ELSEVIER

Automation in Construction 8 (1999) 643–649

AUTOMATION IN CONSTRUCTION

www.elsevier.com/locate/autcon

Addressing construction worker safety in the design phase Designing for construction worker safety

J. Gambatese [*,1], J. Hinze

University of Washington, Seattle, WA, USA

Accepted 29 October 1998

Abstract

Facility designers can positively influence construction site safety by integrating safety considerations into the design process. Although their potential influence on safety has been documented, designers typically lack knowledge of and limit their involvement in construction worker safety. This research effort involved the accumulation of suggestions for improving construction worker safety while in the design phase. Using these design suggestions, a design tool has been developed to assist designers in identifying project-specific safety hazards and to provide best practices to eliminate the hazards. Although use of the design tool is voluntary in the United States, it is one resource which can be used by designers to fulfill their obligations required by the Construction (Design and Management) Regulations in UK. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Construction worker; Design; Hazards; Injuries; Safety

1. Introduction

In the past decade, construction worker safety has become a major concern of the United States construction industry. This is due in part to the high costs associated with construction worker injuries, including the costs of workers' compensation insurance, the indirect costs of injuries, the increased chance of liability suits, and also the rise in criminal prosecutions of employers who allow work in unsafe conditions. While many construction parties might ultimately bear a portion of these costs, the responsibility has primarily been placed on the employer, typically the general contractor.

Through the highly litigious nature of the U.S. construction industry, many parties have been brought into litigation regarding worker injuries. This is especially true of owners, a party to the construction project which is often viewed as possessing the most resources. As a result, many owners have become more concerned about safety performance on their projects. Increased concern is evident in contract language which has tended to become more proactive on safety. It is also evidenced through the increased role that owners now play in monitoring

* Corresponding author

[1] Present address: Department of Civil and Environmental Engineering, University of Nevada, 4505 Maryland Pkwy, Las Vegas, NV, USA.

0926-5805/99/$ - see front matter © 1999 Elsevier Science B.V. All rights reserved.
PII: S0926-5805(98)00109-5

project safety during construction. In addition, owners commonly award contracts to firms who have demonstrated the ability to deliver projects safely.

Despite the changes that have taken place in past years, there remains one party that has not been involved in safety. This party is the designer. Safety has been a topic which, all too often, is overlooked until the start of the construction phase. This practice ignores the effect that designers have on construction safety. Perhaps no one has previously considered the role that designers play in influencing construction safety.

Designers play a very real role in influencing construction worker safety. It is the design that dictates how a project will appear and how a particular project or its components will be assembled. The methods of assembly are often not recognized as being dictated by the designers. In reality, designers influence many decisions about how construction tasks are undertaken. Unfortunately, designers have not been cognizant of their influence and, as a profession, they have not acknowledged the importance or relevance of their role in safety. Some designers have stated that, in order to minimize their liability exposure, they deliberately avoid addressing construction safety.

In the United States, designers are being encouraged by some owners to specifically address construction worker safety in their designs. Designer involvement in the U.S. has largely been a voluntary effort. A clear shift from this is occurring in Great Britain where recently enacted legislation, titled Construction (Design and Management) Regulations [1], has imposed an obligation on designers to address safety during the construction phase.

A common problem designers mention when their influence on safety is intimated is that they lack the skills and training to address construction worker safety. While they might admit that their designs impact safety performance, they contend that they do not know how to change their designs to improve or ensure safety. This brings up the need for a central body of knowledge available for designers to address safety in their designs.

Some designers, especially those in design–build firms, already address construction worker safety in their designs. These designers, of course, work with their fellow colleagues who are responsible for construction of the project. By working together in the same firm, they begin to appreciate each other's concerns. For example, the construction personnel might alert the designer of how a particular connection could hinder worker safety. Good ideas will be remembered and used on subsequent projects. It is unfortunate that this design knowledge is not accumulated and stored in a central location for all designers to access. The development of a central body of knowledge is an important first step in improving the way that safety is addressed by designers. This body of knowledge must then be shared by some means with the design community.

