Improving Construction Safety

A Team Effort

By John W. Mroszczyk

Construction work is extremely dangerous. While the construction industry and government agencies have taken many steps to make work sites safer, construction remains a risky industry in which to work. The number of fatalities in construction is disproportionate when compared to the size of the workforce and to other industries. This problem is not unique to the U.S. Construction fatality statistics are just as alarming in other industrialized nations including the U.K., Australia and New Zealand. Therefore, it is important to understand the nature of construction fatalities and to craft a strategy to improve safety.

Much research has been conducted to understand the nature of construction work. It is known that construction workers are exposed to a wide range of hazards. Construction sites are generally multiemployer work sites. Safety responsibilities can become decentralized with many contractors and tradesman coming and going. Construction projects are fast moving, which increases the likelihood for hazards to be overlooked. Problems often exist with workers and the work site. All of this adds up to a dangerous environment where incidents are multicausal in nature.

This article reviews construction incident statistics to show that the number of construction fatalities is disproportionate compared to the size of the workforce. The statistics indicate the types of hazards involved in construction fatalities and show that falls account for nearly one-third of all construction fatalities. It reviews research that has been conducted to show that construction incidents are multicausal in nature, involving an interaction between hazards, management, equipment, workplace, workers and factors unique to construction. It also discusses the role of various stakeholders (e.g., owners, design professionals, general contractors, subcontractors, workers) in reducing construction fatalities. Finally, the article recommends an eliminate-plan-prevent-protect strategy to improve construction site safety.

IN BRIEF
- Construction work is extremely dangerous. The number of fatalities is disproportionate compared to the size of the workforce.
- This article reviews the statistics, hazards and causal factors related to construction incidents.
- A strategy to improve construction safety is presented. It involves a team effort between design professionals, owners, contractors and workers.

Construction Fatality Statistics

The concern over construction fatalities is supported by the year-to-year trends in fatality statistics. Figure 1 (p. 57) shows total workplace fatalities (all industries) and total construction fatalities in the U.S. from 1992 through 2012 using data from Bureau of Labor Statistics (BLS, 2010). A downward trend exists in total workforce fatalities from more than 6,000 per year in

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The number of fatalities in construction is disproportionate when compared to the size of the workforce and to other industries.

the early 1990s to fewer than 5,000 in recent years. Construction has remained fairly level over that same time period varying between 738 and 1,239 fatalities per year. While these numbers may not seem significant, a nominal construction fatality rate of 1,000 workers per year is 83 workers killed per month or 19 per week in one single industry.

Figure 2 shows a comparison of the fatality rates for all industries combined and construction. Construction employment as a percentage of total workforce employment is fairly consistent at 5%. Yet, construction fatalities as a percentage of total workforce fatalities varied between 15% and 22% during the years 1992 through 2012. Construction fatalities as a percentage of the construction workforce shows a downward trend from 20% in 1992 to less than 14% in 2012. Figure 3 (p. 58) shows the construction fatalities by occupation from 1992 through 2012. The sharp decline in fatalities starting in 2008 can be attributed to the economic conditions and the decline in total hours worked (BLS, 2010).

Specialty trade contractors make up the largest percentage of fatalities. This group includes plumbing, heating, air conditioning, painting and paper hanging, electrical, masonry, carpentry, concrete work, structural steel work and excavation work. Heavy construction and general building contractors split the remaining percentage. General building contractors include residential, industrial and nonresidential contractors. Heavy construction work includes highway and street, bridge, tunnel, water, sewer and utility.

Construction Hazards

To understand these statistics in greater detail, look at the types of hazards found on construction sites. Figure 4 (p. 58) shows the percentage of total fatalities for each hazard category from the BLS data. Falls account for the highest percentage (about one-third) of construction fatalities. Transportation-related fatalities are next with about 25%. Contact with objects accounts for just below 20%. Harmful substances/environments is about 15%.

The four major hazard categories are further broken down based on 2010 BLS data. Table 1 (p. 59) shows the breakdown in fall fatalities. The top three fall hazards are ladders, roof edge and scaffolds. An example of a fall hazard is shown in Photo 1 (p. 59). This photo shows what would have been a deadly floor hole. The floor hole has been properly protected by a guardrail. The orange paint increases the visibility of the guardrails.

Consider the following case study of a fall incident involving a temporary worker (NIOSH, 2007):

> A 43-year-old male temporary worker was fatally injured when he fell from a scaffold plank [Photo 2, p. 59]. The victim had been hired through a temporary labor service to work one day for a roofing contractor on a residential roofing job. The victim was working with a crew of six laborers and a supervisor. The workers were removing old roofing material, hand-carrying the debris in metal trash cans from the roof and dumping the debris into a truck located adjacent to the roof.

The roofing contractor used a ladder-jack scaffold plank as a walking platform for the workers to use while carrying debris from the roof to the truck. The victim was hand-carrying an armful of debris across the plank to the truck when he fell approximately 9 ft to an asphalt driveway below.

Contact with objects is listed in Table 2 (p. 59). The largest area is struck by falling objects. Excavations and trench cave-ins are next, followed by caught-in equipment and collapsing structures. Photo 3 (p. 59) shows an example of a dangerous trenching situation. One worker is inside the trench with equipment along the sides. The trench has no shoring or benching.

Electricity accounts for most contact with harmful substances fatalities (Table 3, p. 60) Contact with power lines is the largest of this group. Photo 4 (p. 60) shows an example of a dangerous electrical hazard. The boom on the concrete pump truck is much too close to the electrical power lines.

The fourth hazard category is transportation fatalities (Table 4, p. 60). Transportation-related hazards can be collisions between vehicles, workers on foot being struck by a vehicle or a noncollision event such as rollover. Photo 5 (p. 60) shows an example of what can be done to protect workers in a traffic area. Shadow vehicles provide notice to approaching traffic and physical protection to workers in traffic situations. Backup alarms and backup cameras can also help reduce collisions.

