Visibility-related fatalities related to construction equipment

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Abstract

The construction industry annually experiences one of the highest fatality rates among the industrial sectors in the United States. The factors that contribute to this reputation include the nature of the work, human behavior, the tools and equipment involved, and also the compact work zones. Industrial fatalities are investigated by the Occupational Safety and Health Administration (OSHA). While OSHA groups the causes of fatalities into a few general categories, too little information is gleaned to effectively target specific problem areas.

To improve safety performance in the construction industry, it is necessary to understand the underlying causes of accidents. With targeted analysis, patterns emerge and causal factors can be identified. These findings may then be used to form the basis for recommendations that will help to improve construction worker safety. Little research has been conducted in this area.

Research was conducted that isolated fatalities in which vision or lack of good visibility was the principal factor or contributing cause. The objective of examining the details surrounding these fatalities was to uncover the contributing factors and to identify the agents that compromised visibility. The study identified 659 fatality accidents from a data pool of 13,511 OSHA-investigated cases. It was discovered that blind spots, obstructions and lighting conditions were the most common factors contributing to vision-related fatalities. This research also analyzed the specific conditions associated with particular pieces of construction equipment.

1. Introduction

The construction industry continues to rank among the most dangerous industries in the United States and worldwide. Construction workers perform tasks daily in often-crowded and sometimes hazardous settings to accomplish their job objectives. These dangers include, but are not limited to falls, electrocutions, contact with faulty or improperly-operated power tools, and working in close proximity to large equipment such as trucks and cranes.

Construction workers consistently sustain a disproportionately high number of fatalities and injuries when compared to workers in other industries. Because of the constantly changing work environment, construction workers are often faced with new hazards that may go unnoticed. In some cases the hazards are not seen by the workers. The objective of this research was to evaluate the circumstances surrounding vision-related fatalities. This paper presents information on the extent to which vision (or the lack of good visibility) played a role in construction worker fatalities and the nature of those circumstances.

OSHA personnel investigate most construction worker fatalities and the underlying causes are grouped into five major categories: falls, struck-by, electrocutions, caught in between, and other. While these categories are informative, they do not provide sufficient detail by which an effective accident prevention program could be developed, i.e., additional causal details are needed.

The goal of this research was to examine vision-related construction fatalities to develop industry recommendations that would help to save workers’ lives. The various circumstantial factors that were identified are presented.

2. Review of the literature

Since its creation in 1971, the Occupational Safety and Health Administration (OSHA) is a government agency with the intent of ensuring a safe work environment for employees by promulgating and enforcing safety regulations. OSHA has had a positive impact on the work environment in the past decades, reducing fatalities by 62% and lowering injury occurrences by 42% (OSHA, 2009). Injuries and fatalities still occur despite the progress that has been made. For example, the Bureau of Labor Statistics (BLS) reported that in 2009, 4.3 of every 100 construction workers were injured on the job, and 607 construction workers died on the job (BLS, 2010).
Safety awareness continues to gain momentum in the construction industry as the collective goal among many contractors is to bring injuries down to zero. OSHA continues to serve as a means for enforcing safety regulations that establish minimum safety standards. OSHA consists of 2150 employees, 1100 of which are compliance inspectors that enforce safety standards on jobsites across the nation. The average yearly number of construction sites estimated to be in the tens of thousands, making it impossible for OSHA to investigate all construction sites. Thus, the main tasks of OSHA inspectors include the reporting of imminent dangers, investigating fatalities, addressing employee complaints, responding to referrals from other government agencies, and conducting targeted inspections (OSHA, 2002).

OSHA recordable injuries fall under one of two categories: injuries which result in lost days of work, and those that do not. “The law requires the recording of work injuries other than minor injuries requiring only first aid treatment, and which do not involve medical treatment, loss of consciousness, restriction of work or movement or transfer to another job. Consequently, a work-related injury must involve at least 1 of these 4 conditions before it is deemed recordable” (BLS, 2009). These injuries are reported on the Log and Summary of the OSHA No. 300 form (Hinze et al., 2005).

OSHA investigates and records job-related injuries that occur throughout the United States. In addition to legally demanding that each employer abide by its guidelines, it also provides a valuable database that allows firms to benchmark their safety practices. The OSHA log data provides a wealth of accident information and a database that allows firms to benchmark their safety practices. As a result, it is estimated that the log data provides a wealth of accident information and a database that allows firms to compare their safety practices to those of other firms (MacCollum, 1995).

