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Work-related injuries and fatalities in the geotechnical site works

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Abstract: Geotechnical site works are comprehensive, and they constitute the first step of the construction process. This study performs data mining of geotechnical works and analyzes the database for the root causes of accidents. The Occupational Safety and Health Administration (OSHA) was chosen for the 1984–2013 time frame with 247 cases. Descriptive statistical analyses were performed to discuss variables such as the end use of the work, project type and cost, soil type and condition, type and degree of injury, cause and type of accident, unsafe acts, and occupation and union status of the victim. The results showed that these accidents have a high frequency of recurrence and have a high severity level (54.3% fatalities). In addition, a total of 838 violations were recorded with penalties reaching 5 million US dollars. This study emphasizes that project-specific countermeasures should be taken regarding the root causes of accidents, leading to vigorous strategies to develop safety measures.

Key words: Occupational safety, Geotechnical site works, Accidents, Excavation, Trench, Cave-in

Introduction

There is an increasing trend among researchers and private company specialists to consider the effects and results of occupational accidents. The construction industry is globally in the top three industries where there is risk of occupational accidents and construction workers are three times more likely to be killed and twice as likely to be injured as workers in other occupations[1–4]. For this reason, the analysis of the accidents that took place in the construction sector was carried out by various researchers[5–10]. However, positive awareness is still limited in research dealing with the details of accidents causes in sub branches of civil engineering works. For this reason, every construction process needs to be investigated separately to provide continuous occupational safety at site works[11–13].

The construction industry consists of different branches of civil and environmental engineering. Among them, geotechnical site works constitute the first step regardless of the end use of the structures. Alteration, renovation, and maintenance or repair of structures also needs the geotechnical processes to be applied for safe and economical solutions[14]. Geotechnical site works are comprehensive; therefore, the potential risk of accidents is diverse from project to project[15, 16]. Unfortunately, accidents occurring in geotechnical site works frequently end up with death, but importance has not been given to the cause of fatalities and injuries[17, 18].

In the past, complete and accurate records of the actual number of fatalities occurring in trenching incidents were not maintained properly. Although the results presented in the literature are limited, the importance of occupational safety in geotechnical site works is revealed by some researchers. Stanevich and Middleton[19] stated that 85 fatal

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excavation cave-ins resulted in 92 fatally injured workers, according to NIOSH (National Institute for Occupational Safety and Health) data. The information was abstracted from the OSHA cases reported from 1974 through 1981 for the construction industry. Suruda *et al.*[20] examined 306 fatal cases obtained mainly from OSHA investigations dating from 1974 to 1986 to investigate fatal injuries from trench cave-ins in the construction industry and found that deaths due to cave-in were a significant risk for construction workers and can be prevented by proper protective measures. Hinze and Bren[17] noted that due to cave-ins and other excavation accidents 100 fatalities per year could be expected. Lew *et al.*[21] discussed the role of the competent person in excavation safety and analyzed the characteristics of accidents based on Fatality Assessment and Control Evaluation (FACE) program and Bureau of Labor Statistics (BLS) records. Lew *et al.*[21] estimated 7,000 injuries as a reasonable approximation of the magnitude of the problem. Suruda *et al.*[22] examined fatal injuries from trench cave-ins in the construction industry for five year periods before and after the revision (in 1989) in the 47 states of the USA, where data were available for both periods. Studies by the French Fédération Nationale des Travaux Publics (FNTP)[23] indicated that within the French construction industry, accidents were both more prevalent (12% higher than average) and more severe (47% higher than average) in the geotechnical engineering sector than in the construction sector as a whole[24]. Many accidents have been reported along with the potential dangers in geotechnical works. More than 30 construction workers are killed each year in the USA in trenching or excavation-related incidents, and many more suffered from injuries and near-misses as reported by Plog *et al* [25]. Plog *et al.*[25] also analyzed detailed data from 162 investigations of serious or fatal trenching-related injuries, conducted by the Division of Occupational Safety and Health in California from January 1993 through June 2004. Between the years 2000 and 2009, 350 workers died in trenching or excavation cave-ins, resulting in an average of 35 fatalities per year[26]. OSHA announced that 23 workers were killed and 12 others were injured in trench collapses in 2016[27].

The primary objective of the study is to evaluate the root causes of accidents in the geotechnical branch of the construction industry. In this research paper, root cause is defined as an elementary reason for any accident related to occupational safety to prevent it from happening in the future. In order to reach this objective it was necessary to establish an information database on work-related accidents in geotechnical engineering applications, sufficient and accurate data mining of geotechnical site works and analysis of the data sets rigorously. Violations and their penalties are inspected for the four major categories of violations. Unsafe acts that caused the accidents are also presented and discussed.

