1-1-2015

# Statistical Approach To Design For Fall Prevention In Construction

Kyunghwan Kim
*Wayne State University,*

**STATISTICAL APPROACH TO**
**DESIGN FOR FALL PREVENTION IN CONSTRUCTION**

by

**KYUNGHWAN KIM**

**THESIS**

Submitted to the Graduate School

of Wayne State University,

Detroit, Michigan

in partial fulfillment of the requirements

for the degree of

**MASTER OF SCIENCE**

2015

MAJOR: CIVIL ENGINEERING

Approved By:

____________________________________________
Advisor Date

**ACKNOWLEDGEMENTS**

It was a fortunate coincidence to meet Dr. Mumtaz Usmen as my professor of required course works and thesis advisor because he has in-depth knowledge and insight especially in the field of construction safety, and that was where I had worked in Korea. It looked like he was enjoying to teach his students in the class, and showed his friendliness every time. While I was working for my thesis, his support helped me build my self-confidence, and encouraged me to undertake achievable goals that are necessary for my career. Whenever I made progress presentations, he gave me beneficial feedbacks and analytical suggestions so that I was able to complete my thesis. For all of his efforts for me, I would like to express my thankfulness to him. I also thank Dr. Kazan for his assistance on statistical analysis part in my thesis.

Finally, I feel thankful for my wife who has supported me continuously during my Master degree courses, taking care of our two lovely children.

## TABLE OF CONTENTS

# LIST OF TABLES



h

## LIST OF FIGURES

# CHAPTER 1

## INTRODUCTION

The statistical records of occupational injuries and fatalities occurring in the construction industry still remain as great concerns for both public and private sectors, despite safety personnel's collaborative efforts to reduce the number of accidents over the past decades. Lew and Lentz(2010) stated that approximately 7.5% of the United States' workforce are employed in the construction industry, whereas roughly 1,000 workers are killed on construction sites each year, accounting for more than 20% of the total work-related deaths, which is the disproportionate percentage of fatalities compared to other industries. In the recent record of occupational fatalities, 796 workers died on construction sites, which are 18% of the total fatalities. Furthermore, 37% of construction fatal injuries were from falls, slips, and trips: 294 out of 796 fatalities were from those type of accidents (Bureau of Labor Statistics, 2013).

It is obvious that the issue of construction workers' safety matters not only in the United States but also to many other countries around the world. The Health and Safety Executive (HSE) of the United Kingdom indicated that the construction industry accounts for one third of all work fatalities: 42 out of 133 occupational fatalities happened in the construction field in 2013 although the rate of fatalities had gradually decreased for decades. The HSE also indicated that the majority of fatal injuries were caused by falls from height. Korean government has struggled to reduce the number of construction accidents since they established the Occupational Safety and Health Acts in 1981 and the professional agency called Korea Occupational Safety and Health Agency (KOSHA) in 1987. However, statistical data shows a similar tendency with the US in the construction industry.

Fall accidents, which accounts for the great proportion of construction accidents, are regarded as one of the top priorities among academic, industrial, and administrative sectors. Xinyu Huang and Jimmie Hinze (2003) analyzed 7,543 OSHA-investigated construction accidents happened between 1990 and 2001, and the researchers concluded that falls are the major cause resulting in serious injuries or fatalities and have certain properties which can be helpful to establish preventive strategies. Although there is no disagreement with the fact that falls are the most important factors safety personnel should focus on, the issues are still considered as the great challenge because of the construction industry's unique characteristics: temporary projects, variability of construction sites, frequent change of workers, etc.

Traditionally, construction workers' safety was considered as contractors' responsibility. OSHA regulations (OSHA 1926.16) place overall responsibility for the job sites' safety on general (prime) contractors because they are in the position that can significantly affect workers' safety monitoring, coordinating and directing the work of the subcontractors. Whereas, subcontractors are responsible only for their employee's safety relevant to their portion of work. However, studies have shown that there is no single entity affecting the safety of construction workers because the workers' safety is influenced by other workers, supervisors, contractors, subcontractors, owners and designers (Lew, J.J. et al., 2010).

The previous researches show the growing evidence that designers' involvement in construction workers' safety and health can be the most effective means because they can eliminate or avoid potential hazards in the projects using design solutions at the design phase; this could be given a higher priority because identifying and eliminating potential hazards proactively in the design process are much more cost-effective than controlling those hazards reactively on construction sites (John A. Gambatese et al., 2008). According to 'the Time/Safety Influence Curve(Szymberski)', the ideal time to influence construction safety is during the concept and design phase, and the ability to influence safety diminishes as the schedule moves from concept to start-up. Szymberski's curve is similar with time/cost curve replacing cost with safety (figure 1 & 2).

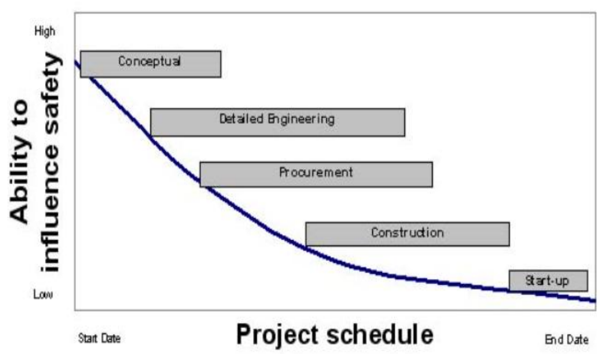



Figure 1: Time/influence curve, Szymberski, 1997 (www.elcosh.org)

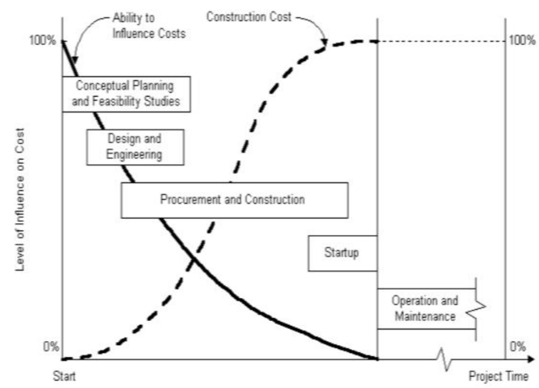



Figure 2: Ability to influence on construction cost over time. Chris Hendrickson, Carnegie Mellon University

Behm(2005) stated that the involvement of design professionals in construction safety is important because construction workers can be influenced by the features of permanent facility and potential hazards can be eliminated or reduced by the designers during the design process; Toole and Gambatese (2008) discussed that the basic idea of design for construction safety is that designers should not include any unnecessary hazards in their projects using design solutions, and if any risk factors still remain after the implementation of safe design, those factors should be informed through the construction documents. Applicable examples of the general design criteria in the conceptual design process were proposed by Jorgensen. K. et al. (2010): Building components that must be manageable in terms of heavy lifting, restriction on substances and materials that might present a nuisance to workers, construction sites and means of access providing enough room for workers to apply good work postures, and suitably designed traffic roads and transport forms on construction sites for those who move around and work at the construction sites.

Internationally, there have been a few decades of efforts promoting the application of design for safety concept. The European Union (EU) acknowledged that approximately one-third of the occupational accidents resulted from the flaws and defects in the owners and consultants' detailed design, and about 60% of fatalities occurred on construction sites resulted from the decisions made before the site work begins. So the EU mandated the consideration of safety in the design phase by placing safety responsibilities on the owners as well as the designers since the advent of the Temporary and Mobile Construction Sites Directive of 1992 (Directive 92/57/EEC). The United Kingdom established the Construction Design and Management (CDM) regulations in 1994 to comply with the EU Directive, and France and other European countries followed enacting similar regulations ever since then (Gibb, 2004). In Australia, the New South Wales State government requires a management strategy for the design process which includes consideration, evaluation, and control of occupational safety and health during construction (NSW Construction Policy Steering Committee, 2000).

