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Analysis of fall accidents from scaffolding in the construction industry

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Research Paper

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Analysis of fall accidents from scaffolding in the construction industry

Falls caused by scaffolding are one of the most common causes of construction accidents. This study aims to represent the primary causes of scaffolding accidents, clarify the characteristics of the incidents, and explore the type of work or action during scaffolding accidents within the construction industry. In this study, 280 reports obtained from the Occupational Safety and Health Administration (OSHA) that occurred during scaffolding accidents between 2019 and 2023 were examined, and the results were analysed using Pareto-Lorenz analysis. Accidents were classified according to the primary causes (employee, equipment, and environment), tasks or activities of victims at the time of the accident, falling distance, time of accidents, occupation, and age of the victims. Results: The most common factors associated with falls from scaffolding were lost balance (employee), scaffold brace failure, scaffold collapse (equipment), and employee falls from scaffolding due to any object falling or hitting the employee (environmental).

Key words:
occupational safety, scaffold, accident analysis, OSHA, risk management

Prethodno priopćenje

Esra Yalçın

Analiza nesreća pri padu sa skele u građevinskoj industriji

Padovi uzrokovani radom na skelama jedan su od najčešćih uzroka građevinskih nesreća. Cilj je ovog istraživanja predstaviti primarne uzroke nesreća na skelama, razjasniti karakteristike slučajeva i istražiti vrstu rada ili radnje tijekom nesreća na skelama u građevinskoj industriji. U ovom istraživanju ispitano je 280 izvješća dobivenih od Uprave za zaštitu na radu (eng. *Occupational Safety and Health Administration* - OSHA), koja opisuju nesreće na skelama između 2019. i 2023., a rezultati su analizirani pomoću Pareto-Lorenzove analize. Nesreće su klasificirane prema primarnim uzrocima (zaposlenik, oprema i okolina), zadacima ili aktivnostima žrtava u trenutku nesreće, udaljenosti pada, vremenu nesreće, zanimanju i dobi žrtava. Rezultati: najčešći čimbenici povezani s padom sa skele bili su gubitak ravnoteže (zaposlenik), otkazivanje potpore skele, urušavanje skele (oprema) i padovi zaposlenika sa skele zbog bilo kojeg predmeta koji je pao ili udario zaposlenika (okolina).

Ključne riječi:
zaštita na radu, skele, analiza nesreća, OSHA, upravljanje rizicima

1. Introduction

Falls from heights remain a critical concern within the construction industry in the world, constituting a substantial portion of occupational accidents [1-3]. Fall-related accidents are the most common causes of fatalities in the construction industry continues to be fall-related accidents [4-6]. Falls from scaffolds are a leading cause of fatal construction accidents [7, 8]. The Bureau of Labor Statistics Census of Fatal Occupational Injuries (CFOI) reported that the number of fatal work injuries 986 workers in the construction sector in the United States in 2021. Notably, 38.33 % of these fatalities resulted from falls to lower levels [9]. According to OSHA, 52 fatal falls to lower levels from scaffolding were reported by the CFOI in 2020 [10]. Research indicates that falls from a height to a lower level constitute over 55 % of all accidents, and construction scaffolding is one of the most prevalent factors linked to incidents resulting in falls and injuries [11].

Scaffoldings, a necessary component in many construction sites, are frequently used by an estimated 2.3 million construction workers, or 65 % of the construction industry [12]. Its fundamental purpose is to support building construction activities conducted at elevated locations with restricted access, forming temporary structures [3, 13]. Scaffolding plays a vital role in constructing new buildings, repairs, and modernising existing structures. The fundamental features of scaffolding include the height, span length, width, maximum weight on the working platform, maximum height of the final working platform, foundations, carrying capacity of the ground, bearing load capacity of the support, anchoring method, and location [3]. In addition to its role as a structural element, scaffold-related incidents are a major cause of injuries and fatalities at construction sites [8].

Consequently, effective safety measures are imperative, positioning scaffolding as a vital element in construction site safety organization [14]. The primary objective of scaffolding is to ensure the safety of individuals at elevated heights. The level of safety is contingent upon myriad factors, including legal, social, economic, environmental, technical, organizational, and human elements. Notably, technical considerations hold particular significance because they directly impact the load-bearing capacity of the scaffolding, consequently influencing the risk of structural failure [13].

Many researchers have conducted surveys on the causes of accidents from a height, prevention strategies, and efficient solutions. For example, Nadhim et al., [15] reviewed 297 articles that contribute to the topic of fall incidents in the construction industry. According to this study, the most common factors were risky activities, individual qualities, site conditions, organizational attributes, tools (scaffolds/ladders), and weather conditions. Wibowo et al. [2] identified factors that cause accidents related to working from a height. Among these factors, the leading causes of accidents related to working from heights are human factors such as physical ability, lack of knowledge, fatigue, lack of procedures, and inadequate safety attitudes and behaviour. Chen and Luo [16] introduced algorithms for fall risk prediction using 1161 falling-related records from OSHA from 2005 to 2015. The findings underscored that the three critical factors impacting the severity of a falling event are the distance from the ground, the occupation of the worker, and the source of the falling.

