Crane-Related Fatalities in the Construction Industry

J. E. Beavers, P.E., F.ASCE[1]; J. R. Moore[2]; R. Rinehart[3]; and W. R. Schriver[4]

Abstract: One of the major causes of fatalities during construction is the use of cranes or derricks during lifting operations. Using the Occupational Safety and Health Administration's (OSHA) case files from fatality investigations during the years 1997–2003, the writers examined the data to determine the proximal causes and contributing physical factors. The research results showed the use of mobile cranes with lattice and telescopic booms, truck or crawler mounted, represented over 84% of the fatalities in the use of cranes/derricks. To reduce the rate of crane fatalities the writers believe that crane operators and riggers should be qualified and requalification should occur every 3 years. Crane safety training must be provided to specialty trade crafts before they are allowed to work around cranes during lifting operations. In addition, a "diligent" competent person [as defined in 29CFR 1926.32(f)] should be in charge of all aspects of lifting operations. Finally, OSHA should improve its system of collecting information during fatality investigations, placing emphasis on intervention strategies to improve usefulness of the investigations to researchers and policymakers inside and outside the Agency.

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Introduction

Construction fatalities continue to occur in the construction industry in spite of the Occupational Safety and Health Administration's (OSHA) comprehensive safety standards specified in Title 29, Part 1926, of the Code of Federal Regulations (OSHA 2003c) and the recommendations made from the research that has been conducted on the subject since the 1990s (e.g., Ringen and Stafford 1996). 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; only agriculture and mining exceeded this rate (Department of Labor 2003).

The United States Occupational Safety and Health Administration (OSHA or "the Agency") Compliance Safety and Health Officers (CSHOs) investigated 7,479 fatalities in the construction industry from 1991 to 2002. In earlier studies, under contract with OSHA's Directorate of Construction and Directorate of Evaluation and Analysis, Office of Statistical Analysis, the Construction Industry Research and Policy Center (CIRPC) at the University of Tennessee analyzed the electronic records of these fatalities, which are available in the Agency's Integrated Management Information System (IMIS). The IMIS records cover the entire nation including both Federal Program and State Program States. Federal Program States are those states wherein OSHA conducts and manages the National occupational safety and health program. As of 2004, approximately 57% of construction employment in the nation was in the Federal Program States (Department of Labor 2004).

In support of its analysis of the IMIS records, CIRPC developed a mutually exclusive list of 29 proximal cause codes of fatal construction events. Each fatal event occurring during the study period was classified and ranked by proximal cause and annual reports were submitted to OSHA (Schriver and Cressler 1991–2002). Schriver and Cressler showed the composite frequency of the top ten proximal causes. "Fall from/through roof" was the number one cause in terms of frequency, followed in rank order by "fall from/through structure (other than roof)," "crushed/runover of nonoperator by construction equipment," "electric shock by equipment contacting power source," and "hit, crushed, fall during lifting operations." These rankings are highly invariant by year (Schriver and Schoenbaum 2003).

One of the major causes of fatalities during construction is in the use of cranes or derricks during lifting operations. Research and recommendations to reduce fatalities during crane or derrick operations have been ongoing during the past several decades, but the incidence of fatalities during these operations continue. In light of this fact, OSHA is in the process of rewriting and publishing its crane and derrick standard (Korman 2004) via the rule-making process. The rewriting has been completed and cost-effective analyses are now being conducted before publishing the revised standard. To support this overall effort, CIRPC reexamined the IMIS data from 1991 to 2002 to specifically look at crane-related fatalities (fatalities that involved cranes or derricks).

[1]Associate Director, Construction Industry Research and Policy Center, College of Business Administration, and Research Professor, Civil and Environmental Engineering, Univ. of Tennessee, 2000 Lake Ave., Knoxville, TN 37966 (corresponding author). E-mail: jbeavers@utk.edu

[2]Director, Administration, Construction Research and Policy Center and Professor Emeritus, Dept. of Economics, College of Business Administration, Univ. of Tennessee, 2000 Lake Ave., Knoxville, TN 37966.

[3]International Consultant on Occupational Safety and Health, Globalsense, Bangalore, India 560038; formerly, Epidemiologist, OSHA's Directorate of Construction.

[4]Director, Construction Industry Research and Policy Center and Adjunct Professor, Dept. of Economics, College of Business Administration, Univ. of Tennessee, 2000 Lake Ave., Knoxville, TN 37966.

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The reexamination showed that crane-related fatalities cut across several of the proximal cause codes originally developed by CIRPC and represents at least 8% of all fatal construction events investigated by OSHA during that period.