Construction vs. General Industry

The construction fatality statistics clearly support the conclusion that construction work is more dangerous than general industry. There are several reasons for this. General industry projects move comparatively more slowly, the work is all under one roof and each job task is well planned out. General industry workers typically have well-defined job descriptions. Work hazards are generally known. For example, a worker in a manufacturing plant might be trained to operate one particular machine or a group of similar machines.

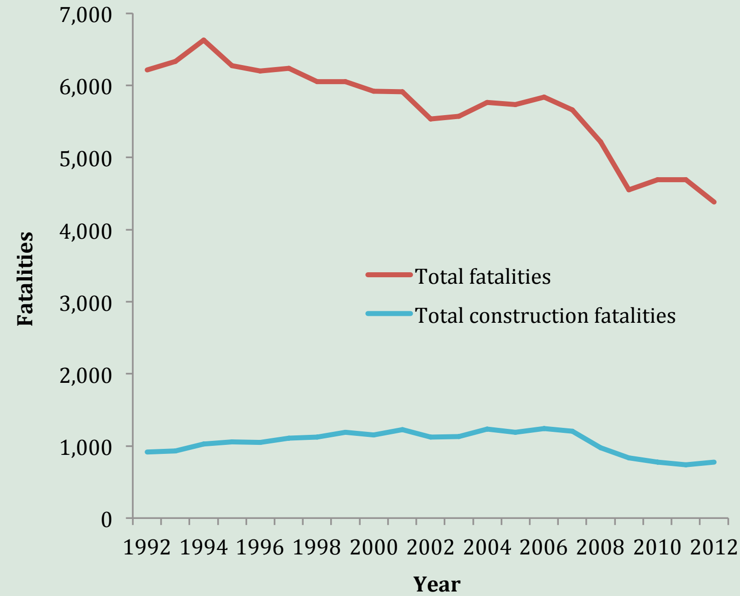
By comparison, construction workers are exposed to a wide range of hazards, such as electricity, toxic substances, work at heights, moving vehicles, trenches, chemicals and confined spaces. No two building projects are alike and projects move comparatively quickly. Work tasks and hazards can be unpredictable. This dynamic environment makes it difficult to create safe, stable work zones.

Other differences exist as well. Construction work is physically demanding. Many construction employees work outdoors and must endure adverse weather conditions. High worker turnover, temporary workers and day workers make it difficult to maintain a trained workforce. Workers may be unfamiliar with construction work, lack the necessary skills or lack understanding due to language barriers. (See "Nontraditional Workers" on p. 66.)

The safety management structure is also different. General industry workplaces are typically controlled by one employer. The management structure is centralized with well-defined OSH

Figure 1

Fatalities: All Industries vs. Construction, 1992-2012



Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

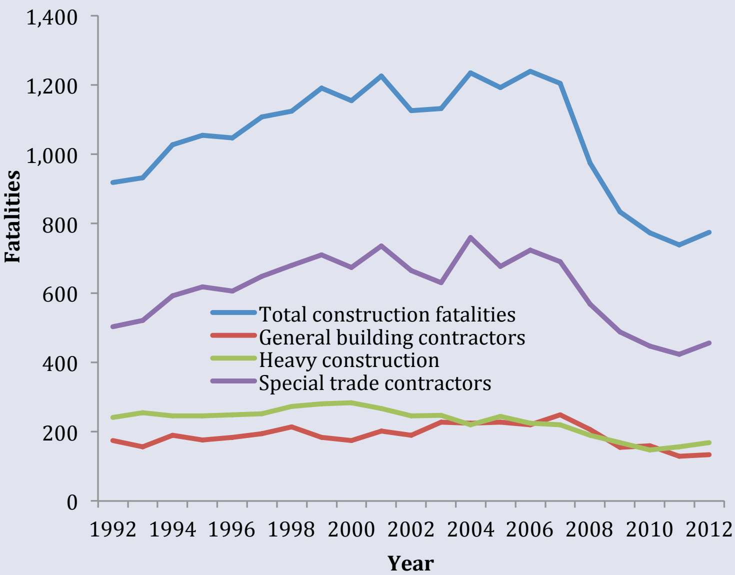
Figure 2

Construction Fatalities & Employment Rates, 1992-2012

Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

Figure 3

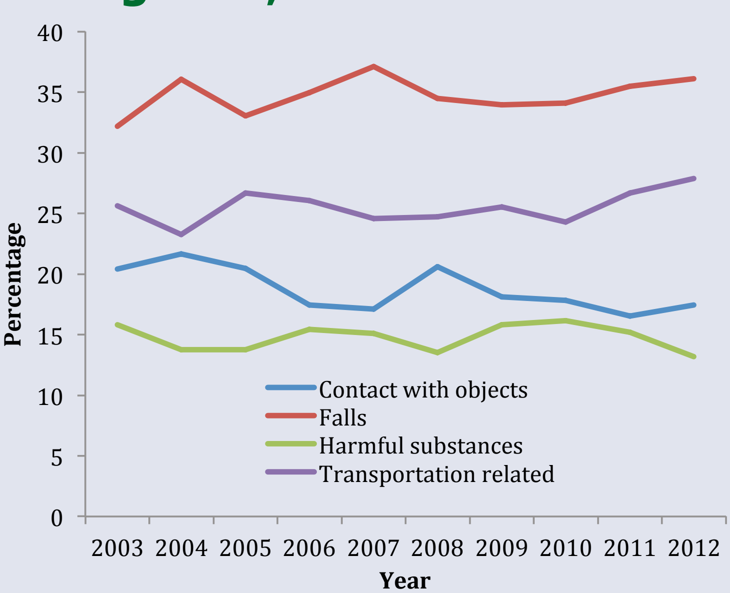
Construction Fatalities by Occupation, 1992-2012



Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

Figure 4

Percentage Total Construction Fatalities for Top Hazard Categories, 2003-2012



Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

responsibilities. Conversely, construction sites are usually multiemployer sites, with many different subcontractors and trades working simultaneously.

Figure 5 (p. 61) illustrates a typical construction management structure. An owner hires a design professional and a general (or prime) contractor. The design professional produces a set of plans. The general constructor hires the subcontractors and chooses the means and methods to construct the building according to the plans. Suppliers and other employers may be on site as well. A project may also have more than one prime contractor with its own subcontractors. Design-build is a yet another variation where contracting and design are done by the same firm.