2. Literature search

Ideas on how to design for construction worker safety have not been well-publicized in the past. Literature discussing the subject is sparse. Research and publications on construction worker safety has mainly focused on the constructor's role because Occupational Safety and Health Administration (OSHA) places the responsibility for safety on the employer's shoulders. The importance of the designer's role in safety has only been briefly mentioned. There is evidence of a need to educate and involve the design community [2], and to eliminate the 'hands off' attitude designers often express towards construction worker safety [3].

A recent study on the role of designers in construction worker safety provides the most relevant information about design decisions concerning safety [4]. The study consisted of surveying design firms and firms conducting constructability reviews regarding their involvement in safety. Conclusions from the study indicate that ''for safety of construction workers to be addressed by designers on a regular basis or as an integral design function on all projects, a dramatic change must occur in the mindset of the design profession.'' The authors recommend that ''one of the means by which designers can become more responsive to the safety needs of construction workers is through education. Designers must be made aware of the various means by which their design decisions impact the jobsite safety conditions for construction workers. Such an educational process could begin with a compilation of the various

design approaches that have successfully addressed construction worker safety on past projects.''

3. Research methodology

The main objective of this research was to search for and develop design suggestions or 'best practices' which could be implemented in the design phase in order to improve safety during construction. The accumulated design suggestions would form the database of knowledge for a design tool to facilitate their implementation.

To fulfill the objective of compiling design suggestions, the research effort focused on the construction community itself. The goal of this effort was to compile as many design suggestions as possible. All safety suggestions applicable to the design phase of any type and size of project were recorded. No design suggestions were discarded based on cost, schedule, relative risk reduction, or other design or construction performance criteria.

Although designing for construction worker safety has only recently been publicized, it was anticipated that some ideas have been developed and are currently in use. Existing design suggestions were sought from two resources: construction industry literature and personnel. As part of the literature search described above, academic research and industry work presented in various publications were reviewed for applicable design suggestions. All design suggestions found were extracted and noted.

In addition to the literature search, construction industry personnel were contacted to solicit existing design suggestions. In-person and telephone interviews were conducted to directly access their knowledge and gain from their past experiences. Major public and private parties involved in construction projects, including owners, designers, constructors, design-builders, and construction managers, were interviewed. In order to reflect the entire breadth of the construction industry, firms of various design and construction disciplines were targeted. So that hazards of all types would be addressed, the interviews focused on firms of various sizes and on personnel involved in a diversity of projects. Personnel employed at a variety of levels within a firm were interviewed to gain information which reflected various levels of work experience.

In addition to the search for existing best practices to improve construction site safety, the research effort included the development of additional design suggestions. Three resources were accessed for developing additional design suggestions: worker safety manuals, safety design manuals and checklists, and the research team's personal knowledge and experience.

It was felt that additional design suggestions could be developed from a review of typical construction site hazards and the safety measures prescribed to eliminate or reduce those hazards. The first source utilized to develop design suggestions was worker safety manuals, such as the OSHA, Army Corps of Engineers, and other state construction safety manuals. These manuals were created to provide guidance for safety practices and conditions on construction sites, and to direct and regulate construction site safety. In reviewing these manuals, an attempt was made to develop design suggestions which would eliminate the need to apply the safety measures or the dangers experienced during implementation of the safety measures.

Another source of suggestions was safety design manuals and checklists. Many large companies, as well as state and national agencies, use safety design manuals or checklists to address safety in terms of the 'end-user', such as the office worker, motorist, or plant operator. A review of these manuals and checklists by the researchers focused on applying the techniques used for enhancing end-user safety to safety during construction.

4. Research results

To date, the research effort to collect design suggestions has been very successful. Since the start of the research in early 1994, over 400 design suggestions have been accumulated. All of the design suggestions are included in the final working version of the design tool.

All of the targeted resources proved to be valuable sources of design suggestions. Table 1 reveals that the majority of suggestions came from safety design manuals and checklists. A good proportion also came directly from the researchers and research team members and through interviews with industry

Table 1
Design suggestion sources

Source	Number of suggestions	(%)
Safety design manuals and checklists	140	35.4
Researchers and research team members	98	24.8
Interviews (in-person, telephone)	80	20.3
OSHA (CFR, publications, data)	34	8.6
Journal articles and periodicals	29	7.4
Other	14	3.5
Total	395	100

personnel. Safety design manuals and checklists typically address hazards during the startup, operation, and maintenance phases of a project. This resource was particularly fertile due to the close relationship between the construction and startup phases, and the construction and maintenance phases. As a result, the design tool will also be useful for improving safety in the startup and maintenance phases.