The current study examines crane-related fatalities for the years 1997–2003 and should be of general interest in support of OSHA's current rulemaking effort for cranes and derricks. The findings are discussed and conclusions given that include recommendations for preventing future crane-related fatalities.

Literature Review

A number of studies of crane-related fatalities have been undertaken in the last 25 years. For the most part, these studies fall into one of two categories:

1. Conceptual; or
2. Empirical.

While the "conceptual" studies often do contain some data, their focus is on possible human factors or equipment issues rather than on the statistical details of fatality cause. A prime example of studies of this kind is the MacCallum (1980) study which can be characterized as a hazard analysis of crane design. He concludes with a number of specific suggestions regarding crane design and operation. Jarasunas (1984a,b) has studied the causes and prevention of crane accidents. In his second paper he concludes his prevention research with the observation that "from a safety engineering viewpoint, the first priority is to make the tools and equipment as safe as possible through the application of known state-of-the-art."

While not contradicting the Jarasunas conclusion, some contributors to the literature have made specific suggestions regarding operator training. For example, Neitzel et al. (2001) reviewed crane safety in the construction industry and pointed out there is currently no federal United States standard requiring construction crane operators to be licensed or certified.

ASCE (1998) published a manual entitled *Crane safety on construction sites*. Within the manual, ASCE published ASCE Policy Statement 424 which made eight safety recommendations in crane operations.

Hakkenin (1993), in a paper on crane accidents in general, points out that as far as training goes, the education of all workers in the crane environment is important. In his limited data base he found that "most of the accident victims were workers fastening or loosening loads or steering loads with their hands during lifting."

The National Institute for Occupational Safety and Health (NIOSH 1995) conducts a Fatality Assessment and Control Evaluation (FACE) program to develop intervention strategies to reduce fatalities in the work force. This program is selective and evaluates only a very small percent of those investigated by OSHA.

Two recent studies can be characterized as primarily empirical. In the first of these, Suruda et al. (1999) examined the IMIS database of crane fatalities for the years 1984–1994 and estimated that OSHA had investigated 502 deaths in 479 events. "Electrocution" was the largest category of crane-related deaths with 198 (39%) reported.

Using the same data base of OSHA fatality narratives, as Suruda, and for essentially the same time period, Shepard et al. (2000) established taxonomy for over 550 crane fatalities. Similar to Suruda et al., the data revealed that power line contact by the crane represented 190 (36%) of the fatal events studied.

The current study is in the mold of these two empirical studies described above. It differs from them in several respects, however. In the first place the data base involves the years 1997–2003, whereas the other studies ended in 1994 and 1995, respectively. Second, the data in the early studies were based upon the IMIS narrative reports while the writers' investigation had available the full OSHA case files which provided information not in the narrative. Furthermore this study is intended to complement the earlier work of others by classifying recent fatal events by proximal cause, contributing physical factor, project end use, construction operation, existence of an employer safety and health program, OSHA citations, and various other factors.

Methods

Potential crane-related fatalities were identified by performing a text search of the narrative information available in the IMIS database for the years 1997–2003 using the key words "crane," "derrick," or "boom." OSHA then provided CIRPC with copies of the case files compiled by the CSHOs in the field who inspected the identified fatalities, but only for the Federal Program States mentioned in the "Introduction." The state plan states were not asked by OSHA to send case files to CIRPC. Therefore, the input data for this study represent approximately half the states in the United States, or 57% of construction employment in 2004, as mentioned above.

CIRPC found 381 IMIS data base files with the words "crane," "derrick," or "boom" and requested these files from the OSHA regional offices of the Federal Program states. CIRPC received 335 (88%) of the case files requested from OSHA and manually reviewed them to confirm that a crane or derrick was involved in the fatality. This resulted in the selection of 125 case files involving 126 cranes and 127 fatalities for analysis (one fatal event, electrocution, resulted in three deaths and one fatal event involved two cranes). The selected case files were then reviewed again to determine for each fatal event:

1. Proximal cause and contributing physical factor(s);
2. Victim's occupation;
3. Work site by end-use function;
4. Construction operation being performed by the crane;
5. CSHO's evaluation of the safety program of the victim's employer;
6. Union representation;
7. Type of crane involved in fatal event; and
8. Number and type of OSHA citations by proximal cause.

Also, an attempt was made to extract information from the fatality case files regarding training and certification of the crane operator, experience of the victim (if other than operator), presence of a competent person at the site of the crane operation, and type of rigging. However, even though analysis of this additional information could be useful to OSHA and its stakeholders, the majority of the case files did not contain information on these additional topics as there was no requirement by OSHA for its CSHOs to collect such data (OSHA 1998). Therefore, some of these factors could not be included in the final analysis.