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OSHA investigates and records job-related injuries that occur throughout the United States. In addition to legally demanding that each employer abide by its guidelines, it also provides a valuable database that allows firms to benchmark their safety practices. The OSHA log data provides a wealth of accident information and the contents found within it allow for a single point of information for identifying exactly what it is that should be addressed in order to reduce injury frequencies.

The US construction industry accounts for around 7% of the total workforce, but construction worker deaths account for about 20% of all industrial fatalities (MacCollum, 1995). This death rate of 15.2 of every 100,000 workers makes construction the third most dangerous industry behind mining and agriculture (NIOSH, 2010). The number of fatalities in the construction industry reached a high in 2004 with a reported 1272 fatalities (see Table 1). Historically, every working day approximately five construction workers die in the United States (OSHA, 2009).

Table 1
Construction fatalities by year (BLS, 2009, 2010).

<table>
<thead>
<tr>
<th>Year</th>
<th>Fatalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>1131</td>
</tr>
<tr>
<td>2004</td>
<td>1272</td>
</tr>
<tr>
<td>2005</td>
<td>1224</td>
</tr>
<tr>
<td>2006</td>
<td>1226</td>
</tr>
<tr>
<td>2007</td>
<td>1204</td>
</tr>
<tr>
<td>2008</td>
<td>969</td>
</tr>
<tr>
<td>2009</td>
<td>607</td>
</tr>
</tbody>
</table>

While these figures are alarming, it does not account for independent contractors, piece workers or the uninsured which would raise the numbers much higher (BLS, 2009). In addition, the majority of today’s job site employees are no longer those of the general contractor but of subcontractors who may not hold the same ideals of safety (Mohamed, 2002). General contractors find themselves in a dangerous situation when they place the responsibility of safety on each individual subcontractor. This can result in chaos due to no central control over the safety of the workers’ environment (MacCollum, 1995).

3. Why construction safety is important

For the period of 1979 through 1989, as a result of an increase in medical, legal and insurance expenses, the cost of injuries rose from an estimated $8.9 billion annually to $17.2 billion annually, and workers’ compensation insurance rapidly increased from $2.74 billion annually to $5.26 billion. Implementing construction safety techniques can substantially reduce construction costs in the long run and have other added benefits such as higher quality of work and improved employee morale (Everett and Frank, 1996).

One-fourth of the construction worker deaths are the result of collisions, rollovers, struck-by accidents, and a variety of other equipment-related incidents. When equipment is brought onto the job site, the general contractor, subcontractor or the equipment rental companies have the responsibility to make sure it is in proper operating condition. The equipment must be deemed safe after inspection for its intended use.

Equipment, machines and tools can be broken into general categories that include transporters such as trucks, forklifts, conveyors, pipelines, railways, roadways, and aircraft (MacCollum, 1995). Trucks, forklifts, and earthmoving equipment (skid steer loaders, scrapers, backhoes, front-end loaders, bull dozers, compactors) are often involved in visibility-related injuries.

It is important that these and other motor vehicles be equipped with restraint devices such as seatbelts, which decrease the severity of injury in the event of an accident. In addition, equipment must be equipped with other operational safety equipment such as horns, head lights, brake lights, directional signals, mirrors, etc. (MacCollum, 1995). Rollover protective structures (ROPS) are a necessity to keep operators safe in the event an equipment rollover.

Drivers of trucks that are backing up do not see when they are steering into danger, resulting in running off the road or in striking workers on the ground. Another increasing danger involved with transporters such as trucks is the use of cellular phones and two-way radios. Operators tend to take their hands off their steering wheels and are distracted by the conversation (MacCollum, 1995).

Although a spotter should always be used when backing up vehicles, audible back-up alarms should also be operational. The regulations (CFR 1926.601 and 29 CFR 1926.602) state that all trucks and mobile construction equipment must be equipped with an operable back-up alarm. These alarms must be loud enough to be audible over the surrounding noises and should be activated whenever equipment is put into reverse.

In particular, alerts should be used for all equipment and construction vehicles that include large blind spots. Blind spots are a frequent cause of visibility-related fatalities (Teizer et al., 2010a).

Closed circuit televisions (CCTV) mounted inside vehicles which are connected to rear-mounted cameras allow the driver to get a real time image of what is directly behind them. Recently, active blind spot measurement and emerging object proximity detection technology have also been tested in construction vehicle-worker interactions (Teizer et al., 2010a,b). Technology also exists to alert the driver of the proximity of the truck bed in relation to potential hazards such as power lines (MacCollum, 1995).

