Analysis of Construction Worker Fall Accidents

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Abstract: The Occupational Safety and Health Administration (OSHA) investigates most worker-related fatalities and many accidents involving serious injuries. A research study was conducted that focused on the data OSHA accumulated on construction worker accidents involving falls. In the construction industry, falls are the most frequently occurring types of accidents resulting in fatalities. The purpose of the study was to identify the root causes of fall accidents and to identify any additional information that might be helpful in reducing the incidence of construction worker falls in the future. While data from January 1990 through October 2001 were examined, particular emphasis was placed on fall accidents that occurred in the last 5 years of this time interval, a period when more data were accumulated and coded in the OSHA investigation reports. Results show that most fall accidents take place at elevations of less than 9.15 m (30 ft), occurring primarily on new construction projects of commercial buildings and residential projects of relatively low construction cost. Furthermore, experience does not seem to diminish accident occurrence; hazards are often misjudged by workers; and various other patterns can also be observed. Most alarming, the results show that fall accidents account for a growing proportion of the total number of construction worker fatalities.

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Introduction and Literature Review

Falls have been the cause of the highest number of injuries and fatalities in the U.S. construction industry, accounting for 33% of all construction worker fatalities for the inclusive years of 1985 to 1989 (OSHA 1990; Hinze 1997).

Several past studies focused on prevention of falls by various methods. For example, Singh (2000) investigated fall accidents occurring on low-rise roofs and evaluated some innovative fall protection measures. He concluded that no single method of fall prevention would prevent all falls on low-rise roofs, but determined that prefabrication was the most promising method, followed closely by the personal fall arrest system (PFAS) and its variants.

Duncan and Bennett (1991) reviewed the performance of various fall protection systems and concluded that both active measures (those that prevent workers from falling, for example, guardrails) and passive measures (those that protect workers after falling, for example, safety nets) are useful in reducing fall injuries. Vargas et al. (1996a, 1999b) developed an expert system that analyzed the causes of construction falls by using fault-tree methods and concluded that guardrails, safety nets, and PFAS can all be inadequate, under differing circumstances.

Weisgerber and Wright (1999) discussed the safety through design approach, which is particularly appropriate for construction, and provided the outline of a comprehensive program to prevent falls at the design phase. Hinze and Gambatese (1996) similarly developed a software program that would help designers address safety in the design phase. Of the many suggestions incorporated in the program, 32.8% related to the prevention of falls.

OSHA (1998) also suggested several methods to control fall hazards, including elimination of or substitution for the operation that can lead to falls, use of engineering controls to guard against falls, informing/reminding workers at risk to avoid fall hazards (through warnings and administrative controls such as training and inspections), and appropriate use of personal protective equipment (PPE).

It is also noteworthy that the regulations for PPE have been implemented to influence the frequency and pattern of occurrence of falls. The most notable revisions of the OSHA regulations involving fall prevention were as follows:

1. 1915.159: Personal fall arrest systems (PFAS). The 1996 revised regulations stipulate that it is not acceptable to use body belts as a personal fall arrest system. Body harnesses were mandated for PFAS to provide proper protection to workers who were involved in falls.
2. 1915.160: Specifications on positioning device systems. This revision, which became effective on January 1, 1998, stated that a positioning device system was not to be used for fall prevention. As a result of this change, only properly tied-off body harnesses are regarded as qualified personal fall-arrest systems.

These changes to the OSHA regulations were intended to drastically impact the incidence of fall accidents.

Research Methodology

This study was conducted to determine the causes of construction fall accidents and to identify any particular patterns related to fall accidents. The study recognized that identifying the causes of

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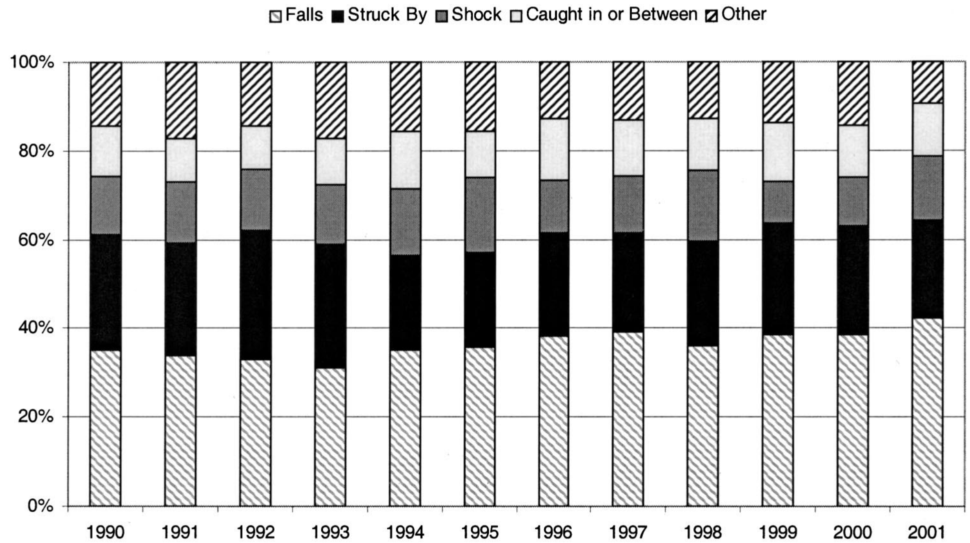

Fig. 1. Breakdown of OSHA-investigated accidents in construction (1/90–10/01)

accidents would provide some valuable insights with which to devise means of accident prevention. Since some significant changes were made to the OSHA regulations, it was also of interest to assess how or if these modifications might have impacted fall prevention in the construction industry.