Common Potential Hazards and Related OSHA Regulations

Workers are exposed to many hazards during excavation, pile driving and compaction work, but the major hazard is the danger of cave-ins[28]. Workers can be exposed to potential cave-ins because of some application errors, such as lack of sloping or benching the sides of the excavation, supporting the sides of the excavation or placing a shield between the side of the excavation and the work area. Any large, heavy movement near an excavation results in vibration of the surrounding soils. This movement can result in soil failure. Heavy loads from large equipment, heavy materials or large spoil piles can be too heavy for the soil to support, resulting in a cave-in. In addition to cave-in hazards and secondary hazards related to cave-ins, there are other hazards from which workers must be protected during geotechnical site works. These hazards include exposure to falls from height, whether into excavations or working in excavations, falling loads and mobile equipment, water accumulation, unsafe access and egress to all excavations, working in confined spaces or in poor conditions underfoot, asphyxiation due to lack of oxygen, hazardous gases, contact with severed electrical cables or improper rescue[21, 24, 28].

Excavation and trenching operations are explained regarding the safety issues in OSHA standard 1926 Subpart P. The standard consists of three subpart titles, namely as scope, application and definitions (1926.650), specific excavation requirements (1926.651), and finally, requirements for protective systems (1926.652). These sections state applying the rules of the standard in the field. The first title gives the definitions related to the subpart in alphabetical order. The second title gives the specific requirements in detail. In the second title, it is emphasized that all underground installations shall be determined prior to opening an excavation. Structural ramps that will be used to access or to egress from excavations shall be designed by a competent person who is qualified in structural design. Special support or shield systems are necessary to protect from cave-ins and from hazards associated with water accumulation, loose rock and soil, from falling loads, vehicular traffic and hazardous atmospheres.

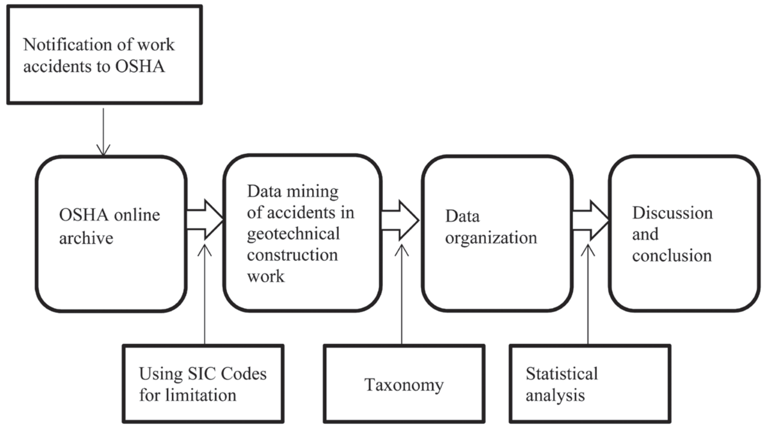

Fig. 1. Flowchart of methodology.

Protection of employees shall be provided to ensure the stability of adjacent structures. The third section explains the Requirements for Protective Systems that must be provided to protect employees in excavations. The standard requires that employees entering excavations which are 1.52 meters or greater in depth shall be protected from cave-ins. The requirements for protective systems are divided into two categories, design of sloping and benching systems and design of support systems, shield systems and other protective systems, each of these two categories come with four options giving flexibility to the designers of the systems[29)].

When examining the database provided by OSHA and creating the subcategories of the variables of this study, which were not given directly in the database of OSHA above mentioned hazards and regulations were carefully detected from the reports.

Methodology

Univariate and cross tabulation analyses were performed on the variables in this study, which investigates the root causes of accidents that occurred during geotechnical site work. In this section, basic information about analysis methods and how they are implemented in the study are explained (Fig. 1).

Data acquisition

OSHA provides detailed information for each case and right to know for academic purposes with a data range varying from 1984 to 2013. OSHA updates and develops its own reporting system regularly. The requirements were revised for recording and submitting records of workplace injuries and illnesses in the 1980s[30, 31)]. The Standard Industrial Classification System (SIC) was used as a limitation of data mining. Standard Industrial Classification (SIC) is a system for classifying industries by a four-digit code[32)]. The SIC codes can be grouped into progressively broader industry classifications: industry group, major group, and division. Within the scope of the study, SIC codes, related to construction were used. Cases occurring during geotechnical work were selected. Extensive elimination of accident cases was performed to achieve accurate and reliable data that is free from bias. Finally, 247 cases that resulted in injuries and fatalities remained to create the database of accidents in geotechnical construction work.

Initial violations and penalties of the cases that form the data set are presented in Figs. 2 and 3 as a summary to emphasize post-accidental responsibilities of the companies. There were 838 violations in four different categories for acts such as serious, willful, and repeat. Serious violations can be assessed when companies should have known of a hazard, but did not protect or insufficiently protected their employees. This condition has the highest frequency within the data set. Willful violations are the most severe type of citation issued by OSHA and carry the highest penalties. Willful violations are reserved for cases where an employer intentionally violates OSHA rules or blatantly and deliberately disregards worker safety. Accordingly, in this study willful violations also have the highest penalties. Repeat violations are an OSHA regulation for which the company has already been issued a citation within the last three years (unless that citation is currently under appeal). Fortunately, repeat violations are in the minority, which could be a result of improved safety rules of the companies after facing dissuasive penalties.

