The Nature of Struck-by Accidents

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Abstract: Construction accidents are broadly categorized into five basic groups, namely falls (from elevation), shock (electrical), caught in/between, struck-by, and other. "Struck-by" accidents accounted for 22% of all construction-related fatalities recorded by the Occupational Safety and Health Administration between 1985 and 1989. Recent (1997 to 2000) data show that the percentage of struck-by accidents constituted 24.6% of the fatalities and serious construction worker injuries. Struck-by accidents primarily involve workers struck by equipment, private vehicles, falling materials, vertically hoisted materials, horizontally transported materials, and trench cave ins. Determining possible causation factors of these accident types is often difficult, due to the broad categories utilized in the accident coding system. This study resulted in gaining insights about the root causes of the struck-by injuries. By finding the root causes, effective methods for accident prevention can be developed.

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Introduction

The Occupational Safety and Health Administration (OSHA) utilizes five basic categories to classify construction injury causes, namely falls (from elevation), shock (electrical), caught in/between, struck-by, and other. These injury categories are often vague and provide little insight into what really caused the accidents or how future ones might be avoided. Since accidents coded as struck-by in OSHA's IMIS database include a broad range of causes of injuries and fatalities, such as cave ins, equipment, and materials being handled, it is evident that the term struck-by does not provide a clear impression of what actually caused any one accident. In order to effectively prevent struck-by accidents, the specific nature of the struck-by accidents must be examined. For one construction firm, the accident prevention measures for struck-by accidents might relate to equipment, while for another firm it may relate to materials handling. In yet another firm, it might relate to trenching practices that prevent cave ins. Looking at the accident details can give insights into the causations of struck-by accidents. The information gathered and analyzed could then be used to develop more effective accident prevention methods.

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Background

OSHA has, as one of its mandates, the requirement to maintain records on occupational injuries. In a report OSHA issued in 1990, based on five years of accident data collected between 1985 and 1989, struck-by accidents comprised 22% of the construction fatalities. The remaining 78% were comprised of falls (33%), caught-in/between (18%), electrical shock (17%), and other (10%) (U.S. Dept of Labor 1990). Recent data indicate that while the percentage of caught in/between and electrical shocks have decreased, the struck-by incidents have not decreased but rather have increased slightly (Fig. 1). Falls typically occurred during activities associated with roofs, scaffolding, ladders, edges of structures, and beam supports. Caught-in/between injuries resulted from trench cave ins and workers being caught under overturned equipment or in moving equipment parts. Electrical shock accidents involved electrical arcs; workers coming in contact with power lines via metal tools, materials, or equipment; and direct contact with the power lines. "Other" causes included accidents involving fire, explosion, poisoning, drowning, oxygen deprivation, inhalation of toxic gas, and natural causes. Struck-by accidents may involve trench cave ins, and workers being hit by equipment or materials. As shown in data collected from 1980, 1985, and 1990, 70% of the struck-by accidents resulted from the following: Struck by a falling object; struck by a crane, boom, or load; struck by a trench cave in; and workers being run over by heavy equipment or private vehicles (Hinze 1997).

As a means of tracking accident data obtained from the injury records, OSHA developed the IMIS database. Information pertaining to each injury/fatality that is investigated is included in the database in coded form along with an abstract. Researchers can access the data to help devise methods by which to prevent future construction accidents or to conduct additional analysis on the data. Along with a unique case number assigned to each recorded accident, information includes the date of accident occurrence, name and address of the employer, and any OSHA citations issued to the employer associated with a particular accident. Victim data are also provided, which include the victim's name, age,

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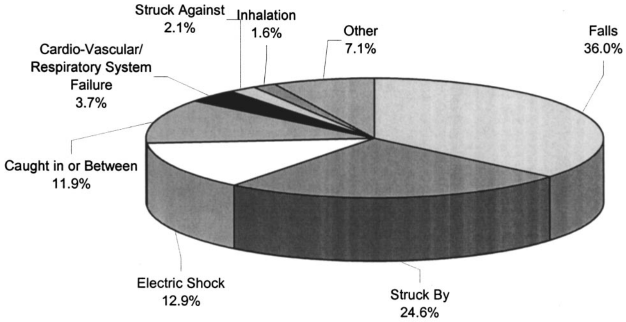

Fig. 1. Type of construction injuries (01/97–12/00)

gender, occupation, part of the body injured, type of injury, and whether the injury was fatal. Information regarding the event itself is coded by event type, hazardous substances involved, environmental and human factors involved, and the source of the injury (material or equipment). While the IMIS records provide valuable information, reliance on the coded data will result in limited information on what actually occurred, i.e., the coded data provides only cursory information.