The main purpose of wearing protective apparel is to protect the workers from dangers in the work environment. The conditions often associated with workers not wearing appropriate safety equipment deal with garment wearability, comfort, fit and style. These factors lead to workers not complying with safety regulations and end in unsafe operating procedures (MacPherson, 2008).

Among the most dangerous segments of the construction industry is the civil construction sector. Contractors have been known to perform an increasing amount of highway construction and maintenance at night because of the effect that these operations have on traffic flows. The work includes the maintenance and construction of bridges, roads, canals, airports and other public works projects. Policy makers have taken notice of the inherent danger of civil construction work and as a result a new safety standards are being introduced. The Federal Highway Administration (FHWA) has

established a policy for the use of high visibility safety apparel (Anonymous, 2005).

On a typical construction site it is very common for workers (mobile) equipment, and other objects to be in close proximity in restricted spaces (Kim et al., 2006). According to OSHA data from 1985 to 1989, “struck-by” accidents comprised 22% of all construction fatalities. Of these cases the most common cause is related to the lack of visibility or a worker being present in the blind spot of equipment (OSHA, 2009). Decreasing vigilance is the result of workers that are engaged in specific tasks while ignoring distracting noises. When a truck or piece of machinery is reversing, a worker can be easily distracted by focusing on the work task alone. In general, workers are probably more vigilant at the beginning of the project when they pay more attention to alarm signals. Alarms can easily become routine to the workers, and the noise is processed more as an annoyance and it tends to be ignored. Equipment that deviates from their usual paths of operation increases the likelihood of accidents (Sawacha et al., 1999).

falls account for one-third of the construction-related deaths. Their numbers have increased over the recent years and in 2007 registered at least 442 fall related fatalities (OSHA, 2009). Whether a construction worker operates heavy machinery or performs other tasks, glare can significantly reduce the visibility of objects. This is even more common in cases involving objects with low contrast (Gray and Regan, 2007). Glare is classified by The International Lighting Vocabulary into two types known as discomfort glare and disability glare. Discomfort glare causes discomfort but does not necessarily cause visual impairment. Disability glare impacts the visibility of an object but does not necessarily cause discomfort (Fekete et al., 2006). Glare, especially the type experienced when the sun is at a low position, effects younger workers in the same manner as older workers. In order to prevent accidents caused by the lack of visibility that glare creates, one must increase their safety margin, or time allotted to complete a particular maneuver, as well as wearing eye protection that reduces the glare (Gray and Regan, 2007).

Accidents involving construction equipment are frequently caused by impaired vision. Related factors include rain, dust, and limited visibility due to cracked or dirty windows. An equipment operator often works in less than optimal conditions and the maneuvering of the equipment is influenced by the operator’s field-of-view, reaction time, and attention/focus level. If any one of these key factors is inhibited, there lies the potential for disaster (Kim et al., 2006; Teizer et al., 2007).

4. Objectives and methodology

OSHA collects information on injuries and fatalities that occur on US construction job sites. The information of interest for this study was contained in the construction fatality investigation abstracts that resulted from visibility-related impairments. The purpose of this research was to examine construction fatalities investigated by OSHA with the intent of identifying and quantifying the root causes of visibility-related fatalities. Results of this study should be helpful in developing preventative measures to create a safer work environment.

The data for this research were obtained from OSHA personnel and included incidents that occurred from 1990 to 2007. The data contained information on 13511 OSHA investigated fatalities. While some of this fatality information is accessible to the public on OSHA’s web site, the public information is generally limited in scope and is not as searchable as the data provided directly by OSHA. The data that were used to investigate the root causes of visibility-related fatalities allowed search functions that are word specific. This word-specific search function included terminology and variations of words and phrases that suggested visibility impairment as causative factors.

Vision search terms included: backed, black, blind, blur, bright, could not see, dark, did not see, did not see, dim, dull, failed to see, gloomy, illuminate, illumination, light, lit, obscure, obstruct, plastic sheet, ran over, reverse, seeing, shine, view, visibility, and vision. The search for the various visibility-related terms yielded 659 individual cases. These specific cases formed the working database for this investigative research study on visibility-related fatalities.

The descriptions of these visibility-related fatalities were examined to determine the primary circumstances or factors that resulted in the worker deaths. Since illumination was a potential contributing factor in all these cases, the type of visibility issue was isolated in these cases. This included the time of day and other available information that would suggest that lighting was an influential factor. This included a determination of whether there was an abundance or lack of illumination at the time of the fatality accident.