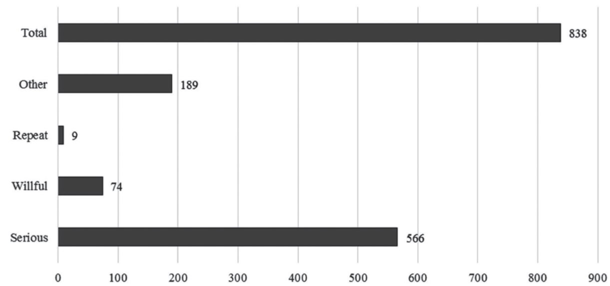

Fig. 2. Initial Violation Summaries of selected cases.

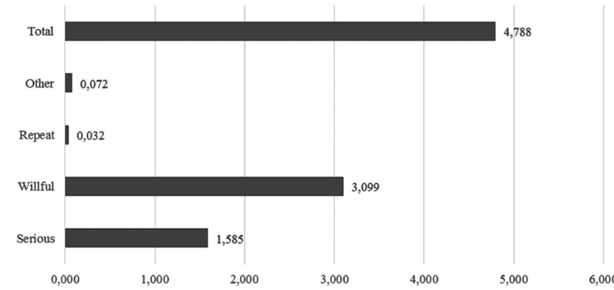

Fig. 3. Initial Penalty (M) Summaries of selected cases.

Univariate analysis

The data categorization used in the occupational accident statistics, the distribution of the variables in each category and the frequency ratio of the variables are important for determining problematic areas and inductive learning. Univariate analysis is usually the first analysis used by researchers who perform statistical analysis in different study fields and on various databases[33, 34)]. The main objectives of the analysis are to explain the data and tell the researcher what is available[35)]. In this research, 12 variables were created by their sub-categories using the OSHA classifications. The purpose of the univariate analysis was data screening, choosing the right variables for explanatory data analysis, and understanding how the information is processed. Consolidation of common terms was applied for some variables. In the end, the results of the univariate frequency analysis of 12 variables were presented using frequency tables in this paper.

Cross-tabulation analysis

General information about the data set can be obtained by examining the results of univariate analysis. After applying univariate analysis to investigate whether there is a meaningful relationship between variable pairs, cross tabulation analysis is carried out. Cross tabulation is defined as the analysis of two categorical variables at the same time to determine whether there is an experimental relationship between them[36)]. One of the objectives of this study is to identify the factors that have an impact on the severity of accidents. For this reason, in addition to univariate, binary analysis was applied to the existing database with cross tabulation analysis.

Cross tabulation analysis produces a contingency table displaying relationship, in the form of joint frequencies of two or more variables. The rows indicate one variable while the columns indicate the other. After the frequency distribution in the cells is included in the cross-tabulation analysis, the second stage is a question of whether there is a significant relationship between the variables. The Pearson χ^2 test is one of the tests that can be used to interpret this relationship successfully[37)]. Pearson χ^2 compares the observed counts with those that would be expected if there were no associations between two variables[38)]. The Pearson χ^2 tests the hypothesis that variables in rows and columns which can be independent or dependent. For this research, the null hypotheses (H_0 and H_1) formulated were as follows:

H_0=There is no association between the variable and degree of injury

H_1=There is an association between the variable and degree of injury

After calculating the Pearson χ^2 value, the *p*-value based on that value (which expresses the importance of the χ^2 value) must be calculated separately. *P*-value is the probability value used in the hypothesis tests in the Pearson χ^2 test. After finding the *p*-value, researchers can decide whether the result is meaningful or not (commonly taken as 0.05). For this reason, the cases where the value of *p* is less than 0.05 are considered to be significant, the hypothesis H_0 is rejected and it is assumed that there is a relation between the variables[35)].

If the null hypothesis is rejected, the next step is to determine the strength of this relationship. The value that can be calculated to evaluate the strength of association between the variables is the value of "Phi & Cramer's *v*". Phi value can be calculated for only 2 × 2 contingency tables, while Cramer's v value can be calculated for tables with more than 2 × 2 rows and columns; both values can vary from 0 to 1. Phi or Cramer's v values and interpretations proposed by Healey[39)] are listed below:

- 0 to 0.1 shows a weak relationship
- 0.1 to 0.3 indicate a moderate relationship
- 0.3 to 1.0 suggest a strong relationship

Cross tabulation analysis was performed to determine statistical relationships and strength between variables. In this research, the variables defined in the study are classified as dependent (degree of injury) and independent variables (other nominal variables). The degree of injury variable, which has the subcategories of fatality, hospitalized injury and non-hospitalized injury, was selected as “Dependent Variable”. The remaining variables were used as independent variables in the analyses. Then, analysis was performed for each independent variable and dependent variable; “*p*” values of each were examined. The results of cross tabulation analysis are presented.

Results

Statistical analysis of the study focused on 247 work-related injury cases in geotechnical site works occurring in the period of 1984–2013. The findings of the analyses are summarized in the following subsections.

Results of univariate analysis

In this section, the above methodology is carefully applied and the outcomes of the research briefly discussed. SIC codes that are used relate to heavy construction work in the field, excavation work and bridge tunnel and elevated highway construction. Heavy construction cases involved in this research included caisson drilling, clearing of land, cofferdams and dam construction, drainage construction, earthmoving, land leveling, land reclamation, pier construction, pile driving, rock removal and trenching while excavation work included foundations, excavation, and grading excluding the grading work for highways, streets, and airport runways.

