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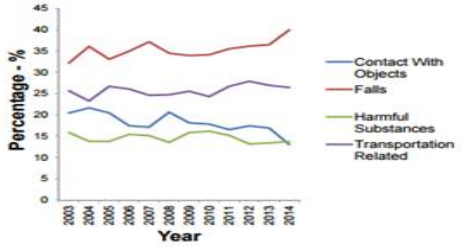
IMPORTANT NOTICE

"Please refer to the announcement in Vol 7/no. 20 of Safety Info dated 15th October 2016 and kindly note that Last Date for nomination / submission of documents is on or before 30th November 2016 by email to: pateljc2002@yahoo.com and ydunn@asse.org."

Construction Incidents with multi-causal factors

It is well known that construction work is dangerous. Construction employment is only 5% of the total workforce, yet has 15% to 22% of the total workforce fatalities. While the construction industry and government agencies have made progress in reducing construction incidents, construction remains a risky place to work. Understanding the nature of construction incidents is important so that further improvements in safety can be realized. To understand how construction incidents occur, we must first identify the factors involved. To start, there are construction workplace hazards. However, hazards are not always identified and eliminated before an incident occurs. Other causal factors contributing to construction incidents include problems with management, the workplace, workers, equipment and conditions unique to construction. This multi-causal aspect makes construction incident prevention complex. This article identifies the top construction hazards. Construction workers are subject to falls, transportation hazards, contact with objects and exposure to harmful substances. The article provides examples from each hazard category and discusses studies that illustrate the various causal factors involved. In addition, the article discusses case studies that illustrate the multi causal nature of construction incidents. A graphical model is proposed to gain further insight into the interaction of the various causal factors. An incident reduction strategy matrix lists the role of each stakeholder (design professionals, general contractors, subcontractors, workers, owners). Further reduction in construction fatalities is possible with a team effort involving the stakeholders acting on hazards and causal factors.

FIGURE 1
Percentage of Total Construction Fatalities
This figure shows the percentage of total construction fatalities for the top four hazard categories for the years 2003 through 2014.

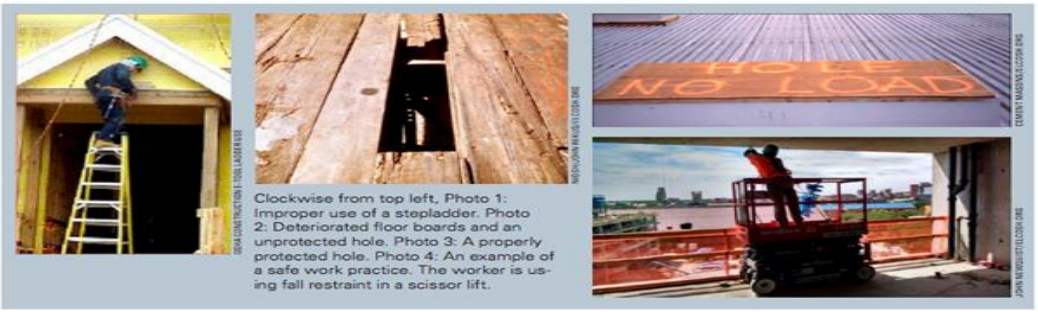


Data from National Census of Fatal Occupational Injuries in 2009 (News release), by Bureau of Labor Statistics, 2010.

TABLE 1
Construction Fatality Fall Hazards, 2010

Fall hazard	Fatalities
Total fall fatalities	264
Ladders	68
From roof edge	43
Scaffolds	37
Nonmoving vehicle	17
To lower level	17
From roof	16
From structural steel	15
Through roof surface	13
Through skylight	11

Data from National Census of Fatal Occupational Injuries in 2009 (News release), by Bureau of Labor Statistics, 2010.



Clockwise from top left, Photo 1: Improper use of a stepladder. Photo 2: Deteriorated floor boards and an unprotected hole. Photo 3: A properly protected hole. Photo 4: An example of a safe work practice. The worker is using fall restraint in a scissor lift.

Construction Hazards

Figure 1 shows the percentage of total fatalities for the four hazard categories. 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 under 20%. Harmful substances/environments is about 15%. Each of the four major hazard categories is broken down in more detail based on historical data.

Falls

Table 1 shows the breakdown in fall fatalities. The top three fall hazards are ladders, roof edge and scaffolds. An example of a fall hazard involving a ladder is shown in Photo 1. This worker is improperly using the top rung of the stepladder. Photo 2 shows worn and deteriorated floorboards. Not only is there an unprotected hole, but many of the boards have deteriorated and are unsafe to walk on. Photo 3 shows a properly protected hole. Hole covers should be marked, secured against unintentional displacement, and capable of supporting workers, equipment and materials that may be imposed on it. Photo 4 shows the use of personal fall restraint when using a scissor lift.