With respect to the design for safety concept, there have been noticeable motions in the United States. The National Institute for Occupational Safety and Health (NIOSH) and its partners developed a national initiative called Prevention through Design (PtD) addressing the importance of design's roles to eliminate or minimize work-related hazards in all industry sectors, and they convened PtD workshops with hundreds of participants in 2007 and 2011. The PtD initiative was also promoted through the National Occupational Research Agenda (NORA) Construction Sector Council focusing on construction industry. This council regards Construction Hazard Prevention through Design (CHPtD) as one of its top 10 priorities. The American Society of Civil Engineering (ASCE) states that design engineers have responsibility for recognizing that safety and constructability are important considerations when preparing construction plans and specifications in its policy on construction site safety (Policy Statement 350), and the ASCE has recently established a committee to deal with the design for construction safety.

Even though the potential benefits of designing for construction workers' safety are evident, the application of the concept has not been widely spread out in the construction industry of the United States because little empirical evidence exists in terms of the viability of designers' intervention on construction workers' safety (Gambatese et al, 2005). The construction industry is vulnerable to safety culture because the cost for safety and health is not incorporated in the bids mainly due to its project based characteristic and its participants' focusing on price, but this circumstance indicates the importance of early consideration of health and safety in the planning phase (Jorgensen, K. et al, 2010). The type of project delivery method is one of the important factors affecting the design for construction safety concept. John A. Gambatese et al. (2005) discussed that in the design-build delivery method, the communication between design and construction team is encouraged to address safety concerns at the design stage. However, the traditional design-bid-build and CM-at-risk methods could hinder the collaboration of the designers and constructors regarding construction workers' safety by isolating the other parties.

Many researchers considered designers' liability concerns and their lack of knowledge and experience as one of the important barriers when applying the design for construction safety concept. So many public and private institutions are providing design professionals with useful design guidelines and suggestions: the Construction Industry Institute has more than 400 design suggestions developed over a period; the Health and Safety Executive (HSE) in the UK and private organizations, for instance Safety in Design(SID), Designers Initiative On Health and

Safety(DIOHAS), and Design Best Practice(DBP), have developed numerous guidelines and related materials that designers could refer to.

However, in spite of these useful resources, the implementation of the design for construction safety concept still remains as a great challenge for designers especially who are less experienced and short of required knowledge and skills. Hazard identification and design optimization take expertise and time mainly due to the complexity of construction projects. Accordingly, when it comes to the application of the design for construction safety concept, there is a need to develop tools and processes that can be helpful for hazard recognition, decision of appropriate design solutions, and creation of new designs (Gambatese, 2008).

This study focused on designers' view in terms of how to identify fall hazards in construction projects and optimize design for fall prevention, and specific statistical approach was introduced focusing on the variables that can give designers significant indication. The author investigated the linkage between fall fatalities and design at the first phase, partly using the previously created methodology. The methodology was attained through literature review in accordance with surveying related regulations, design suggestions, and guidelines. And then the author analyzed the relationship between design and the other seven variables, such as construction end use, project type, project cost, age, fall height, fall location, and Standard Industrial Classification (SIC) code. The primary assumption of this study was that dependent variable (linkage to design)'s relationship with 7 independent variables could provide designers with significant indications with regard to how to identify potential hazards in construction projects, and optimize design for the solution of the identified hazards.

# CHAPTER 2

# LITERATURE REVIEW

The construction industry has frequently been mentioned as one of the most vulnerable areas to work-related injuries and fatalities because approximately 1,000 workers died annually on construction sites, accounting for about 20% of total industry fatalities. In consideration of the number of construction workers employed each year, this percentage is quite disproportionate in its outcomes. Statistical records show that fall accidents are the leading cause of the highest number of accidents in the construction industry of the United States. The records of Bureau of Labor Statistics indicate that 3,448 out of 9,792 construction workers had fallen to deaths, accounting for 35.2% of total construction fatalities over the past decade (from 2004 to 2013), which means an average of 345 workers died due to fall accidents (figure 3).

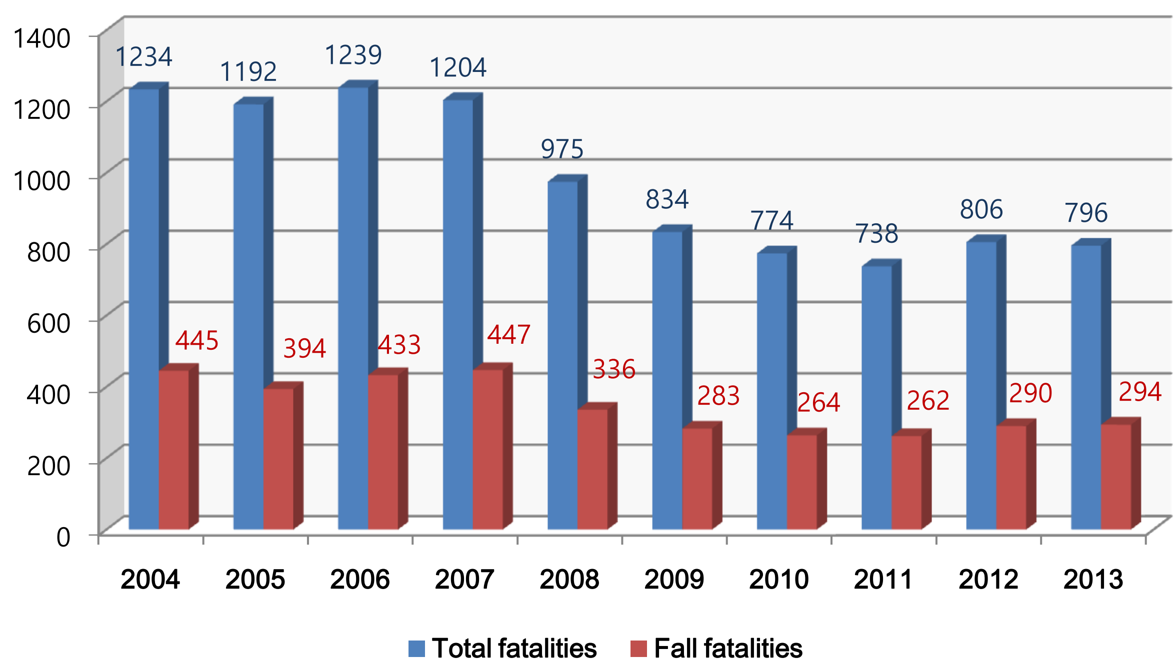



Figure 3 : Total and fall fatalities in the construction industry of the United States (Bureau of Labor Statistics)

Fall accidents have also been an international concern as a major accident type resulting in serious injuries or fatalities in the construction industry because they accounts for the great proportion of all work-related injuries and fatalities. Republic of Korea also has a similar tendency in the records of construction accidents compared to those of the US, except the fact that fall fatalities account for more than 50% over the past decades. The statistical data of Korea Occupational Safety and Health Agency (KOSHA) point out that 3,231 out of 5,880 construction workers died due to fall accidents, accounting for 54.9% of total construction worker fatalities during the past decade (Figure 4). Because of these negative outcomes, continuous studies and examinations for construction accidents have been done to disclose which hazard-factors should be focused on to prevent.