The following seven mutually exclusive proximal causes of crane-related fatalities were used for classifying the 125 case files:

1. Failure of boom/cable;
2. Crane tip over;
3. Electrocution;
4. Struck by load (other than failure of boom/cable);

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Table 1. Crane Fatal Events by Proximal Cause and Contributing Physical Factors

Proximal cause	Contributing factors	Number of events (%)
Struck by load (other than failure of boom/cable)		40 (32)
	Rigging failure	24
	Unbalanced load	3
	Load dropped	10
	Accelerated movement	1
	Equipment damage	5
Electrocution		34 (27)
	Failure to maintain required clearance	34
	Boom contact	15
	Cable contact	12
	Headache ball/sling contact	5
	Jib contact	1
	Load contact	1
Crushed during assembly/disassembly		15 (21)
	Improper assembly	3
	Improper disassembly—pin removal	10
	Improper boom support	6
Failure of boom/cable		15 (12)
	Boom buckling	2
	Boom collapse	5
	Overload	6
	Equipment damage	5
	Incorrect assembly	3
	Cable snap	3
	Two blocking	1
Crane tip over		14 (11)
	Overload	5
	Loss of center of gravity control	3
	Outrigger failure	2
	High winds	2
	Side pull	1
	Improper maintenance	1
Struck by cab/counterweight		4(3)
	Intentional turntable turning	3
	Bridge crane in motion	1
Falls		3 (2)
	Missing hand rails	1
	Improper operation	1
	Improper maintenance	1

5. Falls;
6. Crushed during assembly/disassembly; and
7. Struck by cab/counterweight.

Crane failure modes used by others (MacCollum 1980; Hakkinen 1993; Suruda et al. 1999) e.g., two-blocking or rigging failure, were not identified as proximal causes in this study because no fatalities resulted from such failures or the failures were a contributing physical factor to a proximal cause. Contributing physical factors were defined as the physical factor(s) that contributed to each fatality (e.g., "improper rigging" that led to the proximal cause, "struck by load") and are not mutually exclusive. Finally, CIRPC had developed a coded list of construction operations (Schriver and Cressler 1991–2002) that was recently updated to include cleanup, electrical distribution and transmission, maintenance, and mobilization (Beavers 2004) for a total of 60 comprehensive construction operations. Selected information was extracted from each case file and summarized. Microsoft Access and Excel were used for managing data and generating summary statistics.

Study Results

Proximal Cause and Contributing Physical Factor(s)

The proximal cause and contributing physical factor(s) leading to each fatality are shown in Table 1 in order of frequency. "Struck by load" was the leading cause. The contributing physical factors for this cause were rigging failure, unbalanced load, load dropped, accelerated movement of the crane or load, and/or equipment damage. Because the contributing physical factors are not necessarily mutually exclusive (e.g., in some cases two physi-

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cal factors contributed to a single fatality), the sum of contributing factors does not always equal the total number of fatal events for a specific proximal cause (Table 1).

"Electrocutions" ranked second as a proximal cause. Six physical factors were identified as contributing to this cause; all 34 involved failure to maintain the OSHA-specified distance from energized power lines.

Fatalities caused by "crushed during assembly/disassembly" all involved a lattice boom crane, usually during disassembly, with the two major contributing physical factors being improper boom support and improper pin removal resulting in the boom section crushing the person underneath the boom. There were several contributing physical factors to fatalities resulting from "failure of boom/cable." These included boom buckling or collapse, overload of the crane's capacity, equipment damage, incorrect assembly, cable failure, and two blocking. The contributing physical factors leading to fatalities caused by "crane tip over" were overload, loss of center of gravity control, outrigger failure, high winds, side pull, and improper maintenance. Only two contributing factors were attributed to the proximal cause "struck by cab/counter weight:" intentional turntable turning and bridge crane in motion (i.e., moving the crane to another location). In the case of proximal cause "falls," missing hand rails, improper operations and improper maintenance were identified.

Victims' Occupations

The writers categorized the victims into four worker occupations; (1) crane operator; (2) rigger/laborer; (3) ironworker; and (4) other. "Laborer" was included with rigger because often the person doing the rigging was identified as a laborer in the case file narratives. Of the 69 victims identified as rigger or laborer from the case file narratives, 18 were identified as riggers and 51 as laborers, i.e., laborers represented 74% of the victims doing the rigging. "Other" was a general occupation that consisted of carpenter, truck driver, pile driver, welder, etc. Table 2 shows the proximal cause in relation to the victim's occupation.