The accidents occurring between 1984 and 2013 were analyzed. According to the findings, the majority of the reported accidents occurred in 1994 and 2006. March, June, and November were the peak months where accidents repeated in the selected time range (Fig. 4).

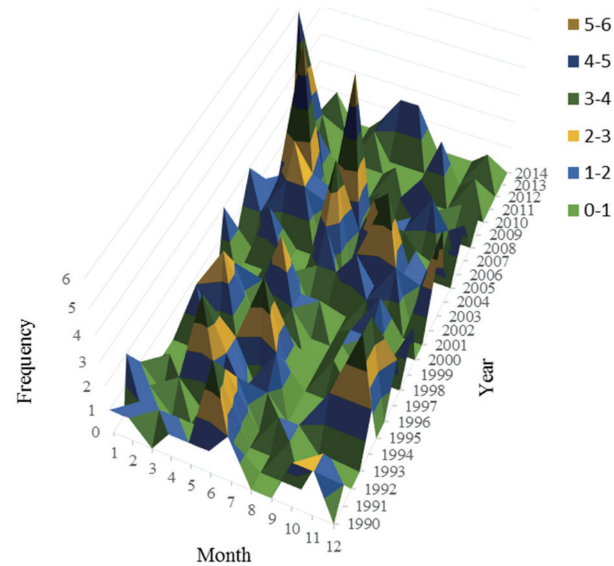

Fig. 4. Frequency of accidents, according to their years and months.

A percentage of 69.6 (%) of the victims were working on a new project or new additions to an existing project. The geotechnical phase of the projects was excavation, landfill, sewer-water treatment, pipeline construction, for commercial building construction or family dwellings as the end use variable. According to the findings, 15.8% of the victims were working on buildings for family dwellings followed by sewer/water treatment (14%). In this research, the family dwelling category showed that the focus of the accidents shifted from life lines to upper structures. It is observed that projects with less than $500,000 cost were more likely to end up with occupational fatal accidents. Limited budgeted projects were mostly manned by small and medium sized contractor companies, which might give less importance to occupational safety and health measures compared to corporate companies[40] (Table 1).

Among all the cases examined, almost half of them (54.3%) resulted in fatalities, (35.6%) resulted in hospitalized injury and only 10.1% resulted in non-hospitalized injuries. The study showed that trenching and installing pipe, excavation, and pile driving were the three main causes of accidents, while trench collapse, struck by a falling object/projectile and wall collapse were the main types of accident. More than half of the accidents were due to fracture (28.3%) followed by asphyxia (25.1%) and bruises/contusions/abrasions (10.9%) (Table 2). Categories of unsafe act are based on research conducted by Toole[41], which considers eight root causes of accidents in construction. Many of these causes are similar to those proposed by Abdelhamid and Everett[42] and Suraji *et al* [43]. The major unsafe acts in accidents were because safe equipment was not provided (41.3%) and unsafe methods or sequencing (21.5%) were used. The first cause is more relevant with cave-in accidents because no shoring, sloping, or trench shield was present at the time of the accident (Table 2).

According to the results, the majority of victims were construction laborers (19.8%) or special trade constructors (9.3%). It should be noted that the occupation of 46.2% of the victims was not reported. Frequency analysis showed that 75.3% of the victims were non-union workers, compared to 24.7% union workers (Table 3).

Another aspect of this study was to determine the soil conditions where the accidents occurred. Unstable, weak,

Table 1. Distribution of project characteristics

Variables	Categories	Frequency	Percent	Cumulative percent
End use	Family dwelling	35	15.8	15.8
	Sewer/water treatment	31	14.0	29.8
	Excavation, landfill	30	13.5	43.3
	Pipeline	30	13.5	56.8
	Commercial building	25	11.3	68.1
	Highway, road, street	21	9.5	77.6
	Other building	20	9.0	86.6
	Bridge	15	6.8	93.4
	Other heavy construction	15	6.8	100.0
Project type	New project or new addition	135	69.6	69.6
	Maintenance or repair	25	12.9	82.5
	Alteration or rehabilitation	23	11.9	94.4
	Other	11	5.7	100.0
Project cost ($)	Under 50,000	27	18.6	18.6
	50,000–250,000	22	15.2	33.7
	250,000–500,000	17	11.7	45.4
	500000–1,000,000	15	10.3	55.7
	1,000,000–5,000,000	30	20.7	76.4
	5,000,000–20,000,000	16	11.0	87.4
	>20,000,000	18	12.4	100.0

soft, previously disturbed soils are more vulnerable to accidents. Therefore, the soil classification of OSHA is briefly described, and the accident database is evaluated for soil conditions.

