Fatalities in Trenching Operations—Analysis Using Models of Accident Causation

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Abstract: More than 65 construction workers are killed each year due to trench related accidents. Accident prevention begins with having a clear understanding of the causes of these accidents. This paper discusses the analysis of 296 fatality reports related to trenching operations from the Occupational Safety and Health Administration (OSHA) in the 1997–2001 time frame. In this paper, two models will be considered to analyze the fatality reports and to find the major relationships between the "how" and the "why" of trenching fatalities. The first model considers the causes related to physical processes, and the second model evaluates causes that can be linked to human behavior. The understanding of the major links between these two models and other factors will help to develop more effective strategies to prevent trenching fatalities.

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Introduction

In the year 2000, the construction industry represented 4.7% of the Gross Domestic Product in the United States (Lum and Moyer 2001). This industry experienced 19.5% of all reported fatalities, although it contributed only 7% of the total workforce. More than 6.52 million people work in the construction industry and approximately 1.5 million of these workers are self-employed. In the same year, construction recorded the highest number of fatal work injuries of any industry. The fatality rate in construction was 12.9 fatalities per 100,000 employees, and there were 503,500 nonfatal injuries and illnesses in construction. Incidence rates for nonfatal injuries and illnesses were 8.3 per 100 full-time equivalent workers in construction.

In addition to fatalities, injuries caused in construction activities are costly in terms of direct and indirect costs to the construction industry. The direct costs include medical costs and other worker's compensation insurance benefits. These direct costs of accidents are not fixed and they vary depending upon the prior safety records of the company and the magnitude of the accident. The indirect costs include lost productivity among co-workers and management, liability claims from injured workers who sue contractors for additional payments beyond their worker-men claims, job schedule delays, added administrative time, training of replacement personnel, and reduced worker morale, especially when fatalities occurred (Levitt and Samelson 1993). Indirect costs have traditionally been calculated by multiplying the direct cost by an indirect cost multiplier. Various estimates of this multiplier range from 2 to 20 times direct costs (Usmen 1994). Everett and Frank (1996) established a range for the indirect cost multiplier (ICM=indirect costs/direct costs) with values between 1.65 and 2.54. Poor safety not only hurts the workers but also the companies that hire them, the families of the workers, and the community. The benefits of improved occupational safety include increased efficiency, competitiveness, and profitability; and reduced delays, disputes, and conflict.

Trenching operations are executed principally by water, sewer, utility lines, and heavy construction companies. The value of construction work executed by these companies represents 2.6% of the total volume of construction in the United States (U.S. Department of Commerce 1997). In total, these companies had 166 fatalities during the year 2000, including trenching operations victims. According to an analysis of workers' compensation claims in the Supplementary Data System of the Bureau of Labor Statistics (BLS), there are approximately 1,000 work related injuries each year due to excavation cave-ins. Of these, about 140 result in permanent disability and 75 in death (National Institute for Occupational Safety and Health 1995).

Cave-ins have been identified as the major cause of fatalities in trenching operations. However, cave-ins are not the only threat to the safety of construction workers in trenching operations. These workers also face hazards associated with working at heights, working with heavy machinery, manually handling materials, and working near sources of existing utilities, such as overhead power lines or gas pipelines. The workers in the underground construction industry, especially water, sewer, and utility lines companies, have traditionally had a higher accident and injury rate than other workers in the heavy construction industry. In the year 2000, 98 fatalities occurred in water, sewer, and utility lines projects, compared with 82 fatalities in highway and street construction, or 33 fatalities in bridge, tunnel, and elevated highway construction (Bureau of Labor Statistics 2001). According to the Occupational Safety and Health Administration (2002), the fatality rate for excavation work is 112% higher than the rate for general construction.

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A trench is defined as a narrow (in relation to its length) excavation made below the surface of the ground. In general, the depth is greater than the width, but the width of a trench (measured at the bottom) is not greater than 15 ft (4.6 m) (OSHA 1989). Current methods of trenching and pipelaying involve construction workers excavating trenches to the required width and depth using surveying methods and approximation to control depth and grade. The bottom of the trench should form a continuous, even support for the pipe. A proper trench bottom will usually require some hand work and possibly some special fill material to provide proper bedding. During the excavation phase, the major challenges to the crew are the presence of utilities, the work in confined spaces, adjacent structures, and the installation process of safety equipment.