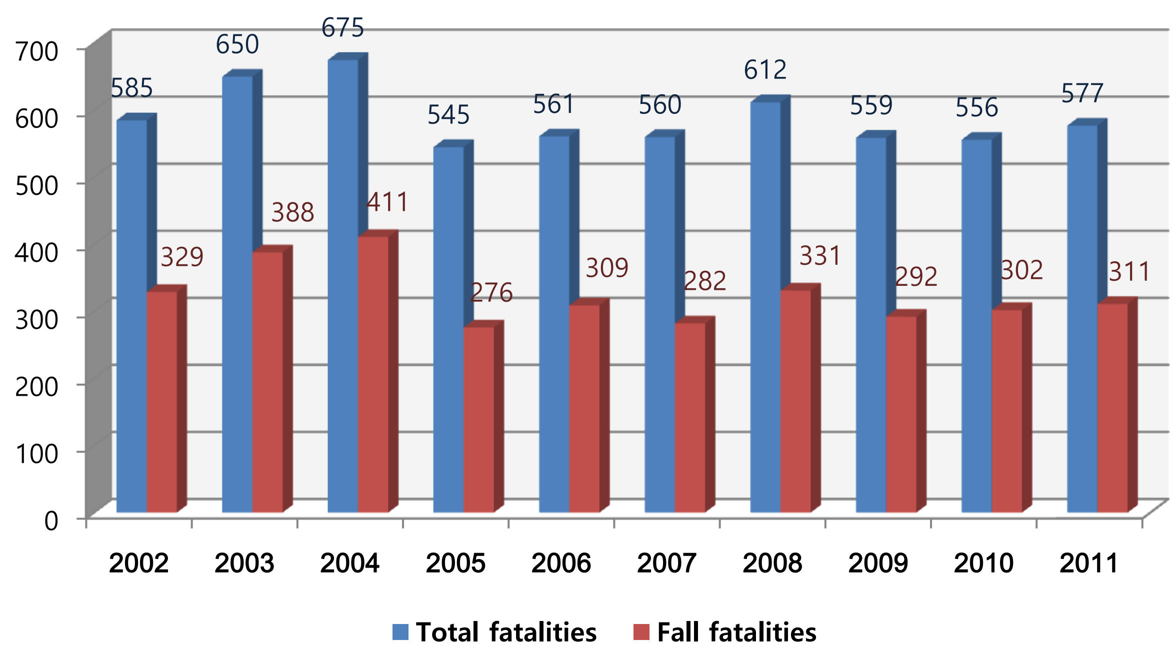



Figure 4 : Total and fall fatalities in the construction industry of Korea (KOSHA)

Chia-Fen Chi et al.(2004) analyzed 621 fatal fall cases falling from height that had occurred between 1994 and 1997 in Taiwan in order to identify the patterns of fatal falls associated with their causation in the construction industry. The researchers used Chi-square test as well as Cramer's and Phi Value to analyze the relationship between contributing factors, which include gender, age, company size, experience and accident event, and cause of falls. The results show that most fatalities were men due to the construction's characteristic of male-dominance. Another point that can be discovered from the results is that more than 55 year-old workers were prone to fatal falls probably because of their declining physical capabilities, and inexperienced and small company workers were vulnerable to the falls as well. The researchers showed the significant relationship between accident events associated with causes of falls and prevention measures using cross tabulation method. With respect to the fall prevention measures, the fall protection guidelines of Manitoba Labor and Immigration Division (MLID) was introduced in 2003, and the guidelines propose six categories which include (1) surface protections, (2) guardrails, (3) surface opening protections, (4) travel restraint systems, (5) fall arrest systems, and (6) safety nets: the first three categories are classified as primary and the rest are secondary, based on the effectiveness of fall prevention. The MLID in Canada indicated that the primary measures are more recommended than Personal Protective Equipment (PPE), such as harness and life line, but the PPE should be secured prior to the installation of the primary measures.

The table of cross tabulation between accident events associated with causes of fall and prevention measures provides safety personnel with significant information in terms of hazard identification and feasible measures that can be applied to solve those identified hazards, and the frequency of each accident scenario indicates the significance of each hazard (table 1). For instance, falls from building girders or other structural steel could have been prevented by the measures of fall arrest system or safety net. However, the researchers also placed emphasis on the importance of safety training and enforcement because 10 fatalities were caused due to the improper use of personal protection equipments.

Table 1 : Feasible prevention measures for each accident scenario
(Chia-Fen Chi et al., 2004)

| **Accident event** | **Cause of fall** | **Frequency** | **Primary** | | | | **Secondary** | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | **Guardrail** | **Warning sign** | **Floor covering** | **Strong roofing material** | **Travel restraint systems** | **Fall arrest systems** | **Safety nets** |
| **Fall from Scaffold** | **Lack of complying scaffold** | **82** | ○ | ○ | | | | ○ | ○ |
| | **Bodily action** | **26** | ○ | ○ | | | | ○ | ○ |
| **Fall from bldg. girders or other structural steel** | **Bodily action** | **14** | | | | | | ○ | ○ |
| | **Improper use of PPE** | **10** | | | | | | ○ | ○ |
| **Fall through floor opening** | **Unguarded opening** | **53** | ○ | ○ | ○ | | ○ | ○ | |
| | **Inappropriate protection** | **23** | ○ | ○ | ○ | | ○ | ○ | |
| | **Removal of protection measure** | **11** | ○ | ○ | ○ | | ○ | ○ | |
| **Fall through roof opening** | **Poor work practice** | **2** | ○ | ○ | ○ | | ○ | ○ | |
| **Fall down stairs or steps** | **Unguarded opening** | **6** | ○ | ○ | ○ | | ○ | ○ | |
| **Fall from roof Edge** | **Bodily action** | **11** | ○ | | | | ○ | ○ | ○ |
| | **Being pulled down** | **11** | ○ | | | | | ○ | |
| **Fall through roof material** | **Lack of complying scaffold** | **43** | | | | ○ | | ○ | |
| **Fall from ladder** | **Overexertion and unusual control** | **4** | | | | | | | |
| | **Unsafe ladder and tool** | **4** | | | | | | | |
| **Jump to lower Level** | **Poor work practices** | **2** | | | | | | | ○ |

Xinyu Huang and Jimmie Hinze (2003) studied 2,741 falls out of 7,543 OSHA-investigated cases that had occurred between 1990 and 200l for the purpose of identifying root-causes. The researchers presumed there might be particular patterns associated with fall accidents. Frequency analysis method was simply adopted in order to analyze several variables' relationship with fall accidents, which include time of fall occurrence, project type, causes, construction end use, fall height, cost, age, type of task performed, location of falls, human errors, immediate source of falls, and SIC code. However, the outcomes of the analysis were quite comprehensive.

Table 2: Distribution of location of falls (Xinyu Huang and Jimmie Hinze, 2003)

| Location of falls | Count | Percentage |
|---|---|---|
| Fall from roof | 333 | 28.36 |
| Fall from/with structure (other than roof) | 227 | 19.34 |
| Fall from/with scaffold | 153 | 13.03 |
| Fall from/with ladder | 133 | 11.33 |
| Fall, other | 102 | 8.69 |
| Fall through opening (other than roof) | 90 | 7.67 |
| Fall from/with bucket (aerial lift/basket) | 37 | 3.15 |
| Fall from/with platform catwalk (attached to structure) | 28 | 2.39 |
| Fall from vehicle (vehicle/construction equipment) | 27 | 2.30 |
| Collapse of structure | 13 | 1.11 |
| Other | 31 | 2.64 |

After the analysis, the researchers concluded that fall accidents have important relationship with certain variables, such as project type, location of falls, and trades. They stated that about 60% of fall cases happened in new projects or new additions, and then alteration or maintenance was followed. They also specified that construction operations performed on certain working surface, for instance roofing, erecting structural steel, and exterior finishing, is susceptible to fall accidents based on the relationship between and falls and fall locations (Table 2). Some useful information for fall prevention was suggested to safety personnel from the results, for instance heights over 30 feet and 31 to 40 year old workers are more susceptible to fall accidents. Moreover, the results of the statistical analysis proved that hazardous locations in regard to fall accidents could be identified. Allan St. John Holt (2001) stated that fall prevention is more effective than fall protection, and the first stage of fall prevention is during the design phase.