To conduct this study, it was first necessary to identify a database that contained the information about fall accidents in the construction industry. The initial intent was to utilize the data already available on the Internet on the OSHA Web site. This database contained some of the data but had not been fully updated since 1996. OSHA was contacted to determine when the database would be updated. The researchers were informed that the updating was time-consuming and would not occur in the immediate future. A special request was made to obtain the files directly from OSHA, and this was granted. The data were provided in Microsoft ACCESS format and were easily converted to files that could be manipulated by the Statistical Package for the Social Sciences.

The data provided by OSHA included all reported OSHA investigations in the United States of fatalities and serious injuries from January 1990 through October 2001. The analysis of the data examined all falls in the construction industry in that time period. Subsequent analysis was focused on the most recent years, the period in which the new fall standards were being implemented. The data were examined in various ways to determine if there were any discernible patterns of accidents involving falls among construction workers.

Description of Fall Accidents

The data for the time period from January 1990 through October 2001 included a total of 7,543 OSHA-investigated accidents. Falls (both from an elevation and from the same level) accounted for 34.6% of the injuries (Figs. 1 and 2). It is obvious that the proportion of falls has increased with time in the past 12 years: the average proportion of falls was 34.1% during the years before 1996 and increased to 38.4% in the following years. The total number of OSHA-investigated construction accidents is relatively constant during these years. A simple analysis reveals that Pearson's correlation between the proportion of the falls and the year is 0.841, which provides strong evidence that the proportion of fall accidents increased during the past 12 years. In the analysis of the other main types of accidents, Pearson's correlations between the years and the proportions of accidents are −0.492 for struck-by, −0.232 for shock, 0.469 for caught-in-and-between, and −0.672 for the other accidents. The data may suggest that the proportion of caught-in-and-between accidents has also increased during the years, while proportions of struck-by and shock accidents have decreased. With the classification of accidents more clearly defined, the proportion of "other" accidents has decreased drastically.

Among the 7,543 construction accidents investigated by OSHA, between January 1990 and October 2001, 2,741 were falls, with 2,687 falls from an elevation and 54 falls from the same level. These accounted for 2,955 OSHA-recordable fall injuries, with some accidents involving two or more workers. Note that in the analysis of the data, some records do not include all the information recorded in others. For this reason, the total number of cases analyzed for different descriptors may vary.

Time of Fall Occurrence

The study examined the timing of accidents, and the occurrence of falls was then compared with the distribution of all injury accidents. As shown in Fig. 3, July, with 820 accidents, is clearly the month when the occurrence of accidents reaches a peak (constituting 10.9% of all accidents), while February, with 493 accidents, is the month with the least accidents (constituting 6.5% of all accidents). Analysis also shows that in winter (December to February) the average proportions of falls and all accidents per month are 7.6 and 6.6%, respectively, while in summer (June to August) the proportions are 9.1 and 10.3%, respectively. This pattern is consistent with other data on construction worker injuries and probably reflects the heightened amount of construction activity occurring in the summer and the reduced level of activity in the winter. Regarding the distribution of fall accidents, the pattern is similar, with 266 falls in July and 196 falls in February, but these differences are not as striking. Even in winter, there are many falls.

It is interesting that in the winter and spring months (December to May) the proportion of falls is larger than that of all acci-

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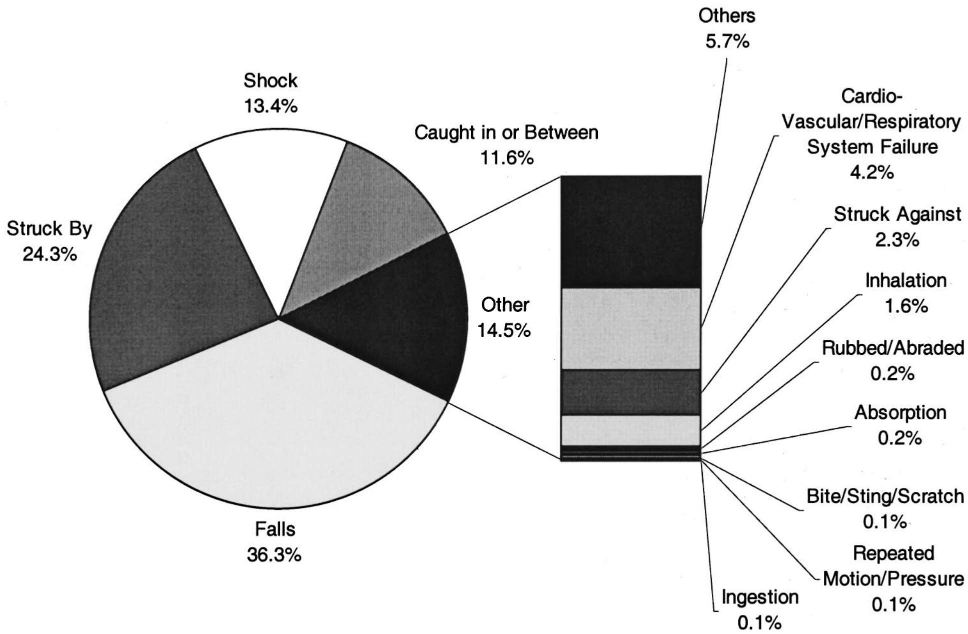

Fig. 2. Causes of construction-fall accidents investigated by OSHA (1/90–10/01)

dents, while in the summer and autumn months (June to November) the proportion of falls is smaller than those of all accidents. This might suggest that the cold weather in winter and spring tends to cause more falls than mild weather in summer and autumn because the movements and reactions of workers are slower and the working surfaces on sites tend to be more slippery in the winter.

