Construction Design
Its Role in Incident Prevention

By Mohammad Kasirossafar and Farzad Shahbodaghlou

IN BRIEF
- Construction remains a highly hazardous industry. The prevention through design (PTD)/design for safety (DFS) concept is receiving greater attention as an effective way to eliminate many hazards.
- This article analyzes the relationship between construction incidents in Iran and project design. The results indicate that 33% of incidents were related to design elements.
- PTD/DFS requires collaboration of all stakeholders, development of new design standards and regulations, and improved availability of PTD/DFS tools.

Being proactive in regard to prevention and mitigation is always more cost effective than reacting to construction incidents. Project owners who hire safety-conscious design teams can also benefit from lower insurance premiums and lower overall project costs.

Occupational incidents cause about 321,000 deaths and 317 million injuries worldwide each year (International Labor Organization, 2013). In Europe, 9.5 fatalities were reported per 100,000 construction workers in 2006. In the U.S., 1 in 5 worker deaths occur in construction (BLS, 2014). According to official statistics in Iran, almost 37% of all industrial incidents (including fatalities and lost-time cases) occur on construction projects despite the fact that construction accounts for only 14% of total employment in Iran according to its Ministry of Labor and Social Affairs.

Despite a lingering perception that most incidents are due to worker negligence, the concept of designing for construction safety is viewed as a viable intervention to improve worker safety (Gambatese, 2004). Construction incidents cause delay, increase cost and can damage a contactor's reputation. Furthermore, hazard identification and risk assessment remain far from ideal in construction. Safety management methods are challenged by lack of communication (e.g., not sharing incident reports, limited resources for risk analysis on smaller projects).

New emphasis on sustainable construction brings with it an increased focus on protecting workers from injury and illness. Traditionally, designers have not participated in efforts to identify and prevent hazards, yet root-cause analysis reveals that design can affect construction worker safety and health (Behm, 2005; Gambatese, Behm & Rajendran, 2008; Gambatese & Hinze, 1999; Toole & Gambatese, 2008). Although it is more efficient to design safety into a process than to manage safety within a process that is naturally unsafe, designers are generally not conscious of their effect on construction safety, nor do they have the required knowledge and experience to play an efficient role in safety issues.

Designing for safety (DFS), also known in the OSH community as prevention through design (PTD), attempts to address this shortcoming. It can be used to attain sustainability through design and ensure maximum levels of safety, energy and environmental returns for workers, the public and the environment. In Iran, no incentives, legal or otherwise, are in place to convince designers to accept PTD/DFS as a standard practice. One main obstacle to this idea is the nature and form of construction projects. The design phase is often performed in isolation from the construction phase. The language and type of contract between owner and designer on the one hand and between owner and contractor on the other hand typically places the responsibility for workplace safety, equipment, methods, techniques, structure and operation squarely on the contractor's shoulders alone (Hinze, 2001).

PTD/DFS addresses worker safety by eliminating or minimizing probable risks in the design of a project's permanent features. For example,

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PTD/DFS can reduce hazards related to working at heights. Selecting prefabricated components, such as prefabricated walls, decreases the number of activities that must be performed at height and, therefore, reduces the risk of fall-related injuries.

Toole and Gambatese (2008) identify four specific trajectories that PTD/DFS is likely to follow:

1) increased prefabrication;

2) increased use of less hazardous materials and systems;

3) increased application of construction engineering;

4) increased spatial investigation and consideration (which includes necessary working distances for each construction trade, and common tools and ergonomic issues such as work overhead or at an awkward angle).

PTD/DFS is based on the premise that "one of the best ways to prevent and control occupational injuries, illnesses and fatalities is to design out or minimize hazards and risks early in the design process" (NIOSH). Identifying hazards is difficult, especially in large and complex designs; however, PTD tools can provide designers with the necessary resources to recognize risks and eliminate hazards.

The main aim of this study was to establish a relationship between design factors and construction incidents in Iran, then define the extent and magnitude of that link.

Literature Review

Szymberski (1997) suggests that the ability to influence safety is significantly larger in the design phase and that it drastically decreases in subsequent phases. Szymberski's time-safety influence curve (Figure 1) shows how construction safety can be influenced in different project phases.