When the trench bottom is ready, a pipelayer enters the trench in order to bed the pipes, joint them, and finally align them together. The pipe is lowered into the trench using a crane or hydraulic backhoes. This process is dangerous due to the utilization of heavy equipment and the presence of overhead power lines, besides the operations with overhead loads, such as pipes and equipment. The connections between pipes are made either mechanically or by hand, depending upon the type and size of pipes to be laid. The backfilling process starts once the pipe is in place. During this process, one of the most commonly used pieces of equipment is the backhoe excavator, because they are easy to operate and provide excellent control. The excavator can remove the soil, transport the pipes, and do the backfilling process. Usually, the crews involved in trenching operations are assisted by a backhoe operator, and two or three pipelayers depending upon the size of the pipes. The crew is also involved in the survey and alignment control process.

Existing Information on Causes of Fatalities in Trenching Operations

The data on occupational accidents can be obtained from several agencies such us the Bureau of Labor and Statistics (BLS), the Occupational Safety and Health Administration (OSHA), the National Safety Council (NSC), and the National Institute for Occupational Safety and Health (NIOSH). Each agency maintains its database for different specific objectives; thus the types of information included in the database and the focus of the investigation vary from agency to agency. OSHA relies primarily on employer reporting or coverage by the news media to initiate a fatality investigation. BLS uses information from the employer but also collects the data through a questionnaire. Both NSC and NIOSH rely on death certificate data (OSHA 1990).

Since 1971, the OSHA has had as one of its directives the role of collecting data on the causes of construction fatalities. This information is collected by OSHA compliance officers when they visit construction sites on which fatalities or serious injuries have occurred, or based on employee complaints. The compliance officers write a brief narrative description or abstract of the incident, with some information about the incident being recorded in a number of code categories (Hinze et al. 1998). OSHA performs programmed and unprogrammed inspections. Unprogrammed inspections are scheduled in response to alleged hazardous working conditions that have been identified at a specific worksite, i.e., imminent dangers, fatalities/catastrophes (or ''accidents''), complaints, and referrals. Apart from inspections based on employee complaints, contractors are initially selected for construction inspections based either on the Dodge Reports or on ''emphasis programs.'' Follow-up inspections also can be a basis for selection.

The Dodge Reports are a listing of construction projects by size and region; they are the primary source used to select construction contractors for random inspections. For instance, each month OSHA's Indiana office receives from the University of Tennessee (under a subcontract to OSHA) a random list of construction projects in Indiana involving $250,000 or more. The list does not distinguish between building and road construction projects. The agency then inspects as many job sites on the list, in order, as possible until it either completes the list or receives a new one. Because many construction-related inspections are scheduled in this way, it is quite possible that a particular contractor may be inspected more than once in a relatively short time while another is not inspected at all (Beckwith and Dale 2002).

The ''emphasis programs'' inspections place emphasis on safety hazards in specific construction operations, such as trenching, scaffolding, and fall protection. Inspectors may inspect any job site in which one or more of these activities are under execution even though the job site is not on the current Dodge Reports list. Many emphasis program inspections occur when an inspector thinks he or she has spotted a violation in a trenching or scaffolding, or fall protection. The OSHA's National Emphasis Program for Trenches requires all compliance officers to be on the watch for trenching and excavation worksites. OSHA will inspect worksites where trenching hazards have been observed and reported—either by the public or an OSHA compliance officer.

Follow-up inspections are a third way of selecting contractors for inspection. In this type of inspection, the agency reinspects a particular job site where violations were found in earlier inspections. Follow-up inspections are most frequently scheduled for long term construction projects. The agency's decision to conduct or not to conduct follow-up inspections is discretionary. The accident inspections are recorded on Accident Investigation Summaries—OSHA-170 forms.

The OSHA inspections reports on injury data provide information that can be of considerable value in identifying the causes of fatalities. These inspections reports include various coded information such as the date of the injury, location of the construction site, identity of the employer, age of the victim, sex, general information about the event type, nature of the injury, cost of the project, number of employees at site, number of employees in total, union status, number of violations, number of serious violations, the Standard Industrial Classification code of the company, abstract of the accident, and a short description of the events. The coded data provides considerable information about the injured individual, the employer, but only general information about the accident itself. Although accident information is coded in general terms in the OSHA reports, the most valuable information is locked away in the abstracts which OSHA does not analyze or summarize on a regular basis (Hinze and Bren 1997).