Equipment was commonly involved in these cases. The different cases were categorized by equipment type. The accidents were also examined to determine whether workers were wearing reflective vests at the time of the accident. The vehicle direction of travel and the use of operable back-up alarms were also examined. While the circumstances associated with each piece of equipment were examined, the focus was primarily on those pieces of equipment that were most commonly involved, namely dump trucks, graders, excavators and passenger vehicles.

5. Results

The information contained in each visibility-related fatality case was examined and the results were categorized. Of the 659 identified cases, the vast majority (594 cases) involved equipment or vehicles. Most of the equipment involved in these cases could be classified as “heavy equipment”. This includes but is not limited to dump trucks, excavators, motor graders, scrapers, forklifts, dozers, cement trucks and roller compactors. Vehicles that are not considered heavy equipment but are involved in the construction process consist of cars, vans, pick-up trucks and truck hybrids that are commonly used on job sites, including “rack trucks”. An example of a typical visibility-related incident as reported on OSHA’s website (2009) is as follows:

“A motor grader operator, employee #1, was released by his employer to take a rest. The motor grader was being used to spread chert on the street of a new subdivision. A new operator was assigned to operate the motor grader. When the motor grader started to back-up, employee #1 was seen on the edge of the northwest corner of the street. When the grader backed up to the piles of chert, employee #1 was not there. Suddenly, employee #1 was observed in front of the grader lying in the street. The grader had struck and killed him”.

5.1. Categorizing visibility-related equipment fatalities

The equipment related visibility-related fatalities are summarized below in Fig. 1. Of 659 cases, 521 were incidents in which workers were struck-by traveling equipment. In total, 594 involved equipment. In addition to being struck-by moving equipment, workers were hit by the buckets of equipment, material being dropped or lowered by the equipment, electrocutions when equipment contacted power lines, rollovers when equipment was operated on slopes that were too steep, and drowning when equipment rolled into ponds or some type of deep water. A total of 65 cases that did not involve equipment related to falling from
roofs, through stairwell/floor openings and through skylights. While these 65 cases were attributed to visibility/awareness issues, further analysis was focused solely on those cases involving equipment.

5.2. Vehicle and equipment type

This research identified the frequency of involvement of different pieces of equipment in visibility-related fatalities. As Fig. 2 illustrates, many types of equipment were involved in fatal accidents. The equipment most commonly involved in these cases were dump trucks with 173 incidents. These were followed by trucks (which may have included some dump trucks), but the type of truck was not clearly stated. Hydraulic excavators and backhoes were grouped together as it was not possible to isolate one from the other in many of the case descriptions.

The cases were evaluated in terms of the type of equipment involved in the accidents. It was found that dump trucks had the highest frequency of involvement in vision-related fatalities. Dump trucks are hauling vehicles that ride relatively high off the ground and are positioned on large rubber tires. The dump truck contains a transportation bed that is enclosed on all sides to prevent material from falling out. This bed creates a large “blind spot” for the operator who must rely on rear view mirrors that provide a limited range- or field-of-view. Objects that are located towards the rear and directly behind the transportation box of the dump truck are often shielded from view (even when mirrors are deployed) and create a potentially dangerous situation when it must travel in reverse. An example of a moving blind spot is reported on the Center of Disease Control and Prevention’s (CDC) website (2010).

“A construction inspector died when an asphalt dump truck backed over him. The truck was bringing hot asphalt to a new road. The decedent was wearing an orange reflective vest and hardhat at the time of the incident. The asphalt dump truck was greater than 2.5 ton capacity and the back-up alarm was operational and functioning properly. The truck traveled approximately 770 feet in reverse before backing over the decedent. The decedent had his back to the vehicle. The truck driver
stated he was traveling approximately 5–10 miles per hour when the incident occurred and that he never saw the decedent.”

5.3. Vehicle and equipment travel direction

The direction of travel of the equipment was of particular interest in this study. Fig. 3 shows that more than half of all visibility-related fatalities occurred when equipment was backing up. Note that when only equipment-related cases are considered ($N = 594$), in 72.6% of the instances the equipment was traveling in reverse. In the equipment-related incidents, in 18.5% of the instances the equipment was traveling forward. The percentile that was labeled “direction not specified” refers to cases where the accident report did not clearly state the direction of travel of the vehicle at the time of the incident and no inference could be made. The “operating but not traveling” percentile refers to cases where the equipment was stationary, for example, when an excavator crushed a worker while trenching or a crane hit a worker while lifting material.

