fatality cases involving crane operations. There were 445 fatality records in the fatality database that contained the word “crane”. In addition, 18 records were found that contained the keyword of “derrick”, and 382 fatality records were identified by searching with the keyword of “boom”. Because of data duplication or no correlation between crane operation and the occurrence of the accident, some fatality cases were eliminated after the initial screening. A total of 571 relevant crane fatality cases were ultimately identified for use in this research.

After identifying the relevant fatality records in the database, a two-dimensional categorizing standard was introduced to further examine and categorize all the fatal accident cases. By referring to relevant literatures concerning causes of crane operation related fatality, it is found that seven mutually exclusive proximal causes of crane-related fatalities were used for classifying the case files in research done by Beavers and his colleagues (2006). After initial screening of OSHA's fatality data, researcher found that in some crane-related cases, workers were actually not struck by boom, cab, counterweight or crane's load. Striking by falling or unstable materials were the direct causes of worker's death. It was necessary to add another direct cause--struck by object (other than Load or Equipment) to the total seven causes identified in the study conducted by Beavers and his colleagues (2006). Thus, the following eight mutually exclusive direct causes of crane-related fatalities were used as the first dimension of the categorizing standard to examine the fatality case files:

- Failure boom/cable (Struck by or Fall);
- Crane tip over;
- Electrocution;
- Struck by load (other than boom/cable);
- Worker falls;
- Crushed by equipment during assembly/disassembly;
- Struck by or caught in/btw by heavy equipment (cab/boom/counterweight); and
- Struck by object (other than Load or Equipment).

Researcher prepare to choose these 8 mutual exclusive direct causes that leads to the fatal accidents as the first dimension of the categorizing standard, such as hit by failure boom/cable, electrocution or struck by load.

On the other perspective, in a previous research conducted by Shapira and Lyachin (2009), 21 contributing factors affecting safety in tower-crane environments were identified. After added 7 other contributing factors to this list, researcher further categorized them into 5 major groups, which are project conditions related factors, environment related factors, human factors, safety management related factors, and other factors. The specific factors in each category are:

- Project conditions related factors: Obstacles and congested site, Failure to maintain power line clearance, Blind lifts/operation, Overlapping cranes, Sight distance and angle, Cab ergonomics, Length of work shift, Miscommunication or Multiple languages, Operator aids, Overload (Load's weight), Load with irregular shape or dimension, Unstable ground condition and No Outrigger/Outrigger failure;
- Environment related factors: Wind, Weather and Visibility;
- Human factors: Operator's proficiency/character, Rigger's proficiency/character, Employment source, Foremen/Super's experience/character, Ironworker's experience/character, Signalmen's experience/character, Improper pin removal in assembly/disassembly;
- Safety management factors: Site-level management, Company-level management and Maintenance management;
- Other factors.

Thus, by introducing these 28 contributing factors affecting safety in tower-crane environments, another dimension of the categorizing standard is identified, such as Length of work shift, unstable ground condition or Operator proficiency.

After further categorizing all the fatality records from database by this two dimension standard, the direct cause and the corresponding contributing factors that resulted in crane-related fatal accident will be exposed. The results of the first stage (typical accident scenarios of crane-related accidents) were used as the input of the second stage to examine the effectiveness of the newly-proposed crane and derrick rule.

Phase 2 Solutions for Typical Crane Accident Scenarios in New OSHA Rule

Many serious crane accidents have occurred on construction sites. Those that took place on crowded urban construction sites drew more of the public's attention. As an organization whose primary mission is to "prevent work-related injuries, illnesses, and deaths" (OSHA 2009), OSHA was put under pressure to redraft it crane and derrick standards to cope with the serious fatal accidents.

The second part of this research was about comparing the results obtained from the first part (the direct causes and the contributing factors that resulted in crane-related fatal accidents) to the changes that were made in the newly-proposed OSHA crane and derrick safety rules. By further comparing the adjustments that have been made in OSHA's newly-proposed crane and derrick rule with the direct causes and contributing factors of fatal accidents, the effectiveness of this newly-proposed standard might be predicted.

If the primary fatal accident causes and their contributing factors are covered by the requirements and adjustments in the new version of the OSHA crane and derrick rule, the new standard will probably be effective in reducing the number of fatal accidents resulting from crane operations. If the proposed improvements and adjustments are not applicable and do not address the primary causes and contributing factors of crane-related fatalities, then major improvements and adjustments are still needed in the crane and derrick rule.

The deliverable result of this comparison phase would be possible improvements and adjustments for the new version OSHA crane and derrick standard. The potential result of the second stage made the third stage of this research necessary.

Phase 3 Best Practices Addressing Specific Crane Operational Hazards

Based on the possible improvements and adjustments to the OSHA crane and derrick rule derived from the previous phases, best practices concerning specific typical scenarios on construction site were proposed. Since the objective of this phase was to cover existing safety hazards during crane operation, the potential best practices would be effective in reducing the number of fatal accidents that relate to crane and derrick operations. Besides proposing best practices to cope with the current risky operations, a few typical accident scenarios involving crane operations were showcased and analyzed.

In addition, as the deliverable and applicable result of phase 3, methods and mechanisms to raise workers' hazard perception and also knowledge for self protection are proposed to alleviate the long-standing problem of construction industry and better protect the safety of construction workers.

CHAPTER 4
RESULTS

OSHA's Integrated Management Information System (IMIS) database contained 571 crane-related fatality accidents that occurred from 2000 to 2009. Most of the accidents led to the death of one construction worker; however, 13 cases caused multiple fatalities (11 cases that led to the death of two workers and 2 cases that each resulted in the death of three and four workers). Thus, there were 587 construction worker deaths associated with the 571 incidents.

Of the 587 workers that were killed, 375 were riggers and laborers (helpers), which represented 64.22% of the worker deaths. There were 105 crane operators that died in these incidents, representing 17.89% of the crane-related worker deaths (Shown in Figure 4-1). Other than these two main groups, there were 33 steel/iron workers, 27 assemblers, 8 signalmen, 7 superintendents/foremen got killed by faulty crane operation during construction activity toke place. At last, 32 other types of workers or pedestrians killed by crane-related accident from 2000 to 2009.

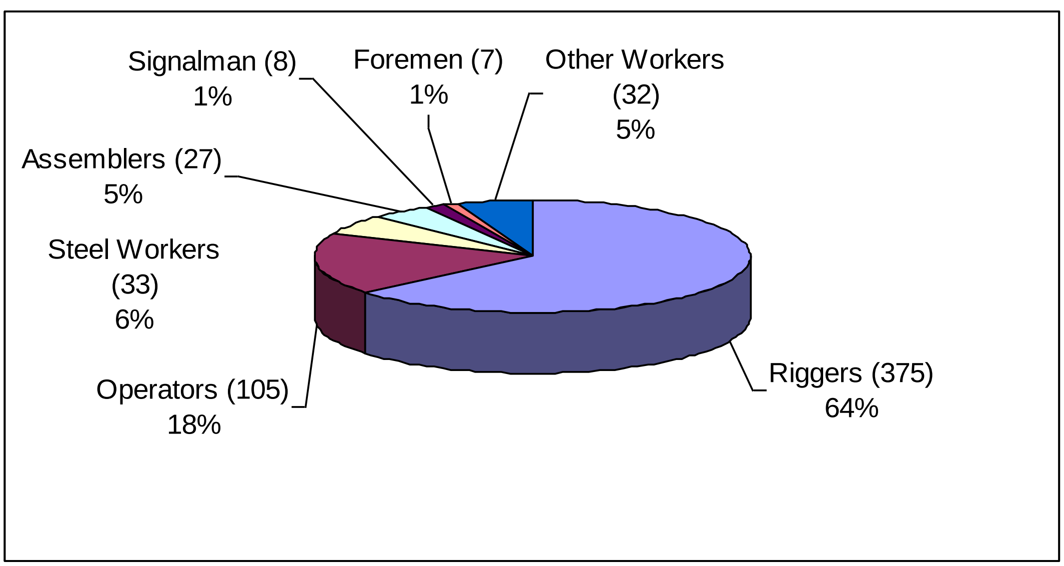

Figure 4-1. Victims' job titles in crane-related accidents (n=587)

The construction industry in North America has traditionally been a mobile-crane culture (Shapira and Glascock, 1996). The statistics of different types of cranes involved in accidents confirmed the statement that mobile crane are the backbone of the U.S. construction industry. For all the cranes or other types of equipment that led to or involved in fatal accidents, 348 of were truck-mounted cranes with rubber tires, with hydraulic or lattice booms, which accounted for 60% of all the equipment involved with worker fatalities (shown in Figure 4-2). Other than mobile cranes, aerial lifts were the second most common type of equipment that were involved in crane accidents (involved in 62 cases, accounted for 10% of all types of equipment). Aerial lifts were mainly designed to transport personnel or materials to higher elevations. Other types of equipment were also involved in serious crane-related accidents, including crawler cranes (involved with 26 cases), concrete pump trucks (involved with 21 cases), digger derrick trucks (20 cases), backhoes (18 cases) and excavators (16 cases).

