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Abbreviations/Terms

Constructor	Includes construction firms, contractors, and subcontractors responsible for building a project and employing construction workers
Design professional	Includes architects, designers, and design engineers responsible for a project's design
Designing for safety	The consideration of construction site safety in the preparation of plans and specifications for construction projects
Disabling injury	An injury that leaves a worker temporarily or permanently disabled
FACE	NIOSH Fatality Assessment and Control Evaluation program
NIOSH	National Institute for Occupational Safety and Health
OSHA	U.S. Occupational Safety and Health Administration

Contents

The author analyzed 450 reports of construction workers' deaths and disabling injuries to determine whether addressing safety in the project designs could have prevented the incidents.

States and developed a model for tracing the root causes of accidents. Their research addressed activities and conditions at the construction site but did not consider potential root causes in the project concept and design phases. The authors attributed unsafe conditions to four main causes: management action/inaction, unsafe acts of workers and co-workers, events not directly human-related (such as equipment failure and natural disasters), and unsafe conditions that are a natural part of the construction site (such as uneven terrain and concealed ditches). Abdelhamid and Everett's approach is consistent with conventional accident root-cause analysis, focusing solely on the actions and inactions of the constructor, rather than adopting a broader view of accident causality that looks at upstream influences, including the design process.

One recent study of causal factors in construction accidents looked at the designer's role. Haslam and others (2003) studied the causes of 100 construction accidents in the United Kingdom, and found that permanent works designers (synonymous with "design professionals" in the United States) could have reduced the risk associated with the accidents in almost half of the cases. The authors also developed a construction accident causality model that described immediate causes, shaping factors, and originating influences in construction accidents. They concluded that the permanent works design influences the workers' activities, the site, and the materials and equipment specified for construction.

Research Methods

The author obtained and analyzed construction accident investigation reports from OSHA State program offices in California, Washington, and Oregon, and from the NIOSH Fatality Assessment Control and Evaluation (FACE) program. These OSHA offices were selected in part because of their proximity to the author at Oregon State University. Also, the reports from these OSHA offices and the FACE data were publicly available at low or no cost. Statistical methods were used to randomly select reports and to analyze the findings. But this study does not claim to be an accurate statistical sampling of all the available data on construction injuries and deaths.

The author initially conducted a pilot review of 25 Oregon OSHA construction accident inspection reports and determined that enough information was available in these reports to link the accident to the design-for-safety concept. For instance, the reports contained detailed notes about the work site hazards and conditions that contributed the incident. A similar review of the FACE data showed that these reports also contained enough information to determine whether there was an association between designing for safety and the construction accidents.

Selection of OSHA Inspection Reports

Oregon and Washington maintain their OSHA inspection reports in a central office, and reports from all districts in these states were included in the analysis. In California, inspection records are maintained individually by each of the 22 California OSHA (Cal/OSHA) field offices in the district where the inspections occurred. Given time and funding limitations, the author chose to obtain records from four Cal/OSHA field offices located near one another (in Torrance, Los Angeles, Anaheim, and Van Nuys). The following criteria were used to conduct a database search of the OSHA inspection reports from the field offices:

- Investigations triggered by an accident reported to OSHA, resulting in a disabling injury or death of a worker (A disabling injury is one that results in the temporary or permanent disablement of a worker.)
- Cases involving firms in Standard Industrial Classifications (SIC) 15 (Building Construction General Contractors), 16 (Heavy Construction Other than Building Construction

Selection of FACE Data

The FACE program studies deaths resulting from occupational injuries. The program's goal is to prevent work-related deaths by investigating work situations posing a high injury risk to workers and then formulating and disseminating guidance on prevention strategies (NIOSH 2003). The FACE program selects construction deaths for study based on direct requests from OSHA as well as on FACE's special-emphasis programs. For instance, recent FACE investigations in the construction industry have targeted Hispanic workers, young workers, steel erectors, and roofers (Virgil Casini, NIOSH, personal communication, Oct. 23, 2003). The complete investigation reports for all industries, including construction, are publicly available on the NIOSH website (

Here are two examples of how the author applied the investigation model shown in figure 1:

- In a case investigated by OSHA, a residential construction worker died after falling over the side of an unprotected platform at the top of a second story stairway. The author reviewed the report and answered "yes" to all three questions (in figure 1), finding that this incident was linked to the design-for-safety concept. The author determined that implementing the following design suggestion by Gambatese (1996) would have reduced the fall hazard and may have prevented the incident: "design and schedule permanent stairways to be built as soon as possible in the construction phase and used by the construction workers."