The data were examined to evaluate the percentage of instances that specific pieces of equipment were traveling in reverse. As shown in Fig. 4, skid steer loaders (14 fatal cases), water truck (12), graders (37), and dump trucks (173) were traveling in reverse in more than 90% of the accidents where these pieces of equipment were involved. In more than 50% of the cases, dozers (34 cases), compactors (14), scrapers (15), tractor trailers (22), and excavators (45) were involved in fatal accidents when traveling in reverse. Note that private vehicles were generally traveling forward. The private vehicles (33 cases) were generally driven through work zones, with several involving alcohol consumption by the drivers. Front-end loaders (29 cases) and forklifts (28) were noted to be involved in some accidents when driving forward but where visibility was limited due to loads being carried, buckets raised to the point where visibility was obscured, or forks raised to the point where vision was impaired.

Overall results show that 431 visibility-related fatalities occurred when vehicles or equipment were traveling in reverse, nearly four times the number of vehicles or equipment that were traveling forward (110). This statistic indicates the magnitude of the potential hazards that exist when equipment travels in reverse.

5.4. Usage of back-up alarms

OSHA has specific regulations regarding the use of machinery when engaged in reverse. OSHA regulations, specifically Title 29 CFR 1926.601(b)(4), state:

“No employer shall use any motor vehicle equipment having an obstructed view to the rear unless:

(1) The vehicle has a reverse signal alarm audible above the surrounding noise level or:

(2) The vehicle is backed up only when an observer signals that it is safe to do so.”

It is common for equipment to have blind spots located in various areas surrounding the equipment. The most commonly known blind spots are to the rear (Teizer et al., 2010a). The back-up alarm is a safety measure intended to warn anyone in the vicinity of blind spots (or within close proximity of equipment parts).

The research investigated 69 specific cases of reversing vehicles that had or did not have (audible) alarms. In 21 of these cases,
equipment was operated in reverse in close proximity to others but did not utilize any alert mechanism. It was specifically noted that from the vehicles and equipment that were involved in visibility-related fatalities, in 56 out of the 69 cases the back-up alarm was not functioning. Note that the other cases did not specifically mention back-up alarms.

The case descriptions provided some information on the presence or absence of a functional back-up alarm, but this was limited to a small percentage of the cases. The types of equipment that were associated with the most cases where back-up alarms were not functional are shown in Fig. 5. Scrapers were involved in 26.7% of the cases where the scrapers did not have functional back-up alarms. In some instances, it was noted that back-up alarms were functional, but that other pieces of equipment were also operating in the area, possibly drowning out the alarm signal. Five instances were reported where the reverse alarm was not heard by the workers nearby because of job site noise. It was found that multiple back-up alarm signals from (multiple) vehicles issuing warnings at the same time, influenced worker judgment, and made the alert signal(s) less effective or ineffectual.

5.5. Reflective vests

Reflective vests are fluorescent and brightly colored. Safety vests reflect light in areas of low illumination and can also make employees more visible in day-time work conditions. Of the reported cases involving visibility-related fatalities, some specifically noted that the employees were wearing reflective vests at the time of the fatality. Specifically, 35 cases reported that the deceased employees were not wearing reflective vests. Since most of the reports did not disclose whether or not the employees were wearing reflective vests, it was not possible to make an accurate assessment of the effect that wearing such apparel has on accident prevention.

5.6. Equipment type

Further review of the data concentrated on the analysis of 289 construction equipment related fatalities where accident reports provided a cohesive and well defined understanding for the evaluation of travel direction, reflective safety vests, and factors contributing to visibility-related fatalities related to specific equipment types. Tables 2 and 3 give an overview of the results for dump trucks, passenger vehicles, motor graders, excavators, and all other equipment that will be discussed in more detail in the following sections.

5.6.1. Dump trucks

Dump trucks were involved in 31% of the struck-by cases that resulted from visibility-related conditions. Of these cases, 90% percent involved dump trucks traveling in reverse and this can probably be attributed to their large blind spot area (truck beds) as well as the frequency that trucks travel in reverse. Table 2 shows the amount of visibility-related fatalities that occurred while dump trucks were reversing compared to when they were traveling forward. There were 74 cases in which the dump truck was traveling in reverse at the time of the struck-by accident and eight cases in which the dump truck was traveling forward at the time of the struck-by accident. It was noted that 33 of the dump trucks in these fatalities were equipped with a back-up alarm, eight had no back-up alarm, and 41 did not mention any back-up alarm.