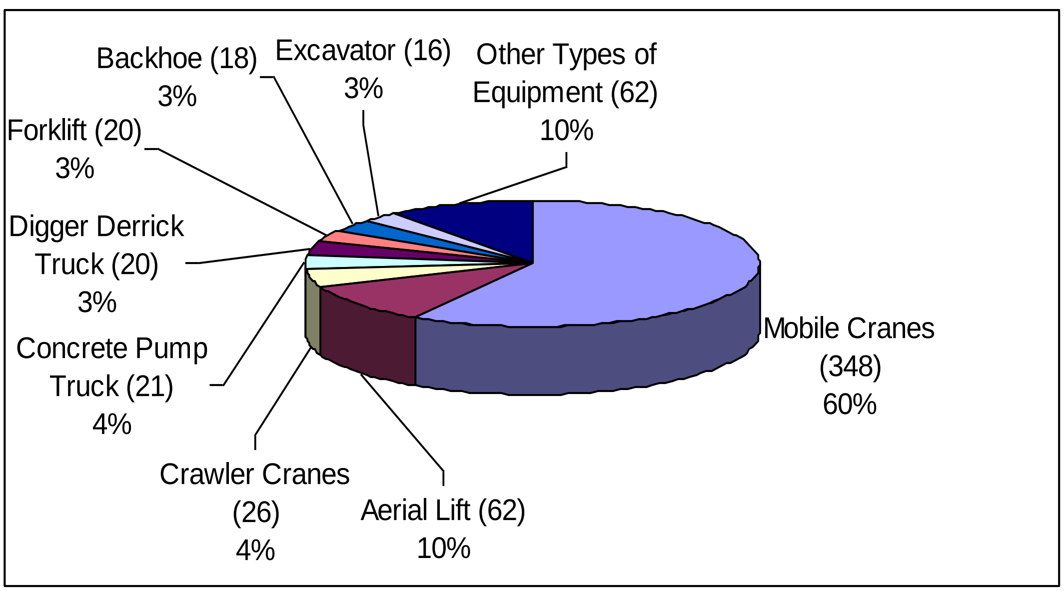

Figure 4-2. Types of equipment that involved in crane-related accidents (n=571)

To obtain a better understanding of the 571 crane-related fatality accidents, and to identify the primary accident causes, eight mutually-exclusive direct causes of crane-related fatalities were defined:

- Failure of boom/cable (Struck by or Fall);
- Crane tip over;
- Shock (electrical);
- Struck by load (other than boom/cable);
- Worker falls (from elevation);
- Crushed by equipment during assembly/disassembly;
- Struck by or caught between equipment; and
- Struck by object (other than load or equipment)

To better capture the essence of how the accident happened in each scenario, and to categorize each of the OSHA fatality cases. It is important to examine the eight mutually-exclusive direct causes. The first direct cause of crane-related accidents was failure of the boom/cable. As a result of such a failure, the operator might be crushed in the cab; a worker working under the crane might be struck by the boom or the crane's falling parts; or the worker working on the crane body has the risk falling from elevation.

The second category of crane-related accidents was the crane tipping over. Various reasons would lead to the crane losing its balance and tipping over. Overloading the crane was the main reason for the crane tipping over. Also, uneven or unstable ground conditions, especially when the outriggers were not properly deployed (crane working on "rubber") might also make the crane's center of gravity shift, resulting in the tipping over of the crane. When tipping over, any employees working in aerial lift baskets or platforms will probably fall or land on the ground if fall protection was not provided or utilized. Also, when a crane tips over, workers located under the radius of the unstable crane might be struck by the crane.

The third direct cause of crane-related accidents is electrical shock. Most of the workers that were electrocuted by making body contact with electrified equipment. A crane might make contact with a power line and if a worker standing on ground made direct contact with the crane or conductive load or cable connected to the crane, the worker's body could become a part of the circuit that led the electricity to the ground. In some cases, electrical workers made direct contact with overhead power distribution line or transmission line with their hands or other parts of their bodies while performing installation or repair work on electrical poles.

The fourth category of crane-related accidents was worker struck by load (other than boom/cable). Most of the workers that were struck by the load being handled were riggers or laborers that were handling loads or they worked as signalpersons that gave directions to the crane operators. With heavy lifting capacity of cranes and the long span of the booms, cranes that were introduced to the industry made material lifting and moving much easier and faster. However, if the load was not properly rigged or connected to the crane hook, it would pose significant hazard to the workers located under the crane boom's working radius.

The fifth direct cause of crane-related accidents was workers falling from elevation. Nearly one third of the crane-related fatalities were due to falling. The iron/steel workers performing steel erection work at certain heights are commonly subject to the risk of falls. When the unfixed steel beam was unsettled, the iron worker who was sitting on or working around that beam might fall from certain height if he was not properly tied off. Also, workers involved in the assembly or dismantling of boom sections might also fall due to loss of balance.

Worker being crushed by equipment (or parts) during assembly/disassembly was sixth category of crane-related accidents. Considering the crane's complex structure, the lattice booms commonly need to be dismantled before relocation. When torn down and moved to a new site, assemblers are in charge of reassembling the crane to its working condition. In case of the assembly/disassembly work was done in such a hurried manner, it could pose a massive safety hazard and lead to fatal accidents.

The seventh category of crane-related accidents pertains to workers getting struck by or caught in/between by heavy equipment. Such accidents are commonly caused by the failure to maintain proper clearances around the working radius of cranes. The last or eighth category of crane-related accidents pertains to workers being struck by objects other than the load or equipment. These accidents might be attributed to disordered site management and the unsafe stocking of material. If stock materials at certain elevation were not properly secured, they might be unsettled and struck innocent workers in case no safety net or other protection in place.

General Statistics on Direct Causes of Crane-Related Accidents

After the direct causes of crane-related accidents were clearly defined, the data could be evaluated. Among the 571 fatality accidents identified, 140 accidents were involved with electrical shock, which represented 24.52% of all the cases (Shown in Table 4-1). The second most common causes of crane-related fatal injuries were worker falls (from elevation), which accounted 22.07% of all the worker death (126 cases). Among the direct causes that accounted more than 10% of the fatal accident samples, 73 workers (12.78% of the entire collection) died from being striking by or being caught in/between by equipment. Being struck by the load (other than boom/cable) was the fourth most common cause with 72 cases (12.61% of the entire collection). Other than these causes, there were 50, 33, 36, 41 deaths respectively from crane tip over, struck by object other than equipment or load, failure of the boom/cable (Struck or fall) and crushed during assembly/disassembly.

Table 4-1. Proportion of fatality cases for each direct cause

Direct Causes	This section contains
Shock (electrical)	140 (24.52%)
Worker falls (from elevation)	126 (22. 07%)
Struck by or caught between equipment	73 (12.78%)
Struck by load (other than boom/cable)	72 (12.61%)
Crane tip over	50 (8.76%)
Crushed during assembly/disassembly	41 (7.18%)
Failure boom/cable (Struck or fall)	36 (6.30%)
Struck by object (other than Equipment or Load)	33 (5.78%)
Total	571 (100%)

Based on the nature of each direct cause, “Struck by load”, “Struck by or caught in/ between equipment” and “Struck by object” accidents all related with workers being struck by something and killed. When these categories were grouped together, the total number of 178 cases surpassed “electrical shock”, and “workers fall”, “struck by”, representing 31.17% of all the crane-related accidents.

The causes that occurred most frequently included “struck by”, “electrical shock”, and “worker falls”. The best practices proposed in this research were those that addressed hazardous operations to prevent workers from being struck by, electrical shock or falls from elevation.

In addition to the eight direct causes, 28 contributing factors were identified that led to the accidents. These factors were categorized into 5 major groups, including project conditions, environment-related factors, human factors, safety management-related factors, and other factors.

Consider a scenario in which a crane operator was crushed in the cab when the crane he was operating tipped over. The “crane tipping over” was the direct cause that led the operator’s death. However, this does not answer the question of “why the crane tipped over?” Additional information is needed to get a clear picture of what actually happened. For example, the load being lifted might exceed its loading capacity. As a result of overload, the crane tipped over. Then, overloading the crane would be identified as the contributing factor on this crane-related accident.

Among the 178 accidents contained in the category of “struck by”, 53 accidents occurred because of the operator’s faulty operation of the crane, which accounted for 29.77% of the cases in this sub-category (shown in Figure 4-3).

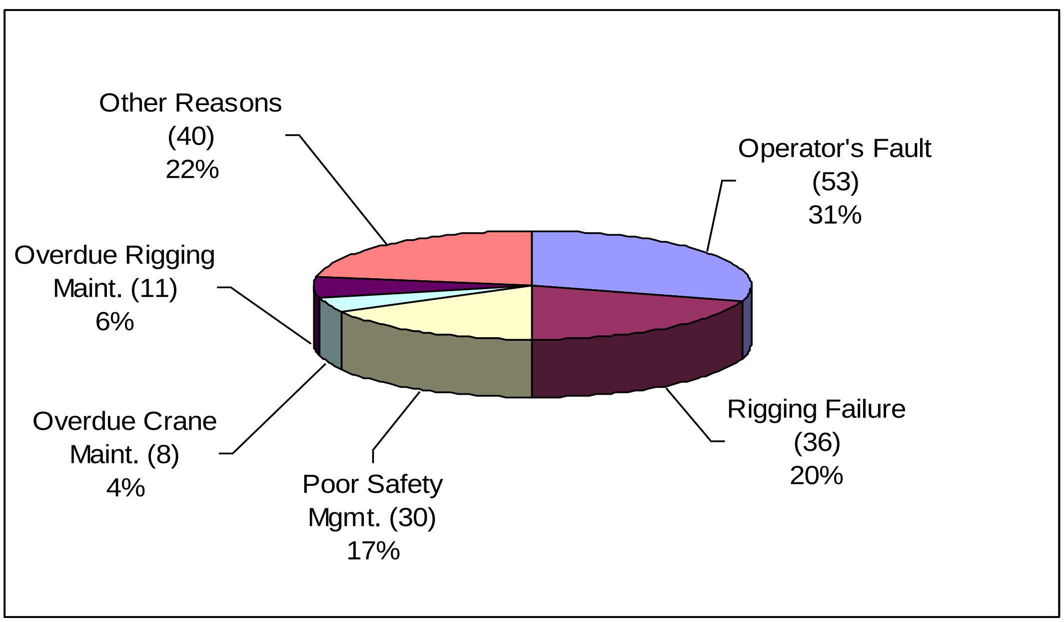

Figure 4-3. Contributing factors of “struck by” accidents (n=178)

In addition, 36 fatality cases (accounted 20.22% in this category) were the result of rigging failure, possibly due to the rigger's insufficient experience or the physical failure of the rigging cable, or the hoisted load falling from the equipment and striking a worker on the ground. Other than poor performance of crane operators and riggers, site safety management could also be a significant contributor to crane-related accidents. A total of 30 fatal accidents (accounting for 16.85% in this struck by sub-category) were related to disordered site safety management.