OSHA standard for ground work follow a variety of U.S. standards. Basically, the soil is categorized into three types, and there is one class for rocks. The order of the stability, stiffness and relative density decrease from stable rock to type A soil, type B soil, and type C soil. The types of soil are determined based on the index and engineering properties of soils and the environmental conditions of exposure. The engineering properties of soils are associated with actual soil behavior, therefore the classification in OSHA standard is performed by examining the soil properties. Laboratory or field data can be used for classification in the OSHA system. Particle size distribution and the percentage of particle size passing through a sieve, especially a No. 200 sieve, is used to determine the quantity of the various sizes of soil particles and the qualities or characteristics of the very fine grains. Type A soils consist of cohesive soils with an unconfined compressive strength of 144 kPa or greater. Type B soils are granular or cohesive soils with an unconfined compressive strength greater than 48 kPa but less than 144 kPa. If a type B soil is previously disturbed it would be classified as a type C soil. Type B soils also include the soils that meet the unconfined compressive strength or cementation requirements for type A but are fissured or subject to vibration; or dry rock that is not stable; or a material that is part of a sloped, layered system where the layers dip into the excavation on a slope less steep than four horizontal to one vertical (4H:1V), but only if the material would otherwise be classified as type B soil. Type C soils cover the group of granular or cohesive soils with an unconfined compressive strength of 48 kPa or less; or a layered system where the layers dip into the excavation or a slope of four horizontal to one vertical (4H:1V) or steeper. Type C soils represent the weakest conditions[44].

Factors such as type of soil, water content of soil, environmental conditions, proximity to previously backfilled excavations, the weight of heavy equipment or tools, and vibrations from machines and motor vehicles can greatly affect soil stability and the hazards that workers face[45]. Soils with low unconfined compressive strengths, unstable granular soils, especially unsaturated sands close to dry conditions, and loess and silt soils may cause stability problems if necessary precautions are not taken. When the soil types and conditions of this study are examined, type C soils, mostly consisting of loose granular soils and weak cohesive soils were involved as a factor causing the accidents. As the soil gets weaker, cave-in of trenches, plane or rotational movements, toppling, sliding, overturning or

Table 2. Distribution of accident characteristics

Variables	Categories	Frequency	Percent	Cumulative percent
Degree of injury	Fatality	134	54.3	54.3
	Hospitalized injury	88	35.6	89.9
	Non-hospitalized injury	25	10.1	100.0
Type of injury	Fractures	70	28.3	28.3
	Asphyxia	62	25.1	53.4
	Bruises/Contusions/Abrasions	27	10.9	64.3
	Sprain/Strain	10	4.0	68.3
	Concussion	10	4.0	72.3
	Electrical shock	8	3.2	75.5
	Amputation	8	3.2	78.7
	Cuts/Lacerations	7	2.8	81.5
	Other	45	18.2	100.0
Cause	Trenching, installing pipe	80	32.4	32.4
	Excavation	71	28.7	61.1
	Pile driving	51	20.6	81.8
	Backfilling and compacting	17	6.9	88.7
	Site grading and rock removal	8	3.2	91.9
	Steel works	5	2.0	93.9
	Forming	5	2.0	96.0
	Other activities-post decking detail work	4	1.6	97.6
	Landscaping	3	1.2	98.8
	Waterproofing	3	1.2	100.0
Type of accident	Trench collapse	85	34.4	34.4
	Struck by falling object/projectile	63	25.5	59.9
	Wall collapse	30	12.1	72.0
	Collapse of structure	16	6.5	78.5
	Crushed/run-over/trapped of operator by operating	14	5.7	84.2
	Fall from height	14	5.7	89.9
	Electric shock, other and unknown cause	9	3.6	93.5
	Other	16	6.5	100.0
Unsafe act	Safe equipment not provided	102	41.3	41.3
	Unsafe method or sequencing	53	21.5	62.8
	Unsafe site conditions	36	14.6	77.3
	Unidentified	23	9.3	86.6
	Poor attitude toward safety	22	8.9	95.5
	Not using provided safety equipment	5	2.0	97.6
	Deficient enforcement of safety	4	1.6	99.2
	Unexpected health conditions	2	0.8	100.0

tilting of structures can be observed as failure types of the soil. The majority of the accidents occurred where type C soil was dominant (65.5%) (Fig. 5). The soil conditions considered water in the soil, frost action and disturbance of soil in this study. Severe changes in ground water table level, saturation of top soil layers due to heavy rain or any other activity that increases the water content of the soil causes loss of soil strength. Heavy rainfall caused 33.3% of the accidents questioned in the database (Fig. 6). A similar loss of strength in soil could be seen as a result of seasonal frosting and thawing. As the soil freezes, the water in the soil expands in volume, causing damage in the micropores of soil structure. The soil cracks and loses its strength. However, frozen soils exist in limited climates, and this study shows that only 10.0% of accidents were related to frost action. Above all, changing the natural deposition state of the soil causes the most important conditions. The degree of disturbance in the soil changes not only its strength but also its engineering properties. If the effects of disturbance are neglected during construc-

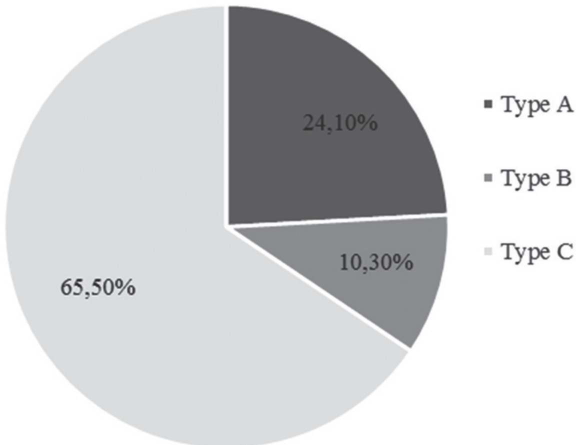

Fig. 5. Distribution of soil types.