TABLE 2
Construction Transportation-Related Fatalities for 2010

Transportation-related fatality type	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

Data from National Census of Fatal Occupational Injuries in 2009 (News release), by Bureau of Labor Statistics, 2010.

TABLE 3
Construction Fatality Contact With Objects, 2010

Contact with object	Fatalities
Total	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

Data from National Census of Fatal Occupational Injuries in 2009 (News release), by Bureau of Labor Statistics, 2010.

Photo 5 (left): Temporary traffic barriers and signs can provide a buffer zone between workers and traffic. Photo 6 (right): An excavation with inadequate shoring.

Transportation-Related Hazard

Table 2 lists the top transportation-related fatalities. Transportation-related hazards can be either collisions between vehicles, workers on foot who are struck by a vehicle, or a non-collision event such as a rollover. The top two are pedestrians struck by a vehicle and highway collision between vehicles. Photo 5 shows how temporary traffic barriers and signs can provide a buffer zone between workers and traffic. Shadow vehicles can be used to provide notice to

approaching traffic and physical protection to workers in traffic situations. Back-up alarms and back-up cameras can also help reduce collisions.

Contact With Objects

The third category is contact with objects, listed in Table 3. The most hazardous area is struck by falling objects. Excavations and trench cave-ins are next, followed by caught in equipment and collapsing structures. Photo 6 shows an example of an unsafe excavation. Only a portion of the excavation has shoring.

TABLE 4
Construction Fatalities Exposure to Harmful Substances or Environments, 2010

Harmful substances/environments	Fatalities
Total	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

Data from National Census of Fatal Occupational Injuries in 2009 (News release) by Bureau of Labor Statistics, 2010.

Clockwise from top, Photo 7: Putting visible signs and overhead flags to alert a driver of the overhead power lines is a best practice. Photo 8: Securing electrical cables to prevent workers from contacting low hanging electrical cables is a good work practice. Photo 9: Unsafe work practice. Spray area should be properly ventilated and spark-producing tools should not be used in a flammable atmosphere.

Exposure to Harmful Substances

Electricity accounts for the majority of fatalities in the exposure to harmful substances category (Table 4). Contact with power lines is the largest of this group. Photo 7 shows a good practice of putting visible signs and overhead flags to alert a driver of the overhead power lines. Photo 8

shows an example of a safe work practice involving electrical wiring. The electrical cables are secured to prevent workers from contacting low hanging cables. Photo 9 shows an unsafe work practice involving noxious substances. The spray area should be properly ventilated and spark producing tools should not be used in a flammable atmosphere.

Other Causal Factors

Hazards are only one aspect of construction incidents. Much research has been conducted to identify other factors. , 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 attributed to 70% of injuries and fatalities. Deficiencies in worker 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; and misperception of the risk. Tiredness and fatigue reduces concentration and also leads to poor decision making. Poor communication between workers was another contributing factor. Problems with the workplace contributed to almost half (49%) of the incidents. Difficulties can arise for the worker if the work space is inadequate. For example, inadequate space to extend stabilizers on a bucket truck can cause the truck to tip over. Local site hazards such as tripping and housekeeping hazards can 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 example that can cause a fall. Toole (2002) studied construction incidents in the U.S. He identified seven factors related to injuries and fatalities:

1) Training: A worker that is not properly trained or not trained at all will not be able to recognize and avoid hazardous conditions.

2) Deficient enforcement of training: For example, a foreman observes a worker not using fall restraint systems and does not take action.

3) Lack of proper safety equipment: The proper equipment must be provided for the task.

4) Task sequencing: A deviation from the safe task sequence can increase the risk of an injury.

5) Unsafe site conditions: Working under unsafe site conditions dramatically increases the chances of a fatality.

6) Not using provided safety equipment: Personal fall protection, gloves, steel toe shoes, eye protection, protective hearing devices, hard hats and respirators should be used when required.

7) Poor worker attitude toward safety: Workers need to understand that all work tasks must be done safely.

Analysis of incidents in other countries also provides insight into how construction fatalities happen. Hamid, Majid and Singh (2008) conducted a study of the Malaysian construction industry. They found a number of factors related to construction injuries and fatalities. Unsafe equipment accounted for 9.7%. Poor job site conditions accounted for 11.1%. Conditions unique to construction such as the high energy nature of the work, mental and physical stamina, and transient workers, accounted for 11.1%. Unsafe methods such as incorrect procedures, lack of knowledge and failure to obey work procedures was 26.4%. Human factors issues, such as

tiredness, long work hours and worker attitudes was 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%.