Under the sub-category of struck by load (other than cable and boom), 28 cases (accounted for 38.89% in this sub-category) were caused by unsafe rigging operations. If the load was not properly secured on the crane hook with durable rigging according to standard procedures, the load might fall directed from the hook and struck the rigger or the laborer on the head. Specifically, load with irregular shape or dimension needed more attention when rigged to the crane hook, since this type of load was much easier to slide from the rigging (if not properly secured) and fall freely during lifting operation. Other than unsafe rigging operations, rigging failure might also lead the load to fall from crane hook and strike workers. The wire rope used for hoisting should to be inspected prior to each work shift. In case of the sign of corrosion, electric arc damage or any other damages that would compromise its strength was identified, it must be replaced immediately. Failure to perform the wire rope inspection or continue to use the wire rope with serious damages would significantly increase the hazard exposure for employees worked under the crane hook.

In the scenario when workers were struck by or caught between equipment, faulty operation by the operator was identified as the contributing factor of 38 fatality cases (represented 52.05% in this category). Due to faulty operation, workers who operated the forklifts to rise to a higher elevation would got caught between the top rail of the lift and overhead structure member and died. Except faulty equipment operation, poor site-level safety management was identified as another main factor that contributed to worker’s death in this category. When the crane boom was swinging, on-site workers should maintain certain clearance with the crane boom’s working radius.

Under the sub-category of worker struck by object (other than Equipment or Load), poor site-level safety management was identified as the main contributor of crane-related accidents. Accidents due to unsafe material stocking accounted for 27.27% in this category. In case the materials were not firmly secured while stocked at certain elevation, it might fall and fatally injured workers when unsettled.

Among the 140 fatality cases caused by shock (electrical), 133 working crews had failed to follow the OSHA crane standard that required maintaining proper clearance when working around the overhead power lines. Thus, “failed to maintain proper power lines clearance” was identified as the most significant contributing factor of worker’s electrocution.

In the scenario when worker fell (from elevation), there was possibility that fatal accidents never happened if workers had their harness on, and tied it off to a secure position. Several accidents happened where there was no fall protection provided or workers failed to safely tie off. OSHA’s safety regulation was ignored completely or paid little attention due to disordered site safety management. Thus, poor site-level safety management was identified as the major contributing factor in this category.

Among all the workers that lost their life due to crane tipping over, crane operator represented 52% of entire victim's population (shown in Figure 4-4). When the crane tipped over, if the operator can not evacuate from cab immediately, the possibility of being crushed in the cab is relatively high. Upon the question of "why the crane tipped over?" there were several answers based on the statistics analysis. 26 % of the cranes that tipped over were due to unstable ground condition (shown in Figure 4-4). In the process of moving the crane with the boom stretched out, when stepped on stairs or uneven ground condition, the crane have a fairly high possibility to lose its balance and tip over. Another significant factor that could lead the crane to tip over is overload. It is quite dangerous to apply load that exceed the crane's maximum capacity during hoisting operation. Especially when the boom was swung to the crane's side, the crane probably would tip over with overloaded structure and crushed employee to death. Other than unstable ground condition and overload, load with irregular shape or dimension, outriggers that were not fully deployed might also add the opportunity for the crane tipping over. Some accidents would not occur if the outriggers were set in place.

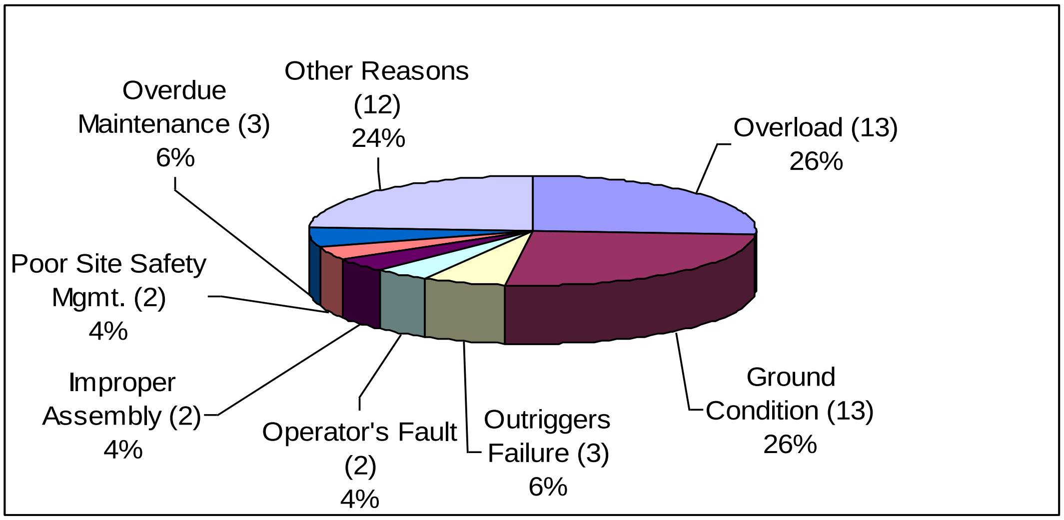

Figure 4-4. Contributing factors in "crane tipped over" accidents (n=50)

In all the 36 cases that related to the boom/cable failure, 11 cases (represented 30.56% of all related cases) were caused by improper assembly (shown in Figure 4-5). Assembly and disassembly operations that take place in hurried manner would increase the possibility of crane structure failure. In case the manufacturer's recommendations were not carefully understood and strictly followed during assembly operation, things could go terribly wrong even if just a single positioning pin was not properly secured. Another contributing factor that could lead to a crane structure failure was overdue crane service and maintenance which accounted for 16.67% of all the related cases. Some companies failed to service their equipment according the manufacturer's recommendations due to financial or other considerations. Using equipment that had already passed their service period limitation could pose a serious safety hazard to employees.

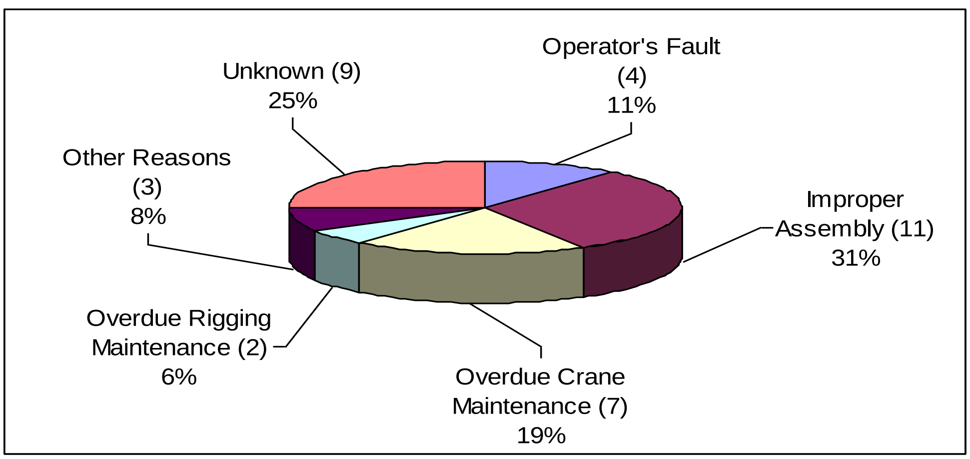

Figure 4-5. Contributing factors in "crane boom/cable failure" accidents (n=36)

In one case, a 43 year-old worker received fatal injuries due to a failed lattice boom on a crawler crane that fell on top of him. The crane had been built in 1964, and was bought by the company on April 29, 2008. The company never performed an annual inspection of the crane or a monthly one, and documentation was not available to indicate any maintenance had been done to the crane. Other than that, several lacings were bent on this crane, and that the angles and spacing of the repaired lacings were uneven. Instead of dismantling this old crane and reclaiming the parts, the company continued to use this crane for lifting operations, which created a massive safety hazard for employees.

In the last scenario, the situation was much more straightforward when the crane crushed during assembly/disassembly. Almost all the decedents' job descriptions were crane assembly/disassembly worker. In 37 out of 41 cases, workers were killed during disassembling of the booms of cranes. The other 4 workers were killed when trying to attach an extension to the boom of the crane. They got struck either by booms that were not safely fixed, or counterweights just dismantled from the crane structures. Unsafe pin removal was identified as the most significant contributing factor in this category of assembly/disassembly. During one case of crane disassembly, an employee tied off to the live load line and was pulled into the hoist drum, resulting in a fatal crushing injury. It was the company's responsibility to hold safety seminars or training sessions to teach the worker how to protect themselves during the assembly/ disassembly operations.

In Depth Analysis--"Struck by" Accidents

As discussed above, 178 crane-related fatality cases were involved with workers got struck by loads, equipment or objects from 2000 to 2009, based in OSHA fatality records. Specifically, 72 cases consisted of workers who got struck by the load; 73 cases consisted of workers who got struck by equipment; and 33 cases involved workers who got struck by objects (shown in Figure 4-6). Among all the decedents, 123 workers' job titles were riggers/laborers (represented 69.10% in this group) and were primarily involved with rigging and lifting operations. Other than riggers/laborers, 29 of the victims were equipment operators.

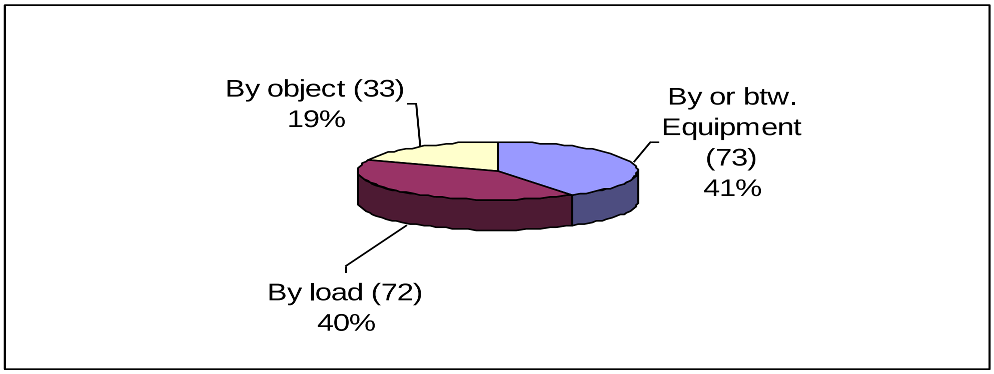

Figure 4-6. Typical scenarios in "struck by" accidents (n=178)

Among all the 178 struck by fatality cases, 105 cases were involved with mobile cranes with lattice booms or hydraulic booms. There were 17 deaths involving struck by aerial lifts. Seventeen accidents involved with backhoes. In several cases the backhoe operator got out of the cab to perform loading or other activities and left the engine running. When the boom swing control was accidentally triggered, the victims were struck by the swinging boom of the backhoe against the machine's outriggers (shown in Figure 4-7).