In 15.8% of all visibility-related fatalities involving dump trucks the workers were wearing reflective safety vests, while 3.7% of workers were wearing some sort of a safety vest, but not a reflective safety vest. Of the remaining 80.5% of the reports, information was not provided on whether the worker wore a safety vest.
Because of the infrequent reporting of this information in the OSHA fatality database, the number of reflective vests worn by workers might actually be larger.

Every case examined in this research was examined for the root causes. The main contributing factors were grouped into four categories. The first of these categories was “too much lighting”. This consisted of glare or a sudden change from a poorly illuminated area to one of very bright illumination that would cause accidents when employees lost visual reference points of surrounding objects.

The second category was “too dark”, instances where there was insufficient lighting. This category often included scenarios of working at times of dusk and dawn when improper illumination of the job site or darkly colored objects can result in workers being injured or involved in fatal accidents.

The third category was “obstructions” and included situations where there was some sort of visual impediment that blocked the operator’s line-of-sight to surrounding workers. An example of such an impediment would be a mound of dirt or fill material that can hide an employee.

The fourth and fifth categories are comprised of “blind spots” and “moving blind spots.” Table 3 shows the type of visibility impairment related to dump truck fatalities and how frequently each type occurred. Blind spots are the most frequently occurring type of visibility impairment with a total of 46 cases reported. Obstructions were the second most frequently occurring type of visibility impairment with 19 cases reported. There were 11 cases where the type of visibility obstruction was not mentioned, five cases where the lighting was too dim or dark and one case where the lighting was too bright.

### Table 3

<table>
<thead>
<tr>
<th>Frequency of factors contributing to visibility-related fatalities by vehicle and equipment type.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>All cases</td>
</tr>
<tr>
<td>Blind spot</td>
</tr>
<tr>
<td>Obstruction</td>
</tr>
<tr>
<td>Not mentioned</td>
</tr>
<tr>
<td>Too dark</td>
</tr>
<tr>
<td>Too bright</td>
</tr>
</tbody>
</table>

5.6.3. Motor graders

Motor graders are the second most frequently used construction equipment that are involved in visibility-related fatalities. Graders have large blind spots and usually operate in tandem with dump trucks in earthwork operations. Such work tasks are typically within limited space that is inherently dangerous and relies heavily on signaling for communication because of the lack of visibility.

Table 2 shows the direction of travel of motor graders involved in visibility-related fatalities. There were 21 cases in which the grader was traveling in reverse at the time of the accident. In six cases the grader was traveling forward and in one case the direction of travel was unknown.

Of the fatality cases, 23 of them reported the grader was not equipped with a back-up alarm. All other cases did not state if the grader was equipped with an alarm. No cases were found of a visibility-related fatality where the motor grader was equipped with a back-up alarm.

Table 3 shows the number of visibility-related fatalities caused by motor graders and their causes. Blind spots were the most commonly cited reason with a total of 14 reports. Nine cases were cited referring to obstruction(s) being the cause of the accident and seven cases did not give any cause. One reported fatality mentioned lighting being too bright. No cases referred to ambient lighting conditions being too dark.

5.6.4. Excavators

Excavators are commonly used in construction to perform various aspects of site work and can be employed on a wide variety of projects ranging from residential to commercial and from industrial to civil. Excavators may be rubber-tired or tracked. They are versatile machines that may spend large amounts of time in a stationary position (track hoe) and they can move frequently (front-end loaders). Extended booms can carry a bucket that further limits the operator’s field-of-view, in particular at long distances and in deep excavations. Excavators must often operate in close quarters, next to buildings, in confined spaces. The presence of workers on the ground is often necessary to navigate the bucket or to load it. Depending on the model, excavators have relatively large blind spots, typically up to 50% of the operator’s field-of-view being obscured (Teizer et al., 2010a). These blind spots may be stationary or moving depending on the location of the excavator bucket. The presence of the boom and bucket at the side and front of the excavator creates an inherently dangerous condition.

Table 2 shows the direction of travel of the excavators involved in a visibility-related fatalities. Most of the excavator-related incidents occurred when the equipment was traveling in the forward direction.

Of the 11 visibility-related fatality cases involving excavators, six cases did not state whether a reverse alarm was used at the time of the accident. Three cases indicated that the excavator was equipped with a reverse alarm and two cases indicated that the excavator was not equipped with a reverse alarm.
Table 3 shows the number of vision-related excavator fatalities and the factors attributed to these fatalities. Obstructions were the most frequent cause associated with excavator visibility-related fatalities; 10 cases being reported. Of 13 fatalities related to blind spots, moving blind spots were mentioned in eight cases. Thus, moving blind spots were the second most frequent cause of all excavator visibility-related fatalities. These two leading causes can be attributed to both the nature of excavation work as well as to equipment configuration and operation.