Designers often cite legal repercussions when expressing their lack of interest in extending their responsibilities for worker safety. Due to legal complications, designers usually avoid participation in safety matters (Hinze & Wiegand, 1992). According to Coble (1997), regulations have had minimal affect on designer participation in improving worker safety.

In 1995, design for safety was required by the U.K. Construction Design and Management (CDM) regulations. The intent was to provide an integrative path that involved designers in safety issues. The regulations also created a new set of responsibilities for the different stakeholders of construction projects. The aim was to bring about a culture change in the industry by requiring all those involved in the development and construction process to consider OSH issues (Baxendale & Jones, 2000).

In 2002, France and some other European countries ratified a set of regulations that place requirements for construction worker safety and health on designers (Behm, 2005; Gibb, Haslam, Hide, et al., 2004). Several regulations in Australia

make designers consider how the structure they design will be safely constructed.

Understanding the economic benefits of PTD/DFS for project owners and other stakeholders is essential for increasing its application in practice. Evidence has verified the positive influence of this approach on cost, time and quality, but additional investigation is needed. Gambatese (2008) presents retrospective evidence that design affects construction site safety but he indicates that one cannot presume that a focus on PTD/DFS would automatically reduce construction incidents and fatalities.

Various studies have concluded that considering safety during the design phase can help avoid fatalities, injuries or incidents, or at least decrease their possibility. Behm (2005) examines the extent to and intensity by which design elements are related to construction incidents. Behm (2005) reviewed 224 randomly selected cases from NIOSH's Fatality Assessment Control and Evaluation program and determined that 42% of fatalities reviewed were linked to project design, which indicates a direct relationship between design and construction safety. Gibb, et al. (2004), evaluated 100 construction incidents and concluded that in almost half (47%), changes in permanent design would have reduced the chance of the incidents.

European Foundation (1991) concluded that 60% of investigated incidents could have been eliminated, reduced or avoided had safety been a greater consideration at the design phase. In a survey of general contractors in South Africa, Smallwood (1996) reports that nearly 50% of the 71 contractors interviewed identified poor design features as a factor that negatively affects construction worker safety. Compared to other project components, design was ranked highest with regard to impact on safety.

Other researchers suggest that designers evaluate the safety-related performance of residential construction designs using a risk-analysis-based approach (Gangolells, Casals, Forcada, et al., 2010). This methodology compares the degree of safety risk level in various construction designs and classifies the significance of the various safety risks for each design. Using this method, designers would be able to compare construction designs

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Figure 1
Time/Safety Influence Curve

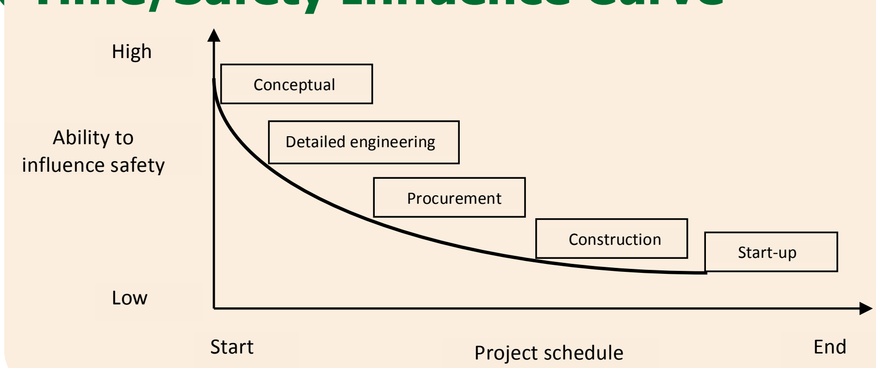

Table 1
Iran's Construction Fatalities Distribution

Fatality type	Percentage
Falls from height	27.2%
Hitting workers with stationary/moving objects	13.5%
Falling materials/objects	8.8%
Becoming caught in/between objects	8.7%
Cuts/blows from objects and tools	12.5%
Thermal contacts or electrical shocks	7.8%
Being hit or run over by vehicles	3.5%
Other types of accident	18%

Note. *Data from Ministry of Labour and Social Affairs,2009.*

and techniques, and, in the design phase, compare their safety risk level and rank the significance of the various safety risks for each design.