The management structure shown in Figure 5 may look good on paper. The general contractor (GC) oversees and is responsible for all the work. This includes scheduling the work, quality of the work and site safety. The GC defines the safety program, holds toolbox talks and performs regular site inspections. The subcontractors should anticipate hazards particular to their work and provide a safety plan to address these hazards. The workers apply the tools of their trade to do the work in a safe manner.

In reality, safety management becomes decentralized with multiple subcontractors on site. One or more subcontractors may create a hazard that puts all employees, including their own, at risk. Hazards go uncorrected or undetected as the project moves quickly to meet deadlines. Workers frequently make their own decisions when it comes to safety.

For example, Subcontractor A removes a chimney, creating floor openings on each level. This subcontractor does not cover the openings exposing all workers on the site to a fall hazard. Subcontractor B is hired exclusively to cover the holes but fails to do so. The GC, which must oversee all this work, may fail in its oversight responsibilities. As a result, any worker in proximity to the floor openings will be exposed to a fall hazard. The exposed worker could be a tradesperson, an estimator or a salesperson.

The following case study (Mroszczyk, 2012) illustrates how the actions of one contractor can create a dangerous situation for another contractor at the site:

> A GC was hired for a bridge construction project. The GC hired a subcontractor for the steelwork. One of the steel subcontractor's employees was installing crossbeams between the girders. He was tied off to a horizontal lifeline. At the same time, the GC employees were installing tongue-and-groove planking between the girders. They were walking back and forth on the planking without fall protection. There was a call for coffee. The GC's employees went for coffee, leaving a small section of planking at the far end unfinished. They did not place a cover, guardrail or warning tape at the opening. The steelworker saw what he thought was a complete, planked walking surface. He unhooked and walked in the same direction as the other workers. It was

Table 1

Construction Fatalities: Falls, 2009

Cause	Fatalities
Total fall fatalities	264
Ladders	68
From roof edge	43
Scaffolds	37
Non-moving vehicle	17
To lower level	17
From roof	16
From structural steel	15
Through roof surface	13
Through skylight	11

Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

nighttime and there were lights shining toward him [Photo 6, p. 61]. He did not see the open hole created by the unfinished planking and fell 20 ft to the ground.

J.VINTON SCHAFER/CCBC CATONSVILLE/ELCOSH.ORG

Photo 1 shows what would have been a potentially dangerous floor hole.

NIOSH

Photo 2 shows the work site where a 43-year-old male temporary worker was fatally injured when he fell from a scaffold plank.

Causal Factors in Construction Fatalities

The existence of a hazard is only one aspect of a construction incident. Many other causal factors come into play. Much research has been conducted in this area. Haslam, Hide, Gibb, et al. (2005), studied causal factors in construction injuries and fatalities in Great Britain. They found that construction incidents result from the interaction between the work team, workplace, and equipment and materials. Problems with workers or the work team contributed to 70% of injuries and fatalities. Deficiencies in training can result in workers making poor choices such as:

- overlooking safety when faced with a heavy work schedule;
- taking shortcuts to save effort and time;
- misperception of the risk.

Tiredness and fatigue reduce concentration and can also lead to poor decision making. Another contributing factor was poor communication between workers.

Problems with the workplace contributed to almost half (49%). Inadequate space or access to perform a certain work task can also create difficulties. For example, inadequate space to extend stabilizers on a bucket truck can cause the truck to tip over. Local site hazards may also exist.

Shortcomings with materials and equipment were identified in 56% of cases. An example of a hazard attributed to materials is a heavy steel angle that must be manually maneuvered into place. Scaffolding (equipment) that is poorly assembled or configured is another potential cause of a fall.

Toole (2002) studied construction incidents in the U.S. He identified seven factors related to injuries and fatalities: training; deficient enforcement

Table 2

Construction Fatalities: Contact With Objects, 2009

Cause	Fatalities
Total contact with object fatalities	138
Struck by falling object	49
Excavation or trenching cave-in	24
Caught in or compressed by equipment	15
Caught in or crushed by collapsing structure	13
Compressed or pinched by rolling, sliding or shifting objects	11
Struck by swinging or slipping object	8
Caught in running equipment	7

Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

NIOSH/JOHN REKUS/ELCOSH.ORG

Photo 3 shows a dangerous trenching situation. Excavations and trench cave-ins are a major hazard on construction sites.

Table 3

Construction Fatalities: Exposure to Harmful Substances or Environments, 2009

Cause	Fatalities
Total harmful substances/environments	126
Overhead power lines	35
Wiring, transformers or other electrical	29
Caustic, noxious, or allergic substances	23
Temperature extremes	19
Electric current of a machine or tool	9

Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

Photo 4 shows a dangerous electrical hazard.

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of training; lack of proper safety equipment; task sequencing; unsafe site conditions; not using safety equipment; and poor worker attitude.

1) Training. A worker who is not properly trained or not trained at all will not be able to recognize and avoid hazardous conditions. For example, a worker who is not trained in fall hazards and restraint systems may not know when fall protection is required, or may tie off to a defective anchor.

2) Deficient enforcement of training. Consider a foreman who observes a worker not using fall restraint systems, yet takes no action. Site management must monitor the site on a regular basis and be knowledgeable about the relevant safety standards and practices. Management must also have the authority to direct the actions of workers, stop the work if a hazardous condition exists and discipline workers who do not work safely.

3) Lack of proper safety equipment. The proper equipment must be provided for the task. The equipment must be inspected and maintained. Safe use of equipment must be enforced.

4) Task sequencing. Tradespeople have developed means and methods to reduce the risk of an injury that depend on certain other tasks to be completed prior to doing their work. A deviation from the safe task sequence can increase the risk of an injury.

5) Unsafe site conditions. Working in unsafe site conditions dramatically increases the chances of a fatality. Examples include walking surface hazards, poor housekeeping, electrical hazards and atmospheric conditions. Having too many tradespeople working in the same area can also be unsafe.