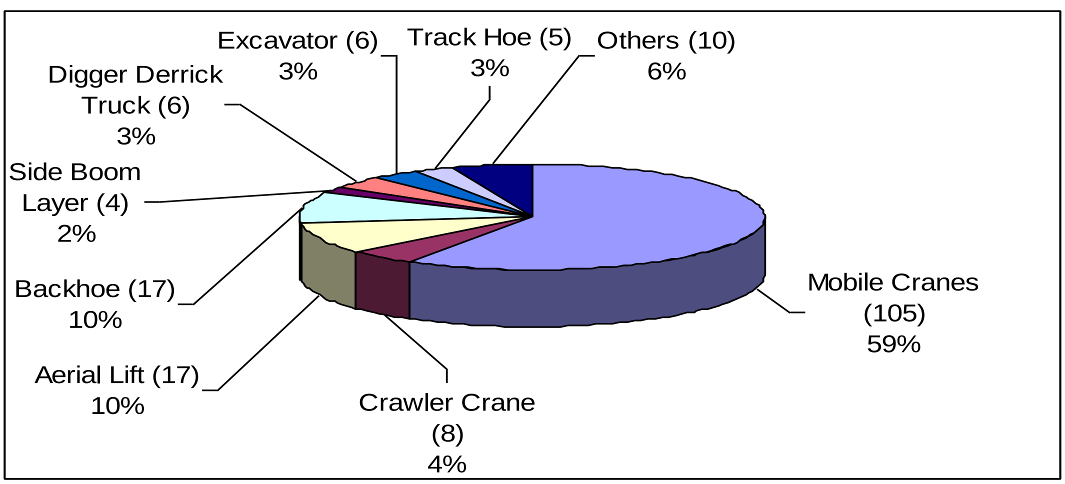

Figure 4-7. Types of equipment involved with in "struck by" accidents (n=178)

In Depth Statistics Concerning "Struck By" Accidents

Operator's faulty operation, rigger's unsafe practice and failure of rigging hardware were identified as three most common factors in "worker struck by load" accidents. Among 72 accidents where workers were struck by loads, 28 cases were due to unsafe rigging operations. In some cases, the load was not properly secured on the crane hook according to standard practices and the load would slide in the wire rope and strike the rigger or the laborer. Specifically, loads with irregular shapes or dimensions needed more attention when being rigged to the crane hook. Eleven accidents were caused by the faulty operation of the crane operators, such as when the crane's boom was moved before the rigging was completely disconnected from the load or the load was hoisted when it was not totally fixed. Subsequently, the loose load fell from supporting parts and pinned worker underneath. Ten worker fatalities were caused by rigging hardware failure. These involved companies either having no rigging assembly inspection done or they continued to use wire ropes even though there were signs of corrosion or other damage that were spotted during their inspections.

Of all the 72 victims that struck by a load, 19 of them were struck by steel beams or other structural members, represented 26% of all victims in this sub-category (shown in Figure 4-8). 5 of them were struck by hoisting pipes, and 5 workers were struck by concrete forms.

Most of worker died in these category were performing erection works of steel members. In several cases, when the steel beam was placed on other supporting members, operator lowered the boom to release the tension on the load line. After that, the operator intended to swing the boom to engage another construction activity. However, the operator forgot that the load still connected to the crane hook by wire rope. When the boom was moved, the unfixed steel beam was unsettled. It fell from high elevation and struck the steel worker or rigger. Several workers were struck by load when performing pipe-laying or material unloading activities. Based on the narrative descriptions, the struck body part was able to be identified in 45 cases. A total of 27 were struck on the head; others were struck on the torso, chest, hip, etc.

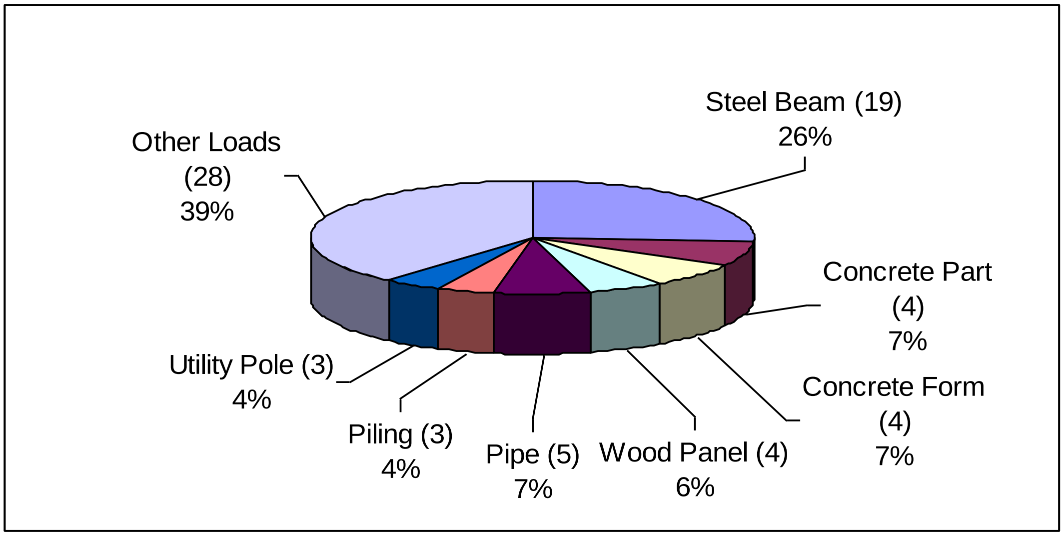

Figure 4-8. Types of loads that struck workers (n=72)

In several cases, workers were engaged in activities that were performed at elevation. Workers were killed when the unsafe-hoisted load fell and struck the workers, or the workers fell from elevation to the ground and got killed. Workers might lose their life by falling from high elevation and land on the ground. “Struck by” was still identified as the direct cause in this scenario, since the workers were struck by the loads which was the leading factor for the workers to lose their balance and fall.

Being caught between the swinging boom and other parts of the equipment and being struck by the swinging boom in its working radius were identified as the most common scenarios in “worker struck by or caught in/between equipment” accidents. Among 73 workers that were killed due to struck by or caught in/between equipment, 16 workers were struck by the mobile crane's swinging boom against other parts on the equipment, such as outriggers, cabs or hydraulic cylinders (shown in Figure 4-9). One typical safety hazard for backhoe operators was noticed. In more than ten cases, the backhoe operator got out of the machine and left the engine running. The operator might intend to load something at the staging area or to talk with other on-site workers. However, when he approached the backhoe on the way returning to the cab, the boom swing pedal or control was accidentally triggered. Subsequently, the operator was struck by the swinging boom against the outriggers or other parts of the machine.

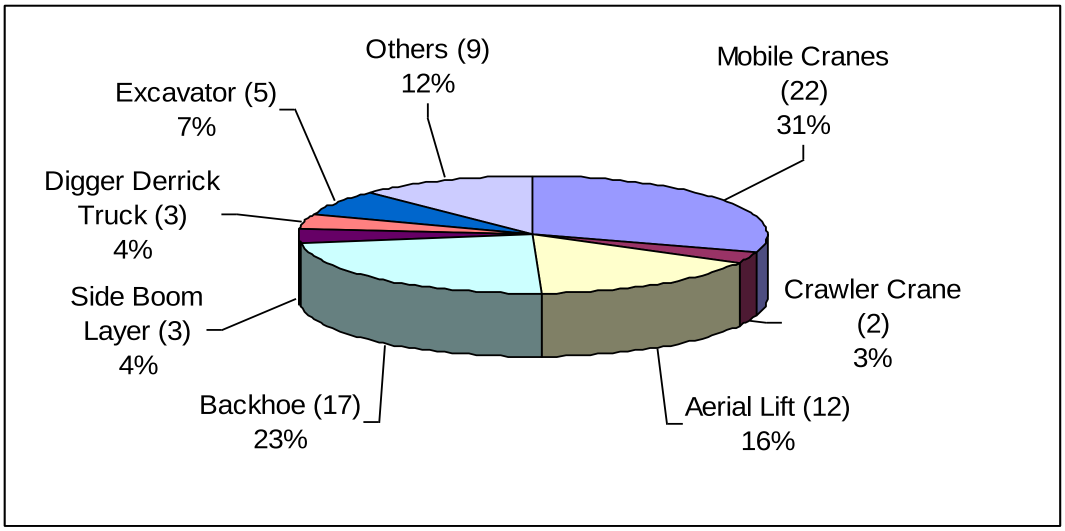

Figure 4-9. Types of equipment involved with "struck by or caught between equipment" accidents (n=73)

Another typical safety hazard identified in this subcategory concerned the operators of aerial lifts or other personnel lifts. In a typical scenario, the aerial lift operator first got into the bucket and was lifted to a certain height using the controls on the operating console. After finishing the work, the operator used the controls to lift the platform to higher level. Without looking upward, the operator's body was caught between the bottom of an overhead steel beam and the platforms control console (in some other cases, the top rail of the bucket). More attention is needed for the operators to use aerial lifts in an area with low overhead clearances.

Struck by unstable objects and struck by falling materials were identified as the most common scenarios in "struck by object" accidents. Among the 33 workers that were struck by objects, 13 were struck by unstable objects such as panels or walls that erected by cranes. In tilt-up construction, the experienced and competent personnel were required to make sure that pre-cast members were totally stabilized and secure with other members that had already been erected before signaling the crane operator to release the tension on the loading cable.

Twelve workers were struck by falling objects. In one case, the forklift operator was booming in and placed the forklift in reverse when the mast of the forklift came in contact with the steel structure. This caused the pre-cast hollow core panels to shift off the forks. The panels fell onto an employee walking underneath. Materials placed above the ground elevation need to be stocked properly and secured on a well-managed construction site. The willful violation of material stocking and having no overhead fall protection installed was the main reason of the worker's death.