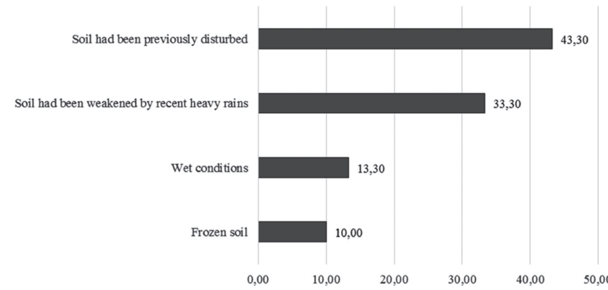

Fig. 6. Distribution of soil conditions (%).

Table 3. Distribution of worker characteristics

Variables	Categories	Frequency	Percent	Cumulative percent
Occupation	Occupation not reported	114	46.2	46.2
	Construction laborer	49	19.8	66.0
	Construction trades n.e.c.	23	9.3	75.3
	Supervisors	18	7.3	82.6
	Machine operators	16	6.5	89.1
	Welders, cutters and metal workers	5	2.0	91.1
	Truck driver, heavy	4	1.6	92.7
	Miscellaneous material moving equipment operators	4	1.6	94.3
	Sales occupations, other business services	3	1.2	95.5
	Carpenter	3	1.2	96.8
	Helpers, construction trades	3	1.2	98.0
	Heavy equipment mechanics and operators	3	1.2	99.2
	Operating engineers	2	0.8	100.0
Union status	Union	61	24.7	24.7
	Non-union	186	75.3	100.0

tion, unexpected soil behavior may cause fatal accidents. The results of univariate analysis support that the 43.3% of accidents caused in disturbed soils have the highest frequency (Fig. 6).

Results of cross-tabulation analysis

In the univariate frequency analysis, the distribution of the generated variable categories was examined. After conducting the univariate analysis, cross-tabulation analysis was carried out to investigate whether a significant relationship between pairs of variables existed. In the cross-tabulation analysis section of the study, the relationship between the degree of injury and other nominal variables were investigated, and each analysis was interpreted. Four of the twelve variables (Occupation, type of injury, cause and type of accident) were found statistically significant, as shown in Table 4. According to results obtained by using Cramer's v value, the degree of injury had a strong relationship with the occupation of the worker, the type of injury, and the cause and type of accident.

The cross-tabulation analysis between the degrees of injury and occupation showed that the occupation was not reported for 68.4% of workers who died because of work accidents. Almost half of the machine operators (43.8%) had fatal occupational accidents; the same result for supervisors (50%). All of the heavy equipment mechanics, operators (100%) and operating engineers (100%) had hospitalized injuries, while sales occupations and other business services (100%) had fatal injuries (Table 5).

According to the cross-tabulation analysis between the

Table 4. Contingency Table−Degree of injury vs. nominal variables

Variables	Pearson's χ^2 (df), p		Phi & Cramer's ν	
Occupation	χ^2 (24)=47.097	p=0.003	crv (24)=0.437	p=0.003
Type of injury	χ^2 (16)=161.628	p=0.000	crv (16)=0.809	p=0.000
Cause	χ^2 (18)=24.078	p=0.152	crv (18)=0.312	p=0.152
Type of accident	χ^2 (14)=30.549	p=0.006	crv (14)=0.352	p=0.006

Table 5. Contingency Table−Degree of injury vs. occupation

Occupation	Degree of injury			Total
	Fatality	Hospitalized injury	Non-hospitalized injury	
Occupation not reported	78 (68.4%)	29 (25.4%)	7 (6.1%)	114 (100.0%)
Construction laborer	19 (38.8%)	22 (44.9%)	8 (16.3%)	49 (100.0%)
Construction trades n.e.c.	10 (43.5%)	11 (47.8%)	2 (8.7%)	23 (100.0%)
Supervisors	9 (50.0%)	7 (38.9%)	2 (11.1%)	18 (100.0%)
Machine operators	7 (43.8%)	6 (37.5%)	3 (18.8%)	16 (100.0%)
Welders, cutters and metal workers	3 (60.0%)	2 (40.0%)	0 (0.0%)	5 (100.0%)
Truck driver, heavy	1 (25.0%)	3 (75.0%)	0 (0.0%)	4 (100.0%)
Miscellaneous material moving equipment operators	2 (50.0%)	2 (50.0%)	0 (0.0%)	4 (100.0%)
Sales occupations, other business services	3 (100.0%)	0 (0.0%)	0 (0.0%)	3 (100.0%)
Carpenter	0 (0.0%)	1 (33.3%)	2 (66.7%)	3 (100.0%)
Helpers, construction trades	2 (66.7%)	0 (0.0%)	1 (33.3%)	3 (100.0%)
Heavy equipment mechanics and operators	0 (0.0%)	3 (100.0%)	0 (0.0%)	3 (100.0%)
Operating engineers	0 (0.0%)	2 (100.0%)	0 (0.0%)	2 (100.0%)
Total	134 (54.3%)	88 (35.6%)	25 (10.1%)	247 (100.0%)