6) Workers not using the safety equipment that is provided to them. Personal fall protection should be used properly. Other PPE such as gloves, steel-toe shoes, eye protection, hearing protective devices, hard hats and respirators should be used when required.

7) Poor worker attitude. Workers need to understand that all work tasks must be performed safely. Poor attitudes (e.g., "I can't be bothered with that"; "I won't be able to finish the job in time") must not be tolerated.

Analysis of incidents in other countries also provides insight into the causes of construction fatalities. Hamid, Majid and Singh (2008) conducted a study of the Malaysian construction industry. They found several factors related to construction injuries and fatalities. Unsafe equipment accounted for 9.7%. Poor job site conditions totaled 11.1%. Conditions unique to construction such as the high-energy nature of the work, required mental and physical stamina, and transient workers accounted

Table 4

Construction Fatalities: Transportation, 2009

Cause	Fatalities
Total transportation fatalities	188
Pedestrian struck by vehicle	45
Collision between vehicles, mobile equipment (highway)	44
Non-collision event (highway)	27
Non-collision event (non-highway)	24
Vehicle struck object on side of road (highway)	22

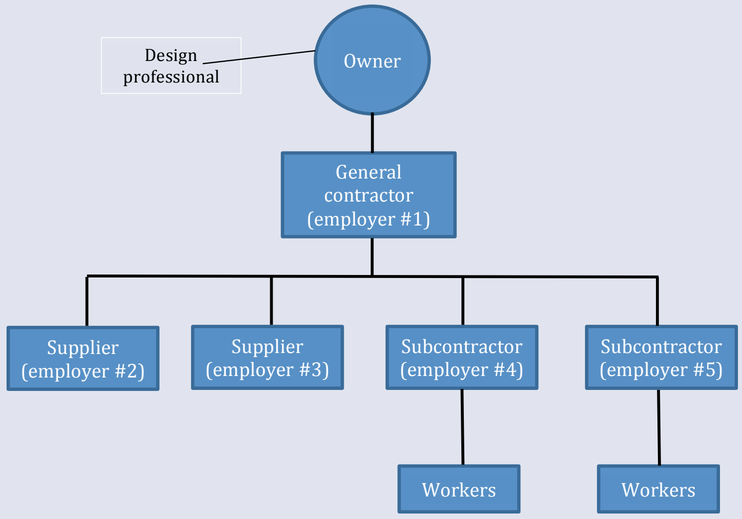
Note. *Data from "National Census of Fatal Occupational Injuries in 2009," by BLS, 2010.*

MOUNT SINAI/ELCOSH.ORG

Photo 5 shows shadow vehicles, which provide notice to approaching traffic and physical protection to workers.

Figure 5

Typical Construction Site Management Structure



for 11.1%. Unsafe methods such as incorrect procedures, lack of knowledge and failure to obey work procedures totaled 26.4%. Human factors concerns such as tiredness, long work hours and worker attitudes accounted for 12.5%. Poor management, such as inadequate warning systems, poor safety policies, failure to comply with regulations and poor inspection, was the final 29.3%.

Role of Stakeholders

Each stakeholder on a construction project (e.g., owner, GC, subcontractors, workers, design professionals) can influence construction site safety. The GC is responsible for the means and methods to be used in the construction of the building in accordance with the contract documents prepared by the design professional. The GC is also responsible for overseeing everyday project operations. The GC's level of site control and the ability to control site safety is high (Toole, 2002).

As part of oversight responsibilities, a GC is specifically tasked with monitoring and coordinating the work of subcontractors. This includes the quality of the work as well as site safety. It is customary and documented in most subcontracts that a GC can direct a subcontract foreman to remove certain workers from the site if their work or behavior is unacceptable (Toole, 2002).

Besides contractual obligations, 29 CFR 1926.16, Rules of Construction, sets forth the role of a GC working on a federally funded project. The GC has a nondelegable duty for overall site safety and assumes all obligations prescribed to employers, whether or not the GC subcontracts any of the work. This would include enforcement of training (29 CFR 1926.21) and regular and frequent inspections (29 CFR 1926.20). The GC should provide a safety program and require that all subcontractors submit their own safety program for their specific work.

It is logical that the management principles set forth in 29 CFR 1926.16 should apply to all construction sites, not just federally funded ones. To conclude otherwise would suggest that worker safety in nonfederal construction projects is of lesser importance than federal projects. Further, it is good management practice in any organization for a manager who does some of the work, assigns some of the work or subcontracts any part of a project to hold overall responsibility for the completion of the project in accordance with the contract and standards. While it would be of interest to OSHA whether a project is federally funded before citing a contractor under 29 CFR 1926.16, the Rules of Construction represent best management practices for all construction sites to ensure that subcontractors at a site are meeting OSH obligations and that the work is being done as safely and possible.

While the GC has overall responsibility, the subcontract employees perform the work. Subcontractors have task safety expertise. Each subcontractor must ensure that its employees are trained, and technically and physically capable of performing the work. If a subcontractor creates a hazard, it must protect its own employees as well as the employees of other employers that may be on the site (Hislop, 1998).

Under 29 CFR 1926.20, subcontractors are also required to conduct frequent and regular inspections. Subcontractors should train their employees on hazard recognition and avoidance (29 CFR 1926.21). Subcontractors should prepare a site-specific safety plan for their work; the plan should specify the anticipated hazards and the control methods to be used.

The construction worker is at the bottom of the chain of command. Workers have little control over the site. They are expected to work in a safe manner and get the job done according to their training (assuming that they are trained). But even the best-trained workers make mistakes. Workers can have memory lapses, poor judgment, inattention, physical stress and other human factors issues.

The prevailing approach in the construction industry is to implement safety measures during the actual construction process. With this approach, bad site decisions (or no decision) can lead to injuries and fatalities. The ideal time to influence safety is in the project's design phase (Szymberski, 1997). A well-thought-out design offers the chance to eliminate hazards on the drawing board by minimizing bad site decisions and other worker actions that can cause an incident. This is where design professionals come in.