Mroszczyk (2006) described the process of Designing for Construction Worker Safety (DfCS) in a straightforward manner. The first step is to identify potential hazards in construction projects, and then eliminate or reduce those identified hazards with appropriate engineering measures and design solutions. If the risk factors cannot be eliminated or reduced by the measures, the information regarding those risks is delivered as forms of warning, instruction and training. The ERIC (Eliminate, Reduce, Inform, and Control) model, proposed under the CDM regulations in the United Kingdom, is very similar to the DfCS as well. However, both of them require the ability of design professionals to identify potential hazards and solve them, for the sake of construction and maintenance workers' safety at the pre-construction stage.

## 2.1. THE DEFINITION OF DESIGN FOR SAFETY CONCEPT AND DESIGNER

Although designers are not responsible for construction safety under OSHA codes and contract terms in the United States, it can be regarded that they have ethical duties on the consideration of construction workers' safety in the design process. This is because the previous studies have shown that conceptual and design phases are important stages that can highly influence construction safety, and design professionals are in the position that can affect the safety of construction workers. The concept of design for safety can be simply defined as the consideration of construction workers' safety during the design phase of a project. Michael Behm (2005) stated that the concept includes: the modification to the original design features in order to apply this concept; paying attention to the preparation of plans and specifications in terms of construction safety; the utilization of specific design suggestions from the previous design for safety practice; and the communications between designers and constructors regarding construction hazards. Briefly, the design for safety concept can be summarized as hazard identification and design optimization collaborating with constructors.

Generally, when the name, designer, is considered, the image of architects and engineers, who design building or bridge projects, comes to mind, but drafts persons who devise shop drawings, and the technicians who design temporary structures, such as scaffolding and shoring structures, are not regarded as designers in the United States. Toole and Gambatese (2008) stated that OSHA and progressive owners are acknowledging that if designers and engineers are not engaged in engineering tasks such as cave-in protection and scaffolding, these important tasks may be implemented by unqualified personnel or not performed. The researchers described that designers have practical reasons likely to be engaged in construction engineering on their projects because they are able to perform it at lower cost due to their understanding of the projects, and design-build delivery method has increased.

On the other hand, designers are interpreted in a broader sense in the United Kingdom. The CDM regulations 2007 define designer as "any person who prepares or modifies a design, or arranges for or instructs any person under the person's control to do so". Under the CDM regulations 2007, designers include architects, quantity surveyors, building designers, drafts persons, engineers, interior designers, industrial designers and even the owner if they specify a certain design. In this respect, the designers in the UK started to consider the safety of temporary work, such as scaffolding, edge protection, false work, and mobile access towers because the construction workers' accidents related to temporary structures are still forming a significant part of total injuries and fatalities in the construction industry.

## 2.2. THE BARRIERS OF THE DESIGN FOR CONSTRUCTION SAFETY

Up to the present, many researchers have discussed the barriers of implementing the concept of design for construction safety (Hinze and Wiegand 1992; John Gambatese 1998; John Gambatese et al. 2003; Hecker et al., 2004; Toole 2004; John Gambatese et al, 2005). Those barriers may be summarized as follows: there are weak or no mandatory regulations for designers (architects and engineers) with regard to designing for construction workers' safety; designers have liability concerns on involving in safety consideration in the design phase; there is a shortage of available safety-related design tools, resources, and guidelines; the collaboration between the designers and constructors at the preconstruction stage is limited due to the traditional contracting structure (Design Bid Build); designers' lack of safety knowledge leads to their difficulty on how to recognize potential hazards in their design process and mitigate those hazards using design solutions for construction workers' safety. From owners and contractors' perspective, additional cost associated with the implementation of the concept has likely been of concern.

Among the barriers above, designers' perspective on the design for safety concept has been considered as one of the most significant factors that should be overcome in order for the concept to be implemented. John A. Gambatese (2005) investigated designers' view regarding the concept. According to the results of the survey where designers got interviewed regarding the design for safety concept, only 37% of the respondents answered that they were interested in and willing to implement the concept, while 47% gave a neutral response and the rest 16% said their negative interest. This research also showed one of the major barriers that designers believe in addressing construction workers' safety at the preconstruction stage is their increased liability when they started to intervene. When asked about their education or training in terms of designing for safety, none of them replied that they had been trained or educated: only 11% of the respondents just took sort of coursework for construction workers' safety. In regard to the question of the impact if the concept were implemented, 74% of the respondents mentioned project cost would be increased, and 21% stated it would limit the designer's creativity. In one interview question, the respondents selected 'construction safety' as the lowest priority among the project criteria which include cost, schedule, quality, aesthetics, etc.

The results of the survey above indicate how designers do not consider construction workers' safety and health as their responsibility in the US. For this reason, John A. Gambatese (2008) stated that it is necessary to create demand for the design for safety concept among design professionals by encouraging them to adopt the concept in their design process, using incentives like supporting resources and monetary benefits. In order for the progressive application of the design for construction safety concept, Toole and Gambatese (2008) made a few suggestions that more construction and safety courses must be included in the design professionals' curricula, and designers should become more informative and communicative regarding project-related information that is not likely to be informed to constructors. The idea of designers' participation in construction safety course in universities or colleges was also contractors' suggestion in a survey (Gambatese, Behm et al, 2008).

On the contrary to the cost concerns of the owners in the previous survey, Tool and Gambatese (2008) discussed that reduced construction hazards through design solutions ultimately contribute to the reduction of project cost, and designers should acknowledge that the implementation of the design for construction safety concept is inevitable in both terms of ethical and practical reasons. The researchers also pointed out that there is a need for surveillance data for the better analysis of the relationship between design and construction accidents.

## 2.3. CODES AND REGULATIONS

Currently, OSHA doesn't have any regulations with respect to the design for safety concept. However, NIOSH and its partners developed a national initiative called Prevention through Design (PtD), and held a few conventions to promote the concept in all industry sectors. NORA construction sector council has struggled to encourage the Construction Hazard Prevention through Design (CHPtD) considering it as one of the top 10 priorities.

The European Union recognized the importance of the design for safety concept from a survey done in 1991 by the EU agency named Eurofound, then the EU established the Temporary and Mobile Construction Sites Directive of 1992 (92/57/EEC) which mandates the consideration of construction workers' safety in the design phase. This directive was intended to have the EU members adopt minimum safety and health requirements in the construction industry, and amended in 2007. The UK established the CDM regulations 1994 to partially comply with the directive, and many other EU countries followed as well. In the research of evaluating the effect of the EU Directive conducted by Dolores Martinez Aires et al. (2009), the results show that the incidence rates of the European countries has decreased since the legislation for compliance with the EU Directive was established in spite of the fact that the regulations were not the only factor to be considered: 10 countries out of 15 EU members that took the survey made an achievement of 10% lower accident rates since the Directive's safety and health requirements came into force.

The CDM regulations might be regarded as one of the representing standard which adopted the design for construction safety concept because the regulations have evolved over a long period of time since their establishment in 1994, undergoing trials and errors. With respect to the effectiveness of the CDM Regulations 1994, there had been little improvement in the statistical records of the construction industry in 2004 since their launch in 1995 although enormous cost and efforts were devoted to (Alasdair N. Beal, 2007). Other researchers discussed that the disappointing results were related to the identified barriers: Designer's lack of construction safety knowledge (Gibb, 2004), and their negligence for the legislation (Cosman, 2004).