In the period October 2000 through September 2001, the top 10 most cited standards by Federal OSHA are listed in Table 1. The data shown include construction standards violated by general contractors (Standard Industrial Classification—SIC 15), heavy and highway contractors (SIC 16), and special trade contractors (SIC 17).

Models of Accident Causation

The effective use of accident causation models can identify the sources of accidents and ultimately reduce or eliminate accidents. Since such models represent, classify, and efficiently organize large amounts of safety-related knowledge, a large number of

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Table 1. Most Frequently Cited Construction Related Standards (Occupational Safety and Health Administration)—(October 2000–September 2001)

Number	Description of the standard	Standard identification	Number cited	$ penalty
1	General requirements for all types of scaffolding	1926.451	7,320	6,971,165
2	Fall protection scope/applications/ definitions	1926.501	4,661	5,770,419
3	Excavations, general requirements	1926.651	1,830	2,479,795
4	Ladders	1926.1053	1,507	696,310
5	Construction, general safety and health provisions	1926.20	1,471	942,617
6	Electrical, wiring design and protection	1926.404	1,326	529,486
7	Electrical wiring methods, components and equipments, general use	1926.405	1,307	351,178
8	Excavations, requirements for protective systems	1926.652	1,268	3,873,320
9	Head protection	1926.100	1,265	755,887
10	Fall protection training requirements	1926.503	1,174	557,385

analysis techniques have been developed which are based upon these models. Accident causation models provide theoretical framework which guides both the retrospective analysis of accidents and the prospective identification of hazards (Lehto and Salvendy 1991).

There is a very substantial collection of accident causation theories, models, and application methods. Lehto and Salvendy (1991) distinguish four groups to classify the models: (1) general models of accidents process; (2) models of human error and unsafe behavior; (3) models of the mechanics of human injury; and (4) application techniques.

The general models of the accidents' process describe the dynamics of accidents using a set of generic principles (such as domino theory, network models, and multilinear sequencing) which can be applied in more specific modeling applications which focus upon human, product, task, or environmental factors. The models of human error and unsafe behavior have various approaches. For instance, one approach would be to focus on inherent and situational traits of the human and how they are related to accidents, i.e., how would the presence of heavy equipment close to the edge of a trench affect the frequency of accidents in trenching. Another approach would analyze accidents from the perspective of human judgment and choice. A third approach describes fundamental reasons for why people make errors based on an understanding of how people process information (i.e., communication model, error mechanisms, decision stage model).

The models of the mechanics of human injury are based on the application of principles of ergonomics and are focused on the effect of cumulative exposure to factors such as noise, heat, or repetitive motion (i.e., biomechanical model, slip resistance, ladder climbing).

Application techniques are frameworks for identifying and analyzing hazards which combine techniques found within accident causation models. For instance, the fault tree analysis is an approach top-down, and begins with a possible accident and works downwards to basic events at the bottom of the tree.

An accident causation model needs to deal with both the event area (i.e., the direct causes or the "how" of accident causation) and the circumstances preceding the event area (i.e., the "why" or underlying factors of accident causation). The answers to the "why" question are concerned with identifying the major causes of accidents. Only by understanding these can the determination of fully effective and appropriate preventions be achieved (Suraji et al. 2001). In previous studies regarding the causes of fatalities in trenching operations (Thompson and Tanenbaum 1975; Stanevich and Middleton 1988; Suruda et al. 1994; Hinze and Bren 1997; Twardowski 1997) the "how" of the accident was considered, but the root causes of the accident were not clearly established. In this paper, two models will be identified in order to analyze the fatality reports and to establish the major relationships between the "how" and the "why" of the trenching fatalities.

The first model is based on research conducted by Toole (2002). This model considers eight root causes of accidents in construction. Many of these causes are similar to those proposed by Abdelhamid and Everett (2000) and Suraji et al. (2001). The key assumption in this model is that the behavior of individual employees is sometimes (but certainly not always) the primary cause of an accident (Toole 2002). This model will be identified as *Behavioral Causes Model* in this paper. The eight root causes described by Toole (2002) are shown in Table 2.