JOHN MROSZCZYK

Photo 6 is from a bridge construction project in which the actions of one contractor created a dangerous situation for another contractor at the site.

Photo 7 was taken after a fall through an unguarded skylight.

Photo 8 shows the metal roof installed on storage bunker.

NIOSH

Design professionals can do their part to reduce construction fatalities by designing buildings that are safer to construct and maintain. Safety in design, design for safety or prevention through design (PTD) is a design philosophy that incorporates hazard analysis at the beginning of a design. Engineering measures are then applied to eliminate the hazard or reduce the risk to an acceptable level. If this cannot be done, then safety devices are implemented, followed by warnings, instruction, training and PPE. This design philosophy is not a new concept. Its application to construction projects has only come about in the past decade.

Design for construction safety (DFCS) is the application of PTD principles to construction projects. It extends the role of the design professional. Design professionals have traditionally designed buildings to comply with building codes, fire codes and state building regulations that emphasize the safety of the end user, not the workers who construct the building. With the DFCS approach, the design professional is asked to incorporate certain design features that make a building safer to construct and maintain.

The DFCS approach can be illustrated by the following example. Safety management practices provide that workers be trained regarding fall hazards including how and when to use fall protection. A worker may or may not use fall protection, or may not use it properly, leading to an incident. DFCS takes a different approach to fall hazards by designing buildings so that fall protection is not needed, or is at least easier to use. DFCS can be extended to the full life cycle of a building including not only worker safety in the construction phase, but the maintenance phase, those who may occupy the building as a workplace and final decommissioning of the building.

DFCS can have a significant impact on construction safety. There is a clear link between construction fatalities and design. Behm (2005) studied 224 fatalities and found that 42% were related to design decisions. In the U.K., 63% of construction injuries and fatalities between 1986 and 1989 were traced back to design decisions or lack of planning. In Australia, 42% of fatalities from 1997 through 2002 were the result of poor design (NZCIC, 2006).

A sample of actions or design features that can be implemented by designers can be found in the literature (Behm, 2005; Hecker, Gambatese & Weinstein, 2004; Lamba, 2013). For example:

- Do not place equipment next to roof edges.
- Design project handrails, guardrails and stair rails to be built during building erection.
- Conduct an extensive engineering survey before demolition or renovation work to determine the structure's condition.
- Design permanent anchorage points for commercial roofs.
- Design steel columns with holes at 21 and 42 in. above the floor to support guardrail cables.
- Design 42-in. roof parapets so that workers can work without the risk of falling.
- Specify temporary straps embedded in the building's concrete frame that can be used for personal fall arrest systems
- Prefabricate structures on the ground then lift them into place to reduce time spent working at height.
- Specify electrical switchgear designed to contain and deflect away an arc within the unit.
- Specify electrical equipment that allows for inspection from outside the panel.

The potential impact that designers can have on construction fatalities is illustrated by the following case study (NIOSH, 2012):

> A 45-year-old Hispanic roofing supervisor employed by a construction company engaged in roofing, waterproofing and construction management. On April 21, 2011, he was supervising the vacuuming of a flat roof. When he picked up the hose to move it out of the way of the vacuum operator, he either tripped or lost his balance and fell through an unguarded skylight and was killed.

Photo 7 shows the incident scene and the unguarded skylight. This fatality could have been prevented had the design professional specified a protective screen over the skylight or guardrails.

Consider another case in which a design professional could have prevented a fatality. It involves a 32-year-old male drill truck operator's helper being electrocuted when the mast of a drill rig contacted two 7,200-V overhead power lines (NIOSH, 2000):

> A contractor engaged an environmental engineering company to drill three monitoring wells for the placement of equipment to collect groundwater data. The location of the last well (which happened to be under four power lines) was marked with a small flag. The operator began to raise the drill rig mast into position when it contacted the power lines. The operator's helper was near the truck unloading equipment when this occurred. The operator survived but the operators' helper was killed.

In this case, the engineer should have specified that the wells be dug away from the power lines, or informed the contractor of the hazards and the need to de-energize the power lines in the plans and specifications.

Owners are yet another stakeholder. They purchase construction services, provide the funding, and are the end users of the building or facility. All owners should have an interest in any construction work that takes place on their property for many reasons. Besides contractor injuries and fatalities, ongoing construction work can damage real property, disrupt operations and create dangerous conditions for others on the site including owners' own employees.

Owners should, therefore, be proactive about construction safety, even if they have little or no expertise in safety. Owners can select contractors with good safety records, encourage designers to address safety issues in the design phase of a project, and participate in the safety management of the project (Huang & Hinze, 2006a; 2006b). A contractor with a good safety record is more likely to continue to work safely in comparison to a contractor with a poor safety record. According to the Business Roundtable (1982), owners should look for contractor management accountability, a qualified staff, written OSH programs and a commitment to safety. Carefully selected safety requirements can be included in the contract documents.

The following case study illustrates what can go wrong if an owner does not select a qualified contractor with a good safety record (Mroszczyk, 2013):

> A recycling company decided to build a storage bunker with a metal Quonset-style roof (Photo 8). To erect the metal roof, the company hired a contractor it had used in the past for concrete work. The contractor had never done this type of work, and was unfamiliar with the installation of this type of roof and with safety practices for working near power lines.
>
> The contractor started erecting sections of the metal roof on a windy day despite installation instructions that specifically stated not to erect the roof in windy conditions. There was a three-phase 34.5 kV power line nearby. An employer of the facility owner saw that the contractor was working near the power lines and that conditions were windy, yet allowed the work to continue without even having the power turned off. A short time later, a gust of wind lifted one of the metal panels into the power lines. A contractor employee who was holding the metal panel received an electric shock, resulting in an amputation.

Owners can also influence construction site safety by encouraging and supporting designers to address safety issues in the design phase of the project. This may require additional design time and increases in design fees. Making construction sites safe and the reduced maintenance costs will be worth any additional design fees.