With respect to proximal cause "electrocution" as shown in Table 2, the writers found a similar, but higher incidence rate than did Shepard et al. (2000) with 74% being a rigger or laborer handling the load compared to Sheppard et al.'s 57%.

Work Site by End Use

The U.S. Census Bureau has developed codes to classify construction worksites by functional end use (U.S. Census Bureau 1997). These codes are divided by the Bureau into "building construction" and "nonbuilding construction" for a total of 48 end-use codes. Thirty four of the 48 end-use types were involved in this study. The most frequent end-use types for building construction were "All other commercial buildings" (defined as buildings intended for use primarily in the retail and service trades, e.g., stores, restaurants, automobile service stations, etc.), "manufacturing and light industrial buildings," and "single family houses, detached." The largest number for nonbuilding construction was "bridge and elevated highways," "highways, streets and related work," "other nonbuilding construction," and "harbor and port facilities."

Construction Operation

The frequency by construction operation having two or more fatal events is shown in Table 3. The highest frequency of crane-related fatalities occurred during mobilization when lifting or moving equipment, including crane assembly/disassembly, and materials at construction site lay down areas, or on the contractors' yards. Mobilization, erection of steel, demolition and pile driving resulted in the highest frequency of fatal events (68%).

These data suggest when these types of construction operations are being implemented, additional safety precautions should be taken.

Employer's Safety and Health Program

CSHOs are required to rate employers' safety and health programs during fatality investigations using the following scale: (1) nonexistent; (2) inadequate; (3) average; and (4) above average. For the 125 crane-related fatalities, only 112 of the case files examined contained copies of the form used to rate safety and health programs [OSHA Form 1A (OSHA 2005b)]. For the data available for review, 60% of the employers were rated as having "average" or "above average" programs while 40% were rated as having "nonexistent" or "inadequate" programs.

Union Representation

The OSHA case files contained information on whether the victim was represented by a union. Union representation was indicated in 37 (29.4%) of the cases. The average and median employment sizes for unionized employers in this fatality study were 1,136 and 85 employees, respectively. The average and median employment sizes for open-shop employers were 204 and 47 employees, respectively. No inferences can be made about the relative fatality rates of union verses nonunion workers, because the relative share of the work being performed by union and nonunion workers is unknown.

Type of Crane

While CSHOs are not required by OSHA to identify the type of crane involved in a fatal event, it is usually included in the descriptions provided in the case files, often in the witness interviews. The writers were able to identify the type of crane in 120 of the 125 case files. One case involved two cranes. Table 4 provides the frequency of crane fatal events with known crane type. Mobile cranes represented over 88% of the fatal crane-related events while those with lattice booms involved over 56% of the fatalities.

Crane type was also examined by proximal cause of the fatalities. The proximal causes "electrocution," and "crane tip over" were associated only with mobile cranes. These data suggest the hazards of electrocution and crane tip over should be emphasized in the safety training of operators and riggers/laborers.

Certification and Experience

As stated, an attempt was made to extract information from the fatality case files regarding training and certification of the crane operator, experience of the victim (if other than operator), presence of a competent person at the site of the crane operation, and type of rigging. In this regard, case files sometimes address these issues. For example, the authors found evidence that crane operators were certified in nine cases and not certified in 10. For the 12 cases where the crane operator was a victim, one was identified as being certified and one case showed the crane operator had 15–20 years of experience.

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Table 2. Proximal Cause of Crane-Related Fatal Events in Relation to Victim Occupation

Proximal cause	Victims	Number of events (%)
Struck by Load (other than failure of book/cable)		40 (32)
	Operator	0
	Rigger/laborer	19
	Ironworker	9
	Other	10
	Unknown	2
Electrocution		34 (27)
	Operator	2
	Rigger/laborer[a]	25
	Ironworker	0
	Other	6
	Unknown	1
Crushed during assembly/disassembly		15(12)
	Operator	3
	Rigger/laborer	5
	Ironworker	1
	Other	5
	Unknown	1
Failure of boom/cable		15(12)
	Operator	1
	Rigger/laborer	9
	Ironworker	1
	Other	3
	Unknown	1
Crane tip over		14 (11)
	Operator	5
	Rigger/laborer	5
	Ironworker	0
	Other	2
	Unknown	2
Struck by counter weight		4 (3)
	Operator	0
	Rigger/laborer	2
	Ironworker	0
	Other	1
	Unknown	1
Falls		3 (2)
	Operator	1
	Rigger/laborer	2
	Ironworker	0
	Other	0
	Unknown	0

[a]Two additional rigger/labor victims electrocuted for a total of 27 victims.