5.6.5. All other equipment and vehicles

The four equipment types that most frequently were involved in visibility-related fatalities were reported individually. All remaining vehicle and equipment types have been analyzed individually but are reported as a single unit.

Table 2 shows the total number of visibility-related fatalities for all remaining equipment types and compares the travel direction of the equipment at the time of the accident. A total of 49 cases reported vehicles traveling in reverse, with 40 cases involving forward direction. Nine reported cases had vehicles involved with unknown travel direction. In two cases the travel direction of the vehicle was not applicable.

Further analysis focused on the total number of visibility-related fatalities for all remaining equipment types and the status of their reverse alarm at the time of the accident. The majority of the cases (32) reported did not state whether or not the vehicle was equipped with a reverse alarm at the time of the accident. Thirteen cases indicated that the vehicle was equipped with a reverse alarm at the time of the accident while eight cases indicated that there was no reverse alarm present.

Furthermore, out of a total of 75 investigated cases, 65 (or 87% of all investigate cases) reported fatalities in which the decedent was not wearing a reflective vest at the time of the accident. There were five reported cases in which the decedent was wearing a reflective vest at the time of the accident and five cases in which the presence of a reflective vest was unknown.

Table 3 shows the total number of vision-related fatalities involving all other equipment types and the stated cause of the accident. Blind spots were the most commonly cited cause of accidents with 47 total occurrences (eight of which were due to a moving blind spot). There were 20 cases that did not mention the cause of the accident and 15 cases referred to obstructions as the main cause. In 10 cases lighting was too dark and in eight cases moving blind spots were the cause of the incident. No cases were reported that lighting was too bright.

5.7. All equipment combined

Although not all accident investigation reports described the ambient environment when an accident occurred, 82 of the fatal cases reported poor or limited visibility as cause of the accident.
ties were the result of five visibility causal factors. These factors in-operations, especially when traveling in reverse.

spots. These blind spots compromise maneuverability and safe attributions to the large range of view that is occluded by blind

dents. Of these "struck-by" accidents, dump trucks were involved

majority of the visibility-related fatalities were "struck-by" acci-

number of these fatalities. For example, it was found that the

1990 to 2007. Research into visibility-related fatality cases showed

that specific safety practices could be implemented to reduce the

6. Conclusion and recommendations

The focus on worker safety continues to grow in importance throughout the construction industry. Safety is a major priority that has been and will likely continue to be emphasized by public opinion, policy makers, and construction managers. Fatalities on construction jobsites are no longer considered a part of doing busi-

ness. As construction research continues to identify areas for safety improvement, there are reasons to suggest that fatality numbers will continue to decline.

This research targeted visibility-related fatalities in the con-

struction industry with the aim of discovering relevant patterns of unsafe practices, such as the frequency of incidents related to vehicles backing up, that need to be addressed in future research. The roles of specific factors that contributed to worker fatalities were identified. By increasing the knowledge base and the known facts surrounding these incidents, the application of an effective safety model would contribute to improve the methods of how construction operations are planned and performed. For example, concepts such as Design for Safety and Prevention through Design (PtD) can address the causes for injuries and fatalities identified in this research (Toole and Gambatese, 2008; Sacks et al., 2009). In particular such work can help focus safety education, training, and technology development to reduce injuries and fatalities before work is started in the field (Pellicer and Molenaar, 2009).

This research determined that visibility-related construction fatalities accounted for nearly 5% of all construction fatalities from 1990 to 2007. Research into visibility-related fatality cases showed that specific safety practices could be implemented to reduce the number of these fatalities. For example, it was found that the majority of the visibility-related fatalities were “struck-by” acci-

dents. Of these “struck-by” accidents, dump trucks were involved in over 25% of the cases. This large number of fatalities can be attributed to the large range of view that is occluded by blind spots. These blind spots compromise maneuverability and safe operations, especially when traveling in reverse.

Research findings further suggest that visibility-related fatali-
ties were the result of five visibility causal factors. These factors in-

cluded excessive lighting, insufficient lighting, visual obstructions, blind spots and moving blind spots. The research findings showed that when equipment was involved in a fatality, over 45% of the incidents were the result of blind spots.

The findings of this research point to key visibility factors that facilitate the occurrence of fatalities. One of the main problem areas was identified as the lack of high visibility of workers on the ground to equipment operators. This could in some cases possibly be addressed by the use of reflective vests by workers. This research showed several victims were not wearing reflective safety vests. Empirical data addresses the absolute necessity for recogniz-
ing objects on the ground to appropriately navigate around them.