The CDM regulations were revised in 2007 focusing on reducing bureaucracy and paper work, improving clarity, and encouraging more integration between duty-holders. Under the CDM regulations 2007, the design for construction safety concept is implemented by the two key players, who are designers and CDM coordinators in a supportive environment by the owner. CDM coordinators' major duties are to coordinate the health and safety aspects of design work cooperating with others involved in the construction project, and facilitate good communication between the owner, designers and contractors. Designers are in an important position where they can identify, eliminate or reduce hazards, which may arise during the construction, with the tools of risk assessment and appropriate design solutions. Then those identified hazards and the suggested design solutions by the designers are reviewed by CDM coordinators. Accordingly, the effectiveness of the CDM regulations highly relies on the competence of the designers and CDM coordinators, and the key players' competence is evaluated based on the two major criteria: knowledge and experience (CDM regulations 2007 Approved Code of Practice).

There was the evaluation of the CDM regulations 2007 in terms of five major objectives: (1) simplifying the regulations to improve clarity, (2) maximizing flexibility, (3) minimizing bureaucracy, (4) encouraging integration between duty-holders, and (5) simplifying the assessment of competence. This evaluation was conducted as a survey type in 2011 by consulting company delegated by the HSE, and the results show that although all the objectives are being mostly or partially met, there still are concerns on minimizing bureaucracy, bringing about integrated teams, bringing about better communications and information flow between project team members, and better competence checks (Evaluations of CDM regulations 2007 (Pilot study)). After the assessment, newly revised CDM regulations 2015 came into force on April 6, 2015 replacing CDM coordinator with principal designer.

One of the important lessons that can be attained through the study of the CDM regulations' history is that it takes time for the design for safety regulations to have effects on construction safety because designers might need time to progress from just awareness to their attitude change and becoming competent professionals in terms of the design for construction safety concept. Another thing that has to be considered in regard to construction safety under the CDM regulations is that the Health and Safety File must be prepared and handed to the owner at the end of construction project by CDM coordinators for the sake of future construction work, such as maintenance, repair, and alteration. The file is drawn up with the assistance of designers and contractors, and includes remaining hazards, key structural principles, information regarding the removal or dismantling of installed equipments, the location of underground services, and as-built drawings of the structure. Studies have shown that the design for safety concept can contribute to construction accident prevention not only for new projects, but also for their subsequent works like maintenance and repair (John A. Gambatese et al., 2008).

## 2.4. RELATIONSHIP BETWEEN CONSTRUCTION ACCIDENTS AND DESIGN

John A. Gambatese (2008) stated that the concept of design for construction safety aims at the prevention of work-related injuries, illnesses and fatalities, and in order to achieve this goal, the first step should be to understand the causal relationship between design features and occupational injuries and fatalities. In the view of construction accident causation and effect, construction safety is influenced by many factors, and design is only one factor among them. Accordingly, collaboration between designer, owner, contractor and other parties is necessary for the effective implementation of the design for construction safety concept (John A. Gambatese et al., 2008). However, it is difficult to find the relationship between construction accidents and design deficiencies in regard to the perspective of cause and effect analysis because design itself is often too complicated, and when accident investigation is implemented, the reports only include very limited factors compared to the various range of factors, such as worker's unsafe behavior, unstable site-conditions, and managerial issues, and the information related to design is not contained.

There have been a few studies trying to identify the relationship between design and work-related accidents in the construction industry. Haslam et al. (2004) studied the causes of 100 non-fatal construction accidents occurred in the United Kingdom in terms of accident-shaping factors, such as worker and site factors, and originating influences, which can be regarded as root causes: specifically construction design and processes, project and risk management, client and economic influences, and safety education and training. The researchers found that approximately half of the accidents could have been prevented from design solutions, and they suggested great consideration should be given to design, equipment and materials. However the study did not suggest any specific evidence on the cases' relationship with design.

There was another previous research in which the relationship between the design for safety concept and construction fatalities was established by reviewing 224 fatal cases randomly selected from the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) program. The researcher developed the criteria to determine whether each fatal case is related to design features, and the criteria used in the study include three questions: whether or not there are (1) physical features of the construction project associated with the design which could have prevented the fatal case, (2) design suggestions from the existing literature which could have reduced the risk if implemented, and (3) other design suggestions that can be created for the prevention of the case. If at least one of the answers to the three questions is yes, then it is regarded that the fatal case is linked to design. The results show that 42% of the fatalities are linked to design (Michael Behm, 2005).

Three years later, John A. Gambatese and Behm conducted an additional research for the results above by employing expert panelists who have construction (safety), design, and academic backgrounds. The researchers had the panelists review 10 sampled fatal cases, and then confirmed the previous research identifying that there is a significant relationship between design and construction safety, based on the results that the panelists expressed a moderate to fair level of agreement with the previous study.

There have been a few trials to apply the concept of design for construction safety to construction projects. Weinstein et al. (2005) investigated a design for safety program called Life Cycle Safety (LCS) program, which was implemented on the project of semiconductor fabrication and research facility (DID) by the Intel Corporation. The LCS program, which can also be regarded as a comprehensive review processes, was established to address safety issues that could arise throughout the project's life cycle: from programming and design to decommissioning. The design review processes were fulfilled by the task force team which consisted of the owner's representative, designers, general contractor, trade contractors, and a third-party consultant in the design phase. The team focused on safety issues associated with design changes in the design process, and they discovered significant information in terms of the design for construction safety concept: early proposals for design changes were most likely to be implemented, which indicated the importance of timing; trade contractors' involvement in design changes was more effective, which means their design suggestions were more frequently adopted probably because the contractors have unique insight and knowledge originated from their experience; and the most common type of design suggestions used in the program were those related to the improvement of access, then fall protection was followed. One of the LCS program's unique characteristics was that the processes of identifying potential hazards in the design phase, and proposing design changes were implemented collaboratively, so the LCS program can be suited to the Design-Build (DB) delivery methods where allow the collaboration between designers and contractors.

Marta Gangolells et al. (2010) studied the way of evaluating safety performances in residential projects in order to assist designers with safety consideration at the design stage. The researchers first identified potential risks that exist in each construction process, using the risk analysis method associated with the consideration of each hazard's probability and severity, and then determined the overall safety level of the construction project. When it comes to the assessment of a project's safety level, performance indicators, such as total perimeter of unguarded balconies, and holes measuring more than 0.4㎡, were developed, then the performance indicators were summed up to evaluate the project's safety level. However, this methodology doesn't provide specific design suggestions for designers to easily apply the design for safety concept to their projects. Furthermore, the measurement of the performance indicators and the analysis of a project's total risk level through reviewing the project documents can be time-consuming and additional burden for designers.

## 2.5. PERSPECTIVES ON THE DESIGN FOR SAFETY

Even though the concept of design for construction safety is one of the leading issues in construction journals, there still remain problems to be solved so that the concept is effectively spread out in the construction industry of the US. Among the barriers, hazard identification and design optimization are regarded as a great challenge especially for designers who are less-experienced and short of the relevant knowledge and skills because of the complexity of construction projects. For the sake of the effective implementation of the concept, the CDM regulations 2007 stipulate that the competence of designers have to be evaluated based on their relevant knowledge and experience. However, the problem is that it takes time for designers to be competitive in terms of the design for construction safety, and a supportive environment, for instance education and training courses, has to be created. John A. Gambatese (2008) stated that when it comes to the application of the design for construction safety concept, there is a need to develop design tools and guidelines that are helpful for designers' hazard recognition, decision of appropriate design solutions, and creation of new designs..

Toole and Gambatese (2008) anticipated that the concept of design for construction safety would develop in a progressive manner along four major routes within decades: increased use of prefabrication and less hazardous materials, the application of construction engineering, and spatial investigation and consideration. Prefabrication can be an effective solution in both terms of safety and economic perspective. This is because this method allows performance location to be shifted from high elevation to ground level by manufacturing building components in well equipped facilities. The prefabrication also contributes to the improvements in cost, schedule, quality, and performance, so this method has been increasingly adopted in the world. Client-oriented designers may be required to consider the inherent hazard level of diverse building components which can be associated with the green building movement. The researchers also stated that designers might be expected to involve in construction engineering partly on construction procedures and methods, and to understand necessary working space for each of various construction trades.