While the coded data are useful in providing general information, specific information regarding the accident must be obtained from the abstract, typically a single paragraph description of the conditions existing at the time of the accident. The abstracts, prepared by the investigating OSHA compliance officers, are based on physical observations and interviews with witnesses. The information on struck-by injuries/fatalities may give the exact type of material or equipment that struck the victim, including some of the events leading up to the accident. Abstract information may indicate the type of safety measures used, if any, along with whether the victim contributed to or helped cause the accident. In many cases, the information traces the sequence of events that led to the accident. It is important to review the abstract carefully in order to make specific recommendations regarding accident prevention.

A previous research project examined the details surrounding construction accidents associated with overhead power lines. That study recommended that the IMIS database needs to be improved to provide better quality of accident information (Hinze and Bren 1996). Bren suggested in his master's thesis that the OSHA accident investigators and data entry employees undergo accident investigation documentation training, which would lead to improved coding and investigation abstracts. He noted that some abstracts were poorly written, often providing little evidence of the nature of the accident. Bren also stressed the need for enforced mandatory state reporting of accidents to OSHA, as some states fail to report each year (Bren 1995).

In another study, construction injuries and fatalities resulting from equipment-related accidents were examined (Thomson 1996). That researcher also suggested that mandatory state reporting of accident data and an improved database were needed. Based on her research, she recommended licensing requirements for heavy equipment operators, which would require annual safety training to renew certification. Thomson also emphasized a need for increased enforcement of OSHA safety standards. It was noted that many injuries resulted from the failure of employees to keep their equipment in full compliance with the OSHA regulations (faulty back-up alarms, failing brake systems, and no rollover protection systems) and in good working order (monitoring equipment fluids and excessive noise).

Another study focused on identifying the root causes of injury/fatality accidents investigated in 1994 and 1995 (Hinze et al. 1998). Results of the research showed that through the use of primary and secondary coding, a greater amount of accident causation information would be provided. That research showed that, in order to reduce struck-by accidents, emphasis should be placed on practices relating to equipment and the prevention of falling materials.

Research Methodology

The primary research objective was to determine the causation factors involved in struck-by injuries/fatalities. This information would provide a means of helping firms focus on identified causes in their worker training efforts. Overall, the end result was to gain knowledge about accident causation so that prevention methods could be more effectively implemented.

The data for this study were obtained directly from OSHA. Specifically, the inclusive OSHA data from 1997 to 2000 were examined in regard to struck-by accidents. These four years were the most current years for which data were made available by OSHA. Also, the data since 1997 provide more detailed information than was formerly included in OSHA reports. The OSHA IMIS documentation provided victim information (without disclosing the victim's identity), a summary abstract of the accident, and regulation citations for each accident.

Specific variables were considered in the analysis to determine possible causation factors. Cases, which were determined to have been miscoded or for which insufficient information was provided, were not included in the study cases. "Caught in/between" cases were also obtained from the OSHA IMIS database. In many cases especially those involving trench cave-in accidents, the cases were coded as either struck-by or caught in/between creating a discrepancy in the data analysis process. Conflicting information between what was provided in the coded victim information section and summary abstract also was encountered in the study. In the compilation process, judgement was required and was primarily guided by the information contained in the abstract and, only secondarily, by the coded information included in the database. The final database included information on 743 struck-by accidents or cases.

Results

When the abstracts were evaluated, several cases were encountered in which vital information was not provided. Others contained typographical errors and miscoded items. In some situations, these cases were not included in the final tabulations. In this study, the number of cases suggests that not all the struck-by accidents were reported for the four-year study period, e.g., some states have no data in the database and others had data in only some years. This may be the result of a failure in reporting to OSHA of all accidents by some states and U.S. Territories.