Table 6. Contingency Table−Degree of injury vs. type of injury

Type of injury	Degree of injury			Total
	Fatality	Hospitalized injury	Non-hospitalized injury	
Fractures	20 (28.6%)	46 (65.7%)	4 (5.7%)	70 (100.0%)
Asphyxia	62 (100.0%)	0 (0.0%)	0 (0.0%)	62 (100.0%)
Bruises/Contusions/Abrasions	6 (22.2%)	8 (29.6%)	13 (48.1%)	27 (100.0%)
Sprain/Strain	0 (0.0%)	7 (70.0%)	3 (30.0%)	10 (100.0%)
Concussion	8 (80.0%)	2 (20.0%)	0 (0.0%)	10 (100.0%)
Electrical shock	4 (50.0%)	3 (37.5%)	1 (12.5%)	8 (100.0%)
Amputation	0 (0.0%)	5 (62.5%)	3 (37.5%)	8 (100.0%)
Cuts/Lacerations	2 (28.6%)	5 (71.4%)	0 (0.0%)	7 (100.0%)
Other	32 (71.1%)	12 (26.7%)	1 (2.2%)	45 (100.0%)
Total	134 (54.3%)	88 (35.6%)	25 (10.1%)	247 (100.0%)

degrees of injury and type of injury, all of the accidents (100%) caused by asphyxia ended with fatalities. Accidents caused by cuts/lacerations substantially ended with hospitalized injury (71.4%); only a small amount of accidents ended with fatalities (28.6%) while there is no non-hospitalized injury in this category. Fractures (65.7%) are a prominent category for hospitalized injuries, which is larger than the sum of the rest of all categories within the scope of hospitalized injuries. Bruises/Contusions/Abrasions as soft injuries compared to others were mostly non-hospitalized injuries (Table 6).

The cross-tabulation analysis of the degrees of injury and cause indicated that more than half of the workers had fatal injuries during trenching and installing pipe operations (51.3%). The rate of fatality is even higher in other operations such as backfilling and compacting (64.7%),

Table 7. Contingency Table−Degree of injury vs. cause

Cause	Degree of injury			Total
	Fatality	Hospitalized injury	Non-hospitalized injury	
Trenching, installing pipe	41 (51.3%)	31 (38.8%)	8 (10.0%)	80 (100.0%)
Excavation	44 (62.0%)	23 (32.4%)	4 (5.6%)	71 (100.0%)
Pile driving	29 (56.9%)	15 (29.4%)	7 (13.7%)	51 (100.0%)
Backfilling and compacting	11 (64.7%)	3 (17.6%)	3 (17.6%)	17 (100.0%)
Site grading and rock removal	3 (37.5%)	4 (50.0%)	1 (12.5%)	8 (100.0%)
Steel works	3 (60.0%)	1 (20.0%)	1 (20.0%)	5 (100.0%)
Forming	1 (20.0%)	3 (60.0%)	1 (20.0%)	5 (100.0%)
Other activities-post decking detail work	0 (0.0%)	4 (100.0%)	0 (0.0%)	4 (100.0%)
Landscaping	2 (66.7%)	1 (33.3%)	0 (0.0%)	3 (100.0%)
Waterproofing	0 (0.0%)	3 (100.0%)	0 (0.0%)	3 (100.0%)
Total	134 (54.3%)	88 (35.6%)	25 (10.1%)	247 (100.0%)

Table 8. Contingency Table−Degree of injury vs. type of accident

Type of accident	Degree of injury			Total
	Fatality	Hospitalized injury	Non-hospitalized injury	
Trench collapse	50 (58.8%)	26 (30.6%)	9 (10.6%)	85 (100.0%)
Struck by falling object/projectile	32 (50.8%)	21 (33.3%)	10 (15.9%)	63 (100.0%)
Wall collapse	22 (73.3%)	8 (26.7%)	0 (0.0%)	30 (100.0%)
Collapse of structure	9 (56.3%)	6 (37.5%)	1 (6.3%)	16 (100.0%)
Crushed/run-over/trapped of operator by operation	8 (57.1%)	6 (42.9%)	0 (0.0%)	14 (100.0%)
Fall from height	2 (14.3%)	12 (85.7%)	0 (0.0%)	14 (100.0%)
Electric shock, other and unknown cause	4 (44.4%)	4 (44.4%)	1 (11.1%)	9 (100.0%)
Other	7 (43.8%)	5 (31.3%)	4 (25.0%)	16 (100.0%)
Total	134 (54.3%)	88 (35.6%)	25 (10.1%)	247 (100.0%)

excavation (62.0%), steel works (60.0%), and pile driving (56.9%) (Table 7).