The second model that is used to analyze the fatality reports is based on Hinze et al. (1998) and will be referred to as *Type of Accident Model*. The most well-known code categories in this model are the five basic cause codes, which are falls, struck by, caught in/between, electric shock, and other. To classify the fatalities using these five basic cause codes, the Occupational Injury and Illness Classification Manual of the Bureau of Labor Statistics (BLS 1992) will be taken into account. The Occupational Injury and Illness Classification Manual (OI&ICM) provides a classification system for use in coding the case characteristics of injuries and illnesses in the Occupational Safety and Health (OSH) program and the Census of Fatal Occupational Injuries (CFOI) program. This manual contains the rules of selection, code descriptions, code titles, and indices for the following code structures: Nature of injury or illness, part of body affected, source of injury or illness, event or exposure, and secondary source of injury or illness. In this paper, the codes for Event or Exposure will be used in each fatality report (BLS 1992). The event or exposure describes the manner in which the injury or illness occurred, based on the source of injury or illness. The major codes considered in the analysis of trenching related fatalities are shown in Table 3.

Analysis of Information

Two-hundred and ninety-six (296) summaries of fatality investigations were analyzed to identify the causes of fatalities specifically related to trenching operations. The fatalities occurred in the period 1997–2001. By conducting a detailed examination of the abstracts, additional information such as depth of the trench, BLS Code of the accident, presence of safety equipment, and behavioral causes based on Toole (2002), was extracted from the reports.

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Table 2. Root Causes of Construction Accidents (Toole 2002)

Root cause	Description
Lack of proper training	An employee was not properly trained in recognizing and avoiding all potential hazards associated with the task he or she is performing
Deficient enforcement of safety	An employee's supervisor knew that prescribed methods for avoiding hazards were not being followed, but neglected to enforce safety standards
Safe equipment not provided	An employer does not provide an employee with equipment necessary to minimize hazards
Unsafe methods or sequencing	The normal sequencing of construction tasks does not occur, resulting in a task being inherently more hazardous than is typical
Unsafe site conditions	The site is inherently more hazardous than are typical construction sites
Not using provided safety equipment	An employee is provided with proper safety equipment, but does not use it properly or does not use it at all
Poor attitude toward safety	An employee may have been properly trained, but does not properly avoid job hazards due to a ''tough-guy'' mentality, laziness, or a perception that prescribed methods would unduly slow job progress
Isolated, sudden deviation from prescribed behavior	A normally competent and safety-conscious employee suddenly and unforeseeably performs an unsafe act due to fatigue, preoccupation, or likewise

Results

According to the information obtained from OSHA, the number of fatalities in trenching operations per year during the period 1997–2000 is shown in Table 4.

The distribution of accidents based on *Type of Accident Model* is presented in Table 5. The major type of accident in trenching operations is cave-ins, followed by caught in or compressed by equipment or objects and struck by object, usually backhoes or pipes during the installation process.

The relationships between the *Type of Accident Model* and *Behavioral Causes Model* are presented in Table 6. For each group in the *Type of Accident Model*, the major human causes are shown. The major human causes in trenching accidents are: safe equipment not provided and unsafe methods or sequencing. The first cause is more relevant when cave-ins fatalities occurred, and the second when equipment and materials maneuvers are necessary on site, especially to move the pipes into the trench, to install the protective systems, to move the trench boxes, and to excavate and backfill the trench. The distribution of fatalities based on *Behavioral Causes Model* is presented in Table 7.

When cave-ins occurred, 49% of the fatalities occurred in projects with costs under US$250,000 and 73% of the fatalities in projects with costs under US$1,000,000. Also, 31% of the accidents occurred in projects with fewer than 10 workers and costs under US$250,000, i.e., when the project is smaller, the likelihood of a trench cave-in is higher. A possible reason is that the smaller projects are executed by small contractors who may not necessarily address the safety standards adequately or they do not have sufficient budgets to provide safety equipment. Besides, since such projects are more widespread, the control of these projects by the inspections conducted by the Federal government is more difficult. Interestingly, of the companies implicated in trenching operations, at least 84% had one violation reported in OSHA records. This indicates that OSHA inspectors were present at the job site at least once, in order to do an inspection and the posterior citation.