The relative success of the interview process can be attributed to the construction industry's interest and willingness to improve safety. This process revealed that personnel in construction and design–build firms were able to contribute a substantial amount of information. These types of firms are directly affected by construction worker accidents and injuries, and their personnel know the inherent hazards in specific designs. Personnel in architectural and consulting engineering firms were not as knowledgeable concerning design suggestions, possibly resulting from a lack of formal education about construction worker safety and their minimal involvement in overseeing jobsite safety.

On-site personnel and others who frequently visit jobsites provided the most design suggestions. These individuals are involved in day-to-day construction activities and regularly address jobsite hazards. Similar design suggestions were offered by personnel who are involved in the design and construction of similar types of facilities.

The great diversity of the construction industry led to the accumulation of design suggestions which reflect all types of design disciplines, project components, and jobsite hazards. With respect to design disciplines, as shown in Table 2, the most significant number of suggestions address the structural and architectural features of work. Suggestions may relate to more than one design discipline.

The accumulated design suggestions can also be sorted according to what project component is affected. Table 3 reveals that piping was addressed most often, followed by electrical/instrumentation and mechanical/HVAC components. Similar to the design disciplines described above, each suggestion may apply to more than one project component.

Components typically designed by the structural engineer (foundation, structural framing, slab-on-grade, floor, roof, stairs, ladders, ramps, walkways, platforms) were addressed a total of 145 times (36.7%). Similarly, components typically within the architect's scope of work (furnishings, finishes, project layout, structure plan/elevation, doors, windows, handrails, guardrails), together with the work schedule/sequence, were addressed a total of 120 times (30.4%). These percentages are echoed in the significant number of suggestions which relate to the structural and architectural disciplines shown in Table 2.

All types of construction site hazards are addressed by the design suggestions. The majority of the suggestions, as shown in Table 4, relate to hazards that may result in falls, followed by electrical shocks, cave-ins, and explosions. Many falls on construction sites occur due to the structural and architectural scope of work—the design of beams, columns, walls, stairways, ladders, etc. Thus, the

Table 2
Design disciplines addressed by design suggestions

Design discipline	Number of times addressed	Percentage of recorded suggestions[a]
Structural	131	33.2
Architectural	120	30.4
Piping/plumbing	76	19.2
Mechanical/HVAC	68	17.2
Electrical/instrumentation	67	17.0
Civil/transportation	64	16.2
Construction management	56	14.2
Other	23	5.8
Total	605	

[a] Since design suggestions may address more than one design discipline, these numbers (expressed as a percentage of the 395 recorded suggestions) exceed 100%.

Table 3
Project components addressed by design suggestions

Project component	Number of times addressed	Percentage of recorded suggestions[a]
Piping	69	17.5
Electrical/instrumentation	56	14.2
Mechanical/HVAC	54	13.7
Structural framing	47	11.9
Stairs, ladder, ramp	43	10.9
Work schedule/sequence	40	10.1
Roads, paving, flatwork	32	8.1
Slab-on-grade, floor, roof	30	7.6
General conditions/ special provisions	26	6.6
Earthwork, sewer, etc.	24	6.1
Furnishings, finishes	20	5.1
Structure plan/elevation	19	4.8
Door, window	16	4.1
Project layout	15	3.8
Foundation	14	3.5
Tank, vessel	14	3.5
Technical specifications	13	3.3
Walkway, platform	11	2.8
Contract drawings	10	2.5
Handrail, guardrail	10	2.5
Total	563	

[a]Since design suggestions may address more than one project component, these numbers (expressed as a percentage of the 395 recorded suggestions) exceed 100%.

resulting large number of suggestions related to falls is expected based on the large number of suggestions related to structural and architectural disciplines and components noted in Tables 2 and 3.