Designers can take several practical actions into consideration to improve construction worker safety. These include asking the contractor how work will be performed, determining component sizes for safe installation and managing the plan for safe work sequencing (Atkinson & Westall, 2010).

Designers can also use various PTD/DFS tools to recognize risks and hazards. The tools are typically categorized in four groups (Gambatese, 2008):

1) checklist-based (e.g., ToolBox);
2) risk assessment forms (e.g., ToolSHeD);
3) design review tools (e.g., CHAIR);
4) 3-D/4-D computer-aided design (CAD) and building information modeling (BIM) (e.g., Revit).

BIM technologies and 4-D CAD can be used to identify project hazards and work in conjunction with PTD/DFS initiatives to improve safety planning. BIM and other visualization tools can help design teams identify hazardous situations. To make BIM more applicable for the PTD/DFS concept, one must first integrate construction materials, equipment and workers into the model for better visualization and simulation. The next step is to add safety hazards to the 3-D model with the support of a hazard database system (Kasirossafar & Shahbodaghlou, 2012).

Study Methods

In this study, the authors attempted to link design issues to construction incidents through a review of cases from Iran as reported by the Iranian Social Security Organization. To achieve this, the team selected reports from a pool of 681 construction incident reports collected by the Iranian Social Security Organization from March 2005 to March 2006. For this study, 100 incidents from this collection were randomly selected. The distribution of fatalities for these selected cases is similar to the distribution of fatalities in Iran (Table 1).

Sample Size Determination

A chi-square test was used to determine whether the incident was related to design, and whether a relationship existed between the four specific characteristics of construction projects. Cramer's V is a statistic measurement of the strength of association or dependency between the variables. Significance level (standard alpha) is a threshold value used to show whether test statistics are statistically significant. The values of 0.05 or even 0.01 are traditional values for standard alpha; in this study, 0.05 was used. Effect size is the magnitude of the effect under the alternate hypothesis. Based on Cohen's definition and the National Survey of Student Engagement, the effect size is assumed to be 0.30 (medium).

Incident Investigation Model

The model used for this study contained three yes/no questions:

1) Did the incident damage the structure, did the damage occur in physical aspects of the project and is the damage related to the design?

2) Is there any existing design suggestion that could decrease the risk of an incident?

3) Is it possible to establish new design suggestions to minimize the risk of an incident?

If at least one question was answered "yes," then the incident was considered linked to design. Behm (2005) also used this model. The investigation model uses the objective list of design suggestions developed by Gambatese (2004).

Model Reliability

Question 1 evaluates the link between a project's physical aspects and an incident. For example, a roofing worker fell through the non-load-bearing corrugated fiberglass panels (indistinguishable from those designed as a walking surface). A different design would have considered an appropriate walking surface for roofing activities or for fall-from-height incidents (e.g., providing inserts or other devices to attach fall protection lines would have prevented the incident).

Question 2 establishes model reliability. In the same fall-from-height incident, designing the parapet with the appropriate height was linked to the incident. Questions 1 and 2 could be answered by anyone with access to investigation reports and a complete list of existing design suggestions.

Question 3 is subjective. It depends on the respondent's familiarity and knowledge of PTD/DFS. For example, one suggestion is to design scaffolding tie-off points into exterior walls of building. For this study, three experts (a designer, a contractor and a safety professional) were selected to answer the questions. The number of errors would be small and limited, since those who replied were from three different groups. The designer may be inclined to ignore the relationship between design and occupational safety; a contractor, due to separation of the construction phase from design, may tend to relate more incidents to design issues; and a safety specialist would assess a spectrum of contributing factors. If at least two of the three experts answered a question "yes," then the answer to that specific question is determined to be "yes."

Results

The research team's review found that 33% of cases were related to project design. Based on this, one can conclude that applying PTD/DFS tools would reduce construction incidents.

Table 2 summarizes the percentage of incidents by designer discipline. For example, in case of an electrical incident, we would look at the electrical design discipline. The chi-square numbers obtained for the analysis were $p = .034$, Cramer's $V = 0.29$, demonstrating the relationship.

In the selected cases, architects were identified as the discipline with the most influence in construction site safety through design.

When the type of construction project was considered, results showed that 31% of cases happened in residential projects, 42% in commercial projects, 17% in industrial projects and 10% in heavy and civil engineering projects. Analysis showed no connection between project type and design elements ($p = .36$).