The existing tools such as Computer Aided Design (CAD) and Building Information Modeling (BIM) can be used to facilitate this concept in the design process; these tools enable designers to virtually recognize potential hazards in their projects using 3D visualization, which can be hardly checked through reviewing the plans and specifications of construction projects. Sijie Zhang et al. (2012) studied the effectiveness of BIM in regard to fall prevention. As shown in many studies, design phase is the time of opportunity to eliminate potential hazards before those hazards appear on construction sites, and Sijie Zhang and other researchers considered that the BIM can be used as an effective tool to assist designers with hazard identification and encourage to have effective communications between designers and safety personnel.

The methodology adopted in the study (Sijie Zhang et al., 2012, BIM and safety) was that OSHA rules and best practices for fall prevention were first interpreted into the rule checking system, and then the target objects, for instance roof, edge of floor, and holes, were identified and classified in the system. In the case study which examined the effectiveness of BIM-based rule checking system, Tekla program, a BIM-based structural engineering and modeling software, was chosen as a basic tool. The results show that potential fall hazards could be automatically and successfully identified, and the corresponding measures, such as guardrails or covers, were also automatically applied. Furthermore, the identification of fall hazards and the prevention measures for those hazards could be associated with estimate process in the system, and this information could be reported including the details like quantity take-off and type of preventions measures. Accordingly, this model using BIM can contribute to saving time and efforts that are needed for safety personnel to identify hazards and quantify safety measures through project documents.

## 2.6. LESSONS LEARNED FROM THE PREVIOUS RESEARCHES

It was discovered that one of the major reasons why the concept of design for construction safety has not been diffused in the United States is Designers’ lack of safety Knowledge and Experience, and the lack of designers' expertise leads to their difficulties on hazard identification and design solution integration. Accordingly, in order for designers to implement the concept, they should have ability to deal with safe design.

In regard to the CDM regulations 2007, the effectiveness of the regulations highly depend on designers' competence, and their competence is evaluated by the criteria of 'Knowledge and Experience’. It could also be found from the history of the CDM regulations that it takes time and cost for designers to progress from awareness to attitude change and becoming competent professionals.

The previous researches proposed some alternatives for the designers' challenge, such as offering safety courses for designers in universities, or encouraging collaboration between designers and constructors. There have been some trials to apply the design for construction safety concept to construction projects like the evaluation of overall safety level of a project. However, there has been no researches suggesting the specific methodology on how to apply the concept of design for safety in terms of designers' hazard identification and design solution integration.

# CHAPTER 3

# METHODOLOGY

Although many research papers in famous journals articulate the concept of design for construction safety, and prove the viability of applying the concept to construction projects, no researchers suggested a specific way to do that, especially for less-experienced designers. Furthermore, designers do not consider construction workers' safety and health as their responsibility, and they have liability concerns in terms of their involvement in safety consideration at the design process in the United States. The previous studies indicate that the negative perspective of designers regarding the design for construction safety is related to designers' lack of safety knowledge and inexperience in the field (John A. Gambatese et al., 2005).

Under the CDM regulations 2007 in the United Kingdom, the effectiveness of the regulations highly depends on the collaboration of duty-holders, and the competence of designers and CDM coordinators. However, the problem is that it takes time for designers to have the ability of hazard identification and design optimization because they need to have required knowledge and practical experience. The pilot study (2011) carried by Heath and Safety Executive (HSE) in the UK shows that the assessment of designers' competence still remains as concerns, even though it has been over 15 years since the launch of the CDM regulations in 1995.

In this respect, this study focused on designers' perspective on the application of the design for safety concept to design process. The objective of the study is to provide designers, who are especially less-experienced and lack of expertise on the concept, with significant indications in terms of hazard identification and design solution integration, using statistical analysis methodology, and the scope of the study was limited to fall accidents. The author first examined the existing design solutions' linkage to 1,587 fatal fall cases which had occurred in Korea, partly adopting the methodology of the previous research (Michael Behm, 2005), then analyzed the relationship between design and other factors which could provide designers with useful information when they implement the design for construction safety concept in their projects. The author assumed that the outcomes of the statistical analysis would contribute to time and cost savings, which are required for inexperienced and less-knowledgeable designers to apply the concept of design for construction safety to their projects.

## 3.1. DATA ACQUISITION

The data source used in this research was extracted from the database of intranet in the Korea Occupational Safety and Health Agency (KOSHA): KOSHA investigators make incident reports and upload them to the database whenever fatal incident happens at construction sites according to the Occupational Safety and Health Acts, and the data can be extracted with the type of Excel file. The author downloaded 1,578 fatal fall cases (1,611 fall fatalities) that had occurred between 2007 and 2012 on construction sites of Korea from the database. The data initially included the following categories: the name of company and project, cost, the date of the accident, the number of workers, the name of the victim, resident registration number, the number of fatalities, incident type, age, the date of the investigation, trade, causes, the summary of the accident, the obligation of the risk prevention plan, and the name of KOSHA branch.

## 3.2. DATA REFINEMENT

The author determined to use seven categorical variables which can be used to analyze those independent variables' relationship with design, based on the initial categories and the possibility of extraction from the original data. The independent variables include (1) Construction End Use, (2) Project Type, (3) Project Cost, (4) Fall Height, (5) Age, (6) Locations of Falls, and (7) Standard Industrial Classification (SIC) code. In reference to the OSHA coding standard, 3 independent variables and their values were initially classified, which include (1), (2), and (7). The rest variables like Project Cost, Fall Height, Age, Location of Falls have the author-defined values because there is no standard recommended.

The values of Construction End Use, Project Type, and SIC code were extracted from the original data, using information such as project name and the summary of incident, and the values of Fall Height and Location of Falls were extracted from the category of the summary of incident, and Age from the resident registration number in the original data. The variable of Project Cost has 6 values based on the Occupational Safety and Health Acts in Korea, where mandatory consulting or the number of qualified safety managers (full-time workers) are specified according to the cost of construction projects.

The author let the variable of Location of Falls have values as many as possible at the initial stage because those values can provide designers with a great indication regarding hazard identification and design optimization. Specifically, Location of Falls indicates the spot where the victims were just before falling from height, so the values can help designers recognize which design components they should focus on, or create new design solutions in terms of the design for construction safety concept. In the data refinement process, some values were renamed for better understanding, eliminated, or created based on their usefulness on the analysis. In case of the variable named location of falls, the initially defined 54 values consolidated to 15 levels through the data refining process for better model. Consequently, the final variables and values of the research database were created as below.