To reduce the number of scaffolding incidents, it is necessary to accurately identify the causes of accidentality during scaffolding. These are particularly important for determining the primary reasons behind occupational accidents and creating practical applications to manage risks and prevent accidents. The primary objective of the research undertaken in this study is to identify the causal factors contributing to workplace accidents. The focus was on delineating the nature of employee tasks during the occurrence of accidents, the demographic attributes of employees, the time of the accidents, and the date of the incidents. Despite extensive research on accident causes in the construction sector, a conspicuous gap persists in the understanding of the intricate relationships between causes and effects, particularly in the context of scaffolding-related falls.

This study seeks to address this gap by drawing inferences from analogous accidents, discerning recurring causes, or sharing features to enhance the scholarly understanding of the subject matter. A thorough contributing factor taxonomy is an essential part of any incident reporting system because it improves the reliability of analysis and helps to quickly identify issues that are common to several incidents [17]. A database of 280 falls from scaffolding accidents, involving 290 people, were analysed. Information related to specific accidents was acquired from the Occupational Safety and Health Administration (OSHA) reports in the US Department of Labor archives. The causes of accidents include an analysis of parameters classified into three major categories based on the 3E factors (employee-equipment-environmental). The causes that had the greatest impact on the frequency of accidents were identified using the Pareto–Lorentz analysis. This allowed the identification of the scenario most likely to occur in a significant number of recurring accidents.

2. Material and method

Data on occupational accidents involving falls from scaffolding in the construction industry that occurred in the years 2019 to 2023 were obtained from the resources of the Occupational Safety and Health Administration (OSHA) of the US Department of Labor archives.The term "scaffold" was included in the Description, Abstract, and Keyword sections. The period from 2019 to 2023 was selected to examine the most recent five years. The initial 337 reports were sourced from various industries and countries, but only those specifically detailing scaffold fall accidents were included, resulting in 280 reports being analysed [18]. The notes published in the report are as follows: accident summary (event date, event time, establishment name, keywords, description of the accident), accident details, and employee details (age, sex, fatality or nonfatality, occupation, distance of fall, and cause).

This study classified the analysis into three groups of factors that cause accidents: Employee, Equipment, and Environmental (3E). Accidents occur as a result of the interactions between various

factors. In this study, the causes were classified and the main reason for each accident was identified based on the information provided in the report. Employee causes are directly related to human actions, behaviour, mental state, and health situations regarding working on scaffolding before falling. Equipment causes are the result of incorrect and defective material factors and include the scaffolding where the accident occurred, the technical condition of the scaffolding, scaffolding damage, and the unsafe condition of the scaffolding. Environmental causes include inadequately organised scaffolding, unsafe workplace conditions, and weather conditions. Nevertheless, the specific tasks or actions performed by employees at the time of each accident, which are believed to be contributing factors, were identified.

To examine 280 accidents, data from 290 individuals with sustained injuries were incorporated into the calculations. First, recurring data were systematically extracted from the reports. This study attempts to answer the following question: What factors contribute to the persistent recurrence of similar incidents in the context of scaffolding accidents? It is not the intention of these limited samples to generalise the findings but rather to identify some lessons learned through the scrutiny of these 280 cases. The analysis utilised frequency percentages to delve into the root causes of accidents involving falls from different heights, providing a comprehensive understanding. Then, using Pareto–Lorentz analysis, we identified the causes that had the greatest impact on the occurrence of accidents. Detailed investigations into the origins of accidents employing Pareto–Lorenz analysis have enabled the identification of causative factors of particular significance in terms of occupational safety [19]. Pareto–Lorentz analysis was utilised for the analysed defects to identify the group which had the biggest impact on the determined issues [20]. The Pareto Principle states that 80 % of the results or effects originate from 20 % of the causes or inputs in many situations. This principle is widely used in management, economics, and business to improve productivity and make better decision-making. It has also been applied in computer science and various human activities. This principle highlights the fact that a significant portion of the results often originate from a minority of inputs. For example, 80 % of the revenue comes from 20 % of customers, 20 % of products generate 80 % of sales, and 20 % of society holds 80 % of its wealth. The Pareto Principle is a simplified version of the mathematics behind the Pareto distribution. The specific numbers 20 and 80 are not fixed and can vary; they are used as rules of thumb. This relationship was 90–10 [21].

3. Results and discussions

In this study, 337 reports were documented using the keyword "scaffold" in the OSHA reporting system from 2019 to 2023, encompassing all incidents related to scaffolding accidents. Following a comprehensive review, 280 reports involving falls from scaffolds were identified for an in-depth analysis of accidents. Among these cases, two were from eight reports, three were from one report, and only one was from the remaining 271 reports. The findings from these reports revealed that 290 individuals suffered harm, with 129 fatalities, and 161 individuals were either hospitalised owing to injuries or experiencing non-hospitalisation-requiring injuries. Furthermore, the analysis indicated that approximately half of the employees (44.48 %) lost their lives as a result of falling away from the scaffolding.