As to the distribution of injuries by day of the week, the occurrence of falls did not show a definitive pattern of occurrence, with an even distribution among the days of the week and the expected drop in occurrence over the weekend.

The data were also examined from the perspective of the hour of occurrence of the accidents. As shown in Fig. 4, the distribution of falls by hour of day is similar to the pattern of all the construction accidents, with the least accidents occurring between noon and 13:00 and most accidents occurring between 10:00 and 11:00 in the morning and between 13:00 and 14:00 in the afternoon. This pattern is similar to findings of previous research on accident occurrence times (Hinze 1997).

Projects Involving Falls

Most of the data analysis was focused on the fall accidents that occurred in the most recent years, representing those falls occurring between January 1997 and October 2001. Some types of information were not systematically recorded in the earlier investigation reports. Thus, the more recent years of data provide a richer resource about the information related to falls.

One aspect of the accidents examined related to the information available about those projects on which the fall accidents occurred. Results show that fall accidents occurred more frequently on certain types of projects, beginning with new construction, then renovation, maintenance, and finally demolition work. From Table 1, it is evident that fall accidents are most frequent on

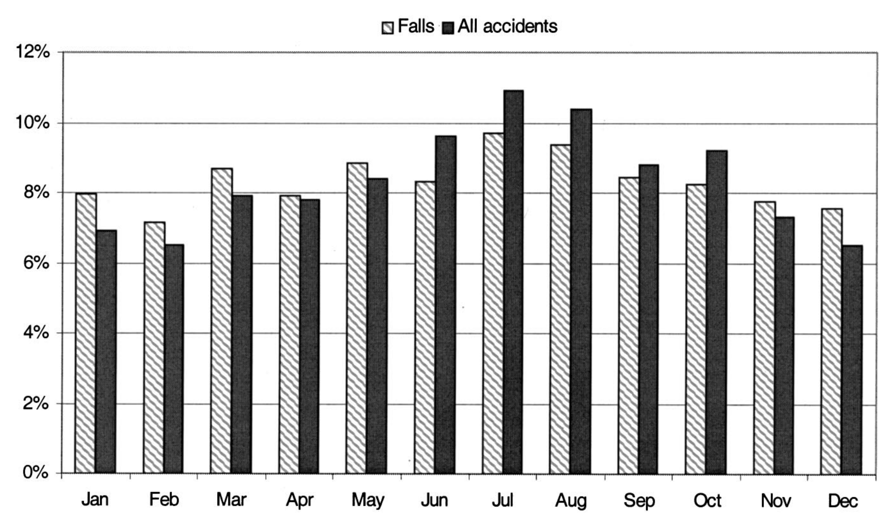

Fig. 3. Distribution of construction accidents by month of year (1/90–10/01)

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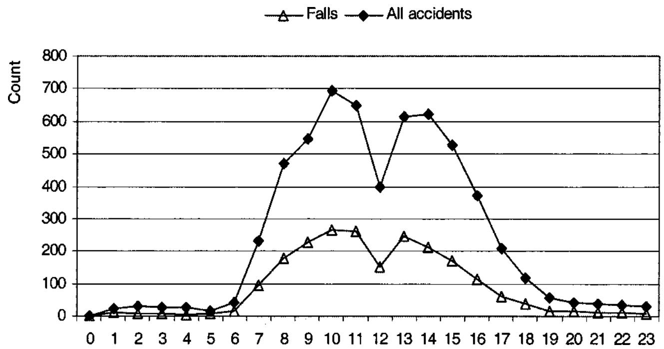

Fig. 4. Distribution of construction accidents by hour of day (1/90–10/01)

Table 2. Distribution of Accidents in Projects Costs (1/97–10/01)

	Falls		All Accidents	
Cost of projects	Count	Percent	Count	Percent
Under $50,000	341	28.10	990	31.50
$50,000 to $250,000	229	18.80	601	19.10
$250,000 to $500,000	119	9.80	289	9.20
$500,000 to $1,000,000	134	11.00	341	10.90
$1,000,000 to $5,000,000	188	15.50	464	14.80
$5,000,000 to $20,000,000	117	9.60	244	7.80
$20,000,000 and over	83	6.80	191	6.10
Subtotal	1,211	100	3,120	100
Not known	4	—	22	—
Total	1,215	—	3,142	—

projects involving commercial buildings and single-family or duplex dwellings, which account for nearly half the falls occurring in the years since 1997. The reasons might be that most commercial buildings are multistory or high-rise buildings, where more fall-related hazards exist. On the other hand, single residential buildings are frequently constructed by small contractors, who often provide relatively informal safety training and inadequate PPE (Glenn 2000).

When the costs of projects were examined, it became evident that those projects with lower costs of construction accounted for most falls. Nearly half the falls occurred on projects with costs of construction below $250,000, as shown in Table 2. The nature of efforts performed on construction projects was also examined, which revealed that nearly 60% of the falls occurred in new projects or additions (Table 3). The patterns regarding the costs of the projects and the types of construction may simply reflect the volume of projects that fall in the lower-cost category or that consist of new construction work.