In the case of riggers identified as the victim, evidence existed showing one as certified and one having 1–5 years of experience.

OSHA Citations

Following each fatality, OSHA CSHOs cite the employers for safety violations against OSHA Standards (OSHA 2005a). These citations are for safety violations that existed at the construction site at the time of the fatality. The citations are based on the CSHO's post fatality inspection and interviews with witnesses to the fatality. The safety violations may or may not have been a contributing factor to the fatality, but demonstrate overall safety at the construction site. The citations are classified as either: serious, willful, or general. A serious violation is where there is substantial probability of death or serious physical harm could result from a condition which exists, or from one or more practices, means, methods, etc. have been adopted or are in use. A willful violation exists where the evidence shows either intentional or plain indifference to OSHA standards.

For the 125 events, the CSHO's cited employers for 398 serious and/or willful (SW) violations. Table 5 shows the top five cited SW violations per citation number. Citation number 1926.550(a)(15) was the highest cited with 41 citations. The top

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Table 3. Frequency of Crane-Related Fatality Events by Construction Operation

Code	Construction operation	Frequency	Percent (%)
37	Mobilization	39	31
37a	Lifting/moving equipment and materials	(30)	(24)
37b	Assembly/disassembly of cranes	(9)	(7.3)
12	Erecting structural steel	19	15
6	Demolition	15	12
40	Pile driving	12	10
58	Trenching, installing pipe	4	3.2
21	Forming	3	2.4
42	Placing bridge girders and beams	3	2.4
48	Precast installation	3	2.4
11	Emplacing reinforcing steel	2	1.6
17	Exterior carpentry	2	1.6
25	Installing HVAC including piping, ductwork and other equipment	2	1.6
44	Pouring concrete piers and pylons	2	1.6
43	Pouring floor decks	2	1.6
	All others (one fatality each)	16	
Total		124[a]	100

[a]One case had no information to determine construction operation.

five citations accounted for 133 of the 398 SW violations. For the forty fatalities resulting from proximal cause "struck by load" (Table 1), 133 citations were issued for an average of 3.15 SW citations per fatality. The citations were ranked in order by subpart number. The top three subpart number violations were Subpart N-cranes, derricks, hoists, elevators, and escalators (OSHA 2003a) with 36 citations, followed by Subpart M-fall protection (OSHA 2003b) with 14 citations, and Subpart R-steel erection with 14 citations. In all there were a total of 12 different subpart citations with numerous sections of each subpart being cited. The most frequently cited section under Subpart N was 1926.550(a)(19), "All employees shall be kept clear of loads about to be lifted and of suspended loads."

For proximal cause "electrocution" there were 109 SW citations for 34 fatalities that resulted in 107 Part 1926 citations and two Part 1910 "Occupational Safety and Health Standard" citations resulting in an average of 3.2 citations/fatality. Subpart N was cited most frequently with 66 SW citations. The top ranked citation within Subpart N was 1926.550(a)(15)(i), "For lines rated 50 kV or below, minimum clearance between the lines and . . . the crane shall be 10 ft," at 21 times. Subpart C-general safety and health provisions ranked second among subparts with 18 SW violations. The most cited citation within Subpart C was citation number 1926.21(b)(2) "the employer shall instruct each employee in the recognition . . . unsafe conditions . . .," which was cited 12 times.

In the case of the 15 fatalities having proximal cause "crushed during assembly/disassembly" there were 39 Part 1,926 citations for an average of 2.6 SW citations per fatality. Subpart N ranked first with 20 SW citations. Among the specific citations within Subpart N, the most frequently cited were 1926.550(a)(1), "The employer shall comply with manufacturer's specifications . . ." and 1926.550(b)(2), "All crawler . . . cranes in use shall meet the applicable requirements for design. . . ." Subpart C-"general safety and health provisions" ranked second with nine SW citations.

Similarly, for the remaining 36 fatal events having proximal causes "failure of boom/cable," "crane tip over," "struck by cab/counter weight," and "falls" there were 90 SW citations. Proximal cause "struck by cab/counterweight" averaged 4.3 SW citations per fatality, and "falls" averaged 2.7 SW citations/fatality while fatalities caused by "failure of boom/cable" and "crane tip over" averaged 1.8 SW citations per fatality.

Table 4. Frequency of Crane-Related Fatal Events by Crane Type

Crane type	Frequency	Percent
Mobile crane with lattice boom	68	56.2
Crawler	(37)	(30.6)
Truck	(31)	(25.6)
Barge	(1)	(0.8)
Mobile crane with telescopic boom	39	32.2
Crawler	(0)	(0)
Truck	(39)	(32.2)
Tower crane	5	4.1
Bridge crane	3	2.5
Container Crane	3	2.5
Jib crane	3	2.5
Total	121[a]	100

[a]One fatal event involved two cranes.