The occurrence times of struck-by accidents were examined. In terms of timing, accident occurrence was most dominant around the hours of 9:00 and 13:00 (Fig. 2), which is consistent with the occurrence times of most construction injuries/fatalities (Hinze 1997). Accident occurrence was highest during March, April, the summer months, and October (Fig. 3). The high incidence of injuries/fatalities in the summer months is also consis-

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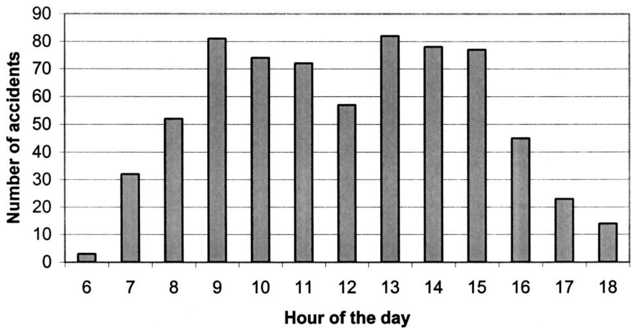

Fig. 2. Frequency of struck-by accidents by hour of the day

tent with other data. The elevated number of injuries/fatalities during October is an anomaly and cannot be readily explained.

Frequency of Cases by Age

The age information for the accident victims was given for all cases studied. As shown in Fig. 4, the age range from 30 to 39 comprised the highest percentage (27.6%) of injuries and fatalities. This high percentage may reflect the age distribution of construction workers. This may indicate a need for additional training. The average age of construction workers in 2000 was 39 years (Center to Protect Workers' Rights 2002). The high range of accidents among workers in their 20's corresponds to that found in the power-line study (Bren 1995). A high frequency also appears in the grouping of 40- to 44-year old workers.

The age range from 55–80 has a low frequency of injuries and fatalities, which may be due to these workers being placed in lead role positions where their many years of experience can be best utilized. In many instances, these types of jobs involve less risk. There are also fewer workers aged 55–80 on construction sites compared to those workers between 30–39 (Center to Protect Workers' Rights 2002).

Frequency of Cases by Material Involved in the Accident

The study determined the number of accidents in which the victim was struck by a particular type of material. A total of 288 injuries/fatalities occurred as a result of the victim being struck by material. The most common material types involved in struck-by accidents are shown in Table 1. The materials most commonly striking a victim were wood assemblies (walls, trusses, and formwork), concrete block walls, soil/rock (trench cave ins), and steel/

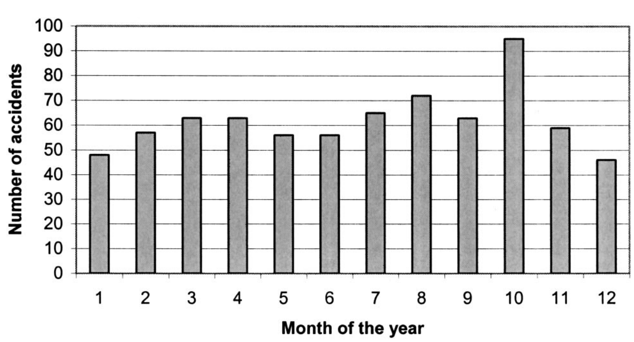

Fig. 3. Frequency of struck-by accidents by month of the year

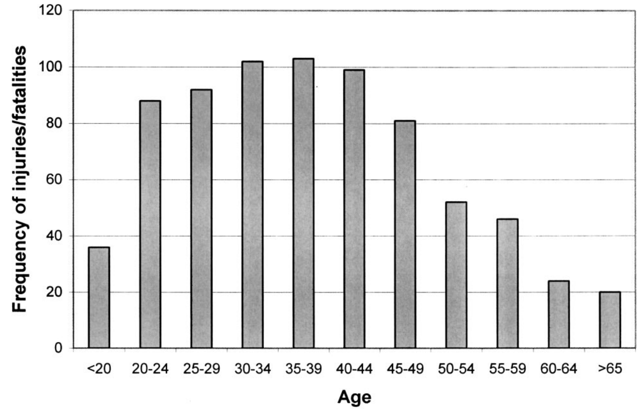

Fig. 4. Frequency of struck-by injuries/fatalities by age

rebar/pipe. Steel, rebar, and metal pipe were categorized together, since metal objects often fell on the victims due to poor rigging when being hoisted.