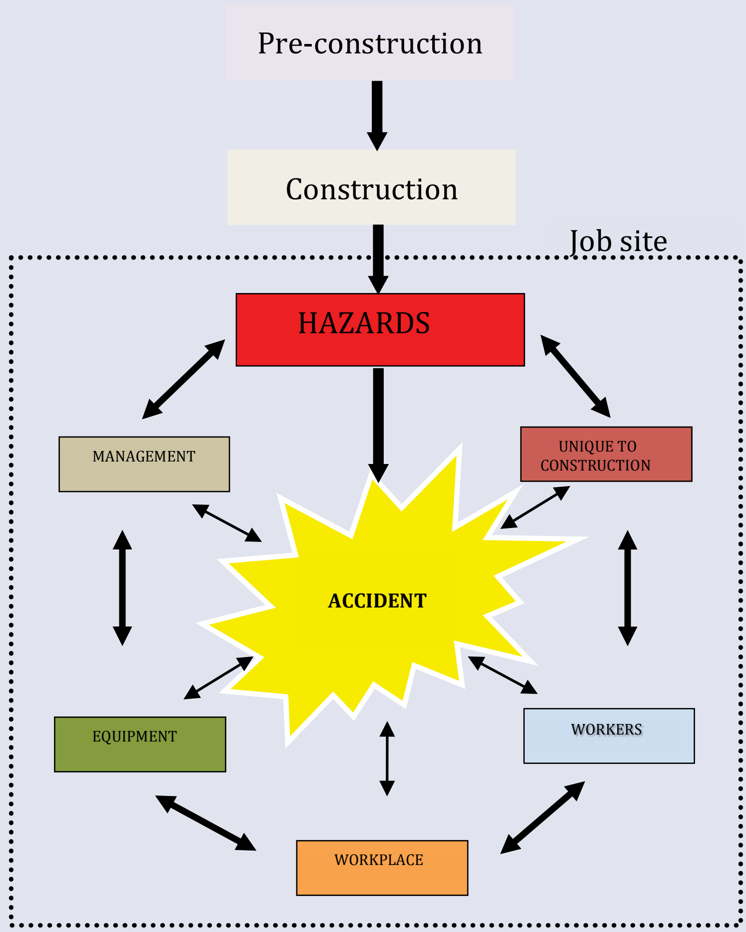
To the extent possible, owners should participate in project safety management. An owner can define safety goals by establishing a commitment

Table 5

Construction Incident Causal Factors

Category	Causal factor
Hazards	•Falls •Contact with objects •Exposure to harmful substances •Transportation
Management	•Lack of training •Deficient enforcement of training •Lack of or inadequate monitoring of site •Deviation from safe task sequencing •Inadequate warning systems •Unsafe means and methods •Poor or no safety policies •Poor or no safety program •Failure to comply with regulations
Equipment	•Defective equipment •Lack of maintenance •Improper equipment •Poorly assembled equipment
Workplace	•Poor communication •Walking surface hazards •Poor housekeeping •Too many trades in one location •Limited work area
Workers	•Taking short cuts •Misperception of the risk •Overlooking safety with heavy workload •Fatigue •Poor decision •Poor attitude towards safety •Not using proper equipment
Unique to construction	•Long work hours •Weather •Physical nature of work •Transient workforce •High energy nature of work •Physical and mental stamina •Changing hazards

Figure 6
Construction Incident Causation Model



to safety during design and communicating this commitment to everyone involved (Hislop, 1998). The Business Roundtable (1982) recommends that owners provide safety guidelines that the contractor must follow, require a formal site safety program and require that the contractor designate a supervisor to oversee site safety. Projects where the owner promoted safety and participated in safety recognition programs have had improved safety records (Huang & Hinze, 2006a; 2006b).

Owners have a legal and moral responsibility to alert contractors of any hidden hazards or unsafe conditions that may be present on the site that could cause injury to construction workers. For example, in remodeling projects the owner should alert contractors about any structurally unsound areas and floor openings that they are aware of. An owner who is also a host employer is required under NFPA 70E to inform contractors of hazards that may not be recognized by the contractor's employees and other information concerning the host employer's installation.

Construction Incident Causation Model

Research indicates that construction incidents are multicausal in nature. They are the result of the random interaction of hazards and other causal factors related to deficiencies in management, equipment problems, unsafe site conditions, worker actions and conditions unique to construction (Table 5, p. 63). In a perfect world, hazards would be eliminated. In the real world, hazards are often created and left unprotected. As a result of one or more of these factors, the worker comes into contact with the hazard and an incident occurs.

Figure 6 shows a proposed construction incident causation model. The model is similar to a model presented by Haslam, Hide, Gibb, et al. (2005). A designer creates a set of plans; the contractor implements the design using whatever means and methods necessary to get the job done; hazards (e.g., falls, contact with objects, harmful substances, transportation) are created during this process.

A hazard alone does not cause an incident; other causal factors (e.g., deficiencies in management, equipment problems, unsafe site conditions, worker actions, conditions unique to construction) come into play. Hazards and causal factors are changing all the time. It is the interaction and coincidence in time and space between the hazard(s) and causal factor(s) that causes an incident.

Consider the following case study (NIOSH, 1998):

> A contractor was demolishing a roof on a commercial building. After the roofing was removed, damaged sheets of plywood had to be replaced. Helpers were assigned to follow the workers who were replacing the plywood, pick up the damaged plywood sheets and dispose of them in a chute. On one occasion, a worker had removed a damaged plywood sheet but had run out of nails to attach the replacement piece. He walked away to get some nails leaving an opening where the damaged piece was removed. The crew was not informed that there was an unguarded opening. The helper came along to pick up the piece of damaged plywood and stepped into the opening. He fell 27 ft to the floor and was killed.

In this case study, the unprotected floor opening was the hazard. The first worker either made a bad decision or was taking a shortcut when he left an opening unguarded to get some nails. There was poor communication because he did not inform any of the other workers that there was an unguarded floor opening. The helper just happened to come along at the precise time that the worker left the area.

Strategy Going Forward

No one can predict the circumstances leading up to an incident. However, eliminating or reducing the causal factors can reduce the number of incidents. A strategy to reduce construction incidents is divided into six areas based on the construction incident causation model: hazards, management, equipment, workplace, workers and unique circumstances. Each stakeholder has a responsibility to eliminate or reduce the causal factors based on the strategy matrix shown in Table 6.