Discussion

C-DAC Consensus Document

The primary purpose of this study was to supplement OSHA's current rule-making effort for cranes and derricks to provide the Agency a backdrop of the causes and circumstances surrounding crane-related fatalities. For example, with respect to the highest proximal cause, "struck by load," in Section 1425 "keeping clear of load" of the C-DAC consensus document, (OSHA 2004a), it is stated that: "when employees are engaged in hooking, unhooking, or guiding the load, or in the initial connection of a load to a component or structure and are within the fall zone, the following

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Table 5. Fifteen Most Frequently Cited OSHA Standards by Number of Serious and Willful Citations Issued to Employers Investigated for Crane-Related Fatality

Citation number	Requirements of standard	Number of SW citations
1926.550(a)(15)	"Except where electrical distribution and transmission lines have been deenergized . . . shall be operated proximate to power lines . . ."	41
1926.21(b)(2)	"The employer shall instruct each employee in the recognition . . . unsafe conditions . . ."	36
1926.550(b)(2)	"All crawler . . . cranes in use shall meet the applicable requirements for design . . ."	21
1926.550(a)(19)	"All employees shall be kept clear of loads about to be lifted and of suspended loads.	18
1926.550(a)(1)	"The employer shall comply with the manufacturer's specifications . . ."	17

criteria shall be met . . . . The materials shall be rigged by a qualified rigger." As noted above, 18 case file narratives identified the victim as a rigger. However, only 14 included an OSHA Form 1B (OSHA 2005b) which lists the victim's occupation, and none identified the victim as "rigger," although one victim's occupation was identified as "hoist crew." Table 6 shows the recorded occupation of the 14 victims. In the case files that involved the 69 victims where the fatality was rigging related, the writers found evidence of one qualified rigger. In the case of the second highest proximal cause, "electrocution," in Section 1427 "operator qualification and certification" of the C-DAC consensus document, it is stated that: "The employer must ensure that, prior to operating any equipment covered under Section 1400, the operator is either qualified or certified to operate the equipment . . . ." Part of that training is stated in Section 1408 "power line safety (up to 350 kV)-crane operations," (g) "training," "operators and crew assigned to work with the equipment shall be trained on the following . . . ." Although crane operator qualification verification is not required when conducting an OSHA fatality investigation, as noted above, the writers found evidence that only nine operators were certified and ten not certified. In most cases it was not the operator that became the victim; it was a rigger, laborer, and/or other. It is clear there continues to be a systemic problem related to training of employees who work around cranes during lifting operations. For the 34 electrocutions, only four victims were identified as riggers while 28 were identified as laborers or other.

Previous Research

This study was also intended to complement the earlier work of other researchers (see "Literature Review") by classifying more recent fatal events involving cranes by proximal cause, contributing physical factor, project end use, construction operation, etc. However, differences in the source data for this study and other studies, in particular Suruda et al. (1999) and Shepard et al. (2000) should be considered. The main difference, other than the years investigated, was that the writers examined the full case files generated by CSHOs to obtain data, while Suruda et al. and Sheppard et al. based their findings on the brief abstracted descriptions and coded information found in the electronic IMIS data base.

OSHA Data

Based on the writers' personal experience, OSHA does not yet have effective tools (data entry form), training program, or quality control system in place to help CSHOs consistently and accurately code and enter fatality inspection data into IMIS. In addition, it appears that little formal guidance is given to CSHOs on how to write effective IMIS abstracts that capture key features leading to the fatality. As a result, the narrative descriptions contained in IMIS are not standardized and are often incomplete. Many are only one or two sentences long. The fatality case files that were made available to CIRPC by OSHA were believed to be the most complete and accurate descriptions of the fatal events investigated by OSHA. The writers suggest that it would be in OSHA's best interest, and in the interest of its stakeholders, for the Agency to improve the way fatality data are obtained by investigation and entered into the IMIS data base. Also, the information collected in the investigation appears primarily to justify and support the violations cited. It should, additionally, provide comprehensive information useful in development of intervention strategies.