Accidents occur because of various factors that influence work processes, including technical, management, and human factors, as well as climatic conditions [19]. Investigating accident characteristics can provide information on the factors that lead to occupational accidents. Researchers have identified that personal and professional factors such as age, gender, experience, education level, job role, and professional status are linked to fatal work accidents [22], as well as how characteristics such as sex, age, occupation, work experience [23-25], day of the week [26, 27], accident time [2, 4], and fall height [4, 28] influence accident rates in the construction industry. This study examined several essential variables, offering insightful information on the dynamics of incidents. A critical factor that helps determine the severity and possible contributing factors is the height at which the injured person falls. A thorough understanding of the events was further aided by examining the time, day, and month of the accident. Analysing the age and professional demographics of the affected employees adds even more depth to the analysis and provides significant information about the people affected.

Examination of the falling distances from the scaffolding revealed that approximately 18 % of the employee's face fell from a height of 6–10 ft (1.83–3.05 m), as shown in Figure 1. Additionally, a substantial 58 % of the incidents occurred within the range of 6–30 ft (1.83–9.14 m). As stated by Chi et al. [28], falls do not necessarily have to be extremely high to be fatal, emphasising the potential for serious injuries or fatal outcomes even at shorter distances. The results of this study support this assertion, revealing that out of 396 fatal incidents, 15 % occurred at relatively short heights, specifically 10 ft (3.05 m) or less, which is equivalent to the height of a one-story building. Moreover, the majority (53 %) of the cases occurred at heights ranging from 11 to 30 ft (3.35 to 9.14 m) [29]. These findings underscore the need for comprehensive safety measures and awareness in the workplace to address the diverse circumstances and heights at which these incidents occur to prevent falls and safeguard employee well-being. Even when working at relatively low heights, it is essential to emphasise the significance of wearing personal protective equipment.

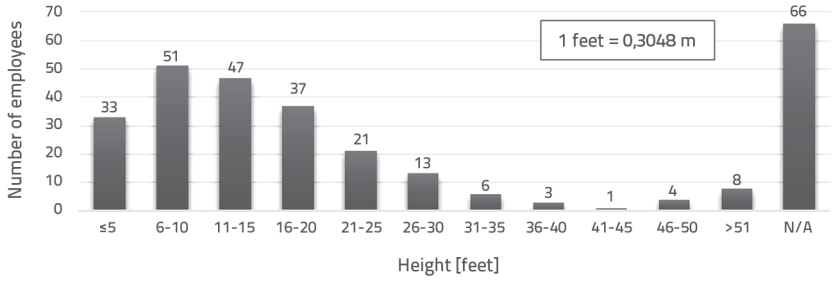

Figure 1. Falling distance in accidents

One study found that individuals in certain age groups are more prone to accidents, whereas others are more susceptible to fatal accidents [4]. In this study, all employees who suffered falls from scaffolding were male, with 290 males involved in the 280 cases reviewed. As shown in Figure 2., 61.37 % of the employees involved in the accident were over 40 years of age. It was observed that 2.75 % of the employees were under the age of 21 and 2.41 % were over the age of 65. Chan et al. [4] reported that individuals aged 45–49 years had the highest incidence of fatal falls. Sawicki and Szóstak [27] examined occupational accidents involving construction scaffolding and found a concentration of injuries among individuals aged 46–50. However, in this study, the highest incidence was observed in individuals aged 51–55. The increased frequency of accidents in this age group is believed to be linked to the routine mindset often adopted by employees with approximately 25 years of professional experience. Additionally, a decline in psychomotor skills may contribute to a higher incidence of accidents in this demographic [3]. Falls among older workers (aged 55 years and above) may be attributed to factors such as diminished sensory capabilities (e.g. declining vision and hearing) and reduced physical strength and flexibility [28].

A diagram of the employees' occupational types falling from scaffolding is shown in Figure 3. The occupation types shown here are discussed in OSHA accident reports. The occupation most commonly associated with falls from scaffolding was construction labourers, comprising 21.03 % of the total (61 people). The jobs related to brick masons, stonemasons, and carpenters are the second most common jobs that the fall of people from scaffolding equally at 11.37 % (33 people). The occupational group with the highest decline in third place was labourers, except for construction, at 6.20 % (18 people). These four occupations accounted for 50 % of all falls from scaffolding.

An analysis was conducted on occupational accidents involving 290 employees, focusing on day, month, and time of occurrence. To investigate the concept of the time and date when an accident occurred, it is essential to observe the changes that may cause accident rates in different months, days, and hours of the day. If an obvious trend is found, there is probably a reason why accidents occur more frequently during that time, and it may be possible to prevent the trend [4]. Figure 4 illustrates the frequency of scaffolding accidents per day, Figure 5 shows the distribution across months, and Figure 6 presents the breakdown by time. The analysis indicated that the highest frequency of accidents occurred on Mondays (21 %). In support of this result, Arquillos et al. [26] and Wibowo et al. [2] found that Monday was the day of the week with the highest number of accidents. According to ILO's data, it has been determined that work accident applications are higher on Mondays, and the number of cases decreases on Thursdays and Fridays compared to other days. Work accidents are more common on Mondays because workers have difficulty concentrating and adapting to the workplace on the first working day of the week and they act more hastily [30]. Most accidents occurred in January. January was identified as the month with the highest number of accidents, probably because of snowy and rainy weather conditions. Furthermore, heavy rainfall can cause slippery working surfaces and lead to more fall accidents. The cumulative incidences of accidents by season were 83, 60, 80, and 57 in summer, autumn, winter, and spring, respectively. The analysis revealed that the highest incidence occurred during summer (June, July, and August), accounting for approximately 30 % of the total occurrences. This is likely due to the warm and hot weather during the season. These conditions can make jobs requiring outdoor work extremely uncomfortable. Employee weariness and exhaustion can be easily caused by high temperatures. Consequently, it is likely that under these conditions, workers are more frustrated, and their bodies do not adapt well to heat, leading them to disregard safety precautions and be more careless,