First, hazards should be eliminated to the extent possible. Design professionals can take the lead by considering and anticipating hazards, and designing

Table 6

Construction Incident Reduction Strategy Matrix

	Design professional	Owner	General contractor	Subcontractor	Worker
Hazards	•Eliminate hazards with good design	•Encourage, support designers to eliminate hazards	•Take measures to prevent, protect against hazards •Frequent site inspections	•Take measures to prevent, protect against hazards •Frequent site inspections	•Alert other workers to open hazards and newly created hazards
Management		•Owner presence, involvement to show safety commitment	•Conduct regular toolbox talks, safety meetings •Have a site safety plan, policy •Require that subcontractors have their own safety plan, policy •Require all workers to be trained •Monitor the site	•Follow general contractor safety plan, policy •Prepare safety plan, policy for specific work •Train workers	
Equipment			•Use proper equipment •Maintain equipment	•Use proper equipment •Maintain equipment	•Use proper equipment
Workplace		•Hire contractors with good safety records	•Hire contractors with good safety records •Frequent site inspections	•Frequent site inspections	
Workers			•Raise awareness	•Raise awareness	•Work safely •Work according to training
Unique to construction			•Regular breaks •Treat temporary, day workers as own	•Regular breaks •Treat temporary, day workers as own	

them out so that workers are not exposed. Owners can help by encouraging and supporting designers. Owners should consider that a short-term increase in design fees can have greater rewards in life cycle costs and a successful, safe project.

Falls account for nearly one-third of fatalities. The top four fall hazards involve scaffolds, ladders, roof edges and lower levels. Certain design features can reduce scaffold incidents:

•Gantry systems can be permanently installed so that scaffolds are not needed when servicing atriums and skylights.

•Consider designing a space to store a scissor lift to be used to service lighting.

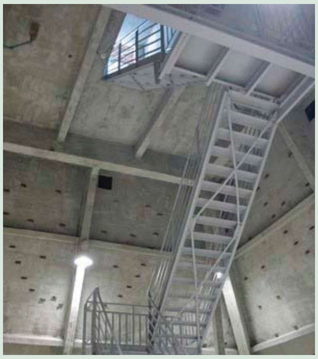
•Davits can be installed so that a permanent suspension system is available whenever scaffolding is needed.

Falls from ladders occur because a worker used the wrong portable ladder, used a defective portable ladder or did not use the ladder properly. Designing permanent, safe stairways or fixed ladders eliminates the need for a portable ladder (Photo 9). Install stairways as early as possible in the construction phase so that ladders are not needed.

Falls from roof edges occur because a worker does not have a safe place to tie off, does not use fall protection or ties off to a structure that is not structurally sound. A parapet wall that also functions as a perimeter guard can eliminate the need for temporary fall protection during construction and maintenance. Permanent roof anchors can be specified so that workers will always have a safe place to tie off.

Specifying holes in columns at 21 and 42 in. above the floor slab makes it easy to install cable or wire perimeter cables (Photo 10). Embedded anchors can provide a safe place to tie off during construction when working near an open side. Straps can be attached to steel rebar then buried in a concrete beam or slab with its connecting D-ring left hanging.

Workers have also been killed due to structural collapses. A steel frame might be designed so that



(Clockwise from top): Photo 9 shows industrial stairs, which are preferred to access a work platform, mezzanine, upper level or roof. Photo 10 depicts why specifying holes in columns at 21 and 42 in. above the floor slab makes it easy to install cable or wire perimeter cables. Photo 11 shows the value of depicting rebar details on design drawings.

it is stable and sound when everything is in place, but can be unsafe during the erection process. Why leave bracing up to a contractor that may not have the experience or structural background of an engineer? Specify bracing on the bid documents so that the structure does not collapse midway through the erection process.

A composite beam might be fine when the concrete has cured, but behaves differently during the construction phase. Concrete has little or no structural strength while it is curing, yet still has dead load. Designers should consider how a noncomposite beam and supporting steel members are loaded during the construction and curing process.

Omitting rebar details at beam/column joints from the drawings can have catastrophic consequences. Congestion of rebar can create voids, or honeycombing in the concrete can cause a collapse (Photo 11, p. 65). Do not rely on the contractor to fill in the details. Include rebar details on the drawing so that there are no questions.

Contact with objects is another hazard area in which designers can improve safety. Trenching incidents occur because contractors do not use shoring and trench boxes, or do not use them properly. Trenchless technology can be specified for utility and similar work. This eliminates the need for a worker to be down in a trench.

Many design features can be implemented to reduce electrical incidents:

•Do not specify groundwater monitoring wells or other facilities near or under power lines.

•Mark the location of existing electrical lines on the contract drawings.

•Design embedded electrical lines deeper than the maximum depth of pipe hanger bolts so that drilling does not penetrate an energized line.

•Specify arc-rated switchgear to deflect arc-flash energy away from work areas where a person would be standing.

•Specify electrical panels that permit inspection and measurements without getting inside the panel.

Avoid confined spaces. This can be achieved by designing spaces to be normally habitable. Instead of putting valves in an uninhabitable space, put them in an open area. Specify primers, sealers and other coatings that do not emit noxious fumes or contain carcinogenic products.

Designers can prepare a well-thought-out site plan to reduce transportation-related incidents. Keep roadways away from sloped areas to avoid vehicle rollovers. Locate material storage areas, job trailers, portable restrooms and roads so that vehicle-vehicle and worker-vehicle contact is minimized.

Eliminating hazards in the design stage will avoid many incidents, but not all. Hazards arise during the means and methods of construction. GCs should conduct regular inspections and take oversight responsibility. Subcontractors also must conduct regular inspections with respect to their work. Preventive measures should take priority over pro-

Nontraditional Workers

Temporary Workers

Temporary workers are used regularly in construction to provide manpower on a time-limited basis. A temporary worker is an employee of a staffing agency. The agency enters into a contract with a secondary employer (called a host or client employer). Temporary workers report to the host employer's job site and are put to work under the direction of the host employer.