- In an incident described in a FACE report, a construction worker died after tripping and falling through a skylight opening. Applying the model, the author answered "yes" to all three questions and thus determined that this incident was linked to the design-for-safety concept. The author found also that the fall hazard and resulting injury may have been prevented by implementing the following design suggestions by Gambatese (1996): "design domed, rather than flat, skylights with shatterproof glass or add strengthening wires and/or design guardrail protection around skylights."

Other examples of how the model was applied are contained in annex A.

Hypothesis Testing

After applying the model and identifying incidents linked to the design-for-safety concept, the author conducted hypothesis testing to determine how the design process or other factors might have affected the incident. For instance, the research sought to determine whether design-linked incidents were related to a specific type of project (residential, commercial, engineering, industrial) or design element under construction at the time of the incident (such as electrical, masonry, and thermal/moisture protection). The aim of this analysis was to identify the design-related efforts that would be most effective in improving worker safety.

Results and Discussion

Table 2 summarizes the results of applying the investigation model (figure 1) to the OSHA and FACE reports. The research findings linking the incidents to specific design suggestions are presented in annexes B and C. Detailed results of the statistical analysis can be obtained by contacting the author at: behmm@mail.ecu.edu. Also, Behm (2005) contains a more detailed description of the results summarized here.

Table 2: Incidents linked to designing for safety

Source of reports	Q1: Physical aspects?			Q2: Existing design suggestion?			Q3: New design suggestion?			Is incident linked to design-for-safety concept?		
	Yes	*Maybe*	*No*	*Yes*	*Maybe*	*No*	*Yes*	*Maybe*	*No*	*Yes*	*Maybe*	*No*
OSHA (n=226)	4 1.8%	8 3.5%	214 94.7%	40 17.7%	4 1.8%	182 80.5%	27 11.9%	4 1.8%	195 86.3%	48 21.2%	9 4.0%	169 74.8%
FACE (n=224)	10 4.5%	0 0%	214 95.5%	78 34.8%	6 2.7%	140 62.5%	42 18.7%	0 0%	182 81.3%	88 39.3%	6 2.7%	130 58.0%
Total (n=450)	14 3.1%	8 1.8%	428 95.1%	118 26.2%	10 2.2%	322 71.6%	69 15.3%	4 0.9%	377 83.8%	136 30.2%	15 3.3%	299 66.5%

As table 2 shows, the author linked 48 (21.2%) of the 226 OSHA-investigated incidents to the design-for-safety concept and categorized 9 (4.0%) as “maybe” linked. A greater percentage of FACE cases were found linked to the de

existence of overhead power lines and their location in relation to the new structure. Additional study findings are summarized below.

New design modifications and suggestions: Thirty new design-for-safety suggestions have been developed as a result of the analysis (summari

Table 4. Incidents classified by design element under construction

Design element under construction	**OSHA**	**FACE**
Specialties	2	0
Equipment	4	9
Furnishings	1	0
Special Construction	2	0
Conveying Systems	3	4
Mechanical	13	10
Electrical	17	17
Site Work	64	57
Concrete	11	14
Masonry	3	6
Metals	21	30
Wood and Plastics	23	12
Thermal/Moisture Protection/Doors and Windows	27	48
Finishes	17	17
Total	208	224
Incidents linked to design	**57 (27.4%)**	**94 (41.9%)**

The analysis of the FACE data also found that the design-linked construction deaths (94 of 224) were related to the design element being constructed at the time of the accident ($p = 0.001$, Cramer's V Concrete 1-lino.484(t 41butenked 2he de)]TJ-2911

- Implementing the design-for-safety concept can benefit new construction, demolition, and renovations alike. Also, applying the concept can improve construction worker safety regardless of the size of the employer or the type of project (residential, commercial, industrial, and engineering).