The travel direction of equipment was found to be important in describing risk to workers on construction sites. A high percentage of accidents occurred when equipment was traveling in reverse. The findings confirm the escalated risk that is involved when operating heavy equipment in reverse. Pro-active solutions to addressing this dilemma include requiring all equipment operators to familiarize themselves with site layouts and areas of foot travel (Ning et al., 2010).

There are several other methods to improve the vehicle opera-
tor's visibility. For example, improved operator's field-of-view through design changes in equipment cabins could potentially lead to further reductions in visibility-related incidents (Teizer et al., 2010a); and construction equipment manufacturers are continu-
ously evaluating how to design equipment more safely by reducing the amount of blind spots caused by the equipment body structure or through providing safe and secure entry/exit to/from the vehicle.

The use of two-way radios or hand signaling can improve communications and compensate for the inability of operators to visually see objects while traveling in reverse. As addressed in Teizer et al. (2010b), more advanced pro-active real-time warning technol-
ogy may help ground workers, vehicle and equipment operators to be aware of each other.

Additional methods of alerting workers on the ground to the close proximity of equipment includes ensuring that all equipment is equipped with operable reverse warning systems or that flag-
gers/spotters assist in equipment maneuvers. Additionally, the use of spotters on the ground that maintain constant communica-
tions with equipment operators is also an important facet of safe procedures and their importance cannot be overstated. Spotters can direct the movement of equipment as well as alert passing vehicles and workers of the presence of danger.

While certain operations were found to be more dangerous in reverse, some equipment experienced higher accident rates when traveling forward. These cases were specifically recognized in excavator operations. This can be attributed to the movable blind spots that are created by moving extensions of the equipment. Since excavators require the constant adjustment of the bucket height, the increased likelihood of a broken line-of-sight to a po-
tential victim remains a significant factor of concern.

Moving blind spots require the operator to exercise a greater le-
vel of vigilance and to conduct repeated vicinity checks to identify workers on the ground, along with other major obstructions. This research suggests that there is a need to conduct inspections of areas that may appear unconventional to the operator. Several of the cases that were analyzed involved a worker located under-
neath the equipment or inside of an excavation. Operators are typi-
cally not accustomed to workers being in certain locations. Safety training should familiarize the operators with the potential of striking workers on the ground. Potential conflicts should be ex-
pected in all areas of operation, including underneath the equip-
ment and anywhere in the vicinity of the task performance area. This also involves checking areas previously known to be clear of personnel. Certain areas may have been re-occupied prior to the operator's return. Excavations and travel paths that may have pre-
viously been clear of workers may later become occupied and tak-
ing this for granted could result in an accident.

Illumination factors are an important aspect of construction
safety; however, they are frequently not recognized in accident
descriptions. When an accident occurs, the typical response is to
attribute it to the most obvious agent. For example, a
worker may be struck-by and killed by a vehicle. Conventional
industry procedure is to classify this incident as a “struck-by” fat-
ality, and the assumption from this occurrence is that equipment
is dangerous. While this may in fact be a “struck-by” accident, closer
examination of the root cause may reveal that vision impairment
was the primary factor and the equipment, because of its size
and weight, was a secondary factor. This research showed that in
about 7% of all visibility-related cases, lighting was the primary
contributing factor. Overall, standards and guidelines in reporting
accident and fatality events can be improved to allow for more
thorough root cause analyses.

A study of the time of day when accidents occurred showed a
correlation between lighting factors and accident frequency. It
was noted that a disproportionate number of accidents occurred
between 6 pm and 6 am, a time period when few construction
operations take place. In some instances it was impossible to single
out glare as the key contributing factor. Causative factors were
clear when the incident reports specifically stated that the equip-
ment operator was blinded by glare.

Similar difficulties existed when quantifying the effect that a
lack of illumination had on visibility-related fatalities. With this
assumption in mind, it is likely that actual cases involving insuffi-
cient illumination occurred more frequently than reported in these
findings. Several cases were found where there were poor lighting
conditions. What can be concluded from the OSHA fatality data is
that reflective PPE worn by employees on the jobsite when these
conditions occur would improve the operator’s awareness of work-
ers on the ground and reduce the likelihood of accidents. Increas-
ing jobsite illumination through the use of spot lighting or
warning signals (in the case of highway construction) would help
considerably in making potential victims visible to operators and
drivers.

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