The category with the largest number of struck-by cases involved timber or wood assemblies of walls, trusses, and formwork. One such case involved a carpenter completing formwork at the corner of a block wall. A "snorkel" pump accidentally hit the wall causing a 1.73 m section of wall form to fall and hit the carpenter in the head resulting in his death. In one accident involving soil/rock, four workers were installing a rubber flexible liner in a 12-ft deep excavation. The workers were hammering stakes into the vertical excavation walls to hold the liner in place when one of the walls caved in and covered one of the workers. The worker died of massive head injuries, while the other three workers escaped the accident unscathed.

In one of the steel/rebar/pipe cases, two ironworkers rigged structural steel beams to be hoisted by a crane from a truck to a storage area. After the beam was secured in a sling with sorting hooks, one of the workers walked under the beam as it was being lifted. The beam became detached from the sling and struck the worker, resulting in his death. One of the tree cases involved a worker who was punctured by a tree trunk. The worker apparently stepped too close to the debris, containing tree limbs, being dumped and was pierced by a tree limb, resulting in a fatal wound.

Table 1. Frequency of Cases by Material Involved in Struck-by Accidents

Material	Frequency	Percent
Wood framewall/truss/formwork	61	21.2
Concrete block wall (collapse)	45	15.6
Soil/rock	39	13.5
Steel/rebar/pipe	34	11.8
Fuel in the air (explosion)	24	8.3
Concrete	13	4.5
Tree	12	4.2
Brick/block	10	3.5
Line/cable/rope	6	2.1
Tank	5	1.7
Lumber	4	1.4
Other	35	12.1
Total	288	100.0

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Table 2. Frequency of Cases by Equipment Involved in Struck-by Accidents

Equipment	Frequency	Percent
Truck	196	39.4
Private vehicle	57	11.5
Crane	47	9.5
Backhoe/excavator	62	12.5
Loader	30	6.0
Forklift	22	4.4
Bulldozer	23	3.6
Hoisting	12	2.4
Roller	11	2.2
Saws	9	1.8
Scraper	4	0.8
Other	29	5.8
Total	497	100.0

Frequency of Cases by Equipment Involved in the Accident

Information was reviewed to determine the equipment types involved in struck-by accidents. The most common types of equipment involved in struck-by accidents are summarized in Table 2. The three highest-frequency categories (representing over 60% of all equipment-related struck-by cases) included trucks, private vehicles, and cranes. One case involved the driver of a maintenance truck that was traveling up a hill when the truck stalled. The truck began to roll backward. The driver failed in his attempt to jump free and was crushed under the truck.

Frequency of Cases by Human Factors Involved

Human factors are involved when the causes of accidents are attributed to the failure of an individual to act promptly to avoid it. The individual may be the injured party or any other person who may have been in a position to prevent the accident. Human factors are involved in virtually all accidents if it is assumed that all accidents are avoidable. The 743 case studies were reviewed and the contributing factors were grouped into 15 different human factors categories, as summarized in Table 3. The most common human factor contributing to struck-by accidents was misjudgement of a hazardous situation, comprising 35.8% of all cases.

These findings show that accidents were not necessarily caused directly by the victims, but may result from the lack of action or the use of inappropriate action by any one person in the activities leading up to the accident. The responsible party or parties may include the project manager, superintendents, foremen, mechanics, or other workers. It is generally accepted that accidents are the result of a series of events preceding the accident itself and that the elimination of certain actions may be a means of avoiding the accident (Hinze 1997). Thus, all individuals associated with a task play some potential role in an accidents' occurrence.

Frequency of Cases by Environmental Factors Involved

Environmental factors, which were involved in all of the 743 case studies, were reviewed. The contributing factors fell into 11 different environmental factors categories (Fig. 5). The most common environmental factor contributing to struck-by accidents was an overhead moving or falling object, comprising 30.8% of all cases. Coding within this category is often confusing in regard to the issue of material movement. In one of the cases, an employee was helping to place a precast concrete beam. The beam fell off its supports and onto the employee. This was coded under environmental factors as "material handling equipment/method." It also appears that this case could be coded as an overhead/falling object action. The coding of this category would also be clearer if the material were described as moving horizontally, moving vertically, or materials being dropped.