Table 3. Bureau of Labor and Statistics Codes

Division	Group	Code	Description
0			Contact with objects and equipment
	02		Struck by object
		021	Struck by falling object
		029	Struck by object n.e.c
	03		Caught in or compressed by equipment or objects
		031	Caught in running equipment or machinery
		039	Caught in or compressed by equipment or objects, n.e.c.
	04		Caught in or crushed in collapsing materials
		041	Excavation or trenching cave-in
		044	Caught in or crushed in collapsing structure
		049	Caught in or crushed in collapsing materials, n.e.c.
1			Falls
	11		Fall to lower level
		1124	Fall from ground level to lower level
3			Exposure to harmful substances or environments
	31		Contact with electric current
		311	Contact with electric current of machine, tool, appliance, or light fixture
		313	Contact with overhead power lines
		314	Contact with underground, buried power lines
	38		Oxygen deficiency
		381	Drowning, submersion
		389	Other oxygen deficiency, n.e.c
5			Fires and explosions
	52		Explosions
		522	Explosion of pressure vessel or piping
9			Others events or exposures
		9999	Nonclassifiable

Note: n.e.c.=not elsewhere classified.

Table 4. Number of Fatalities in Trenching Operations (1997–2000)

Year	Fatalities
1997	69
1998	72
1999	83
2000	82

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Table 5. Distribution of Fatalities by *Type of Accident Model*—Bureau of Labor Statistics Codes

Group	Type of accident	Code	Description	Percent
02	Struck by object			15.2
		021	Struck by falling object	5.4
		029	Struck by object	9.8
03	Caught-compressed by equipment or objects			16.6
		031	Caught in running equipment or machinery	1.4
		039	Caught in or compressed by equipment or objects	15.2
04	Caught-crushed in collapsing material			54.7
		041	Excavation or trenching cave-in	51.4
		044	Caught in or crushed in collapsing structure	1.7
		049	Caught in or crushed in collapsing materials	1.7
11	Fall to lower level			0.7
		1124	Fall from ground level to lower level	0.7
31	Contact with electric current			7.8
		311	Contact with electric current of machine, tool, appliance, or light fixture	0.7
		313	Contact with overhead power lines	5.1
		314	Contact with underground, buried power lines	2.0
38	Oxygen deficiency			1.7
		381	Drowning, submersion	1.0
		389	Other oxygen deficiency	0.7
52	Explosion			2.4
		522	Explosion of pressure vessel or piping	2.4
99	Others			1.0
		9999	Other events or exposure	1.0

When contact with electric current was the primary type of accident, 70% of the fatalities occurred in projects with costs under US$1,000,000, and when caught-compressed by equipment or objects was the type of accident, 63% of the fatalities occurred in projects with costs under US$1,000,000. When cave-ins fatalities occurred, 8% of the reports mentioned some protective system in place. The most common system mentioned was trench box. Sixty-three (63%) of the time, the trench box was not properly used. Based on the reports, in cases where protective systems were available on the site, fatalities occurred when: the workers were struck by materials being lowered or dropped into the trench shields, or when the workers left the trench box, or when the box was placed over the surface near the trench but was not put in place. Hinze (2002) studied 114 accidents that occurred in the period from 1984 to 2001 and involving trench boxes. Of the 114 accidents, 67 accidents involved fatalities. The root causes of these fatalities were: workers venturing out of the trench box (25%), improper sloping above the trench box (13%), being struck by excavator bucket (10%), faulty rigging or bad practice (10%), trench box available but not being used (9%), and other causes (33%). When examining the types of accidents involving trench boxes, it is apparent that the OSHA regulations regarding the use of trench boxes are adequate, however, improper use of trench boxes on sites can result in serious injuries or fatalities.

The distribution of the cost of the project when a fatality occurred is shown in Fig. 1. In projects with costs under US$250,000, the major causes of fatalities were lack of safety equipment (47%) and unsafe methods or sequencing (28%). In 55% of the projects with cost under US$50,000, the major cause was lack of safety equipment. When lack of training was the major cause of the fatality, 57% of the projects had costs under US$1,000,000. In projects with costs below US$1,000,000, the likelihood of trenching accidents is higher, especially when the contractor does not provide adequate safety equipment, or does not have specific safety training sessions in trenching issues.