Table 1. Distribution of Accidents in Projects by Type of Facility Being Constructed (1/97–10/01)

	Falls		All Accidents	
End use of projects	Count	Percent	Count	Percent
Commercial building	404	33.30	715	22.80
Other building	212	17.40	412	13.10
Single family or duplex dwelling	211	17.40	503	16.00
Multifamily dwelling	113	9.30	183	5.80
Manufacturing plant	79	6.50	168	5.30
Tower, tank, storage elevator	71	5.80	103	3.30
Bridge	28	2.30	94	3.00
Other heavy construction	21	1.70	94	3.00
Highway, road, street	16	1.30	381	12.10
Sewer/water treatment plant	14	1.20	76	2.40
Powerplant	13	1.10	33	1.10
Powerline, transmission line	10	0.80	116	3.70
Contractor's yard/facility	5	0.40	42	1.30
Pipeline	4	0.30	91	2.90
Shoreline development, dam, reservoir	4	0.30	24	0.80
Refinery	3	0.20	21	0.70
Excavation, landfill	2	0.20	63	2.00
Subtotal	1,210	100	3,119	100
Not known	5	—	23	—
Total	1,215	—	3,142	—

Fall Height

Of the 2,741 fall accidents, 1,018 of the investigation reports indicated the height of the projects and the number of stories. Of those projects where falls were involved, 807 projects (81%) are either one, two, or three stories. The average facility height of the projects (whether a building or other type of facility) was 11.41 m (37.4 ft); that is, most falls happened on projects that were not particularly high.

Of the fall accidents that occurred since January 1997, investigation records provided additional information of interest that was not available for accidents occurring in earlier years. For example, the elevation from which the falls originated and the fall distances of the workers are now being consistently recorded for most accidents. Among the 1,215 falls that occurred since January 1997, more than 70% occurred at elevations of less than 21.35 m (70 ft).

The distribution of fall heights is shown in Fig. 5. The average elevations of the fall height (the elevation where the fall originated) and fall distance are 10.8 m (35.4 ft) and 10.64 m (34.9 ft), respectively. More than 70% of the fall accidents can be expected to occur within the elevation between 0 and 9.15 m (30 ft). The elevation of a project can be regarded as one of the most hazardous aspects of the construction site. According to the OSHA regulations (CFR1926 Subpart M), fall prevention must be implemented at all elevations above 1.83 m (6 ft). It might be inferred that the implementation of fall-prevention techniques is too relaxed at the lower elevations in some projects.

Table 3. Distribution of Accidents by Nature of Construction Effort (1/97–10/01)

	Fall		All Accidents	
Type of construction effort	Count	Percent	Count	Percent
New project or new addition	721	59.30	1,640	52.20
Alteration or rehabilitation	219	18.00	565	18.00
Maintenance or repair	189	15.60	531	16.90
Demolition	41	3.40	101	3.20
Other	41	3.40	283	9.00
Subtotal	1,211	100	3,120	100
Not known	4	—	22	—
Total	1,215	—	3,142	—

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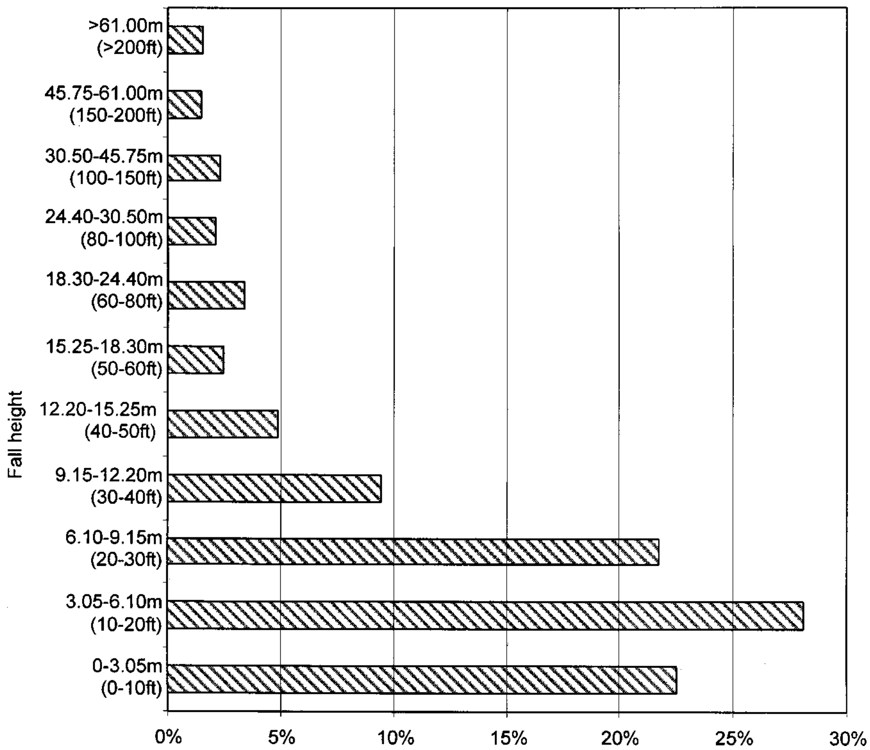

Fig. 5. Distribution of height of construction fall accidents (1/97–10/01)

Injuries Resulting from Fall Accidents

In total, 2,741 fall accidents resulted in 2,955 injuries. The occupations of most injured workers are construction laborers, roofers, carpenters, structural metal workers, painters, brickmasons and stonemasons, electricians, supervisors, drywall installers, plumbers, and pipefitters. Since workers in these trades often work in environments with fall hazards, they are the most susceptible to injury by falls. Of the nature of the injuries resulting from falls, fracture, concussion, and bruise/contusion/abrasion are the most frequent types and cover nearly two-thirds of all the injuries. Half of the injured were hurt on their heads, and about one-third of the injured suffered multiple injuries. Other parts of body often injured by falls include the chest, neck, back, abdomen, and legs. By comparison, for all the injuries (not restricted to fall accidents), the most frequent types are fracture, electric shock, and concussion. Head injuries account for about one-fourth of all the injuries, followed by the multiple injuries. A sobering fact is that two-thirds of the workers involved in falls were killed, which highlights the serious nature of this type of accident.