Figure 2. Age distribution of employees who have fallen

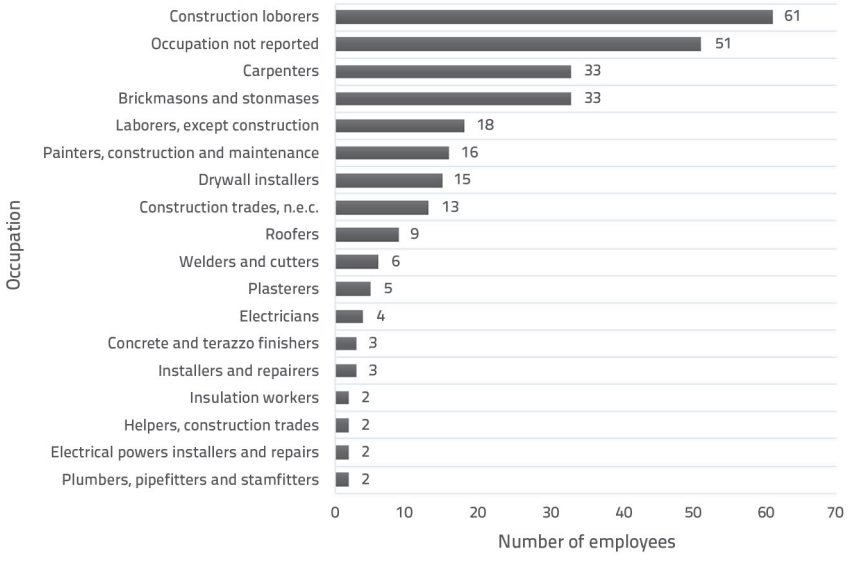

Figure 3. Occupational distribution of employees who have fallen

resulting in a higher frequency of accidents. Other studies support this finding [4, 25]. This study highlights the significant correlation between seasonal variations and workplace accidents. Therefore, taking appropriate safety measures in response to temperature fluctuations in the workplace is crucial for preventing occupational accidents. Although it is impossible to change the weather, worker behaviour must be adjusted accordingly [15].

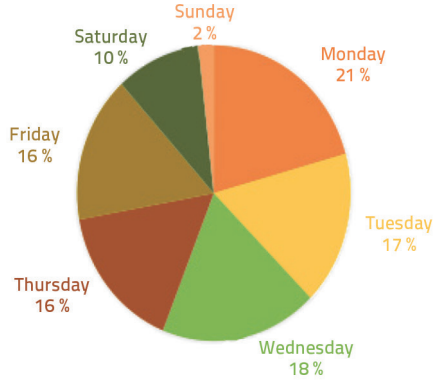

Figure 4. Day of scaffolding fall accidents

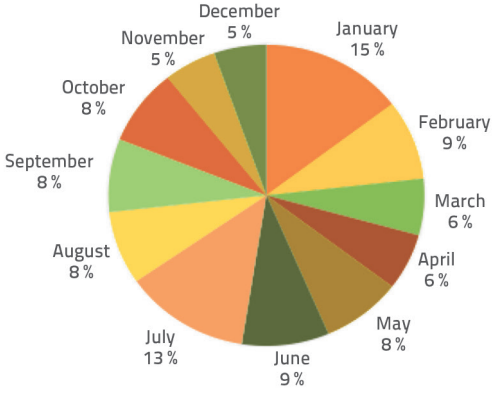

Figure 5. Month of scaffolding accidents

Most scaffolding accidents occurred between 7:00 and 10:00 a.m. (40 %) in this study. Research on work accidents in Türkiye determined that most work accidents occurred between 08.00 and 16.00 and during the first 3 h of the working day [30]. These findings reflect the essential observation that occupational accidents generally occur during the first hour of the working day. There could be several reasons for this pattern, such as employees not being adequately rested or facing challenges adapting before commencing their tasks.

This study analysed the factors contributing to accidents, categorising them into three main groups: Employee, Equipment, and Environmental (referred to as 3E), based on Chi et al. [28]. The statements were classified according to OSHA report results without additional commentary. In the examination of 280 accidents, 209 causes, each representing the primary cause, were identified. An analysis of 209 causes of falls from scaffolding revealed that 48.32 % were attributed to employment-related factors, 38.28 % to equipment-related issues, and 13.40 % to environmental factors. An essential point to highlight in this analysis is that, in all these accidents, employees lacked fall protection or did not wear Personal Protective Equipment (PPE). Despite these flaws, they were not explicitly classified as faults in the analysis because the study involved only fall accidents. In group 3E, a Pareto–Lorenz analysis was performed. This study aimed to identify the most significant causes within each group. Table 1 encompasses the classification of causes based on the employees, equipment, and environmental factors identified in the analysed accidents. This includes the prioritisation of causes within each group, frequency of these causes, corresponding percentage, the cumulative number of causes, and percentage of cumulative numbers.