Difference in Causes

The current study coded proximal causes differently from Suruda et al. (1999) and Shepard et al. (2000) which, on the surface, led to different findings. For example, Suruda et al. and Shepard et al. observed "electrocution" as the most important proximal cause, representing 39 and 36% of the crane fatalities, respectively. Surudu et al. observed "struck by moving load" as the cause of 4% of the fatalities while Shepard et al. observed that "fall of suspended load" hitting the victim as the cause of 10% of the fatalities. In this study, "struck by load" was the number one proximal cause at 32% and "electrocution" was ranked second with 27% of

Table 6. Rigger Identified Victim Occupations

Frequency	Victim occupation
3	Laborer
2	Foreman
1	Finisher/carpenter
1	Electrical apprentice
1	Hoist crew
1	Form builder
1	Electrician's helper
1	Rod buster
1	Steel erector
1	Boilermaker
1	Crane operator
4	Unknown

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all fatalities reviewed. For example, most of the difference between these studies can be explained by comparing the 2003 case files used in this study with the Suruda et al. study. Application of the Suruda et al. coding criteria to the authors' 2003 case files produced nine "electrocution" events and only one instance of "struck by moving load." Using the writers' coding scheme, however, there were nine cases of "electrocution" and seven "struck by load." The Suruda et al. criteria coded the six missing entries for "struck by load" as four "rigger failure" and two "control confusion" causes. In this study, these factors were considered to be contributing physical factors to the proximal cause "struck by load." Nevertheless, as reconfirmed by this study, electrocution remains one of the primary causes of crane-related fatalities and serious efforts are being made by industry to confront the problem (OSHA 2004a). Considering all of the writers' case files and comparing results with Shepard et al. "fall of suspended load" fatalities, the writers' contributing physical factor "load dropped" (Table 1) should be equivalent to Shepard et al. "fall of suspended load" and it represents 8% of fatalities versus 10%.

Writers' Findings

It may also be of interest to compare the writers' findings with what OSHA has identified as the major causes of crane events (OSHA 2004b). OSHA defines the major causes as: (1) contact with power lines; (2) overturns; (3) falls; and (4) mechanical failures. These four causes are synonymous with the writers' proximal causes of electrocution, crane tip over, falls, and failure of boom/cable. However, struck by load (other than boom/cable failure), crushed during assembly/disassembly, and struck by cab/counterweight are not included as major causes by OSHA. The Agency should consider modifying its list of major causes to match those observed in this study (Table 1).

The writers also examined the victims' occupations (Table 2). One finding that resonates from these data is that most workers who die from crane-related events are not crane operators; rather they are specialty trade workers (e.g., laborers, carpenters) who may not automatically be included in training programs related to crane safety. Special attention regarding training and awareness should be paid to these workers whose normal day-to-day activities do not involve crane-related work, but who may from time to time be required to work with cranes.

The end-use function of the construction worksites involving cranes was analyzed. The highest frequency of crane fatalities occurred in end-use functions "all other commercial buildings" and "manufacturing and light industrial buildings." This may be due to the fact that these buildings are largely constructed of steel and steel erection requires the use of cranes. It is also true that these end-use types include a relatively larger share of total construction activity. No inferences can be made about the rate of crane-related fatalities by end-use type, because the use of cranes and volume of construction varies substantially by end-use type.

Table 3 showed the construction operation "mobilization" had the highest frequency of fatalities, more than twice the second highest frequency. Thirty of the mobilization events were from lifting/moving equipment and materials and nine events from assembly/disassembly. The high fatalities in "mobilization" would be expected, because mobilization is a fundamental part of all construction operations, involving significant use of cranes for loading and unloading. Since each mobilization event is likely to be unique, and because of the variety of trades that may be involved, it is especially important that a "diligent" competent person be on hand to coordinate this activity and assist the crane operator. The competent person must be knowledgeable of OSHA standards, but should also review and implement any engineering or safety plans related to the project. The writers add the word "diligent," because oftentimes a competent person was present at the site of a crane-related fatality but did not appear to act in a diligent manner in assuring safety at the work site.

The existence and quality of employer occupational safety and health programs was also examined. CSHOs are required to rate seven aspects of programs during fatality investigations, based on their OSHA training on the subject and professional judgment. On average 40% of the employers experiencing fatalities had occupational safety and health programs rates as "nonexistent" or "inadequate." Since similar data from construction employers at worksites without fatalities are not available, it is not possible to compare the results with construction industry norms. However, OSHA has noted a relationship between the application of sound management practices in the operation of safety and health programs and low incidence of occupational injuries and illnesses. The Agency advises all employers to institute and maintain in their establishments a program that provides systematic policies, procedures, and practices that are adequate to recognize and protect their employees from occupational safety and health hazards (OSHA 1989). Chapter 2 of the ASCE manual *Crane safety on construction sites* (ASCE 1998) discusses a site safety plan that should be prepared by the prime contractor/construction manager which covers all phases of safety on the construction site including crane safety. Such a plan (Project safety and health plan) is required by the Department of Energy (DOE 2002) prior to commencing any work on a project worksite. In the ASCE manual a *crane safety plan* is part of the site safety plan which includes lift plans that describes procedures for each lift.