Certain other causal factors are:

- Uncertainty of hazards: Higher risk for demolition and refurbishment.
- Site congestion: Higher risk for restricted sites.
- Time pressure: Risk is higher for tight deadlines.
- Fragmentation of the project team: Risk is higher when the management team is contracted out. Design build has a lower risk.
- Fragmentation of the workforce: Risk is higher when multilayer contracting exists.

Case Studies That Illustrate Multi causal Nature of Construction Incidents

The following case studies suggest that construction incidents are unplanned events arising from multiple causal factors.

Case Study No. 1

A contractor was demolishing a roof on a commercial building. After the roofing was removed, damaged sheets of plywood needed to be replaced. A helper was assigned to follow the workers who were replacing the plywood, pick up the damaged plywood sheets, and dispose of them in a chute. At one point, a worker had removed a damaged sheet of plywood but had run out of nails to attach the replacement piece of plywood. 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 below and was killed. In this case the hazard is the unprotected floor opening. The worker should not have left the floor opening unprotected. The following causal factors contributed to the helper's fall:

- The first worker either made a bad decision or was taking a shortcut when he left the opening unguarded to get some nails.

  There was poor communication at the site because the worker did not inform the rest of the crew.

- It is questionable whether the worker(s) and the helper were trained.
- The helper happened to come along at the wrong time while the opening was unprotected. If he came along before the worker left to get nails or after the worker returned, the incident would not have occurred.

Case Study No. 2

A 47-year-old electrical worker died when he fell through a skylight while installing solar panels on the roof of a warehouse. The warehouse had a surface area of 650,000 sq ft. There were

357 skylights on the roof. The worker was carrying two panels and was trying to walk around 18 in. of clearance around one of the skylights He turned, walked backward, tripped over the raised edge of the skylight, and landed on the skylight. The skylight broke and the worker fell 40 ft to the floor below (Photo 10).

Photo 10 (top): The skylight the electrical worker fell through. Photo 11 (bottom): Bridge construction project case study (Mroszczyk, 2012).

The worker had received training and participated in site-specific safety awareness meetings. The general contractor had reviewed the job safety requirements and determined that fall protection was not necessary because the skylight was marked that it was "tested “. No such test criteria existed. The following causal factors contributed to this incident:

- The workers were not trained in proper materials handling while working on the roof.
- The general contractor acted on misinformation and assumed fall protection was not necessary.

- The owner and/or property manager should have either installed skylight screens, installed guardrails around each skylight, or informed the general contractor that the skylights were unsafe.

- Communication should have occurred between the owner and/or property manager so that personal fall protection could have been put in place.

Case study No. 3

This case study illustrates how the actions of one contractor can create a dangerous situation for another contractor at the site: A general contractor was hired for a bridge construction project. The general contractor hired a subcontractor for the steel work. One of the steel subcontractor's employees was installing cross beams between the girders. He was tied off to a horizontal lifeline. At the same time, the general contractor 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 general contractor'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 steel worker saw what he thought was a complete, planked walking surface. He unhooked and walked in the same direction as the other workers. It was nighttime and there were lights shining in his eyes. He did not see the open hole created by the unfinished planking and fell 20 ft to the ground (Photo 11). The hazard in this case study was the unprotected opening. The following causal factors contributed to this incident:

- The employees of the general contractor made a bad decision when they decided to leave the opening unprotected. •There was poor communication on the site. The employees of the general contractor did not alert the steel worker that a section of the planking was not finished.

- The general contractor employees did not follow regulations and their own safety manual when they left the opening unprotected.

  There were human factors issues as well. The steel worker did not see the opening. It was dark and there were lights were shining in his eyes. He saw the other workers walking on the planking and assumed it was safe.

Construction Incident Causation Model

The research indicates that construction incidents are multi-causal in nature. Incidents result from a random interaction of hazards and other causal factors that can be grouped into five categories: management, equipment, workplace, workers actions and conditions unique to construction. The categories and the causal factors are listed in Table 5.

Table 5
Construction Accident Causal Factors

Types of Causal Factors	Causal Factors
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 • Multi-layer contracting
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 • Site congestion • Uncertainty of hazards
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 • Time pressure

A graphical model could be useful in developing a strategy to reduce fatalities. Figure 2 shows a proposed construction incident causation model. A designer creates a set of plans. The contractor(s) implement the design using whatever means and methods necessary to get the job done. Hazards (e.g., falls, contact with objects, harmful substances, transportation) may be created during this process. Ideally, the general contractor, subcontractors and workers should interact to eliminate or guard hazards before an incident occurs. However, hazards and causal factors can be random and change with time. Deficiencies in management, equipment problems, unsafe worksite conditions, worker actions and conditions unique to construction can leave hazards unprotected. Additional hazards can arise any time during construction from one

or more of the causal categories. It is the interaction and coincidence in time and space between the hazard(s) and the causal factor(s) that causes an accident.