Table 3 : Research data taxonomy

| Variables | Values |
|---|---|
| 1. Construction End Use | 1. Industrial |
| | 2. Residential |
| | 3. Commercial |
| | 4. Heavy, Highway |
| | 0. Others |
| 2. Project Type | 1. New project or new addition |
| | 2. Maintenance or repair |
| | 3. Alteration or rehabilitation |
| | 4. Demolition |
| | 0. Others |
| 3. Project Cost | 1. Under $300K |
| | 2. $300K - $2M |
| | 3. $2M - $12M |
| | 4. $12M - $80M |
| | 5. $80M - $150M |
| | 0. $150M over |
| 4. Age | 1. 19 - 25 |
| | 2. 26 - 35 |
| | 3. 36 - 45 |
| | 4. 46 - 55 |
| | 5. 56 - 65 |
| | 0. 66 over |
| 5. Fall Height | 1. Less than 6 ft |
| | 2. More than 6' less than 10' |
| | 3. More than 10' less than 20' |
| | 4. More than 20' less than 30' |
| | 0. More than 30' |

| | |
|---|---|
| 6. Location of Falls | 1. Scaffold<br>2. Roof<br>3. Steel structure<br>4. Ladder<br>5. Edge of floor<br>6. Hanging scaffold by rope<br>7. Floor near openings<br>8. Other construction equipments<br>9. (Gang) form<br>10. Edge of stairway<br>11. Ceiling structure<br>12. Facilities installed in building<br>13. Shoring system (steel structure)<br>14. Dumping bed of truck<br>0. Others |
| 7. SIC code | 1. 1711: Plumbing, heating, air-conditioning<br>2. 1721: Painting (Waterproofing)<br>3. 1731: Electric work<br>4. 1741: Masonry and other stonework<br>5. 1742, 1751: Plastering, drywall, insulation, and Carpentry work<br>6. 1743: Terrazzo, tile, marble, mosaic work<br>7. 1761: Roofing, siding, and sheet metal work<br>8. 1771: Concrete work (Formwork, Reinforcing)<br>9. 1791: Structural steel erection<br>10. 1793: Glass and glazing work<br>11. 1795: Wrecking and demolition work<br>12. 1796: Installing building equipment, nec.<br>13. 1799: Special trade contractors<br>0. Others |

## 3.3. FATAL FALL ACCIDENTS' LINKAGE TO DESIGN

There have been a few previous researches trying to identify that construction accidents are actually related to or prevented by design solutions. In this study, the methodology created by Michael Behm in his PhD dissertation (2005) was partly introduced, in order to find out the connection between the design for construction safety concept, and 1,587 fatal fall cases occurred in the construction industry of Korea. The researcher developed criteria to determine whether each of the fatal cases was actually linked to the design for safety concept. The criteria include three questions, to be specific whether or not there are (1) the physical aspects of construction projects associated with the case is connected to design, (2) design suggestions from the existing literature that could have reduced the risk of the case, and (3) new design suggestions that could be created to prevent the case. This study only adopted the second question as criterion for the sake of objective analysis: whether or not the existing design suggestions and guidelines could have eliminated or reduced the risk associated with the fatal fall case.

The author first collected the existing design suggestions and guidelines for the usage of explanatory materials on determining whether or not each fatal fall case is related to the design for construction safety. The Health and Safety Executive (HSE) provides sources of practical examples on how designers can apply the concept of design for safety in the website(Appendix 2). These sources include Safety In Design (SID), Designers Initiative On Health And Safety (DIOHAS), Design Best Practice (DBP) in the United Kingdom, WSH council in Singapore, and Safe Design Australia. Consequently, 44 design suggestions and guidelines, in which fall prevention is concerned, were collected mostly from the sources offered by the HSE in the UK (Appendix 1). Interestingly, among the collected 44 design suggestions and guidelines, 13 suggestions and guidelines have been developed for roofing, 7 for structural steel work, and 5 for maintenance or repair. This fact is related to the previous finding that roofing and structural steel constructors would get significant benefits from the implementation of the design for construction safety concept. (Gambatese and Behm et al, 2008).

Table 4: The examples of design suggestions and guidelines

| Location of falls | Fall event | Design suggestions & guidelines |
|---|---|---|
| Roof | Falls from/through roof | - Metal railing, barriers, wire mesh or use of non-fragile material around/on roof lights<br>- Roof parapet on the edge of roof<br>- Multiple roof anchors<br>- Considering roof access for maintenance<br>- Designing gutter inside building to reduce access to roof |
| Steel structure | Falls from steel structure | - Specifying holes in columns at 21 and 42 inches above each floor<br>- Designing safety seats at column connections<br>- Pre-assembling at the ground level (e.g. staircase framing with handrail, pipe-racks)<br>- Prefabrication |
| Edge of floor | Falls from edge | - Specifying guardrail system around edge of floor (e.g. cast-in socket) |
| Ceiling structure | Falls through ceiling | - Designing secondary grid inside ceiling to aid mechanical or electrical work |

Finally, each fatal fall case was analyzed to determine its linkage to design, based on the question: whether or not the fall accident could have been prevented if more than one of the 44 design suggestions and guidelines were applied to the construction project during the design process. If the answer was "Yes", then it was concluded that the case was connected to the design for construction safety concept. During the process of determination on each fatal fall case's linkage to design, the variable of 'location of falls' and the category 'summary of accidents' in the original data were utilized. Location of falls means the spots where victims were just before falling from height, so this variable can represent fall hazard and assist the author in finding appropriate design suggestions and guidelines. Summary of accidents briefly describes how each fall case did happen based on five W’s and one H. The examples of design solutions used on the determination of each case's linkage to design are given in, but not limited to the table 4.

### 3.4. STATISTICAL ANALYSIS

Frequency analysis was first conducted in order to discover the distributions of values in each variable, and then cross tabulation between dependent variable and each of independent variables was done for the purpose of identifying each independent variable's effect on design. The number of each cell in a cross-tabulation table indicates how many observations become involved in each combination between two cross-tabulated values, and the observations mean the frequency of the combination-value (Hulya Cakan, 2012). The cross-tabulation analysis was associated with Pearson Chi Square test and Phi or Cramer's value, using the SPSS program. This test is usually adopted to identify the significance of the relationship between two variables where p-value indicates whether or not the observed data are consistent with the hypothesis that was previously formulated. If the p-value is less than 0.05 (confidence level of 95%), the null hypothesis, which is the two variables are independent, is then rejected. This mean the relationship of the two tested variables are statistically significant. In addition, Phi or Cramer's value was introduced to check the relative strength of the relationship between the two variables:

if the value indicates 0-0.1, it means weak relationship; 0.1-0.3 means moderate relationship; 0.3-1.0 means strong relationship (Healey, 2011). In this study, dependent variable (linkage to design)'s relationship with each of 7 independent variables was examined.

Finally, logistic regression analysis was implemented using the SPSS program in order to identify how the fall cases' linkage to design can be predicted from the information contained in independent variables. This method is appropriate to models whose dependent variable has binary values. Additionally, the Hosmer and Lemeshow test was adopted to measure the model's goodness of fit. If the significance value is less than 0.05, then it means the model is poorly fitting.

# CHAPTER 4

# RESULTS AND DISCUSSIONS

## 4.1. FREQUENCY ANALYSIS

Frequency analysis was first performed to identify values' distribution in each coded variables. Only the frequency of dependent variable which indicates design's relationship with fatal falls was designed as bar chart (figure 5), while the rest independent variables' frequency was shown as the table in which each variable and the frequency of its values can easily be compared with others (table 5).