The construction site hazards addressed by the design suggestions are distributed in a manner similar to OSHA's fatality statistics. OSHA's analysis of construction fatalities from 1985 to 1989 [5] revealed that the majority of fatalities (33%) were due to falls from elevation. This is comparable to the percentage of suggestions recorded that relate to fall hazards (33.7%). Similarly, the percentage of suggestions recorded that relate to electrical shock hazards (14.9%), is close to OSHA's reported electrocutions that amounted to 17% of all fatalities. Although OSHA statistics show that 'struck by' and 'caught in/between' hazards are responsible for 22% and 18% of the fatalities, respectively, similar high percentages are not reflected in the distribution of recorded suggestions. This is probably due to the additional categories that are reflected in Table 4, many which might be regarded as subsets of struck by and caught in/between.

The following is a sample of the design for safety suggestions recorded:

(1) *Suggestion*: design components to facilitate pre-fabrication in the shop or on the ground so that they may be erected in place as complete assemblies.

Purpose: reduce worker exposure to falls from elevation and being struck by falling objects.

(2) *Suggestion*: design parapets to be 42 in. (1.07 m) tall.

Purpose: while the Uniform Building Code standards require parapets to be just 30 in. tall (0.76 m), modifying the design to increase the parapet height to 42 in. (1.07 m) would also satisfy OSHA guardrail requirements. This modification eliminates the need to construct guardrails during construction, and also during future roof maintenance operations.

(3) *Suggestion*: design beam-to-column double-connections to have continual support for the beams during the connection process by adding a beam seat, extra bolt hole, or other redundant connection point.

Purpose: continual support for beams during erection will eliminate falls due to unexpected vibrations, mis-alignment, and unexpected construction loads.

Table 4
Construction site hazards addressed by design suggestions

Construction site hazard	Number of times addressed	Percentage of recorded suggestions[a]
Falls	133	33.7
Electrical shock	59	14.9
Cave-in	53	13.4
Explosions	52	13.2
Fire	41	10.4
Toxic substances	33	8.4
Work area	31	7.8
Environment/climate	28	7.1
Vehicular traffic	25	6.3
On-line equipment	20	5.1
Struck by objects	20	5.1
Worker issues	18	4.6
Obstructions	17	4.3
Heavy equipment	12	3.0
Confined spaces	10	2.5
Caught in/between	6	1.5
Lighting	5	1.3
Total	563	

[a]Since design suggestions may address more than one jobsite hazard, these numbers (expressed as a percentage of the 395 recorded suggestions) exceed 100%.

(4) *Suggestion*: allow adequate clearance between the structure and overhead power lines. Bury, disconnect, or re-route existing power lines around the project before construction begins.

Purpose: overhead power lines which are in service during construction are hazardous when operating cranes and other tall equipment.

(5) *Suggestion*: design and schedule a permanent stairway to be constructed at the beginning, or as close as possible to the start, of construction.

Purpose: timely erection of permanent stairways can help eliminate fall and other hazards associated with temporary stairs and scaffolding.

Included in the research effort was the compilation of the recorded design suggestions into a design tool. The main objective of the design tool was to provide a simple means by which a designer could be alerted of project-specific construction safety hazards, and be introduced to a variety of design suggestions which would eliminate or reduce the identified hazards. To fulfill this objective, a computer program, titled Design For Construction Safety ToolBox, was created.

The program allows the user to access the suggestions by focusing on the project in one of three ways or paths: project components, construction site hazards, or project systems. Regardless of the path taken, the user has complete access to all of the design suggestions. All of the topics within each category can be independently addressed. By selecting a topic (component, hazard, or system), the program narrows its focus to only safety concerns and design suggestions regarding the topic chosen. After selecting a topic, the program presents questions about the project. Answers to the questions guide the program's search for applicable safety concerns and design suggestions. The program then presents safety concerns and various design suggestions to mitigate those concerns.