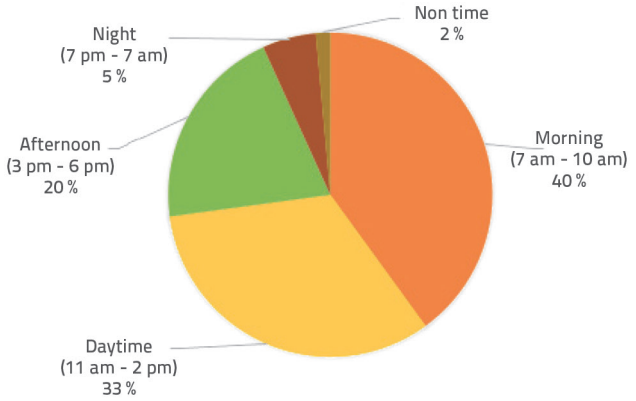

Figure 6. Time of scaffolding fall accidents

The dataset analysis revealed employee-related, equipment-related, and environmental causes. Figures 7, 8, and 9 present Pareto–Lorenz charts that show the frequencies of each identified cause within the 3E groups. The causes were arranged in descending order of occurrence, and the Lorenz curve illustrated the cumulative percentage share of these causes. This study aimed to identify the most specific causes in each group. It was hypothesised that the essential causes would be those present in approximately 80 % of scaffolding-related accidents.

Among the studied scaffolding accidents, 101 employee causes were identified. The causes identified by the dotted areas are extremely important for preventing scaffolding falls. These represent 83.16 % of all identified employees, resulting in a, b, c, and d in Table 1. Figure 7 shows the results of the identified employee causes.

a: Most scaffolding falls are caused by loss of balance. Employees on scaffolds may lose their balance owing to various factors such as uneven surfaces, slippery conditions, or even human error. However, the reports do not state why the employees lost balance or why it may be unknown. Lack of Proper Fall Protection. Even if the specific reason for employees losing their balance is not always stated or known, the absence or inadequacy of fall protection measures significantly increases the risk of accidents. Similarly, Gurcanlı and Müngen [31] found in their study that loss of balance was the main cause of scaffolding accidents while working on the scaffolding.

b: The unsafe behaviours contributing to fall accidents were primarily linked to "Adopting unsafe posture or position". This

Table 1. Causes of the scaffolding accidents by the frequency of occurrence

The causes of the scaffolding accidents					
Cause arising from employee	**n**	**%**	**C-n***	**C-n %****	
Lost balance and fell	50	49.50	50	49.50	**a**
Unsafe behaviour	15	14.85	65	64.35	**b**
Slipping as he stepped and fell	10	9.90	75	74.25	**c**
Medical events	9	8.91	84	83.16	**d**
Moving the mobile scaffolding while standing on it and fell	5	4.95	89	88.11	**e**
Stepped backward	4	3.96	93	92.07	**f**
Working in an incorrect position	2	1.98	95	94.05	**g**
Move the scaffold and the scaffold tipped over.	2	1.98	97	96.03	**h**
His hand missed-slipped a ladder rung and fell	2	1.98	99	98.01	**ı**
Employee became distracted	1	0.99	100	99.00	**j**
Struck his head	1	0.99	101	100	**k**
Total	101				
Cause arising from equipment	**n**	**%**	**C-n***	**C-n %****	
A scaffold brace failed and the scaffold collapsed	16	20.00	16	20.20	**a1**
Scaffold platform-plank broke-failed-separated	14	17.50	30	37.50	**b1**
Scaffold tipped over	9	11.25	39	48.75	**c1**
Scaffold collapse	7	8.75	46	57.50	**d1**
Securing the scaffolding to the wall failed/loosened.	6	7.50	52	65.00	**e1**
An opening created by a missing plank—a hole	5	6.25	57	71.25	**f1**
Insecure scaffolding: absence of guards, unlocked wheels, and no outriggers	4	5.00	61	76.25	**g1**
A scaffold that was not equipped with a guardrail	3	3.75	64	80.00	**h1**
Any object of became stuck in the wheel of the scaffold and pulled the scaffold, which did not have its wheels locked	3	3.75	67	83.75	**ı1**
Wheels of the scaffold were unlocked, the scaffold tipped over	2	2.50	69	86.25	**j1**
Scooting motion on the scaffold platform due to unlocked wheels	2	2.50	71	88.75	**k1**
Scaffold guardrails, when the guardrails gave way	2	2.50	73	91.25	**l1**
Suspended scaffold swung	2	2.50	75	93.75	**m1**
Working from a rolling scaffold	2	2.50	77	96.25	**n1**
A gap in the scaffolding's inboard edge	1	1.25	78	97.50	**o1**
Scaffold slid sideways	1	1.25	79	98.75	**p1**
Poor scaffolding engineering design	1	1.25	80	100	**h2**
Total	80				
Cause arising from environmental	**n**	**%**	**C-n***	**C-n %****	
The employee falls from the scaffolding owing to any object falling or hitting the employee	13	46.42	13	46.42	**a2**
A ladder set on top of a scaffold	9	32.14	22	78.57	**b2**
Slippery surface	2	7.14	24	85.71	**c2**
The power went out, and the employee fell	1	3.57	25	89.28	**d2**
Extreme temperature	1	3.57	26	92.85	**e2**
Sustained an electric shock	1	3.57	27	96.42	**f2**
Struck by a motor vehicle the scaffold	1	3.57	28	100	**g2**
Total	28				
There is no reason, just fell from scaffold***	71				