Recommendations

1. The construction industry should implement the concept of designing for construction safety as a standard practice to reduce safety risks to workers. The previously developed design-for-safety suggestions (Gambatese 1996; Gambatese, Hinze, and Haas 1997) and the new suggestions based on this research (see annexes B and C) can provide a foundation for implementing the concept. However, implementing the design-for-safety concept is not a panacea. Rather, it is one element in a systems approach for preventing injuries and deaths among construction workers. Also, the constructor continues to play a critical role in ensuring worker safety and must adhere to the design-for-safety specifications.
2. Designers should include fall protection in specifications for roofs, skylights, and structural steel construction.
3. Designers should include barriers and other measures that prevent contact with electrical and other utilities.
4. Designers should consider incorporating design-for-safety measures in all types of projects (residential, commercial, and industrial) as well as new projects, renovation, and demolition.
5. Root-cause accident analysis and other accident investigations should routinely consider whether design-for-safety modifications could have prevented the incident. As safety professionals demonstrate the link between the design-for-safety concept and construction incidents, they will drive its implementation as a method to reduce overall project risk.
6. The U.S. Department of Health and Human Services should consider broad-based methods and initiatives to integrate the concept of designing for construction safety into construction projects to achieve their goal of reducing deaths and injuries by 30% by the year 2010 (HHS 2000). These initiatives should include guidance documents on the implementation of the design-for-construction-safety concept, recommendations to OSHA for consensus standards that include design for safety, and funding for further study.

Future research

Follow-up research related to the current project should include a second reviewer to evaluate reports, in order to increase the reliability and validity of the results. The author also suggests eliminating “maybe” as a potential response and using only a “yes”/“no” option when applying the model. A Delphi panel (panel of experts) consisting of construction industry professionals could be established to examine the validity of the responses and to determine the feasibility of implementing each linked design suggestion.

Suggestions for future research on designing for safety are as follows:

1. The economic benefit of implementing the design-for-safety concept to all construction entities (designer, owner, and constructor) must be further evaluated, in order to provide additional incentives for implementing the concept.
2. Project owners increasingly are purchasing owner-controlled insurance programs (OCIPs), which lump together project risks for all parties in an effort to realize economies of scale (Hinze 2001). Research is needed to demonstrate the effectiveness of designing for safety in reducing costs associated with workers' compensation insurance premiums. Also, incorporating design for safety within an OCIP should be further investigated as a method to reduce overall project risk.
3. The model developed for this study should be applied in actual on-site investigations of deaths and disabling injuries. This type of research would enable the gathering of specific design-related information and could test the feasibility of implementing each suggestion. The FACE program, which is well-suited to conduct such investigations, should consider a special emphasis focus on the role of the design in construction deaths.

Michael Behm

Annex B. Existing Design Suggestions Linked to Incidents

The design suggestions presented in this section were originally developed by Gambatese (1996). The concept of designing for construction safety includes modifications to the permanent features of the project and preparation of plans and specifications for construction in such a way that construction site safety is considered. It also includes hazard control and communication of risks regarding the design in relation to the site and the work to be performed. The research findings linking the incidents described in the FACE reports and OSHA reports to these design suggestions are presented below.

Design suggestion	NIOSH FACE reports	OSHA reports	Total
Design special attachments or holes in members at elevated work areas to provide permanent, stable connections for supports, lifelines, guardrails, and scaffolding.	47	23	70
Disconnect, reduce voltage, or re-route power lines around the project before it begins.	13	5	18
Include the name, address, and telephone number of local utility companies on the drawings.	12	4	16

Locate on contract drawing the existe

Design suggestion	NIOSH FACE reports	OSHA reports	Total
Design the finished floor around mechanical equipment to be at one level (no steps, blockouts, slab depressions, etc.).	1	0	1
Allow for pedestrian traffic to be isolated from construction vehicular traffic.	1	0	1
Design and schedule materials and equipment to be painted and/or insulated prior to erection or placement.	1	0	1
Allow adequate clearance between the power lines and the structure.	1	0	1
Employ police officers to patrol around the project site to help with traffic control.	1	0	1
For pre-cast concrete members, provide inserts or other devices to attach fall protection lines.	1	0	1
Re-route the power lines around the project site before construction begins.	1	0	1
Avoid road work and maintenance during peak traffic volume periods of the day.	1	0	1
For access doors through floors, use doors that immediately provide guarded entry around the hole perimeter when the door is opened.	1	0	1
Design members which are of consistent size, light weight, and easy to handle.	1	0	1
Avoid stair landings constructed separate from the stairs.	1	0	1
Consider using prefabricated stairways which can be erected as one assembly.	1	0	1
Design and schedule safe tie-ins to existing utilities.	1	0	1
Ensure that the electrical system design meets all National Electric Code requirements and the requirements of National Fire Protection Association.	1	0	1
Consider using pre-fabricated metal timber fasteners for wood connections			

Annex C. New Design Suggestions Linked to Incidents

New design suggestion	NIOSH FACE reports	OSHA reports	Total
When specifying roofing materials which are not suitable for walking, such as corrugated fiberglass panels, ensure they are distinguishable from safe secure walking surfaces on the roof, or install guardrails around the surfaces not suitable for walking.	1	0	1