As to the age distribution of the injured (Fig. 6), the ages of those workers most frequently involved in falls are between 31 and 40, with the overall average being 38.3. The distribution is quite similar to the age distribution of all workers involved in accidents, which has an average of 37.2. Pearson's correlation of the proportions in different age ranges between the falls and all accidents is 0.987, which shows strong evidence of a positive relationship between them.

Fig. 6 shows that the proportions of those injured in falls younger than 35 are smaller than those injured in all accidents, while for the injured older than 35, the proportion of falls is larger than for all the accidents (except for the age group from 55 to 60).

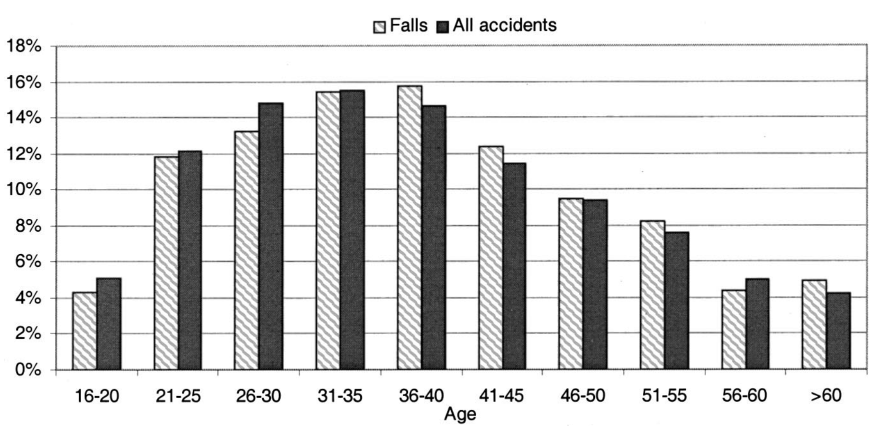

Fig. 6. Age distribution of workers injured on construction sites (1/90–10/01)

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Table 4. Type of Task Performed When Fall Occurred (1/97–10/01)

Working activities	Count	Percent
Roofing	252	21.63
Erecting structural steel	99	8.50
Exterior carpentry	89	7.64
Exterior masonry	57	4.89
Installing equipment (HVAC and other)	54	4.64
Demolition	53	4.55
Temporary work (buildings, facilities)	47	4.03
Interior carpentry	44	3.78
Exterior painting	43	3.69
Installation of decking—initial laying of deck	33	2.83
Installing interior walls, ceilings, doors	30	2.58
Steel erection of solid web connecting	25	2.15
Installing plumbing, lighting fixtures	22	1.89
Forming	21	1.80
Interior plumbing, ducting, electrical work	21	1.80
Installing metal siding	18	1.55
Fencing, installing lights, signs, etc.	17	1.46
Installing windows and doors, glazing	17	1.46
Other activities—installing ornamental and architectural steel	16	1.37
Other activities—post-decking detail work	16	1.37
Other activities	191	16.39
Subtotal	1,165	100
Not known	50	—
Total	1,215	—

If the proportion of falls is calculated in different age groups, it is apparent that the proportions of age groups below 35 (about 32%) are lower than those above 35 (about 36%).

The data may suggest that experience in construction for more years may not necessarily lead to a decrease in fall accidents, but rather that younger workers tend to be more alert and flexible when fall hazards occur. It should also be mentioned that among all the injured, 17 were below the age of 16 years. Generally, these young workers are injured when working as helpers on construction sites.

Causes of Fall Accidents

Work Operations and Fall Occurrence

The nature of the work being performed when the fall accidents occurred was also examined in this study. Table 4 shows the most frequent types of tasks performed when fall accidents occurred. Among the different tasks or types of work performed, roofing, erecting structural steel, and exterior carpentry are most often associated with falls and are also operations necessarily conducted at points of elevation or on temporary structures, where fall hazards are often present.

Falls during these operations were generally related to certain human errors. For example, among the falls involving roofing, 33.3% were related to the misjudgment of workers about hazardous situations, 13.5% were associated with insufficient or lack of PPE, and 11.5% were caused by removed or inoperative safety devices. These falls occurred at a relatively lower elevation. About 75% of the falls during roofing occurred at elevations of less than 9.15 m (30 ft), and 45% within 6.10 m (20 ft). This may suggest that workers on these projects may underestimate or ignore the fall hazards at lower elevations. To avoid falls, tasks performed above 1.83 m (6 ft) should be analyzed thoroughly and conducted with great care. Workers performing these tasks should be well trained and equipped with adequate and appropriate PPE.