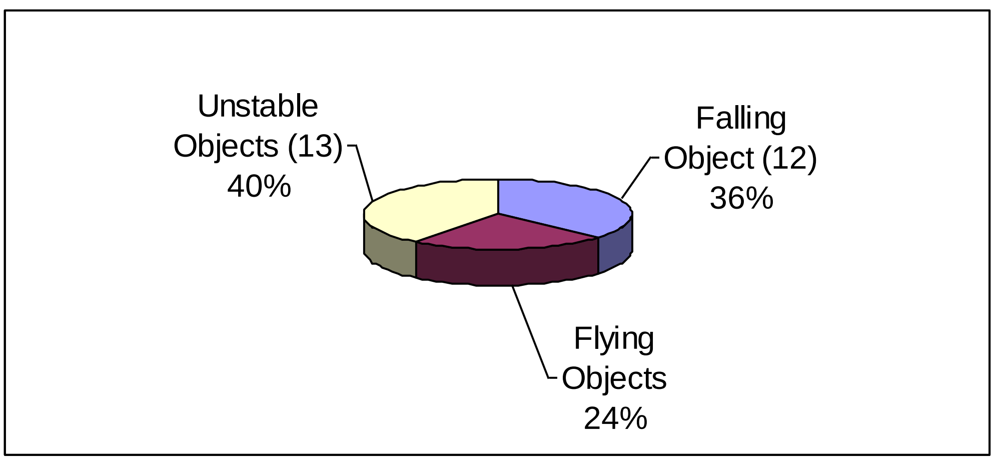

Figure 4-10. Types of objects that struck workers (n=33)

Relevant Requirements in Newly-Proposed OSHA Rule

In the newly-proposed crane and derrick rule, OSHA specified that upon the completion of crane boom assembly, the equipment must be inspected by a qualified person to assure that it is configured in accordance with manufacturer's equipment criteria. Equipment must not be used until it has passed such an inspection. A competent person must begin a visual inspection prior to each shift that the equipment will be used, which must be completed before or during that shift. The inspection must consist of an observation for apparent deficiencies. Taking apart equipment components and booming down is not required as part of this inspection unless the results of the visual inspection or trial operation indicate that further investigation necessitates taking apart the equipment components or booming down is needed.

These requirements about post-assembly inspection would significantly lower the possibility that structural failures or parts failures due to improper assembly. Thus, the number of victims that were struck by equipment (due to a boom failure) is going to be effectively reduced.

To avoid the "struck by load" accidents caused by rigger's unsafe practice, OSAH made new requirements for Rigger Qualification in newly-proposed crane and derrick rule. Employers must use qualified riggers during hoisting activities for assembly and disassembly work. Additionally, qualified riggers are required whenever workers are within the fall zone and hooking, unhooking, or guiding a load, or doing the initial connection of a load to a component or structure. In essence, employers must make sure the person can do the rigging work needed for the exact types of loads and lifts for a particular job with the equipment and rigging that will be used for that job.

To prevent “struck by load” accidents happening due to Operator’s faulty operation, OSHA made requirements for crane operator when workers are out of sight. Before a crew member goes to a location that is out of view of the operator, the crew member must inform the operator that he/she is going to that location.

Where the operator knows that a crew member went to a location, the operator must not move any part of the equipment (or load) until the operator is informed in accordance with a prearranged system of communication that the crew member is in a safe position. Also, to reduce the accidents caused by faulty operation, the situations like blind lifts need to be avoided. Otherwise, a competent spotter is required to give directions and instructions when the operator’s view is compromised.

To minimize the number of fatality cases that lead by failure of rigging hardware, OSHA also required that a competent person must begin a visual inspection prior to each shift the equipment is used, which must be completed before or during that shift. The inspection must consist of the observation for apparent deficiencies of wire ropes (running and standing) that are likely to be in use during the shift. The deficiencies include significant distortion of the wire rope structure such as kinking, crushing, un-stranding, bird-caging, signs of core failure or steel core protrusion between the outer strands. The inspector also needs to pay attention to significant corrosion, electric arc damage (from a source or heat damage, improperly applied end connections, and significantly corroded, cracked, bent, or worn end connections.

A monthly inspection and also annual/comprehensive inspections are to be conducted by a qualified person on wire ropes in use on equipment. If a deficiency is identified, an immediate determination must be made by the qualified person as to whether the deficiency constitutes a safety hazard.

These requirements about wire rope inspection would significantly lower the possibility of load line failures. Thus, the number of victims that are struck by the load (because of cable line failure) is going to be effectively reduced. Therefore, according to the comparison between the accident cause statistics and OSHA rules, the newly-proposed crane and derrick standard would be effective in preventing the “struck by” crane accidents.

To further prevent assembly/disassembly workers from being struck by boom, counterweights or other parts of crane, OSHA made requirements concerning the safety of assembly/disassembly operations in the newly-proposed crane and derrick rule. When assembling or disassembling equipment (or attachments), the employer must comply with all applicable manufacturer prohibitions and must comply with either manufacturer procedures applicable to assembly and disassembly, or employer procedures for assembly and disassembly. Assembly/disassembly must be directed by a person who meets the criteria for both a competent person and a qualified person, or by a competent person who is assisted by one or more qualified persons. Before commencing assembly/disassembly operations, the assembly/disassembly director must ensure that the crew members understand their tasks, the hazards associated with their tasks and the hazardous positions/locations that they need to avoid.

To avoid the condition that worker being struck by the swinging boom in crane’s working radius, OSHA made related requirements in section of work area control in the newly-proposed rule. The requirements of this section apply where there are accessible areas in which the equipment's rotating superstructure (whether permanently or temporarily mounted) poses a reasonably foreseeable risk of: (i) Striking and injuring an employee; or (ii) Pinching/crushing an employee against another part of the equipment or another object.

To prevent employees from entering these hazard areas, the employer must train each employee assigned to work on or near the equipment ("authorized personnel") in how to recognize struck-by and pinch/crush hazard areas posed by the rotating superstructure and erect and maintain control lines, warning lines, railings or similar barriers to mark the boundaries of the hazard areas. Where any part of a crane/derrick is within the working radius of another crane/derrick, the controlling entity must institute a system to coordinate operations.

By imposing requirements like post assembly inspection, wire rope inspection and operation rules for crane operator when workers are out of sight, the number of "struck by" accidents will certainly be reduced.

In Depth Analysis--Shock (Electrical) Accidents

Shock (Electrical) accidents accounted for 17% of all construction-related fatalities recorded by the Occupational Safety and Health Administration between 1985 and 1989. From 2000 to 2009, 140 crane-related fatality cases involved workers who were electrocuted by direct/indirect contact with overhead power lines. Same with the "struck by" category, most of the workers that were electrocuted (97 out of 140, accounted for 69.29%) were riggers/laborers. When crane booms are stretched and maneuvered to engage in work near overhead power lines, worker safety is jeopardized if adequate clearance is not maintained. When the swinging booms or load lines make contact with power lines, the riggers or laborers whose hands were on the tagline to guide the lifting object would become a part of the circuit that led the electricity to the ground and subsequently, got electrocuted. However, when the boom of a crane makes contact with overhead power lines, the survival opportunity for the operator in the cab was better than for the rigger or laborer. In most cases, the operator will be safe as long as the operator remains in the cab. Among the 140 crane-related electric shock accidents, 30 of the victims were operators (accounting for 21.43% of all decedents). When the boom made contact with the high voltage power line, most of operators tried to escape from the cab immediately. However, dangerous behavior during escape was the reason that led to their deaths. The decedents typically got electrocuted when their hands were on the crane’s body and their feet made contact with the ground. Actually, the act of evacuation made them body became a part of the circuit that led the electricity to the ground. A few decedents in this category were electrical workers or street signal workers.

In Depth Statistics Concerning Shock (Electrical) Accidents

Between all the heavy equipment that is involved with the electrocution of workers, 79 pieces of equipment were mobile cranes like truck-mounted cranes or boom trucks, which are very common in North American construction industry (shown in Figure 4-11). Eighteen victims in this type of accident got killed by working with aerial lifts. Seventeen decedents were holding controllers next to concrete pump trucks to guide the concrete pipe when concrete was pumped into forms. When the pumping pipe needed to be repositioned, the boom on the concrete pump truck needed to be moved (higher, lower or horizontally) accordingly. The boom then made contact with the overhead power line. The worker holding the tagline became a part of the circuit that led the electricity to the ground, resulting in an electrocution.

Other than mobile cranes, aerial lifts and concrete pump trucks, drill rig (digger derrick truck) and excavator were identified as the involved equipment in 14 and 6 electrocution cases, respectively. Commonly, the boom of the drill rig made contact with the power line when the boom was raised to pull the drill rod out of the ground after completing the hole drilling activities. Side boom unit (2 cases involved), track hoe (2 cases involved), crawler crane (1 case involved), derrick crane (1 case involved) were also found to involve with crane-related electrical shock accidents.