According to the U.S. Department of Commerce (1997), 92% of the water, sewer, and pipeline companies have fewer than 50 employees and these companies represent 2.9% of the total labor force in the construction industry. Analyzing the number of employees on site when the fatality occurred, in 63% of the cases the job site had fewer than 10 workers and 83% of the times the companies had fewer than 49 employees in total. When the project had fewer than 10 workers on site, in 48% of the fatalities the major cause was lack of safety equipment. When lack of safety equipment was identified as the major cause of the fatality, 84% of the companies had fewer than 50 employees in total. The distribution of fatalities based on the Standard Industrial Classification (SIC) is shown in Table 8. A detailed analysis of the water, sewer, pipelines companies, and plumbing, heating and air conditioning companies is presented in Table 9. The distribution of the age of the victims of trenching fatalities is shown in Fig. 2. According to the reports, the average age of the victim was 36 years.

80% of the fatalities involving workers younger than 18 years old occurred on projects with fewer than 10 workers. Young workers are less mature, have less judgment and work experience than adults, and are less likely to challenge their supervisors about dangerous tasks (Greenhouse 2002). Since no data was available on the distribution by age for workers in trenching operations, it was not possible to determine if younger workers were statistically more or less safe than older workers.

According to the interviews conducted with safety directors from construction companies located in the Midwest, the majority of the construction workers start working when they are nearly 20 years old. Taking into account that the average age of the victims is 36 years, it can be assumed that the victims in trenching operations were working in construction at least 10 years before they

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Table 6. Relationships Between the Type of Accident Model and Behavioral Causes Model

Code	Type of accident	Behavioral causes	Percent
02	Struck by object		
		Unsafe methods or sequencing	58
		Lack of proper training	31
		Deficient enforcement of safety	4
03	Caught in or compressed by equipment or objects		
		Unsafe methods or sequencing	47
		Lack of proper training	37
		Isolated, sudden deviation from prescribed behavior	6
04	Caught in or crushed in collapsing materials		
		Safe equipment not provided	75
		Deficient enforcement of safety	9
		Unsafe methods or sequencing	7
31	Contact with electric current		
		Unsafe methods or sequencing	70
		Lack of proper training	30
52	Explosions		
		Unsafe methods or sequencing	43
		Deficient enforcement of safety	29
		Lack of proper training	14

were involved in the fatal accident. Hence, even though the construction workers may have received some kind of general training, specific training in trenching operations and adherence to safety procedures is essential to prevent accidents. However, in many instances, construction workers tend to take unnecessary risks, and the ''tough guy'' culture continues to prevail on job sites.

Table 7. Distribution of Fatalities Based on *Behavioral Causes Model*

Root cause	Fatalities (%)
Lack of proper training	16.6
Deficient enforcement of safety	6.8
Lack of safety equipment	42.2
Unsafe methods or sequencing	27
Unsafe site conditions	0.3
Not using provided safety equipment	2.7
Poor attitude toward safety	0.7
Isolated, sudden deviation from prescribed behavior	3.7

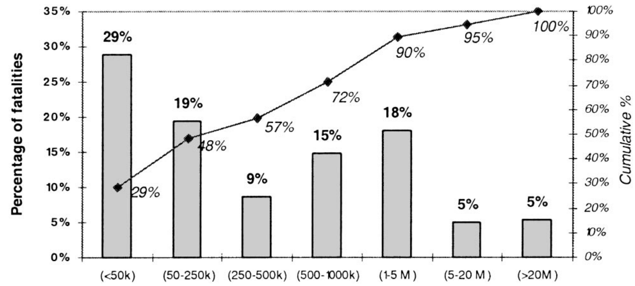

Fig. 1. Project cost

The distribution of accidents based on the month of the year is shown in Fig. 3. Trenching operations accidents can happen in any month of the year. However, during May and October, peaks in frequency of fatalities were observed. According to Hinze and Bren (1997), the presence of more subsurface water in the ground during October may perhaps explain the high incidence during October. Also it is possible that the pressure to complete projects before the onset of winter can lead to increased activity, and hence, the high level of fatalities during the month of October.