Table 5. Distribution of Location of Falls (1/97–10/01)

Location of falls	Count	Percent
Fall from roof	333	28.36
Fall from/with structure (other than roof)	227	19.34
Fall from/with scaffold	153	13.03
Fall from/with ladder	133	11.33
Fall, other	102	8.69
Fall through opening (other than roof)	90	7.67
Fall from/with bucket (aerial lift/basket)	37	3.15
Fall from/with platform catwalk (attached to structure)	28	2.39
Fall from vehicle (vehicle/construction equipment)	27	2.30
Collapse of structure	13	1.11
Other	31	2.64
Subtotal	1,174	100
Not known	41	—
Total	1,215	—

It is also noteworthy that about 11% of the accidents involved workers who were performing nontypical types of tasks not generally included in the scheduled tasks that are planned and familiar to the injured. This was noted with accidents involving roofing, demolition, and temporary work. In one incident, a roofer finished his task and was in the process of descending to go to lunch when he fell to the ground. These types of activities, although occurring less frequently, should be emphasized for workers because they are often neglected in safety training.

Location of Falls

More than half the falls are related to environmental factors involving the working surface or facility layout conditions. Falls from roofs are undoubtedly the most frequent accidents, especially in commercial buildings and single-family or duplex dwelling projects, on which over 63% of falls from roofs since 1997 occurred. As shown in Table 5, most falls took place from roofs, from/with structure, from/with scaffold, from/with ladder, and through openings. These locations account for about 80% of all construction fall accidents and are also the most hazardous locations where workers are susceptible to fall accidents. Provision of adequate preventive equipment in these locations is essential to avoid falls.

Human Errors Resulting in Falls

Although human errors are not acceptable excuses for inefficient safety management practices, analysis of the human errors involving falls can assist in identifying the root causes of falls. As shown in Table 6, misjudgment of a hazardous situation is the most frequent type of human error involving falls, accounting for about one-third of all accidents. Further analysis shows that the distribution of misjudgment for different ages is roughly similar to the age distribution of fall injuries (Fig. 7), except for the age group between 21 and 25. Pearson's correlation between the proportion of falls by misjudgment and all falls in different age ranges is 0.979, which suggests a strong positive relationship between them.

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Table 6. Distribution of Human Errors Contributing to Falls

Human errors	Falls Since 1997		All Fall Accidents	
	Count	Percent	Count	Percent
Misjudgment of hazardous situation	374	30.78	916	33.42
Safety devices removed or inoperative	170	13.99	403	14.70
Equipment in use not appropriate for operation or process	106	8.72	243	8.87
Insufficient or lack of protective work clothing and equipment	104	8.56	226	8.25
Malfunction of procedure for securing operation or warning of hazardous situation	68	5.60	156	5.69
Operational position not appropriate for task	59	4.86	131	4.78
Procedure for handling materials not appropriate for task	40	3.29	89	3.25
Insufficient or lack of engineering controls	38	3.13	78	2.85
Insufficient or lack of written work practices program	36	2.96	83	3.03
Malfunction of perception system with respect to task environment	11	0.91	33	1.20
Malfunction of neuro-muscular system	6	0.49	19	0.69
Defective equipment: knowingly used	5	0.41	22	0.80
Distracting actions by others	3	0.25	8	0.29
Malfunction of procedure for lock out or tag out	2	0.16	6	0.22
Insufficient or lack of housekeeping program	2	0.16	4	0.15
Insufficient or lack of respiratory protection	1	0.08	1	0.04
Other	189	15.56	322	11.75
Subtotal	1,214	100	2,740	100
Not known	1	—	1	—
Total	1,215	—	2,741	—

Further analysis shows that among the injuries in each age group, the proportion of human errors categorized as ''misjudgment of hazardous situation'' does not show significant differences; most of the values are around 30%. It is possible that age or experience do not significantly improve judgment where hazardous situations are concerned. Also, it is noteworthy that workers between the ages of 21 to 25 should be trained and educated with greater care. Of course, it must be recognized that ''misjudgment of hazardous situation'' is a subjective assessment and is difficult to verify.

If the relationship between fall height and human error is analyzed, most falls associated with human errors occurred at lower elevations. For example, more than half of falls related to ''misjudgment of hazardous situation'' were less than 6.10 m (20 ft) in elevation, and 23.5% of them were less than 3.05 m (10 ft). As to falls associated with ''insufficient or lack of protective work clothing and equipment,'' 40% were within the elevation of 6.10 m (20 ft). Therefore, it is plausible that workers tended to act unsafe more frequently in lower elevations, especially under 6.10 m (20 ft).

Inadequate or inappropriate use of fall protection PPE and removed and inoperative safety equipment contributed to more than 30% of the falls. This situation does not change significantly after 1996, when the OSHA regulations on PPE were significantly re-