*C-n: Cumulative number ** C-n%: Cumulative number %
*** The reports indicate that there was no specific reason provided; the incidents were simply noted as falls from scaffolding

encompasses actions, such as stepping on hazardous ground or overreaching while engaged in work tasks. If employees have no safety culture, they may not adopt a safe posture or position on the scaffolding because they are not concerned about safety issues.

c: The third important factor is employee slipping while taking a step and falling down the scaffolding. Factors such as the inability to take the right step while taking steps or tripping while taking a step are related to a person's attitude, carelessness, and tiredness.

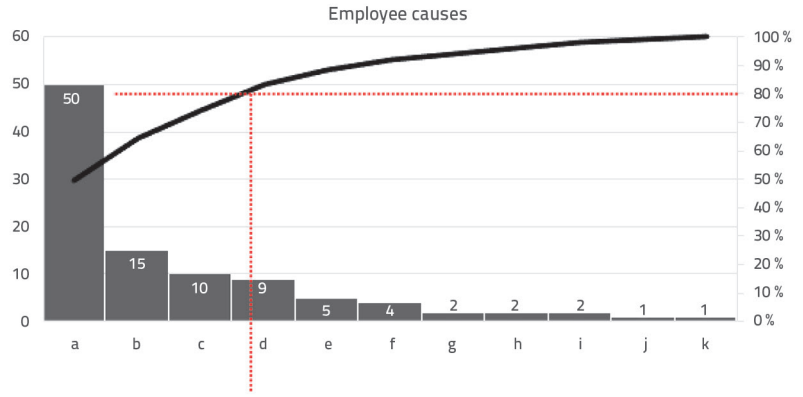

Figure 7. Pareto–Lorenz chart illustrating identified employee causes

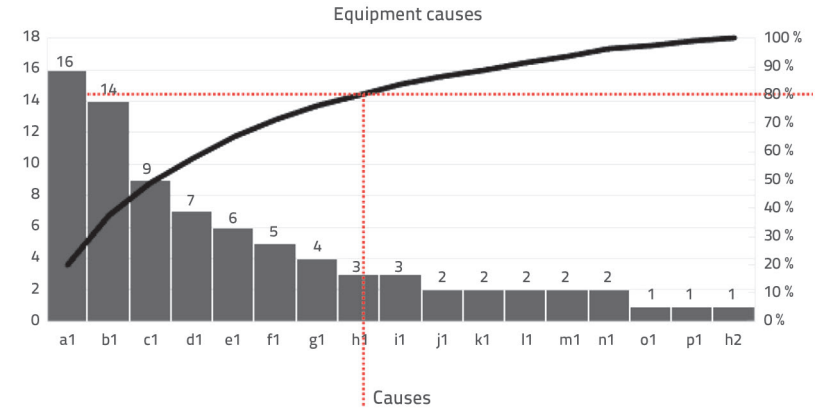

Figure 8. Pareto–Lorentz chart illustrating identified equipment causes

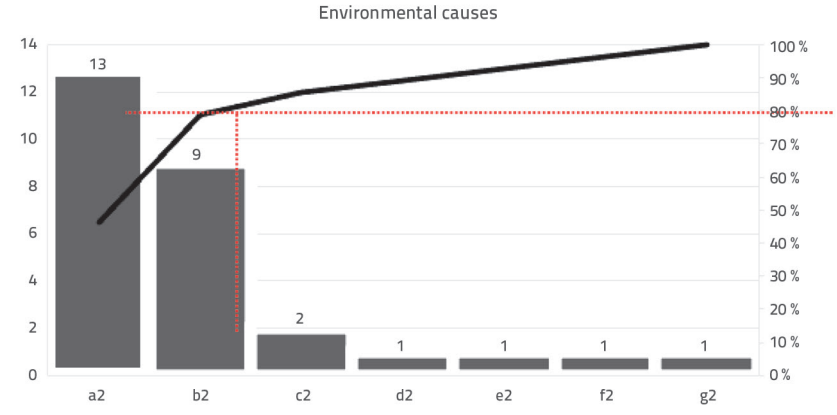

Figure 9. Pareto-Lorenz chart illustrating identified environmental causes

d: Working on scaffolding and preparing for emergencies is paramount to ensure the safety and well-being of employees. Instances such as heart attack, dizziness, and heatstroke can be particularly concerning, especially when fall protection measures are not in place.