Role of Stakeholders

The construction incident causation model suggests that the number of incidents can be reduced by paying close attention to hazards and the causal factors. The more hazards and causal factors that are acted on, the less of a chance of an incident. Table 6 shows a matrix of stakeholder responsibilities versus each causal factor category.

Table 6
Construction Accident 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 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 subcontractors with good safety records • Frequent site inspections	• Frequent site inspection	
Workers			• Raise awareness	• Raise awareness	• Work safety • Work according to training

Unique to construction			• Regular breaks • Treat temporary /day workers as own	• Regular breaks • Treat temporary /day workers as own	

First, hazards should be eliminated to the extent possible. Design professionals can take the lead by considering and anticipating hazards, then designing them out so workers are not exposed. Owners can be helpful by encouraging and supporting designers. Owners should consider that a short-term increase in design fees can have greater payoffs in life cycle costs and a successful, safe project. Let's look at falls, which account for nearly one-third of fatalities. The top four fall hazards involve scaffolds, ladders, roof edges and lower levels. Design features that can reduce scaffold incidents include:

- 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, which can be used to service lighting

- Davits can be installed so that a permanent suspension system will always be available whenever scaffolding is needed. Falls from ladders occur when workers use the wrong portable ladder, a defective portable ladder, or do not use the ladder properly. Designing permanent, safe stairways or fixed ladders eliminates the need for a portable ladder (Photo 12).

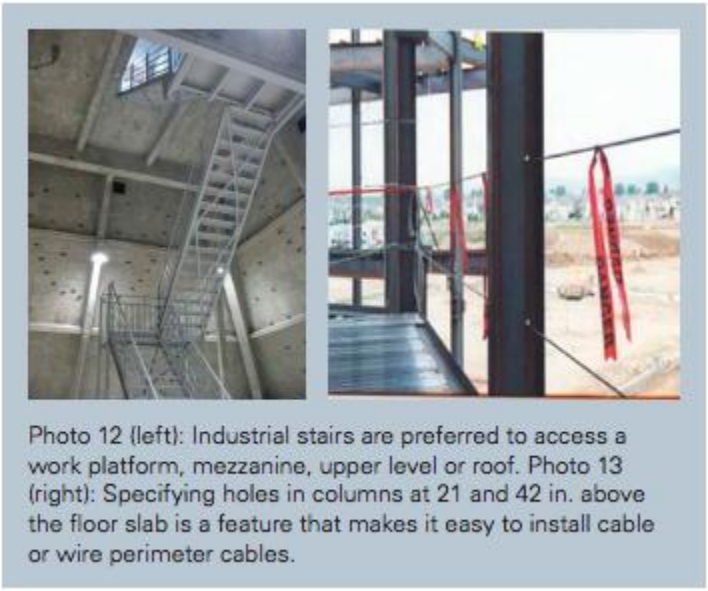


Photo 12 (left): Industrial stairs are preferred to access a work platform, mezzanine, upper level or roof. Photo 13 (right): Specifying holes in columns at 21 and 42 in. above the floor slab is a feature that makes it easy to install cable or wire perimeter cables.