Table 3. Frequency of Cases by Human Factors Involved in Struck-by Accidents

Human factor	Frequency	Percent
Misjudgment of hazardous situation	266	35.8
Malfunction of procedure for securing operation or warning of hazardous situation	68	9.2
Procedure for handling materials not appropriate for task	53	7.1
Operational position not appropriate for task	51	6.9
Equipment in use not appropriate for operation or process	39	5.2
Safety devices removed or inoperative	32	4.3
Insufficient or lack of engineering controls	25	3.4
Insufficient or lack of written work practices program	21	2.8
Distracting actions by others	12	1.6
Malfunction of perception system with respect to task environment	12	1.6
Insufficient or lack of protective work clothing and equipment	11	1.5
Defective equipment: knowingly used	8	1.1
Malfunction of procedure for lock-out or tag-out	4	0.5
Insufficient or lack of housekeeping program	1	0.1
Other	140	18.8
Total	743	100.0

Of the 743 cases, 229 cases categorized the environmental factor involved as an overhead–falling object action. These cases were examined to determine the material that was falling most frequently. The most common material, involved in 29% of the overhead–falling object accidents, involved rock or soil, followed by steel/rebar/pipe at 21%, and timber at 13%. In one of the cases, a beam was being hoisted into an excavation and swung to one side and struck a laborer who was standing on steel beam shoring in the excavation. The worker received lacerations on his arm, thigh, and head.

Of the 62 cases involving overhead–falling object action and where equipment was involved, the accidents most often involved cranes (55%), followed by hoisting equipment (13%). From these findings, it appears that rigging of steel/rebar/pipe may be an area of concern.

Frequency of Cases by Number of Victims

Of the 743 cases examined, 675 accidents or 90.8% involved fatalities. The number of victims per accident ranged from one to

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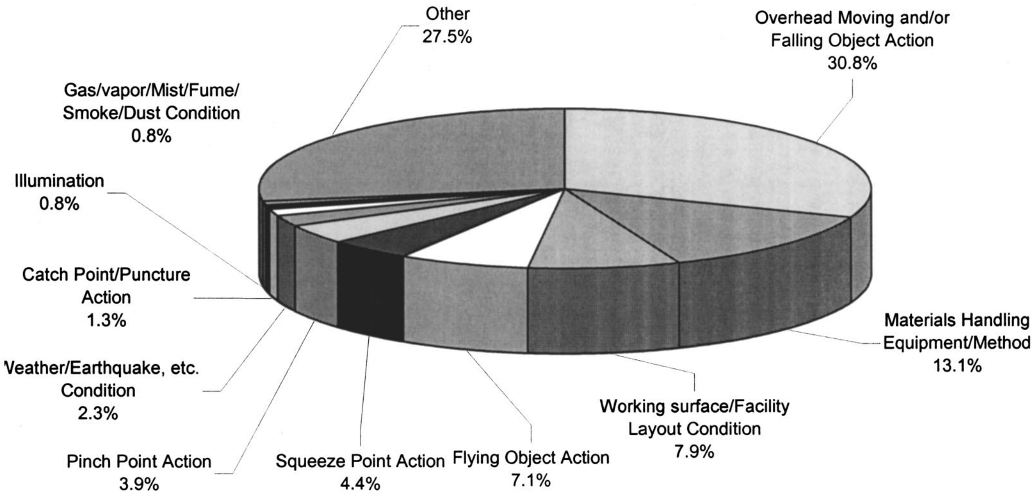

Fig. 5. Environmental factors in struck-by injuries/fatalities

nine persons. Of the fatality accidents, 1% had five or more victims, 3% of the cases had three or four victims, and 11% had two victims. The majority of the cases, comprising 84% of the sample, had one victim.

The data from previous years (dating back to the 1980's) were examined to identify multiple-victim accident cases. Of the 97 multiple-victim cases examined, 29 involved equipment. The most common equipment type associated with multiple-victim accidents involved private vehicles as noted in 38% of the cases. Cranes accounted for 21% and trucks accounted for 17% of multiple-victim accidents. The percentage of multiple-victim cases involving private vehicles is considerably higher than the percentage of struck-by cases involving private vehicles. Thus, a comparison was made to see if more fatalities resulted in the three major equipment categories than in equipment struck-by accidents overall.