a1, c1, d1: Failure of a scaffold brace is a critical issue that can compromise the overall stability of the structure. Overloading any of the vertical elements, such as stands and base jacks, causes damage to the entire vertical frame module or scaffold. The operation of a scaffold depends on its anchoring state. A scaffold may tip over because of a lack of anchoring [14]. Collapse of the entire scaffold system may occur owing to factors such as inadequate materials, poor workmanship during assembly, or overloading beyond the specified capacity of the scaffold. Scaffolding collapse can also occur when the structure lacks solidity owing to poor construction materials or insufficient engineering considerations. In such cases, the scaffolding may be unable to support the weight, resulting in catastrophic failure. Strict quality control measures must be followed during the fabrication and assembly processes to ensure the structural integrity of scaffolding systems. Furthermore, scaffolding tipping over is a significant risk, particularly when not properly secured or subjected to external forces, such as high winds [29]. The results of this study agree with the findings of Hamdan and Awang [8], who showed that scaffold collapse or broken planking giving way are the most common hazards at construction sites involving scaffolding.

b1: The plank setup is an important part of the scaffolding because it holds a temporary load. Many scaffolding accidents are caused by mistakes in plank assembly. If a scaffold plank is unstable, insecure, in poor condition, or overloaded, it can easily slide off and break down. To avoid accidents, it is critical to use appropriate materials and carefully inspect the planks [32].

e1: Different types of ties are used to fasten facade scaffoldings. The most common connection type is the attachment of the scaffolding to the structure via holes drilled into the structure using elements such as tie

Table 2. Task or activity performed by an employee at the moment of the fall

Work/action performed at the time of the accident	Number	[%]
Painting	23	8.67
Construct a scaffold	20	7.54
Roof	20	7.54
Exterior masonry	19	7.16
While climbing down from the scaffold	18	6.79
Climbing a scaffold frame/ reach a scaffold without a ladder	15	5.66
Install masonry block	14	5.28
Ceiling/ acoustic ceiling	13	4.90
Installing-repair drywall	12	4.52
Dismantling scaffolding	11	4.15
Working on the gutters and installed exterior siding	9	3.39
Remove-apply stucco from	8	3.01
To place-removing planks-platforms on the scaffold	6	2.26
Stepped/accessed onto the scaffold	6	2.26
Installing–removing insulation	5	1.88
Cleaning	5	1.88
Walked down onto the scaffold platform	5	1.88
Performing maintenance and repair work	5	1.88
Attempting to remove–install a beam /installing joist hangers, beam	4	1.50
Concrete pour from the platform	4	1.50
Installing concrete blocks	4	1.50
Setting up a mobile scaffold/vertical lift	3	1.13
Electrical work	3	1.13
Installing equipment (HVAC and others)	3	1.13
Installing windows	2	0.75
Making measurements	2	0.75
Climbed the extension ladder	2	0.75
Installed pieces of awing-hanging tarps	2	0.75
Unloading material onto scaffolding	2	0.75
Moving a plank on a scaffold	2	0.75
Descending a frame ladder that had been placed on the scaffold	2	0.75
Removing scaffolding from concrete forms	2	0.75
Pushing the nail gun against the wall	2	0.75
Others (16 separate works/actions in total)	16	0.37
Total	265	
N/A	15	

elements and wall support rods. Important considerations in this type of binding are as follows: the structures must be sufficiently durable for anchoring and anchor binding must be performed correctly [33]. Failure to secure the scaffolding properly may cause it to collapse, tip over, or shake.

f1: The lack of a plank not only affects the stability of the scaffold but also exposes workers to the risk of tripping or falling through the opening. To reduce these risks, it is critical to conduct regular inspections to identify and address any holes in the scaffolding.

g1: Scaffolding poses a significant safety hazard because of the absence of guards on the top platform, lack of locked wheel casters, uncontrolled rolling and sliding of wheels, and the critical safety features of outriggers. This combination of deficiencies may compromise the overall stability and security of scaffolding systems.

h1: Guardrails are elements that have a direct impact on the safety of scaffold workers. The purpose of a guardrail is to prevent people from falling outside the edge of the platform

[13]. Similar to this study, Hamdan and Awang [8] highlighted the significance of guardrails in preventing scaffolding accidents. When guardrails are missing, workers are at a considerably higher risk of falling, which can result in serious injuries or fatalities. This highlights the importance of strict adherence to safety regulations and guidelines that require the use of guardrails and other safety measures for scaffolds.

In the group of scaffolding accidents studied, 28 environmental causes were identified in scaffolding accidents. The causes identified by the dotted areas are extremely important for preventing scaffolding falls. These represented 78.57 % of all identified employee causes that a2, b2 in Table 1. From Figure 9, we can conclude that the identified environmental causes were

a2: Approximately 46 % of scaffolding fall accidents caused by environmental factors occur when employees are struck by objects or equipment, causing them to fall as a result of the impact with the object. The critical point here is that employees are not only at risk of injury from direct contact with falling objects but also risk losing their balance and falling from the scaffolding structure. Several preventive measures should be implemented to address the dual risks faced by the scaffolding workers.

b2: Falls from ladders, particularly when used in addition to scaffolding, highlight a safety issue in construction settings. Slipping off a ladder has caused accidents in several reported cases, with the precarious setup atop the scaffolding exacerbating the risk. Ladders collapsing, sliding out from underworkers, or being knocked over have all been reported in incidents. These scenarios highlight the importance of stringent safety protocols, such as proper ladder placement, secure anchoring, and regular inspection, when using ladders for scaffolding. According to OSHA, more than 100 people die each year from falling down. Ladder slippage (top or bottom), overreaching, slipping on the tread(s), defective equipment, and the inappropriate choice of the ladder for a particular task contribute to ladder falls [34].