The distribution of fatalities based on the time of the day is almost uniform from 8:00 a.m. through 4:00 p.m. The highest number of cave-ins occurred between 12 and 2:00 p.m. According to Hinze and Bren (1997), it is possible that during the lunch break the apparent cohesion of the trench walls has begun to relax. After a half-hour lunch, the trench walls are in a greater state of stress than when the excavation work was initially performed.

The depth of trench when a fatality occurred is shown in Fig. 4. The information was available in 176 reports. The others reports did not have information regarding the depth of the trench.

The average depth of the trench was 3.1 m (10.3 ft). All the fatalities caused by electrocution occurred in trenches less than 3 m (10 ft) deep. Between 0 and 1.5 m (5 ft), the major causes of accidents based on *Behavioral Causes Model* are unsafe methods or sequencing (50% of the times) and lack of training (29% of the times). According to the existing standards, if the trench is less than 1.5 m (5 ft) and examination of the ground by a competent person provides no indication of a potential cave-in, the trench does not require a protective system. However, fatalities can take place due to inappropriate operations, especially with equipment and materials in the immediate vicinity. When the trenches were deeper than 1.5 m (5 ft), the major cause based on *Behavioral Causes Model* is lack of appropriate safety equipment. According to the existing OSHA standards, it is necessary to provide adequate protective systems in trenches deeper than 1.5 m (5 ft).

Table 8. Distribution of Fatalities by Standard Industrial Classification Codes

SIC code—description	Fatalities (%)
1623—Water, sewer, pipeline, communications and power line	34
1794—Excavation work	20
1711—Plumbing, heating and air-conditioning	13
1629—Heavy construction	8
1542—General contractors-nonresidential buildings, other than industrial	5
1521—General contractors-single-family houses	4
1799—Special trade contractors	3
Others	13

Table 9. Analysis of Water, Sewer, Pipeline and Plumbing, Heating and Air-Conditioning Companies

	Water, sewer, pipeline, communications and power line (SIC code: 1623)	Plumbing, heating and air-conditioning (SIC code: 1711)
Major causes based on *Behavioral Causes Model*	Safe equipment not provided 48% Unsafe methods or sequencing 28% Lack of training 12% Not using provided equipment 5% Others 7%	Safe equipment not provided 57% Unsafe methods or sequencing 19% Deficient enforcement of safety 14% Isolated, sudden deviation 8% Others 2%
Percent of companies with OSHA violations	86	81
Percent of companies with serious OSHA violations (See Note)	80	78
Percent of companies with less than 10 workers on site when the fatality occurred	67	76
Percent of projects with costs under US $500,000	51	78

Note: A serious violation is defined as one in which there is a substantial probability that death or serious physical harm could result, and the employer knew or should have known of the hazard.

The geographical distribution and worker status of the victims was also analyzed. During the period 1997–2001, 46 states reported fatalities in trenching operations. The state with the highest number of fatalities is Texas (12%), followed by California (7%) and Michigan, Missouri, and Ohio with (5%). Of the 296 trenching fatalities, 250 (84%) occurred on nonunion projects and 46 (16%) occurred on union projects. Even though the fatality reports did not reveal the ethnic background of the victim, the significant Hispanic population (in many cases, undocumented workers) in Texas and California could explain the higher number of fatalities in trenching operations in these states. Hispanics are a significant segment in the U.S. construction workforce. For instance, the number of Hispanic hourly construction workers in the U.S. increased from 14.4% in 1999 to 17.0% in 2000. Compared to 1999, the number of construction fatalities involving Hispanic workers increased 24% in the year 2000 (BLS 2001). Lack of proper communication about safety procedures may explain the high number of fatalities among Hispanic workers. The size of the Hispanic workforce is expected to increase even more if construction demands have to be met. Hence, the construction industry needs to develop safety and skills training programs for the growing Hispanic community (Goodrum 2002).