In the cases involving only trucks, cranes, and private vehicles, 84.3% of the cases resulted in fatalities, while 74.8% of all equipment struck-by accidents resulted in fatalities. In cases where the three major equipment types resulted in at least one fatality, the percentage of fatalities for private vehicles was 94.7%, for trucks it was 85.5%, and for cranes it was 74.5%. Since private vehicles were involved in the largest number of cases by frequency, and 94.7 % of the cases were fatal, increased efforts in work zone safety should be implemented. This may include automated traffic control; heavy barricades (Jersey barriers), lane closures, or road closures if necessary. A case in which closing a road would have prevented the accident involved an employee working on a scaffold which was suspended from the side of a highway overpass. The street was still open for vehicular traffic when a truck with a high load hit the scaffold platform. The scaffold broke loose from the support, resulting in the collapse of the scaffold and the employee fell to his death on the street below.

Of the 97 multiple-victim cases studied, 68 cases involved materials. The most common material type was soil/rock (trench cave ins) as noted in 22% of the cases. The second most common material type associated with multiple-victim accidents was steel/rebar/pipe, followed by wood framewall truss formwork, each comprising 15%.

Frequency of Trench Cave-in Accidents

Since trench cave ins were often noted among the struck-by cases, the data were examined to determine the frequency of these types of accidents. Trench cave ins were associated with 13.5% of the struck-by cases. The number of trench cave-in accidents is probably actually greater than this as a cave-in injury/fatality could also be coded as a caught-in-or-between accident or an other accident, depending on the specific circumstances involved in the accident. In one of the cases coded as struck-by, the owner of a company was working inside a 3–5-m-deep trench that had no sloped trench walls or shoring and did not have a trench box. The bottom portion of the trench-wall collapsed and struck the owner. The area had been previously disturbed by a sewer line installation and the construction of a building. This case was coded as struck-by. In another case, a foreman was installing a sewer line in a 4-m deep and 1.5-m wide trench, which was lacking any type of worker protection in the trench. The trench was dug through old septic tank field lines and had been caving in during the installation of the sewer line. As the length of pipe was being lowered in the trench, the trench caved in and trapped the foreman. Hydraulic shoring jacks and a trench box were available on the site, but were not used. This was coded as a caught-in/between accident, but might just as well have been coded as a struck-by accident. Note that there is only a subtle difference between the two cases described and yet they are coded differently. If the same code, such as cave in, had been used for both causes, more useful data could be obtained.

Frequency of Cases by Equipment Associated with Struck-by Material Accidents

Equipment types associated with accidents, where the employee was struck by material, were reviewed. Cranes, trucks, and backhoes were the equipment types most frequently involved in accidents where the employee was struck by material. In accidents involving a crane, the worker was struck by: Steel/rebar/pipe in 27.3% of the cases, by concrete in 21.2% of the cases, and by wood framewall truss formwork in 12.1% of the cases. In accidents involving a truck, the employees were struck by: Steel/rebar/pipe in 33.3% of the cases and concrete in 22.2% of the

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Table 4. Frequency of Cases by Possible Prevention Methods

Prevention method	Frequency	Percentage
Adequate protective support system	69	14.1
Proper training	63	12.8
Spotter working at site/working audible alarm	52	10.6
Proper securing material	30	6.1
Equipment properly maintained	25	5.1
Adequate shoring and bracing	22	4.5
Turnoff equipment/set brake/chock wheels	15	3.1
Proper equipment clearance	15	3.1
Use of proper sized equipment/proper installation of equipment	14	2.9
Proper use of lanyards, lifelines, and seatbelts	12	2.4
Use personal protective equipment	12	2.4
Proper protective safeguard on equipment	11	2.2
Comply with manufacturer's specifications	11	2.2
Proper demolition procedures	10	2.1
Use of warning signs/barricades	8	1.6
Safe loads not exceeded	7	1.4
Proper amount of manpower used for a task	7	1.4
No extra passengers on equipment	7	1.4
Other	101	20.6
Total	491	100.0

Note: For many cases, possible prevention methods could not be suggested because of insufficient information.

cases. For accidents where a backhoe was used, the material types which struck the worker included: Soil/rock in 64.7% of the cases and steel/rebar/pipe in 11.8% of the cases. In one-half of the backhoe cases, the data regarding the material were either not applicable or missing.

Prevention of Struck-by Accidents

In approximately 66% of the cases, suggested prevention methods were devised by the writers, implying that most accidents were preventable (Table 4). Also, in the 743 cases reviewed, the OSHA compliance officers felt that compliance with OSHA standards would have prevented 60.3% of the accidents.