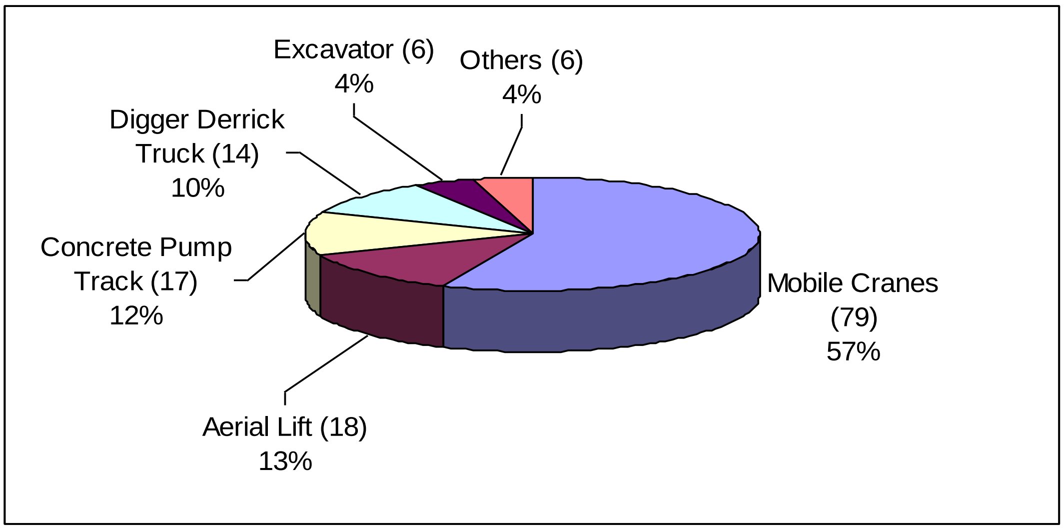

Figure 4-11. Types of equipment involved with “shock (electrical)” accidents (n=140)

Among 140 crane-related accidents, the voltage of involved power line was provided in 90 cases. The voltage ranged from 480 V to 220 KV (transmission line). The voltage in 69 cases (49.29%) was in the range of 7,000-20,000V. Multiple injuries were relatively common in these electrical shock accidents. There were 22 fatality cases that involved more than one victim (injured or killed). In one case, 4 on-site laborers/helpers received an electric shock and one of them was electrocuted. Lack of necessary information for self protection might be a reason for multiple injuries. Several workers or foremen were electrocuted by reaching and making contact with the bodies of workers who had already been electrocuted. They were trying to free the worker from the power line. In such cases, using an insulated object would be a safer way to take the power line away from the victim.

Objects that made direct contact with power lines were identified in 128 cases (shown in Figure 4-12). The crane boom made contact with the power line in 67 cases. The load line (wire rope) made contact with the power line in 25 cases. Other than equipment that made contact with the power lines, 14 cases were identified where workers made direct contact with high voltage power lines. To be specific, hands were the main body part that victims used to make direct contact with power lines.

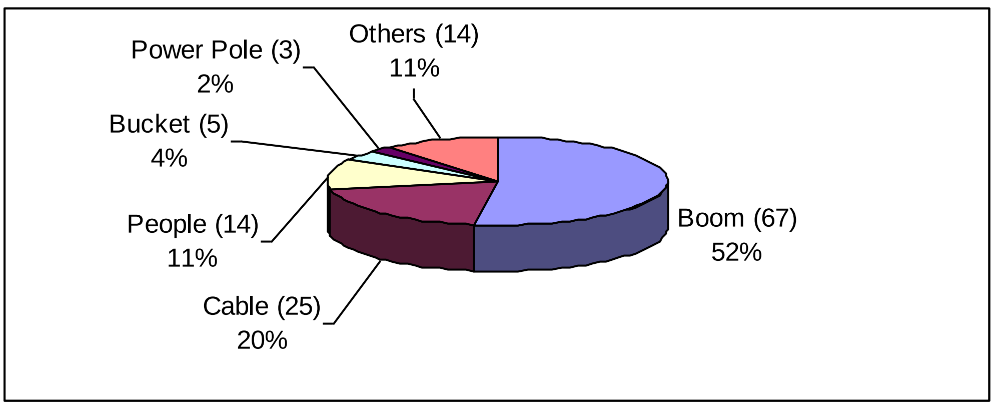

Figure 4-12. Objects that made contact with power lines (n=128)

Movement of the heavy equipment at the time of the electrical contact was provided in 57 cases. There were 21 fatal accidents when the crane operator raised the boom into the power line. In 12 fatal accidents the cranes were maneuvered to move into certain positions. Lowering and swinging were identified as the boom movement in 9 and 8 cases, respectively. Additionally, the crane's boom maintained still (no movement) when the electrocution happened. In these 5 cases, worker made direct contact with power lines while working on an aerial lift or elevated platform.

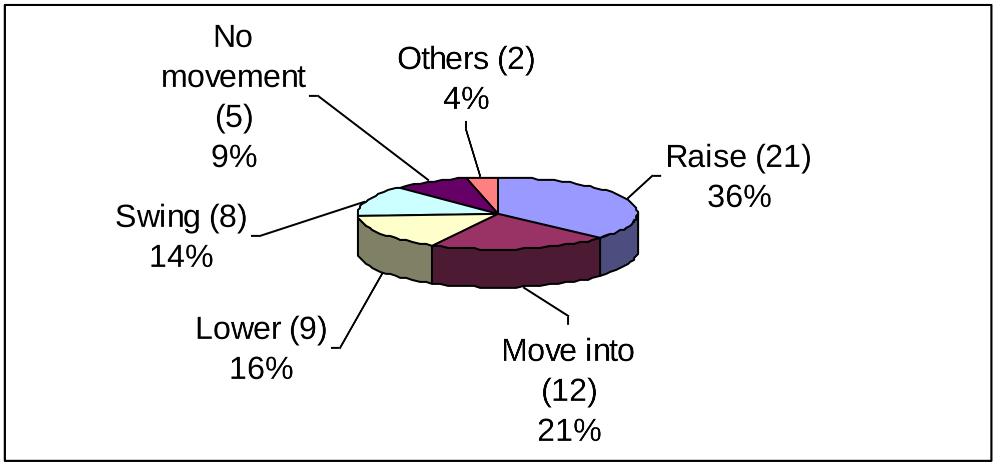

Figure 4-13. Movement of equipment when accidents happened (n=57)

Relevant Requirements in Newly-Proposed OSHA Rule

In the newly-proposed crane and derrick rule, hazard assessments and precautions inside the work zone is required by OSHA before beginning equipment operations. The employer must identify the work zone by either demarcating boundaries to prohibit the operator from operating the equipment past those boundaries, or defining the work zone as the area 360 degrees around the equipment, up to the equipment's maximum working radius.

Then, the employer must determine if any part of the equipment, load line or load (including rigging and lifting accessories), if operated up to the equipment's maximum working radius in the work zone, could get closer than 20 feet to a power line.

If any part of the equipment has possibility to violate the 20 feet clearance with power line, the employer has three options:

Option (1)--De-energize and ground. Confirm from the utility owner/operator that the power line has been de-energized and visibly grounded at the worksite.

Option (2)--Ensure that no part of the equipment, load line, or load (including rigging and lifting accessories), gets closer than 20 feet to the power line by conducting a planning meeting with the operator and the other workers who will be in the area of the equipment or load to review the location of the power line(s), and the steps that will be implemented to prevent encroachment and electrocution. If tag lines are used during equipment operation, they must be non-conductive.

After that, the employer must also erect and maintain an elevated warning line, barricade, or line of signs, in view of the operator, equipped with flags or similar high-visibility markings, at 20 feet from the power line or at the minimum approach distances under Table A (shown in Table 4-2). If the operator is unable to see the elevated warning line, a dedicated spotter must be used to help maintain the clearance.

Under option (2), the employer also needs to implement at least one of the following measures:

- A proximity alarm set to give the operator sufficient warning to prevent encroachment.
- A dedicated spotter who is equipped with a visual aid, and also effectively positioned to gauge the clearance distance, is needed to maintain continuous contact and give timely information to the operator so that the required clearance distance can be maintained.
- A device that automatically warns the operator when to stop movement, such as a range control warning device. Such a device must be set to give the operator sufficient warning to prevent encroachment.
- A device that automatically limits range of movement, set to prevent encroachment.
- An insulating link/device, installed at a point between the end of the load line (or below) and the load.

Option (3)--Determine the line’s voltage and the minimum approach distance permitted under Table A. Determine if any part of the equipment, load line or load (including rigging and lifting accessories), while operating up to the equipment’s maximum working radius in the work zone, could get closer than the minimum approach distance of the power line permitted under Table A.

If so, then the employer must implement the required measures under option (2) to ensure that no part of the equipment, load line, or load (including rigging and lifting accessories), gets closer to the line than the minimum approach distance.

Table 4-2. Minimum power lines clearance distances (Table A)

Voltage (nominal, kV, alternating current)	Minimum clearance distance (feet)
up to 50	10
over 50 to 200	15
over 200 to 350	20
over 350 to 500	25
over 500 to 750	35
over 750 to 1,000	45
over 1,000	as established by the utility owner/operator or registered professional engineer who is a qualified person with respect to electrical power transmission and distribution

Equipment operations in which any part of the equipment, load line, or load (including rigging and lifting accessories) is closer than the minimum approach distance under Table A to an energized power line is prohibited, except where the employer demonstrates that all of the following requirements are met:

(a) The employer determines that it is infeasible to do the work without breaching the minimum approach distance under Table A.

(b) The employer determines that, after consultation with the utility owner/operator, it is infeasible to de-energize and ground the power line or relocate the power line.

(c) Minimum clearance distance is determined by professionals and effectively maintained. The power line owner/operator or registered professional engineer who is a qualified person with respect to electrical power transmission and distribution determines the minimum clearance distance that must be maintained to prevent electrical contact in light of the on-site conditions. The factors that must be considered in making this determination include, but are not limited to: conditions affecting atmospheric conductivity; time necessary to bring the equipment, load line, and load (including rigging and lifting accessories) to a complete stop; wind conditions; degree of sway in the power line; lighting conditions, and other conditions affecting the ability to prevent electrical contact.

A planning meeting with the employer and utility owner/operator (or registered professional engineer who is a qualified person with respect to electrical power transmission and distribution) is held to determine the procedures that will be followed to prevent electrical contact and electrocution.

The procedures developed are needed to be documented and immediately available on-site. The equipment user and utility owner/operator (or registered professional engineer) meets with the equipment operator and the other workers who will be in the area of the equipment or load to review the procedures that will be implemented to prevent breaching the minimum approach distance established in paragraph (c) of this section and prevent electrocution.

The utility owner/operator (or registered professional engineer) and all employers of employees involved in the work must identify one person who will direct the implementation of the procedures. The person identified in accordance with this paragraph must direct the implementation of the procedures and must have the authority to stop work at any time to ensure safety.

Except requirements during lifting operation, in the newly-proposed crane and derrick rule, OSHA also establishes procedures and criteria that must be met for equipment traveling under or near a power line on a construction site with no load.