The research team also considered contract type—public, private or a public-private partnership—to assess any relationship to the design concept. Results show that 51% occurred on public-private partnership projects, 32% on private projects and 17% on public projects. It was concluded that the type of construction contract had no relationship to design-related incidents ($p = .47$).

The research team also examined the relationship between design-related incidents (33% of cases) to the design element being constructed when the incident occurred ($p = .0026$, Cramer's $V = 0.32$). Construction Specification Institute (CSI) categorizes elements in 16 divisions (Table 3). Each design element was tested to find a relationship and to identify specific elements that should be redesigned or carefully considered during the design process. The category of metals and site work received 40% and 36% more "yes" responses, respectively, than the expected frequency assumption of a chi-square test. This finding suggests that many PTD/DFS suggestions can have a positive effect (e.g., fall prevention where lifeline systems and fall protection measures could be designed into a building's permanent features).

The results of this review indicate that identifying and eliminating hazards during the design phase is likely feasible and economical. To fully realize the PTD/DFS concept, the design profession must undergo a substantial cultural change since most designers do not wish to get involved in safety. In addition, involving contractors early in the design process creates a collaborative process that brings together design expertise and means and methods expertise to improve safe work practices.

Conclusion

Construction incidents affect social and environmental sustainability, slow project pace and add to overall cost. One effective way to prevent and control construction incidents is to minimize their likelihood during the design phase. The main goal of PTD/DFS is to reduce risk through the appropriate selection of various design options.

This study aimed to confirm a relationship between construction incidents in Iran and design-related factors. Results show that 33% of cases reviewed were associated with design elements. In Iran project delivery systems are moving rapidly from traditional design-bid-build methods to design-build projects. This will encourage seamless design and construction and potentially produce better design and closer inspection. However, even when designers and contractors work together in a common space, major safety challenges remain. The main responsibility for worker safety is still often put squarely on contractors. As long as this thinking prevails, designers cannot live up to their full potential in improving construction safety.

Since designers often have no inclination to address job site safety, they lack necessary knowledge and experience in this area. Therefore, it is necessary to start discussions with designers at the funda-

Table 2
Incidents by Designer Discipline

Discipline	Percentage
Architectural	32%
Structural	30%
Civil	18%
Mechanical	10%
Electrical	10%

Table 3
Incidents by Design Element

Design element	Percentage
General requirements	0%
Site work	28%
Concrete	8%
Masonry	3%
Metals	19%
Wood and plastics	1%
Thermal and moisture	13%
Doors and windows	3%
Finishes	5%
Specialties	0%
Equipment	8%
Furnishings	0%
Special construction	0%
Conveying systems	0%
Mechanical	5%
Electrical	7%

Identifying and eliminating hazards during the design phase is likely feasible and economical. To fully realize the PTD/DFS concept, the design profession must undergo a substantial cultural change. In addition, involving contractors early in the design process will create a more collaborative process.

mental level. Another effective action might be to add safety-related instructions to the design curriculum at the university level. Various standards and regulations (e.g., CDM) encourage designers to identify construction safety risks and mitigate them at the design phase. Similar regulations enacted worldwide could lead to greater designer involvement in construction safety.

Construction safety is affected by many factors. It is vital to remember that design is only one of those factors. Therefore, the PTD/DFS concept should be applied in parallel with planned proactive measures in order to decrease the rate of incidents as well as improve worker safety. **PS**

References

ASSE. (1994). Position paper on designing for safety. Des Plaines, IL: Author.

Atkinson, A.R. & Westall, R. (2010). The relationship between integrated design and construction and safety on construction projects. *Construction Management and Economics, 28*(9), 1007-1017.

Baxendale, T. & Jones, O. (2000). Construction design and management safety regulations in practice: Progress on implementation. *International Journal of Project Management 18*, 33-40.

Behm, M. (2005). Linking construction fatalities to the design for construction safety concept. *Safety Science, 43*(8), 589-611.

Bureau of Labor Statistics (BLS). (2014). Census of fatal occupational injuries. Retrieved from www.bls.gov/news.release/cfoi.nr0.htm

Coble, R. (1997). Knowing your role in construction safety to avoid litigation. *Journal of the American Institute of Constructors, 21*(3), 25-28.