Summary

The research indicated many different types of materials and equipment are involved in struck-by accidents. The major characteristics associated with higher incidents of struck-by injuries and fatalities are as follows:

- Employees in their 30's,
- Construction work involving wood assemblies, block walls, soil/rock, and steel/rebar/pipe,
- Construction work involving trucks, private vehicles, and cranes,
- Human factors involving misjudgement, insufficient/lack of protective work clothing or equipment, and insufficient/lack of engineering controls, and
- Environmental factors involving overhead/falling object action.

Many injuries and fatalities were the direct result of the failure to comply with existing OSHA regulations. Most of these struck-by accidents resulted from violations of the standards, especially: 1926.201 (signaling), 1926.251 (material handling), 1926.550 (cranes), 1926.652 (trenching), and 1926.602 (material handling equipment).

Conclusions and Recommendations

Accident prevention programs should focus on the major types of equipment and material involved in struck-by accidents. More safety regulations may be needed in the area of crane operations and safe rigging of materials. Many of the cases involving falling materials resulted from improper rigging. With field personnel properly trained in rigging loads and in safely operating cranes, a reduction in the number of crane-related accidents should result. A high number of truck and private vehicle accidents occurred on highway projects that were not necessarily associated with the construction activities. In many cases, employees were not given sufficient protection from moving traffic. In other cases where the accident was associated with the construction activities, back-up audible alarms were either not operational or missing.

For contractors and employees, two areas should be the primary focus: Improved crane safety and more accident prevention methods implemented on highway projects. To improve crane safety on construction work sites, a crane operator certification program should be implemented allowing only certified employees to operate cranes. Both riggers and crane operators should undergo training for the proper rigging of material, since many of the accidents involved the falling of loads during material hoisting. Extensive planning of the site layout should be conducted to minimize material movement over employees. The location of the crane should be such that workers have less exposure to materials passing overhead.

Effective accident prevention methods should be implemented on highway projects. As a means to reduce truck and private vehicle accidents not necessarily associated with the construction activities, heavy barriers, lane closures, and road closures should be considered to protect the employees. To reduce accidents resulting from equipment movement, the functioning of back-up alarms on equipment should be checked prior to each day's use and that the alarm be audible in ambient conditions at the work site. Also, greater care in planning the site layout should have traffic separated from the walking workforce.

Overall, improved safety training of employees is needed to insure accident-free construction sites. Safety should be emphasized at the beginning of each workday detailing the anticipated hazards in the tasks to be performed. Reorganization of tasks or flow of work may be considered as a method to improve safety at the job site. In each organization, safety needs to become the responsibility of every employee.

For OSHA personnel, changes in capturing information would improve analysis, which would result in the development of improved methods of accident prevention. Clarification regarding the coding of environmental factors is suggested with regard to the movement of materials, whether it is moved horizontally, hoisted vertically, or simply dropped. Coding was an obvious concern in the trenching accidents. Clearer codes might lead to more effective measures being developed to make construction sites safer. It may be advantageous to create a separate category for trench cave-in accidents, so that analysis on all trench-related accidents could be done collectively.

A simplified coding system should be developed to include information presently incorporated only within the abstract. This would make the data more easily accessible to researchers and the

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root causes could be identified more readily. An example of this would be to include a category of "trench cave-in" for all trench cave-ins which are currently coded as a struck-by, caught in/between, or other. Other suggested categories would include: Struck by construction equipment, struck by private vehicle, struck by horizontally moving material, struck by vertically hoisted material, and struck by falling material. This classification would simplify and ease the retrieval of information.

Many accidents were the direct result of the failure to comply with existing OSHA regulations. No assessment was made to evaluate the adequacy of the OSHA standards for particular circumstances. A study should be conducted to evaluate if the standards are adequate to prevent struck-by accidents. For example, perhaps signaling regulations (1926.201) should be re-evaluated to determine if more specific guidance is warranted. Material handling equipment regulations (1926.602) may be reviewed regarding the sequence of events preceding the struck-by accidents. Two other areas that should be evaluated are rigging equipment for materials handling (1926.251) and the operations of cranes (1926.550).

Once methods of accident prevention are determined, they need to be discussed with regulatory officials and with industry leaders in order for implementation to take place on a broad scale. Effective communication on accident prevention methods will lead to a reduction in the number of injuries and fatalities on construction sites.

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