The data in the reports inform us about the different types of accidents to which different lines of work on scaffolding are prone. Table 2 shows the various actions or activities associated with fall injuries recorded at the time of the fall. The top three activities or actions associated with scaffolding accidents involving falls from large heights were painting (8.21 %), constructing a scaffold (7.14 %), and roofing (7.14 %). Chan et al. [35] support the finding that the painting trade is responsible for a high number of fall injuries. One of the most difficult tasks in the construction industry is scaffold construction, erection, and dismantling. When erecting and dismantling scaffolds, reaching and lifting, awkward postures (such as twisting and holding overhead and bending), and the use of force (e.g. when attaching cross braces and damaged parts) are all required. The risk of falling from high heights increases significantly owing to instability issues [36]. Scaffolding, construction, and dismantling accidents were identified in 31 reports.

Roofing workers are vulnerable to fall-related hazards because of the fragile nature of roofing materials and the handling of heavy tools or equipment [15]. In this study, 20 employees fell from the scaffolding while performing roof-related work. Gurcanlı and Mungen [31] presented an analysis of 1117 expert reports in construction that roof work and painting/plastering on scaffolding each were responsible for 56 % and 7.1 % of all fatalities, respectively.

The limitations of this study should be acknowledged and addressed in future studies. This study is based on a limited number of public scaffolding accident reports on falls at construction sites. However, numerous near-misses occur even when workers do not fall from the scaffolding. Future studies could analyse scaffolding incidents by considering actual falls and near-misses. Although the data collected offer a comprehensive overview of scaffolding accidents, some information may still be missing.

4. Conclusion

Analysing the collected data is critical for understanding the types of hazards involved when scaffolding is used. Furthermore, the analysis aids in determining the highest-ranking factor that causes the most injuries and deaths from scaffolding accidents at construction sites. The database used in the study consisted of information obtained from the archives of OSHA accident reports and 280 scaffolding accidents in which 290 people died or were injured. This study classified the causes of falls from scaffolding in occupational accidents involving the construction industry into three groups: employee, equipment, and environmental. According to this, 48.32 % of the 209 causes were employee-related, 38.28 % were equipment-related, and 13.4 % were environmental. The Pareto–Lorentz method was used to conduct a cause-and-effect analysis, which revealed the factors that had the greatest influence on the occurrence of accidents.

This study shows that lost balance, unsafe behaviour, slipping as employee steps, and medical events are classified as types of employee-related hazards. The use of Personal Protective Equipment (PPE), especially safety harnesses and independent lifelines, before starting work has emerged as a critical component in mitigating the risks associated with the identified employee-caused hazards. These act as preventive measures, creating a barrier between employees and potential hazards, and reducing the likelihood of accidents and injuries. To improve workplace safety, organisations must prioritise the proper selection, training, and consistent use of PPE.

Scaffold accidents are frequently influenced by critical equipment failures, and each factor significantly compromises employee safety. The collapse of a scaffold owing to a failed brace is a major hazard, underscoring the importance of robust support structures. Similarly, platform and plank breakage, failure, and separation increase the risk by introducing instability to the working surface. Another formidable threat is tipping over or scaffold collapse, which may occur owing to poor balance or unequal weight distribution. Failures to secure the scaffolding to the wall result in compromised security because

any loosening can lead to instability and potential collapse. The absence of a plank that leaves an opening or hole in the scaffold structure is a direct hazard that exposes workers to the risk of inadvertent falls and serious injuries. Insecurity is compounded by factors such as a lack of guards, unlocked wheels, and the absence of outriggers. A scaffold without a guardrail poses risks, particularly in situations where workers are exposed to elevated heights. Addressing these equipment-related concerns is critical for creating a safe working environment on scaffolds, necessitating the implementation of comprehensive safety measures to effectively mitigate these potential hazards. In the case of environmental factors, the employee fell from the scaffolding because of any object falling or hitting the employee, and a ladder set on top of the scaffold was found to be the two most essential causes.

These findings raise serious concerns about workplace safety protocols, necessitating a thorough review of scaffolding practices. The findings highlight the importance of addressing the potential hazards associated with the use of ladders on scaffolds and of arguing for the implementation of enhanced safety measures and strategic management practices. The compiled data emphasise the critical need for targeted safety measures and enhanced protocols, particularly in high-risk activities such as painting, scaffold construction, and roofing, to reduce the prevalence of scaffolding-related accidents. Accordingly, the prevalence of fall-related accidents in scaffolding work can be significantly reduced by tailoring safety measures to the complexities of each high-risk activity, implementing stringent protocols, and fostering a safety culture, resulting in a safer working environment for all stakeholders involved. The statistics examined in this study were limited to OSHA accident reports on construction. However, the findings are useful for safety practitioners who may adopt necessary measures to prevent fall-from-height accidents in the future.

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