These workers are at increased risk of injury because many of them change job site assignments several times a year. They are not always trained. Host employers are less willing to devote training resources to temporary workers because they are not permanent employees. It is not uncommon that a temporary worker is killed after only 1 or 2 days on the job.

Both the staffing agency and the host employer have responsibilities regarding the safety of temporary workers depending on their respective position to address hazards. Staffing agencies might provide general safety and health training. Agencies should inquire into the conditions of their employees' assigned workplace. The host employer is better suited to provide training tailored to the specific workplace. Host employers must treat temporary workers like any other workers with regard to training and safety protection (OSHA, 2014).

Day Laborers

Day laborers work on short-term informal agreements with contractors. This workforce is usually organized in open-air markets, worker centers, on the street or outside home improvement stores. These workers often are immigrants (legal and illegal) and other marginalized citizens. Many day laborers face language barriers.

Because of their informal work agreements and transient nature, day laborers are difficult to reach. They are unlikely to have the protection and training required by more formal employment arrangements. A recent study found that only 40% of day workers receive safety training. Many workers get no more than instruction on how to do the work, but lack safety training (Seixas, Blecker, Camp, et al., 2008). Injury rates for day laborers are nearly impossible to obtain. One study estimates the injury rate for day laborers in construction at about five times the BLS rate (Seixas, et al., 2008). Contractors that hire day laborers have a moral obligation to train them and treat them like any other worker. It has also been suggested that work centers and community-based organizations consider offering training for these workers.

tective measures whenever possible. For example, it is preferable to put a secured cover over a floor opening than implement a personal fall arrest system. Workers who discover an open hazard or create a hazard should alert their supervisor so that other workers on the site are not put at risk.

Management is the next focus area. If management does not put the rules, practices, and policies it creates into practice, workers will care less (Hamid, Majid & Singh, 2008). The GC has a large role in this because it is the only employer on the site that knows the subcontractors and what work is being scheduled. The work should be carefully planned out to identify potential hazards so that safety rules and plans can be made. A job hazard analysis should be conducted to identify potential hazards. Contractors should communicate that safety is a priority by treating productivity, quality and safety as three related parts of the project.

The GC should monitor the site on a regular, frequent schedule. Any open hazards should be promptly addressed. It should be reiterated: Preventive measures should take priority over protective measures. The work should be stopped if a person is observed to be working in an unsafe manner. Careful attention should be paid to task sequencing so that unplanned hazards are not introduced.

The GC should also conduct regular toolbox talks and safety meetings. Toolbox talks provide a continuing method to inform and train workers. A subcontractor representative and workers should be invited to project-wide safety meetings. A stand-down is another method to raise safety awareness. This is a job site break to talk directly to workers about safety, discuss job hazards, inspect equipment, train and teach.

The GC should have a site safety plan/policy, and require that all subcontractors have their own safety plan/policy for their portion of the work. The GC should require and confirm that all workers are trained. Subcontractors should follow the GC safety plan and their own plan. Subcontractors must ensure that their workers are trained.

All contractors should make sure the proper equipment is used on the site. Equipment should be maintained. Unsafe equipment should be set aside and secured so that it cannot be used until it is repaired or replaced. For example, a damaged ladder should either be destroyed or chained and locked so that a worker looking for a ladder cannot use it.

Workers should work safely according to their training. Contractors can help by raising safety awareness. Workers should feel free to alert supervisors of unsafe conditions.

Conclusion

The nature of construction makes it difficult to create safe, stable work zones. Construction workers are exposed to a wide range of hazards such as electricity, toxic substances, work at heights, moving vehicles, trenches, chemicals and confined spaces. Construction projects move quickly and hazards can be unpredictable. Workers must endure physically demanding work, and often must make their own site decisions. They may be distracted, fatigued, untrained or have language barriers. Safety responsibilities can become decentralized with multiple employers on site.

Fatalities are multicausal resulting from the interaction of hazards with deficiencies in management, equipment, workplace, workers and conditions unique to construction. The hazards and causal factors change over time. A construction incident model illustrates the multicausal nature of construction incidents.

Each stakeholder (e.g., design professional, GC, subcontractors, workers, owners) has a role to play in a strategic effort to reduce hazards and causal factors. Design professionals can take the lead by eliminating hazards with well-thought-out designs. Eliminating hazards or reducing risk whenever possible will minimize bad site decisions and other worker actions that cause incidents.

The GC is specifically tasked with monitoring and coordinating the work of subcontractors and has the highest level of control over the site. The GC should exercise this control to:

- prequalify subcontractors based on past safety record and current safety performance;
- anticipate and control hazards by planning work;
- mandate that all workers be adequately trained;
- monitor the site on a regular basis to correct hazards and check subcontractor compliance with safety requirements;
- hold regular safety meetings to review upcoming work and the safety measures that might be required;
- hold toolbox talks to educate workers regarding safe practices;
- provide a site-wide safety plan that all subcontractors are to follow;
- require that subcontractors provide a safety plan for their specific work.

Subcontractors must train their employees and follow the site safety plan as well as their own. A hazard created by a subcontractor employee should be addressed so that it does not pose a risk to the subcontractor's employees or to employees of other employers on the site.

Raising awareness can also help. Managers can conduct a safety stand-down by breaking for a toolbox talk, discussing job hazards and inspecting safety equipment. Workers should work safely according to their training and alert other workers of any open hazards that they find. Owners should only hire contractors with good safety records. Owner presence and involvement will help to show a commitment to safety.

Construction will continue to be a dangerous industry. The steps taken by various groups and agencies have created a downward trend in the fatality rate. However, the rate is still unacceptable. This article has provided a review of how construction incidents occur. The proposed eliminate-plan-prevent-protect strategy involving design professionals, GCs, subcontractors, workers and owners will make further headway in the reduction of construction fatalities. **PS**

Each stakeholder, from design professional, GC, and subcontractors to workers and owners, has a role to play in a strategic effort to reduce hazards and causal factors.

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