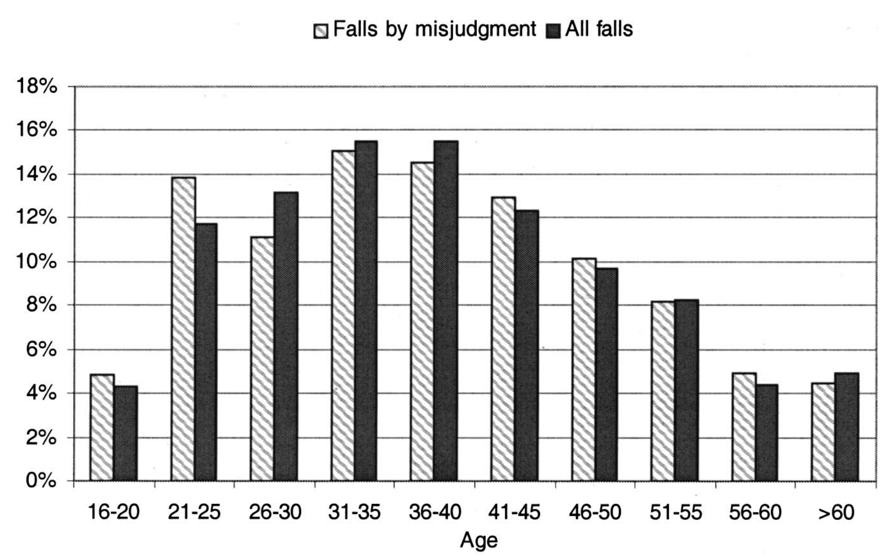

Fig. 7. Proportion of falls by misjudgment for different ages (1/90–10/01)

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Table 7. Distribution of Immediate Sources of Falls (1/90–10/01)

Immediate sources of falls	Count	Percent
Working surface	911	33.24
Buildings/structures	566	20.65
Bodily motion	338	12.33
Ladder	246	8.97
Hoisting apparatus	138	5.03
Materials handling equipment	52	1.90
Dirt/sand/stone	34	1.24
Motor vehicle (highway)	27	0.99
Motor vehicle (industrial)	25	0.91
Other	404	14.74
Total	2,741	100

vised. Typical examples are work being performed without having a tied-off full body harness when working at an elevation, which has been a major problem of falls on jobsites. Several falls also occurred when a body harness was unhooked to facilitate movement to a different location. Therefore, adequate provision and proper use of fall protective PPE are necessary to ensure worker safety.

Immediate Sources of Falls

A contributing factor in one-third of the fall accidents was the working surface (Table 7). The accidents included typical situations where workers slipped on sloped roofs and fell to the ground, fell through floor openings, or slipped on the walking surface of scaffolds and fell. Inadequate fall preventive equipment in buildings/structures and/or failure of buildings/structures also caused some workers to fall. These falls can be effectively prevented by the use of the appropriate fall preventive equipment.

OSHA Inspections of Fall Accidents

The states where falls occurred were also examined, showing that Texas, Florida, California, New York, and Illinois are the top ranking states in the frequency of all accidents and in the frequency of fall accidents (Fig. 8). Among the top 10 Standard Industrial Classification (SIC) codes associated with the largest

Table 8. Top 10 Construction-Related SIC Codes with Frequency of Falls (1/90–10/01)

SIC	Description of SIC	Frequency	Percent
1761	Roofing, siding, and sheet metal work	498	16.85
1791	Structural steel erection	395	13.37
1542	General contractors—nonresidential buildings, other than industrial	209	7.07
1799	Special trade contractors, not elsewhere classified	206	6.97
1751	Carpentry work	192	6.50
1721	Painting and paper hanging	173	5.85
1731	Electrical work	169	5.72
1741	Masonry, stone setting, and other stone work	167	5.65
1711	Plumbing, heating and air conditioning	115	3.89
1541	General contractors—industrial buildings and warehouses	115	3.89
	Total	2,955	100

number of falls, only 6 are listed in the top 10 with the highest frequency of all accidents (Table 8). These codes are 1761 (roofing, siding, and sheet metal work), 1791 (structural steel erection), 1542 (general contractors-nonresidential buildings, other than industrial), 1799 (special trade contractors, not elsewhere classified), 1731 (electrical work), and 1711 (plumbing, heating and air conditioning). In contrast, SIC 1623 (water, sewer, pipeline, and communications and power line) and 1611 (highway and street construction, except elevated highways), which rank as Nos. 1 and 2 in frequency of all accidents, are listed only as Nos. 15 and 20 in frequency of falls.

When comparing fall accidents with all construction accidents, the average penalty for fall injuries is higher than for the aggregate of other accidents. For example, the average and median values of the imposed penalty for fall-related accidents were \$8,917 and \$2,250, respectively, in contrast to \$7,757 and \$1,800 for the overall accidents. Meanwhile, the number of violations in fall inspections ranged from 0 to 118, with an average of 2.92, which is larger than that of all construction inspections that have an average of 2.68 violations. It was also found that more serious violations occur in fall inspections than in overall inspections. The Bureau of Labor Statistics (BLS) web site ⟨http://www.bls.gov/iif⟩ provided the most frequent citations to construc-

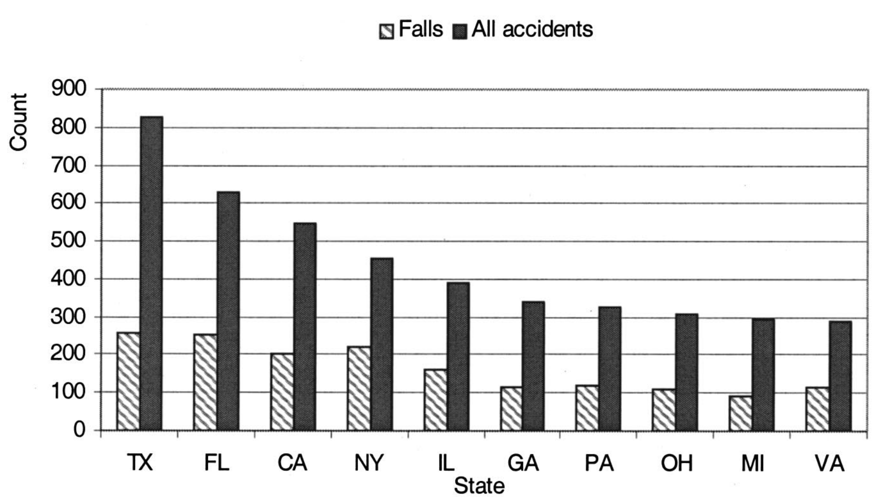

Fig. 8. Top states in frequency of falls and all accidents (1/90–10/01)