5. Conclusions

Although interest in construction worker safety in the United States has expanded to owners of construction projects, this interest has not spread throughout the design community. Except for those employed in design–build firms, designers are typically not involved in the safety watch. Designers typically distance themselves from the responsibility for construction worker safety mainly because of their lack of knowledge of safe designs and the possibility of increasing their liability exposure. Today's design codes and regulations in the U.S. reflect this attitude, and worker safety rests on the constructors' shoulders. Currently, no national reference standards exist to bridge the gap between existing design standards and construction worker safety.

In Great Britain, the CDM Regulations have successfully addressed the need for designers to focus on worker safety, and outline mandatory steps for action. The CDM Regulations direct the designer to participate in the identification and reduction of health and safety risks. ''The Regulations are not prescriptive; they avoid setting standards. Emphasis is placed on identifying hazards and the assessment of risk [6].'' The CDM Regulations require designers to play a role in the identification of risks, with limited guidance on how this assessment is to be made. ''Many designers currently lack skills in designing to avoid or reduce health and safety risk and they feel uncomfortable and threatened by the [R]egulations [7].'' ''The challenge facing designers is the ability to seek out and discover or develop other techniques or construction methods to produce the same or similar results than a more inherently high risk option [6].'' ''It is suggested then that the designer develops a methodical approach to recording the design considerations with reasoned outcomes [6].''

Complimenting the British effort, this research takes that next step in addressing construction worker safety. In an effort to provide designers with the required knowledge and tools, design suggestions have been accumulated which provide designers practical examples of how to design for construction worker safety. A workable software package has been developed which can effectively and efficiently address project-specific hazards on all types and sizes of construction projects. The design tool will be useful not only for improving safety in the construction phase of a project, but also during the startup, maintenance, and de-commissioning phases.

While designer involvement in construction worker safety in the U.S. is voluntary, the CDM Regulations are mandatory. The Design For Con-

struction Safety ToolBox is one resource which can be used by designers to fulfill their obligations required by the CDM Regulations in Great Britain. It is interesting that this research seems to have the same general objective as the CDM Regulations. There is little overlap in the actual work, and in fact, the efforts are highly complimentary.

6. Recommendations

Consideration of construction worker safety by designers can eliminate common safety hazards and reduce worker injuries. These benefits lead to a reduction in project costs and liability potential. Although these points are widely understood and accepted, a gap exists between constructors and designers in their knowledge of and commitment to jobsite safety. As a result, information on designing for construction site safety must ultimately be drawn from the construction personnel and transferred to the designers. Designers must be educated regarding designing for construction worker safety. It should be recognized that construction workers are unique facility users and their safety warrants the attention of designers.

Addressing safety in the construction phase not only requires soliciting and publishing design suggestions, but also requires designers to change their traditional mindset. This requires a major education effort in the design community. In the United States, because of the possible increased liability exposure, designers may be reluctant to employ these safety designs. However, this reluctance will be diminished when owners, those employing the designers, insist that designers address construction safety concerns. Thus, owners must provide the initial impetus, by requesting or requiring through contract terms, that designers consider construction worker safety in their designs.

Distribution and use of the design tool will help foster this change in the construction industry. Extensive use of the tool will generate additional design suggestions which can then be cycled back into the software in future versions. Continued use of the tool will also lead to further development of the program's functionality to better fit the needs of the design community.

References

[1] The Construction (Design and Management) Regulations, SI 3140 HMSO (1994).
[2] R.E. Raggs, J. Cunningham, Safety and efficiency in steel construction—the Broadgate experience, Civil Engineering (London) (May 1988) 35.
[3] S. Morpurgo, Accident prevention at dam construction sites, International Water Power and Dam Construction 44 (8) (1992) 13.
[4] J. Hinze, F. Wiegand, Role of designers in construction worker safety, J. Construction Eng. Manage. 118 (4) (1992) 677–684.
[5] U.S. Department of Labor, Occupational Safety and Health Administration, Analysis of Construction Fatalities—The OSHA Data Base 1985–1989 (1990).
[6] R. Joyce, The Construction (Design and Management) Regulations Explained, Thomas Telford Publications, London (1995).
[7] J. Jeffrey, I. Douglas, Safety performance of the UK construction industry, Proceedings of the Fifth Annual Rinker International Conference Focusing on Construction Safety and Loss Control, Univ. Florida (1994) pp. 233–253.