Regarding the types of cranes involved in the fatal events, mobile cranes represented 88.4% of the fatalities (Table 4). Electrocutions involved only mobile cranes and all were the result of a crane's boom and/or wire rope getting extremely close to or touching high voltage lines. With respect to crane tip over, mobile cranes by their nature are more susceptible to tip over than other types of cranes. Crushed during assembly/disassembly occurred only with mobile cranes with lattice booms.

Finally, the writers examined the OSHA citations filed against the victims' employers by proximal cause for each fatal event. By reviewing its own citation experience, OSHA may obtain a better understanding of how the current standards were applied to the most serious events involving cranes. The citation history also may be helpful in assisting employers to appreciate the types of safety deficits which relate to compliance with OSHA safety standards. While it can be argued that there is some subjectivity applied by CSHOs as to the specific standards cited for a given situation (e.g., two CSHOs investigating the same fatality without knowledge of the other may cite a different mix and severity of OSHA standards), it is reasonable to assume that had the employers complied with all of the standards, many, if not all, of the fatalities observed here would have been prevented.

Conclusion and Recommendations

Crane-related fatalities are substantial, representing more than 8% of all construction fatalities investigated by OSHA, and most if not all are preventable. 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 cranes. However, it is not known

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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."

The data allowed the writers to examine the proximal causes of fatalities (i.e., what happened immediately before the fatal event) by a variety of factors. However, possibly more important than identifying the immediate causes of fatal events, is understanding the distal (contributing factors) causes.

For the 119 victim occupations identified, only 12 were crane operators, leaving 107 victims (90%) who were riggers, laborers, ironworkers, carpenters, etc. Based on this fact, it appears to the writers 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. The most frequently cited OSHA standards (Table 5) in this study focused on preventing both proximal and distal causes of fatalities. More detailed information is available on the OSHA standards violated by employers in the CIRPC report on this research (CIRPC 2005).

The hierarchy of control at a construction site starts with the employer's assignment of a "diligent" competent person in charge of the overall crane operations. This person must also be trained in general site crane operations; he/she needs to be involved in the development of the overall site construction safety plan. This person must have complete authority to stop crane operations at any time an unsafe work environment is observed. Second, the employer must employ a qualified crane operator. The crane operator must have the complete authority to stop crane lifting operations if unsafe conditions are observed. Next a qualified rigger must be in charge of all rigging activities. The qualified rigger must also have the authority to stop all unsafe rigging operations. Finally, everyone working around crane operations must have training in crane operation.

Based on the findings from this study, the following recommendations are provided:

1. Employers should have a system in place to assess the "hazardousness" of each of their construction worksites in relation to the potential for a crane-related event. One way to do this could be to examine compliance with the 15 most frequently cited OSHA standards listed in Table 5 as part of their occupational safety and health program;
2. As a minimum, employers should have a crane safety plan that describes the procedures for each lift. The crane safety plan can be part of the site safety plan;
3. A "diligent" competent person should by assigned by the manager of construction operations to be in charge of overall crane operations with complete authority to stop unsafe operations;
4. This research suggests that several types of crane-related construction fatalities will not be reduced until crane operators and riggers are required to be qualified with requalification perhaps every 3 years;
5. Crane operators must have the authority to stop crane lifting operations if an unsafe lifting operation is observed;
6. The rigger must have the authority to stop rigging operations if an unsafe rigging operation is observed;
7. Ironworkers, laborers, carpenters, etc. who are going to be required to work around or near cranes must have some crane safety training before they are allowed to do the work. Of the 119 victims, 75% of the victims identified in this study had such occupations;
8. Although there is no OSHA requirement, the data from the case files suggest a "diligent" competent person [as defined in 29CFR 1926.32(f)] should be in charge of all aspects of lifting operations;
9. OSHA should consider modifying its list of major crane-related fatality causes to match those observed in this study (Table 1); and
10. OSHA should continue to improve its system of collecting information during fatality investigations, including emphasis on intervention strategies, from top management down to field staff. During the collection of data OSHA needs to ensure that the data are accurate and capture all relevant features of the situation in which the fatality occurred in order to improve usefulness to researchers and policymakers inside and outside the Agency. This would provide data access to more researchers interested in studying the determinants of crane-related and other occupational fatalities.

Based on the writers' review of the C-DAC Consensus Document (OSHA 2004a) some of these recommendations are forthcoming in the proposed new rule changes while some are unique to the findings of this study.

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