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Table 9. Standards Cited for SIC 17[a] (10/99–9/00)

Standard	Total citations	Total inspections	Total penalties ($)	Description of standards
1926.451	5,521	2,069	5,694,146	General requirements for all types of scaffolding
1926.501	2,969	2,585	3,555,916	Fall protection scope/applications/definitions
1910.1200	1,230	628	117,956	Hazard communication
1926.1053	1,076	810	470,408	Ladders
1926.020	956	845	555,819	Construction, general safety and health provisions
1926.503	877	802	440,888	Fall protection training requirements
1926.100	840	832	485,562	Head protection
1926.404	832	711	320,756	Electrical, wiring design and protection
1926.454	823	718	377,922	Training requirements for all types of scaffolding
1926.405	800	595	222,703	Electrical, wiring methods, components, and equipment, general use
Total	27,613	8,824	21,330,277	

[a]SIC 17 includes all construction special trade contractors (data source: ⟨http://www.bls.gov/iif⟩).

tion special trade contractors (SIC 17; see Table 9), which account for most falls (about 80%). Nearly half the citations are associated with fall hazards on the jobsite or lack of training about falls, which might provide a hint that construction fall protection training should emphasize care in the use of scaffolding and ladders.

Conclusions and Recommendations

Falls are the most frequent accidents on construction jobsites. From the analysis of fall accidents in the construction industry, it is obvious that falls are the cause of many serious injuries and fatalities. At the same time, analysis of the data shows that falls have certain properties that may be of help in devising preventive approaches.

In the past OSHA, the construction industry, and various researchers have worked intensively to find countermeasures to prevent falls. However, some measures do not work as well as expected. For example, since the OSHA regulations on PPE for fall prevention were revised in 1996, neither the quantity nor pattern of falls on construction sites has changed significantly; in fact, the proportion of accidents caused by falls has actually increased. This may stem from the strong economy that the U.S. construction industry has enjoyed in the years following 1995. The strong economic growth has resulted in the hiring of many workers, a large proportion being inadequately trained. Clearly OSHA's continued focus on falls is well warranted, and more training of the workforce is needed as well.

For the construction industry, fall hazards analysis and communication of related findings are necessary to ultimately impact the occurrence of fall accidents. It was noted that falls commonly occur on projects that can be characterized as small and relatively low in cost and that involve new construction of commercial buildings and residential projects.

Hazards on sites that may cause falls should be detected through rigorous examinations of construction sites and eliminated through effective preventive approaches. The accumulation of information on past accidents can disclose which hazards are most common on construction sites. Operations susceptible to falls include roofing, erecting structural steel, and exterior carpentry. Falls are often associated with workers on roofs, scaffolds, ladders, and floors with openings. Occupations such as construction laborers, roofers, carpenters, and structural metal workers are commonly involved in falls and should be specifically addressed through fall prevention efforts. It should also be noted that fall hazards and human errors at elevations of less than 9.15 m (30 ft), where over half the falls originated, warrant particular attention in terms of hazard analysis and safety inspections. Fall hazards mapping, as suggested by Gambatese and Stewart (1999), can serve as a very useful technology to indicate where fall hazards exist.

Through the analysis of fall accidents and fall-related near misses as well as fall-related citations, the most hazardous locations on sites can be identified. Providing fall preventive equipment to workers, including full-body harnesses, along with the proper training, should reduce the number of falls. The lack of safety training is often a contributing factor for many falls. According to the analysis, misjudgment by workers may account for about one-third of construction worker falls. Especially for workers employed in particular occupations that involve certain tasks, thorough fall prevention training should be provided. Effective training of workers can greatly decrease unsafe acts. Traditional safety training, restricted to the verbal and manual descriptions of the OSHA regulations, may not be sufficient to enable the workers to detect and eliminate all fall hazards. Innovative training approaches should be considered and thoroughly evaluated.

Allan St. John Holt (2001; page 159) mentioned that "fall prevention is far more effective than fall protection, which often involves personal protective equipment. Reliance on people to make the 'right' decision about wearing personal protective equipment has been shown by events to be unsatisfactory—they forget, decide not wear it in view of the expected short exposure time, or do not wear or use it correctly. The first stage in fall prevention is during the design process, which influences the construction method." Although it is still difficult to recognize how many falls are directly caused by unreasonable designs, safer plans developed through specific design decisions can decrease the occurrence of falls.

For the researchers, many topics related to falls need to be investigated in greater detail. For example, the current personal fall arrest systems (PFAS) can effectively protect workers after they fall from an elevation. While these may constrain the movement of workers, as with steel erection operations, such approaches should be examined further. Some workers fell because they did not tie off their body harnesses, either because they felt it troublesome to be tied off to a fixed anchorage or because they had unhooked the lanyards to change their positions. More flexible PFAS might be able to save more lives, and different kinds of new technology that can help prevent falls and protect workers from injury by falls should be developed.

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