Esabati, M. (2012). Safety recommendations of construction inspection director for land preparation and excavation phases. Ministry of Labor & Social Affair, Iran: Retrieved from http://bazresikar.mcls.gov.ir/fa/home/tosieemeni

European Foundation. (1991). From drawing board to building site (Publication No. EF/88/17/FR). Retrieved from http://bit.ly/1G9QETI

Gambatese, J.A. (1996). *Addressing construction worker safety in the project design.* (Unpublished doctor dissertation). University of Washington, Seattle, WA.

Gambatese, J.A. (1998). Liability in designing for construction worker safety. *Journal of Architectural Engineering, 4*(3), 107-112.

Gambatese, J. (2004). An overview of design-for-safety tools and technologies. *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium, USA,* 109-117 .

Gambatese, J.A. (2008). Research issues in prevention through design. *Journal of Safety Research, 39*(2), 153-156.

Gambatese, J.A., Behm, M. & Rajendran, S. (2008). Design's role in construction accident causality and prevention: Perspectives from an expert panel. *Safety Science, 46*(4), 675-691.

Gambatese, J.A., Hinze, J. & Behm, M. (2005). Viability of designing for construction worker safety. *Journal of Construction Engineering and Management, 131*(9), 1029-1036.

Gambatese, J.A, Hinze, J. & Haas, C. (1997). Tool to design for construction worker safety. *Journal of Architectural Engineering, 3*(1), 32-41.

Gangolells, M., Casals, M., Forcada, N., et al. (2010). Mitigating construction safety risks using prevention through design. *Journal of Safety Research, 41*(2), 107-122.

Gibb, A., Haslam, R., Hide, S., et al. (2004). The role of design in accident causality. In S. Hecker, J. Gambatese and M. Weinstein (Eds.), *Designing for safety and health in construction* (pp. 11-21). Eugene, OR: University of Oregon Press.

Haslam, R.A., Hide, S.A., Gibb, A.G.F., et al. (2003). Causal factors in construction accidents (Health and Safety Executive Report RR 156). Retrieved from www.hse.gov.uk/research/rrpdf/rr156.pdf

Health & Safety Executive. (1994). Construction (design and management) regulations (Statutory Instrument No. 3410). London, U.K.: Author.

Hinze, J. (2001). *Construction contracts* (2nd ed.). New York, NY: McGraw-Hill.

Hinze, J. & Wiegand, J. (1992). Role of designers in construction worker safety. *Journal of Construction Engineering and Management, 118*(4), 677-684.

Huang, X. & Hinze, J. (2006). Owner's role in construction safety. *Journal of Construction Engineering and Management, 132*(2), 164-173.

International Labor Organization. (2013). World Day for Safety and Health at Work 2013. Retrieved from www.ilo.org/safework/events/meetings/WCMS_204594/lang--en/index.htm

Kasirossafar, M. & Ghaderi, R. (2011). Construction safety in design process, *Proceedings of the 2011 Architectural Engineering Conference, Oakland, CA, USA.*

Kasirossafar, M. & Shahbodaghlou, F. (2012, Oct). Application of visualization technologies to design for safety concept. *Proceedings of 6th Congress on Forensic Engineering, San Francisco, CA, USA.*

Ku, K. & Mills, T. (2010). Research needs for building information modeling for construction safety. Retrieved from http://ascpro.ascweb.org/chair/paper/CPGT159002010.pdf

Manuele, F.A. (2008, Oct.). Prevention through design: Addressing occupational risks in the design and redesign processes. *Professional Safety, 53*(10), 28-40.

NIOSH. Prevention through design. Retrieved from www.cdc.gov/niosh/topics/ptd

Smallwood, J.J. (1996). The influence of designers on occupational safety and health. *Proceedings of the First International Conference of CIB Working Commission W99, Implementation of Safety and Health on Construction Sites, Portugal*, 203-213.

Szymberski, R. (1997). Construction project safety planning. *TAPPI Journal, 80*(11), 69-74.

Toole, T.M. & Gambatese, J. (2008). The trajectories of construction prevention through design. *Journal of Safety Research, 39*(2), 225-230.

Trethewy, R. & Atkinson, M. (2003). Enhanced safety, health, and environmental outcomes through improved design. *Journal of Occupational Health and Safety, 19*(5), 465-475.

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