The employer must ensure that the boom/mast and boom/mast support system are lowered sufficiently to meet the requirements of this paragraph, and the clearances specified in Table T (shown in Table 4-3) are maintained. Also the employer needs to consider the effects of speed and terrain on equipment movement (including movement of the boom/mast), so that those effects do not cause the minimum clearance distances specified in Table T to be breached.

Table 4-3. Minimum power lines clearance distances while traveling with no load (Table T)

Voltage (nominal, kV, alternating current)	Minimum clearance distance (feet)
up to 0.75	4
over 0.75 to 50	6
over 50 to 345	10
over 350 to 750	16
over 750 to 1,000	20
over 1,000	as established by the utility owner/operator or registered professional engineer who is a qualified person with respect to electrical power transmission and distribution

If any part of the equipment while traveling will get closer than 20 feet to the power line, the employer must ensure that a dedicated spotter who is in continuous contact with the driver/operator is used. The dedicated spotter must be positioned to effectively gauge the clearance distance. When necessary, equipment that enables the dedicated spotter to communicate directly with the operator should be used.

In Depth Analysis--Workers Falls (From Elevation) Accidents

In the construction industry, falls are the most frequently occurring types of accidents resulting in fatalities (Huang and Hinze, 2003). Based on the fatalities recorded by OSHA, worker falls (from elevation) accidents accounted for 33% of all construction-related fatal accidents from 1985 and 1989. As discussed above, 126 crane-related accidents were caused by worker falls (from elevation). In this category, “poor site safety management” was identified as the contributing factor of a large portion of accidents. Other contributing factors included misunderstanding/miscommunication, unstable ground conditions, faulty equipment operations and long overdue crane maintenance.

In Depth Statistics Concerning Workers Fall (From Elevation) Accidents

Most of the workers got killed by falling from elevation (81 out of 126) were laborers/helpers. Among the entire 126 victims fell from elevation, 18 of them are steel/iron worker (accounted for 14.29% of all decedents). Most of them were engaged in steel erection installation works on certain elevation. It was extremely dangerous to sit or stand without fall protection on the steel members that were being installed. In the condition that the unfixed steel member was unsettled by outside force, the member would probably lose its balance and fall with the worker from certain elevation. Due to no fall protection provided or no place to tie off, worker might receive fatal injury.

Of all the heavy equipment that was involved with fall accidents, 76 were mobile cranes such as truck-mounted cranes or boom trucks. There were 43 workers that fell from aerial lifts. Interestedly, the survival opportunity for workers that fell from aerial lift and had fall protection properly tied off was still relatively low. In some cases, when aerial lifts or forklifts tipped over or flipped over due to unstable ground conditions or some type of outside forces, the workers that were completely tied off fell to the ground with the bucket and received fatal injury.

The distance that workers fell was provided in 100 cases. Of these cases, 35 worker fall accidents took place at elevations of less than 30 feet, 41 workers fell from elevations of between 30 feet to 60 feet and 24 workers fell from 62 to 390 feet (shown in Figure 4-14). Almost half of the decedents fell from aerial lift buckets or platforms while performing work at elevation. Six victims fell from steel beams and six fell from tower cranes.

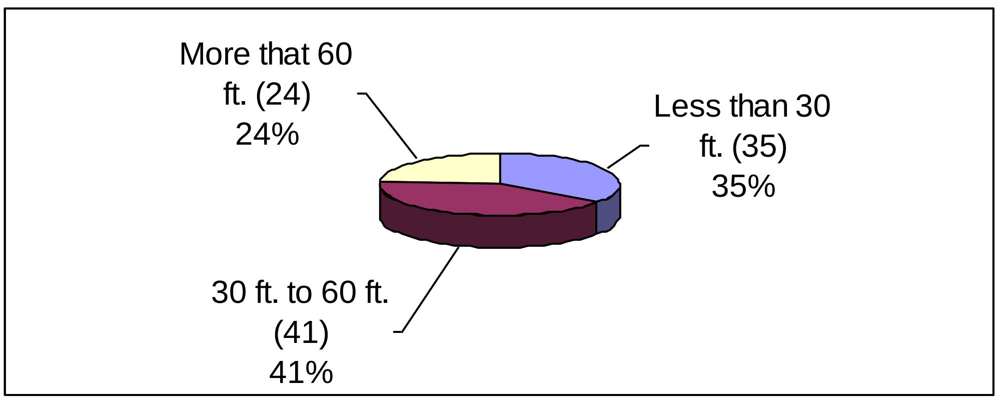

Figure 4-14. Distribution of elevation heights when fall occurred (n=100)

Among all the fall accidents, the actual situation of whether the worker had fall protection fastened and safely tied off was available in 99 cases. Seventy four workers (accounted for 74.74%) had no fall protection provided or chose not to use it, while 13 victims had their harness on but had no place to safely tie off (shown in Figure 4-15). Among all the worker fall cases, one case was particularly interesting. According to the narrative description in OSHA's information system, 2 workers were moving a climber rig into position on a tower crane which at the time was at the 46th story of a high-rise building being constructed. Due to mechanical failure, the climber fell to the 39th floor where it struck a brace. A worker without fall protection fell with the climber and received fatal injuries. On the other hand, the climber hung from the frame of the crane and received minor injuries with fall protection applied.

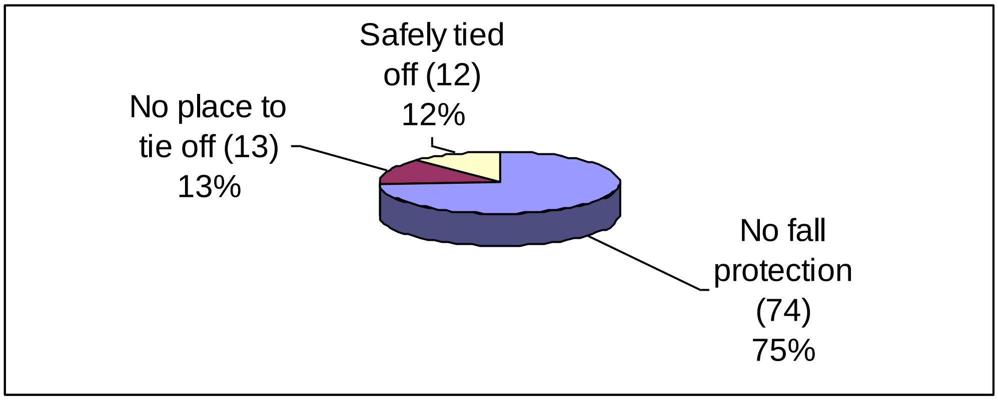

Figure 4-15. Distribution of fall protection conditions when fall occurred (n=99)

Relevant Requirements in Newly-Proposed OSHA Rule

Since workers fall from elevation might happen during various construction activities, the new crane and derrick rule had no intention to comprehensively cover all the safety regulations concerning fall hazards already address in other subparts of the OSHA regulations. In the newly-proposed rule, OSHA applied more stringent rules to prevent workers fell from falling from equipment. Equipment with lattice booms must be equipped with walkways on the boom(s) if the vertical profile of the boom (from cord centerline to cord centerline) is 6 or more feet. The walkways must be at least 12 inches wide. Guardrails, railings and other permanent fall protection attachments along walkways are not required, and prohibited on booms supported by pendant ropes or bars if the guardrails/railings/attachments could be snagged by the ropes or bars.

The employer must maintain in good condition originally-equipped steps, handholds, ladders and guardrails/railings/grab rails. Equipment must be equipped so as to provide safe access and egress between the ground and the operator work station(s), including the forward and rear positions, by the provision of devices such as steps, handholds, ladders, and guardrails/railings/grab rails.

Personal fall arrest system components must be used in personal fall arrest and fall restraint systems and must conform to the criteria. For non-assembly/disassembly work, the employer must provide and ensure the use of fall protection equipment for employees who are on a walking/working surface with an unprotected side or edge more than 6 feet above a lower level when moving point-to-point on non-lattice booms (whether horizontal or not horizontal) or on lattice booms that are not horizontal or on horizontal lattice booms where the fall distance is 15 feet or more.

The employer also must provide and ensure the use of fall protection equipment for employees while working at a work station on any part of the equipment (including the boom, of any type), except when the employee is at or near draw-works (when the equipment is running), in the cab, or on the deck.

For assembly/disassembly work, the employer must provide and ensure the use of fall protection equipment for employees who are on a walking/working surface with an unprotected side or edge more than 15 feet above a lower level, except when the employee is at or near draw-works (when the equipment is running), in the cab, or on the deck.

OSHA Fatalities Data 2007-2009

Differing from the fatality data from 2000 to 2006, the OSHA fatality data for 2007, 2008 and 2009 were more detailed and structured. Among all 138 crane-related fatality accidents recorded from 2007 to 2009, each of them was descried with parameters such as: Activity NO., Standard Industry Classification (SIC), Event Date, Event Time, Direct Cause, Abstract and Detailed Description. Since these fatality records were in such a detailed fashion, more results could possibly be drawn from the more recent data. According to the OSHA fatality data, 47 crane-related fatal accidents happened in 2007, 55 cases happened in 2008, 36 cases happened in 2009.

The Standard Industrial Classification (SIC) is a United States government system for classifying industries by a four-digit code. 15 (General Contractors of Building Construction), 16 (Heavy Construction Contractors) and 17 (Construction Special Trade Contractors) are common numbers in the first 2 digit for construction industry. Upon analysis of the OSHA statistics, sub-groups that were mostly involved with crane-related accidents was sub-group 1791, Structural Steel Erection (14 fatality cases involved), which accounted for 10.14% of all the fatal crane operation accidents during 2007 to 2009 (shown in Table 4-4). Companies included were special trade contractors primarily engaged in the erection of structural steel and of similar products of pre-stressed or pre-cast concrete. To get structural steel in place and connected with other structural members, crane were used to hoist and move structural steel within the construction site. If operational procedures and safety regulations were not carefully understood and followed during hoisting operations, accidents would be more likely to occur.