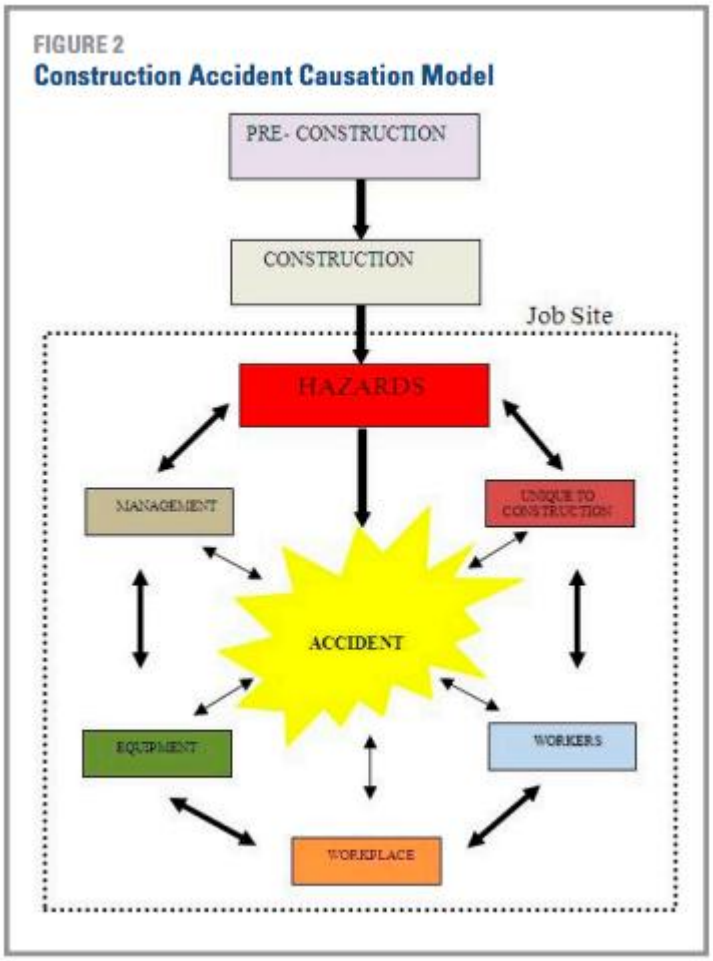
Install stairways as early as possible in the construction phase so that ladders are not needed. Falls from roof edge occur because a worker does not have a safe place to tie off, does not bother to use fall protection, or ties off to a structure that is not structurally sound. A parapet wall that also 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 is a feature that makes it easy to install cable or wire perimeter cables. 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 is left hanging (Photo 13). Eliminating hazards in the design stage will reduce a significant percentage of incidents, but not all. Hazards can arise during the means and methods of construction. General contractors should conduct regular inspections and take oversight responsibility. Subcontractors also must conduct regular inspections with respect to their work. Workers who discover an open hazard or create a hazard should alert the supervisor so that others 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 they create into practice, the workers will care less. The general contractor has a large role in this regard because it is the only employer on the site that is aware of 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 and frequent schedule. Any open hazards should be promptly addressed. Work should be stopped if any employee 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 safety 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. They should require and follow up that all workers are trained. The subcontractors should follow the GC safety plan and their own plan. The subcontractors must make sure their workers are trained. All contractors should ensure that proper equipment is used on the site, and that equipment is maintained in good working order. Unsafe equipment should be set aside and secured so that it cannot be used until it is repaired or replaced. For example, damaged ladders should either be destroyed or chained and locked so that a worker looking for a ladder does not use it. Workers should work safely according to their training. Contractors can help by raising safety awareness. Workers should feel free to alert their supervisors of any unsafe conditions. A number of measures can be taken regarding those factors unique to construction. Contractors should provide regular breaks for the workers. Stretching exercises can also be helpful. Transient workers should be trained as if they were permanent employees.

Conclusion

The nature of construction work makes it difficult to create safe, stable works zones. Construction workers are subject to a wide range of hazards such as electricity, toxic substances, work at height, moving vehicles, trenches, chemicals and confined spaces. Construction projects move fast and hazards can be unpredictable. Workers must deal with physically demanding work. They often must make their own site decisions. Workers may be distracted, fatigued, untrained or have language barriers. Safety responsibilities can become decentralized with multiple employers on site. Fatalities are multi-causal resulting from the random interaction of hazards with deficiencies in management, equipment, workplace, workers and conditions unique to construction. The hazards and the causal factors change with time. A construction incident model (Figure 2) illustrates the multi-causal nature of construction incidents and the random interaction.



Each stakeholder (e.g., design professionals, general contractors, subcontractors, workers, owners) has a role to play in a team effort to reduce hazards and causal factors. Design professionals can take the lead by eliminating hazards with well-thought-out designs. Eliminating a hazard or reducing the risk whenever possible will minimize bad site decisions and other actions that cause incidents. The GC is specifically tasked with monitoring and coordinating the work of the 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 the work.
- Mandate that all workers be adequately trained.
- Monitor the site regularly 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 must follow.

- Require that subcontractors provide a safety plan for their specific work.

Subcontractors must train their workers 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 and the employees of other employers on the site. Raising awareness can also help. Managers can conduct a safety stand-down by taking a break 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. They should support designers to reduce potential hazards in their designs whenever possible. Construction will continue to be a dangerous industry for workers. The steps taken by several groups and agencies have created a downward trend in the fatality rate. However, the fatality rate is still unacceptable. An understanding of how construction incidents happen has been presented. A team effort involving design professionals, general contractors, subcontractors, workers and owners will make further headway in the reduction of construction fatalities.

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