The cross-tabulation analysis of the degrees of injury and type of accident demonstrated that more than half of the trench collapses (58.8%), struck by a falling object/projectile (50.8%) and the collapse of a structure (53.3%) categories as a type of accident ended with fatalities, which shows the severity of accidents. According to findings, approximately every three of four workers (73.3%) lost their lives because of wall collapse (Table 8).

Discussion and Conclusions

This study addresses geotechnical site work as a part of the construction process. The importance of occupational safety and health and the need for pre-planning in geotechnical works are demonstrated with the help of statistical analysis. To highlight the research needs of the subject, the OSHA database related to geotechnical accidents was deeply investigated, and 247 cases were determined to be eligible in sufficient detail for use in this study. Raw data of the cases were divided into several variables, which can be used to define the accident and support statistical analyses. Each variable is interpreted according to its rate of occurrence. The variables with the highest occurrence level should be considered as the primary reasons for accidents, and precautions given in the corresponding regulations should be taken before starting the site work, and renewal of the strategies should be considered if necessary.

Major outcomes of the study with the relevant comparable findings of the literature are summarized as follows:

• According to the findings, 15.8% of the victims were working on buildings for family dwellings followed by sewer/water treatment (14%). In 2002, Lew *et al.*[21] found that sewer systems (35%) and water supply systems (15%) are areas with the highest trenching related fatalities. Suruda *et al.*[20] also found the same result, most of the deaths occurred in the sewer line construction industry. This proves that desired improvement on this issue has not been achieved and more work has to be done to reduce the potential hazards.

• It is observed that projects with less than $500,000 cost were more likely to end up with occupational fatal accidents. Abraham[46] also mentioned that 72% of the fatalities occurred in projects costing under US $1 million. This point emphasizes that small-mid range companies still could not afford enough training and may fail to provide the appropriate equipment or methods because of losing the work offer[40]. This finding is in conformity with the regulatory review of 29 CFR 1926, Subpart P, where small firms were mentioned to have higher violation and fatality rates. This finding also shows much has not changed since the publication of the review[48].

• Trench collapse, struck by a falling object/projectile and wall collapse were the main types of accident. Lew *et al.*[21] found that trench collapse was the main cause of accidents in a group of accidents consisting of excavation and trench cave-ins. Plog *et al.*[25] propounded that trench collapse and struck by falling object are the most repeated types of accident. Brooks[27] also found that more than half the fatalities were a result of collapse of excavation walls.

• Trenching and installing pipe, excavation, and pile driving were the three main causes of accidents. These three operations constitute 81.8% of the total accident rate. In all three operations, the rate of fatality in work-related accidents are more than fifty percent.

• More than half of the accidents were due to fracture (28.3%) followed by asphyxia (25.1%) and bruises/contusions/abrasions (10.9%). Plog *et al.*[25] also found that fractures, bruises/contusions/abrasions and asphyxia are the top three types of injuries, which is almost the same.

• The major unsafe acts in accidents were because safe equipment was not provided (41.3%) and unsafe methods or sequencing (21.5%) were used. Arboleda and Abraham[47] also found that safe equipment was not provided in many cases (42.2%) and unsafe methods or sequencing (27.0%) were the major causes of accidents. Specifically, for cave-ins, it was reported in the accident files that there was no shoring, sloping, or trench shield present during the time of the accident. In order not to repeat similar accidents, attention should be paid to take precautions and inspect the workplace.

• According to the results of this study, the majority of victims were construction laborers (19.8%) or special trade constructors (9.3%). Plog *et al.*[25] also found that construction laborers and special trade constructors were the most injured workers. It should be noted that the occupation of 46.2% of the victims was not reported. The reason this description lacking is probably due to the negligence of filling out accident notification reports. However, this is an important input to understand which occupational groups are at high risk in geotechnical site works. Providing this information by employers should be compulsory in order to take occupation specific precautions in the field.

• Frequency analysis showed that 75.3% of the victims were non-union workers, compared to 24.7% union workers. The database of this study demonstrated that the number of union workers was significantly higher in the 1970's and earlier. However, the number of union workers has declined substantially since then. Higher labor costs of union workers is a reason for this substantial decrease. This may explain the reason behind the big difference between the two levels[35].

Statistical analyses in this study revealed the importance and the seriousness of occupational safety in the geotechnical field. According to the findings of the study, the frequency analysis among all the examined cases show that slightly over half of them (54.3%) resulted in fatalities; in other words, one of the two people who had an accident lost their lives. As a result of work accidents ending with deaths and injuries, employers pay penalties at higher rates based on the violations they have committed. In this research, due to accidents that occurred, employers had a total of 838 violations and paid about $5 million in penalties. Therefore, it is necessary to discuss what can be done to reduce the frequency and the severity of accidents by taking lessons from past accidents. Project specific precautions also should be considered according to the circumstances in the field such as soil type, soil conditions, trench depth, etc., as every project of geotechnical works has its own critical conditions as soil is not a man-made material. However, it is necessary to address that the OSHA database used in the study may be limited to that it is biased toward fatal cases.

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