Sub-group 1623, Water, Sewer, Pipeline, and Communications and Power Line Construction came in second, with 13 crane-related fatality accidents. The companies included in this sub-group were general and special trade contractors primarily engaged in the construction of water and sewer mains, pipelines, and communications and power lines. Cranes were generally used in pipe laying operations or moving workers to higher elevations during communication tower maintenance or repairs. A large portion of cranes in use for pipe-laying were “side boom layers”. In case of overload or unstable ground conditions, the hoisted load (pipe) was moved to the side of the crane with the swinging boom, the equipment was probably going to tip over which could cause fatal accident.

Table 4-4. Distribution of victims’ trades according to SIC (2007-2009)

Types of work	Frequency
Structural Steel Erection	14
Special Trade, Not Elsewhere Classified	14
Pipeline, and Power Line Construction	13
Concrete Work	11
GC-Nonresidential Buildings	10
Heavy Construction, Not Elsewhere Classified	9
GC-Single Family Houses	8
Bridge, Tunnel, and Elevated Highway Construction	8
Electrical Work	8
Highway and Street Construction	6
Roofing, Siding, and Sheet Metal Work	6
GC-Industrial Buildings and Warehouses	5
Other Trades	26
Total	137

Concrete work (sub-group 1771) was involved with 11 crane-related fatal accidents from 2007 to 2009. These subcontractors were generally special trade contractors primarily engaged in concrete work, including Portland cement and asphalt. This industry includes the construction of private driveways and walks of all materials. Workers from this sub-group generally received fatal injuries while pouring concrete from a pump truck, or stripping concrete forms. In case a worker worked with a concrete pump truck that was located just under overhead power lines, when the concrete pump pipe needed to be relocated to continue pouring more concrete, the boom of the concrete pump truck might have been moved and made contact with overhead power lines. As a result, workers holding the pipe directly with their hands or with conductive tag lines would probably get electrocuted.

When the employee was in the process of stripping concrete forms, a 100% tie off rule is absolutely important to ensure worker safety. Victims in most of the cases were wearing their harness but chose to tie off to the concrete form being stripped. When the form was disengaged with the concrete, the worker would fall from or with the form to the lower level and get killed. General Contractors-Nonresidential Buildings (Sub-group 1542) also was involved in 10 crane-related accidents from 2007 to 2009.

Type of tasks performed when accidents occurred were provided in 94 cases among all the 138 crane-related accidents that occurred from 2007 to 2009. Of these, 22 accidents happened when employees were performing crane assembly/disassembly operation, which account for 23.40% of the cases (shown in Table 4-5). Electrical works was the second largest task that led to crane-related accidents. Twelve accidents took place while victims were engaging in electrical pole erection, electrical line installation or repairs. The number of employees killed while performing structural steel installation and roofing work were both 9.

Table 4-5. Type of work performed when accident occurred (2007–2009)

Types of work	Frequency	Percentage
Crane Assembly/Disassembly	22	23.4
Electrical	12	12.77
Structural Steel	9	9.57
Roofing	9	9.57
Concrete Construction	7	7.45
Underground Utility	7	7.45
Demolition	5	5.32
Bridge Construction	5	5.32
Foundation	4	4.26
Painting	3	3.19
Other works	11	11.7
Subtotal	94	100

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

The analysis of crane-related accidents identified the primary direct causes and major contributing factors associated with each direct cause. The primary direct causes were worker struck by (31.17% of all the fatalities), electrical shock (accounted for 24.52% of all the fatalities) and workers falling from elevation (22.07% of all the fatalities). Other than these direct causes, failure the boom/cable, crane tip over and crushed by equipment during assembly/disassembly also led to significant numbers of fatal injuries of construction workers.

Best Practices Addressing “Struck By” Accidents

As discussed above, 178 crane-related fatality cases from 2000 to 2009 were caused by workers who were struck by loads, equipment or objects. Specifically, 72 cases were related to workers being struck by the load being hoisted; 73 cases were related to workers being struck by equipment; and 33 cases were related to workers being struck by objects.

Among all the accidents that were caused by workers being struck by the load, unsafe practices of riggers, failure of rigging hardware and faulty operations of the operators were identified as three most common direct causes. According to OSHA’s newly-proposed rule, employers must use qualified riggers during hoisting activities for assembly and disassembly work. Additionally, qualified riggers are required whenever workers are within the fall zone and hooking, unhooking, or guiding a load, or doing the initial connection of a load to a component or structure. Requirements like post assembly inspection, wire rope inspection and minimum rigger qualifications would significantly reduce the possibility of unsafe rigging practices or rigging hardware failure.

To further reduce the accidents due to faulty operations by operators, OSHA could specify that foremen or designated spotters are needed to make sure the load was completely disconnected from the crane boom before the boom was moved in the newly-proposed crane and derrick rule. Also, to reduce the accidents caused by faulty operation, the situations like blind lifts need to be avoided. Otherwise, a competent spotter is required to give directions and instructions when the operator's view is compromised.

Caught in/between the swinging boom and other parts of the equipment and being struck by the swinging boom in its working radius were identified as the most common scenarios in "worker struck by or caught in/between equipment" accidents. To better protect workers from struck by or caught in/between accidents, the new crane and derrick standard would be more effective to have operation standards targeting specific equipment. For instance, the backhoe operation standard might clarify the safety hazards of loading/unloading materials using backhoe. When the operator left the cab to load materials or communicate with other on-site workers, the engine of the backhoe must be switched to the off position. This will prevent the boom swing control being accidentally triggered by some means. The aerial lift operation standard might stipulate that workers must carefully check the surrounding conditions before commencing with the lifting operation to avoid striking any overhead structural members.

Struck by unstable objects and falling materials were identified as the most common scenarios in "struck by object" accidents. During construction lifting operation, especially in tilt-up construction, the employer needs to designated one experienced and competent personnel to make sure that pre-cast members were totally stabilized and secure with other members that had already been erected before signaling the crane operator to release the tension on the loading cable.

Due to poor site safety management, materials stocked at certain elevations were not safely secured. To address such hazards, the employer needs to make sure materials stocked above the ground elevation are arranged orderly at a designated location, and the employer should make sure all the materials were properly secured to minimize falling materials hazards. Also, the installation of overhead falling protection (safety net) would effectively protect workers from being struck by falling objects.

Best Practices Addressing "Electrical Shock" Accidents

From 2000 to 2009, 140 construction workers received fatal injuries due to electrocution. From the analysis of accidents of electrical shock, it was obvious that many accidents could be avoided if workers were equipped with minimum levels of hazard awareness to prevent accidents from happening and also survival knowledge to protect themselves when the accidents do occur.

To prevent "electrical shock" accidents; the newly-proposed crane and derrick rule would be more effective to target specific equipment, and it could better protect employees from receiving electrical shock around specific types of equipment (such as concrete pump truck). For example, to better protect the laborers and helpers working around concrete pump trucks, it is necessary to impose more stringent power line clearance requirements when the employer guides pipes with a tag line to pour concrete from a concrete pump truck. Utilization of nonconductive taglines for pipe guiding is also a method to minimize worker electrocution. To better protect driller worked around drill rig, before entering the working zone, employee need to conduct a hazard assessment concerning over head power lines condition. The possibility of over head power line contact needed to be considered, when raise boom to pull drill out of ground.

In OSHA's newly proposed crane and derrick rule, it is required to implement a hazard assessment and precautions inside the work zone. Before beginning equipment operations, the employer must determine if any part of the equipment, load line or load (including rigging and lifting accessories), if operated up to the equipment's maximum working radius in the work zone, could get closer than 20 feet to a power line. If so, certain precautions like power line de-energizing, utilization of proximity devices or barrier cables need to be implemented to avoid power line contact. The chance of power line contact would be lowered if a competent spotter was designated to help the crane operator maintain safety clearance. Additional training should also be offered that targets specific trades that are more likely to be involved with electrical shock accidents.

Best Practices Addressing "Workers Fall" Accidents

As discussed above, 126 crane-related accidents' direct causes were coded as worker falls (from elevation). In this category, "poor site safety management" was identified as the contributing factor of a large portion of accidents. Other contributing factors included misunderstanding/miscommunication, unstable ground conditions, faulty equipment operations and long overdue crane maintenance. Concerning most fall accidents, fall protection either was not provided or workers were not properly tied off to secure their safety. Since the OSHA regulations on PPE for fall prevention were revised in 1996, neither the quantity nor pattern of falls on construction sites has changed significantly; in fact, the proportion of accidents caused by falls has actually increased (Huang and Hinze, 2003).

Many fall accidents could be avoided if workers were more experienced in identifying potential fall hazards and they would protect themselves while working at high elevation. Before beginning work, employees need to implement hazard assessments and precautions inside the work zone. If any fall hazard (floor opening or leading edges) was identified, the employer needs to make sure certain precautions such as personal protection equipment, guide rails or safety nets are provided to ensure worker safety. Additional training to target specific trades that are typically involved in fall accidents (steel erection crews, crane assembly/disassembly crews and roofing crews) would be helpful to minimize the risk of falls. Further case study of fall accidents and fall-related near misses would provide useful insights to help workers raise their fall hazard awareness.

Since workers falling from elevation might occur during various construction activities, the new crane and derrick rule had no intention to comprehensively cover all the safety regulations concerning fall hazards already address in other subparts of the OSHA regulations. Employers need to refer to Subpart E - personal protective and life saving equipment, Subpart M - fall protection and other related subparts in OSHA's construction safety and health regulations to ensure employees' safety while working at certain elevations.

Research Specific Recommendations

This research has attempted to explore the direct causes of crane-related accidents and to propose best practices accordingly. These practices will have to be constantly reviewed and revised.

Consideration could be given to studying the effectiveness of these proposed best practices when undertaking different construction projects. It would be beneficial to conduct surveys regarding the difficulties encountered while implementing these practices on project sites and the level of compliance obtained. Information could be collected from different source levels, including project managers, superintendents, foremen and trade workers.

Based on the comparison made between the newly-proposed crane and derrick rule and the identified typical crane-related accident scenarios, it is evident that the standards and requirements in the new rule effectively cover significant hazards involving crane operations. If these standards and requirements are strictly followed and effectively implemented, the occurrence of crane-related accidents would be significantly reduced. Thus, further research consideration should be focused on how to achieve better compliance of this newly-proposed crane and derrick rule.

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BIOGRAPHICAL SKETCH

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