Summary

In this paper, two different models, namely the *Behavioral Causes Model* and the *Type of Accident Model* were identified to analyze accidents in trenching operations, which were available from OSHA records in the 1997–2001 time frame. Based on the *Behavioral Causes Model*, the major causes are: lack of safety equipment, practice of unsafe methods or sequencing, and lack of proper training. Based on the *Type of Accident Model*, the major causes of fatalities in trenching operations are: cave-ins, caught in or compressed by equipment or objects, and struck by object. In cases where cave-ins occurred, safety equipment was not provided in a majority of the cases. When the victim in the trenching fatality was struck by materials or equipment, a critical combination of lack of training and unsafe methods or sequencing caused the fatality.

The findings of this study show an alarming trend that the employers, especially smaller contractors (for example, contractors having less than 50 workers), and those working on small projects (costs below US$250,000), tend to have higher rates of fatalities. In many cases, the fatalities can be attributed to failure to provide adequate protection systems or failure to use these systems and other construction sequences in a safe manner. For improved safety in trenching operations, it is necessary to provide adequate and appropriate safety equipment at the right time, reinforce specific training in the use of such equipment and safe construction procedures, institute a more effective planning process prior to onset of trenching operations in order to identify the hazards on the job site, and define the strategies to prevent accidents.

Based on interviews conducted with construction practitioners located in the Midwest, the existing safety standards are deemed to be reliable and can help to prevent fatalities in trenching operations when they are correctly applied. However, in many instances, construction workers take unnecessary risks, and the ‘‘tough guy’’ culture continues to prevail on job sites. For instance, in many cases, when the trench is to be open for less than 3 h, the crews involved in trenching operations tend to ignore the safety requirements, i.e., use of safety equipment, detailed analy-

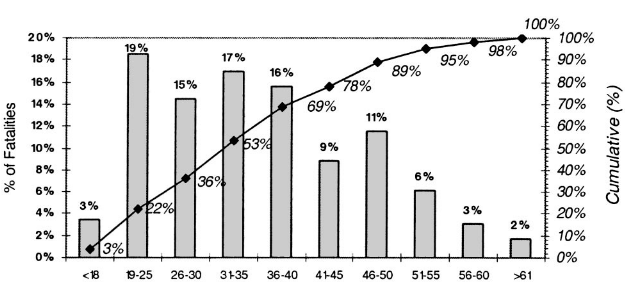

Fig. 2. Distribution of the age of the victim

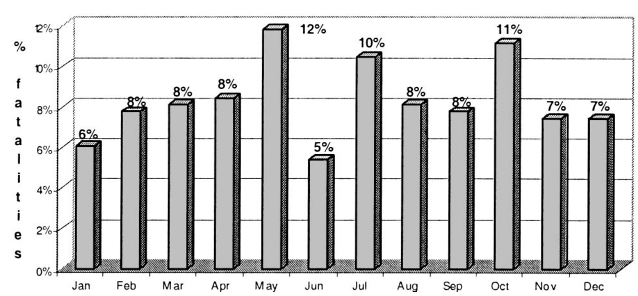

Fig. 3. Distribution of accidents according to month of the year

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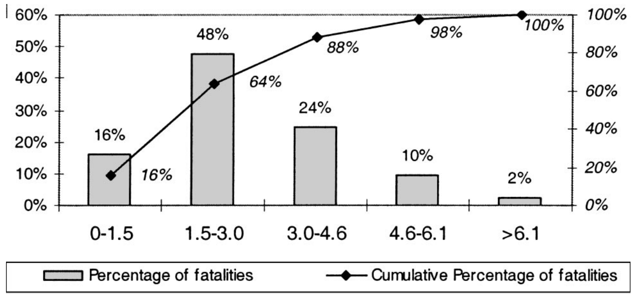

Fig. 4. Depth of trench

sis of soil condition, presence of competent person, etc., because they believe that the pipelaying operation will be completed and the trench closed, without posing any safety risk.

To prevent fatalities on job sites, the construction companies have been developing strategies (such as daily safety planning meetings, increasing involvement of owners in planning for safety, increasing accountability by workers and support by top management, control of minor accidents, etc.) to improve the safety of workers. These strategies are based primarily on prior experiences of safety directors, and have the potential to decrease construction fatality rates. However, the impacts of these strategies have not been analyzed on a systematic basis. The understanding of the links between the *Behavioral Causes Model* and the *Type of Accident Model* provides the initial step in identifying and analyzing trenching accidents in order to formulate viable strategies used to prevent the trenching accidents.

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