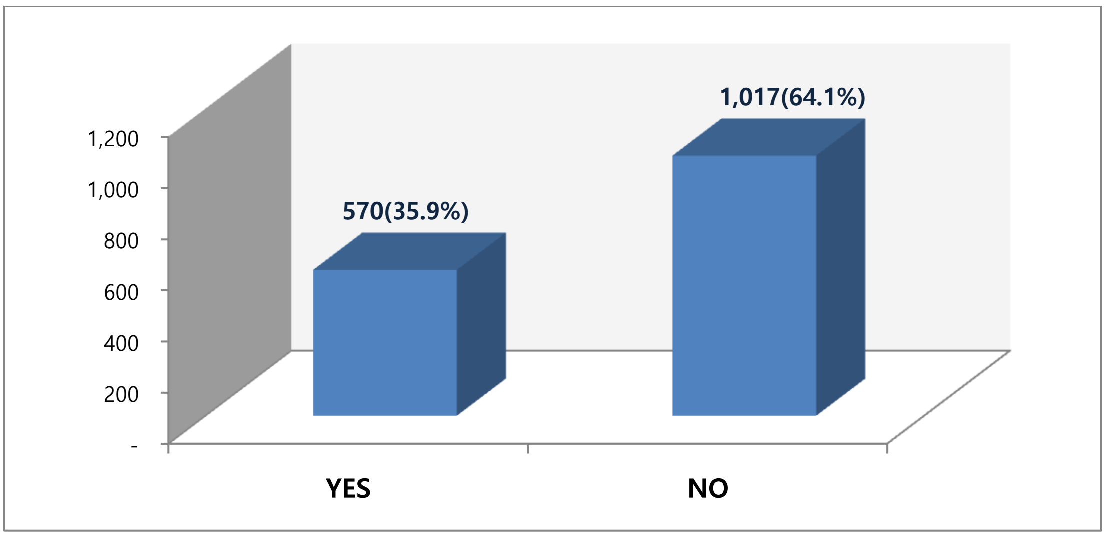



Figure 5 : Frequency analysis for linkage to design

In reference to the figure 5, it was discovered that 570 out of 1,587 fatal fall cases are related to design solutions accounting for 35.9%, which indicates the magnitude of fatal falls associated with design factors. The fatal cases, which are not related to design, are the accidents happened on the areas where design solutions have not been developed, for instance falls from bridge and concrete structure, construction equipments, utility pole, form shoring structure, etc. However, this result shows a bit low percentage compared to the previous researches. This is probably because the criteria used in this research was too simple and straightforward, which means only when there were the existing design suggestions and guidelines that could have reduced the risks associated with each fatality, it was concluded that the fatal fall case is link to design. Any design features and components in each fatal case that might be related to design or created as new design solutions were excluded from the factors of the criteria for the sake of objectivity. Another thing needed to be mentioned is that although some fatal cases might have been prevented by the collected design suggestions and guidelines, if those solutions are related to temporary structures, such as scaffold and walking tower, then it was determined that the cases were not linked to design. This is because designers do not consider temporary structures as their responsibilities, and this portion of construction project is actually carried out by (sub) contractors.

Table 5 : Frequency analysis for independent variables

| Variable | Value | Frequency | Percentage |
|---|---|---|---|
| Const. End Use | Industrial | 402 | 25.3% |
| | Residential | 360 | 22.7% |
| | Commercial | 148 | 9.3% |
| | Heavy, Highway | 142 | 8.9% |
| | Others | 535 | 33.7% |
| Project Type | New project or new addition | 1,110 | 69.9% |
| | Maintenance or repair | 265 | 16.7% |
| | Alteration or rehabilitation | 83 | 5.2% |
| | Demolition | 43 | 2.7% |
| | Others | 86 | 5.4% |
| Project Cost | Under $300K | 590 | 37.2% |
| | $300K - $2M | 324 | 20.4% |
| | $2M - $12M | 293 | 18.5% |

| | | | |
|---|---|---|---|
| | $12M - $80M | 226 | 14.2% |
| | $80M - $150M | 85 | 5.4% |
| | $150M over | 69 | 4.3% |
| Age | 19 - 25 | 15 | 0.9% |
| | 26 - 35 | 108 | 6.8% |
| | 36 - 45 | 350 | 22.1% |
| | 46 - 55 | 613 | 38.6% |
| | 56 - 65 | 400 | 25.2% |
| | 66 over | 101 | 6.4% |
| Fall Height | Less than 6 ft | 104 | 6.6% |
| | More than 6' less than 10' | 135 | 8.5% |
| | More than 10' less than 20' | 459 | 28.9% |
| | More than 20' less than 30 | 296 | 18.7% |
| | More than 30' | 593 | 37.4% |
| Location of Falls | Scaffold | 303 | 19.1% |
| | Roof | 228 | 14.4% |
| | Steel structure | 159 | 10.0% |
| | Ladder | 95 | 6.0% |
| | Edge of floor | 87 | 5.5% |
| | Hanging scaffold by rope | 87 | 5.5% |
| | Floor near opening | 85 | 5.4% |
| | Other const equipments | 78 | 4.9% |
| | (Gang) form | 60 | 3.8% |
| | Edge of stairway | 31 | 2.0% |
| | Ceiling structure | 18 | 1.1% |
| | Facilities installed in bldg | 18 | 1.1% |
| | Shoring system(steel structure) | 18 | 1.1% |
| | Dumping bed of truck | 12 | 0.8% |
| | Others | 308 | 19.4% |
| SIC code | 1711: Plumbing, heating, air-conditioning | 66 | 4.2% |

| | | |
|---|---|---|
| 1721: Painting(Waterproofing) | 147 | 9.3% |
| 1731: Electric work | 109 | 6.9% |
| 1741: Masonry and other stonework | 75 | 4.7% |
| 1743: Terazzo, tile, marble, mosaic work | 5 | 0.3% |
| 1761: Roofing, siding, and sheet metal work | 215 | 13.5% |
| 1771: Concrete work(Formwork, Reinforcing) | 186 | 11.7% |
| 1791: Structural steel erection | 149 | 9.4% |
| 1793: Glass and glazing work | 51 | 3.2% |
| 1795: Wrecking and demolition work | 63 | 4.0% |
| 1796: Installing building equipment, nec | 53 | 3.3% |
| 1799: Special trade contractors | 152 | 9.6% |
| 1742, 1751: Plastering, drywall, insulation and carpentry work | 141 | 8.9% |
| Others | 175 | 11.0% |

The frequency analysis of independent variables is shown in the table 5, and each variable has its own characteristic of distribution. With respect to construction end use, industrial projects are the leading field where 406 workers (402 cases) were killed falling from height, accounting for 25.3%, then residential projects are followed (22.7%). New project or new addition is the majority type of projects where 1,110 fatal falls occurred, which accounts for 69.9%, and another point to be considered is that 269 workers (16.7%) fell from height while they were doing maintenance or repair tasks. This is a substantial proportion of the total fatal falls that is needed to consider. In this respect, the CDM regulations 2007 have CDM coordinator draw up the Health and Safety file being with designers and contractors' assistance, and hand it to the owner at the end of projects for the purpose of future work such as maintenance, repair, alteration, and rehabilitation (CDM regulations 2007 Approved Code of Practice). The projects under the construction cost of two million dollars account for 57.6% (914 cases). Those projects are usually carried out by small sized construction firms and rarely inspected by KOSHA agents or government.

The workers whose ages are between 46 and 55 are vulnerable to fall accidents accounting for 38.6%, and then 55 - 65 year old workers are followed (25.2%). In terms of fall height, the result shows that the average of fall height is 35.5 feet which is similar with the findings of Huang and Hinze (2003). However, the fact that 615 workers (593 cases) fell from the height of more than 30 feet accounting for 37.4% is worthy of notice, and the fall accidents which occurred above the height of 6 feet accounts for 93.4% even though fall prevention and protection measures are mandatory over 6 feet above by the Occupational Safety and Health Acts in Korea. This result indicates that (sub) contractors and workers were not adhering to the regulations in regard to fall prevention.

Huang and Hinze (2003) stated that over half percentage of fall accidents are associated with environmental factors, such as working surface or facility layout conditions. In this respect, the variable of location of falls, where the fatal workers were just before falling from height, was segmented to 54 values at the first stage, based on the assumption that this variable could be a significant indication for the design for construction safety concept. And then the values were consolidated to 15 values. The value of others in the variable means that the locations are not related to the developed design suggestions and guidelines, which include bridge and concrete structure, construction lift, tower crane, utility pole, form shoring structure, etc.

The frequency analysis for location of falls shows that the leading factors are falls from scaffold which include scaffold for exterior finishing, movable scaffold, and walkway, whereas the frequency of the cases linked to design indicate that roof and steel structure are the most significant factors that should be considered. 389 workers (387 cases) fell from roof and steel structure, accounting for 24.4%, and 352 cases (354 workers) were related to design (figure 6). John A. Gambatese (2008) stated that roof and steel structures are where the constructors can obtain significant benefits from the design for construction safety concept. In addition, 172 workers fell from edge of floor and floor near openings, accounting for 9.9%.

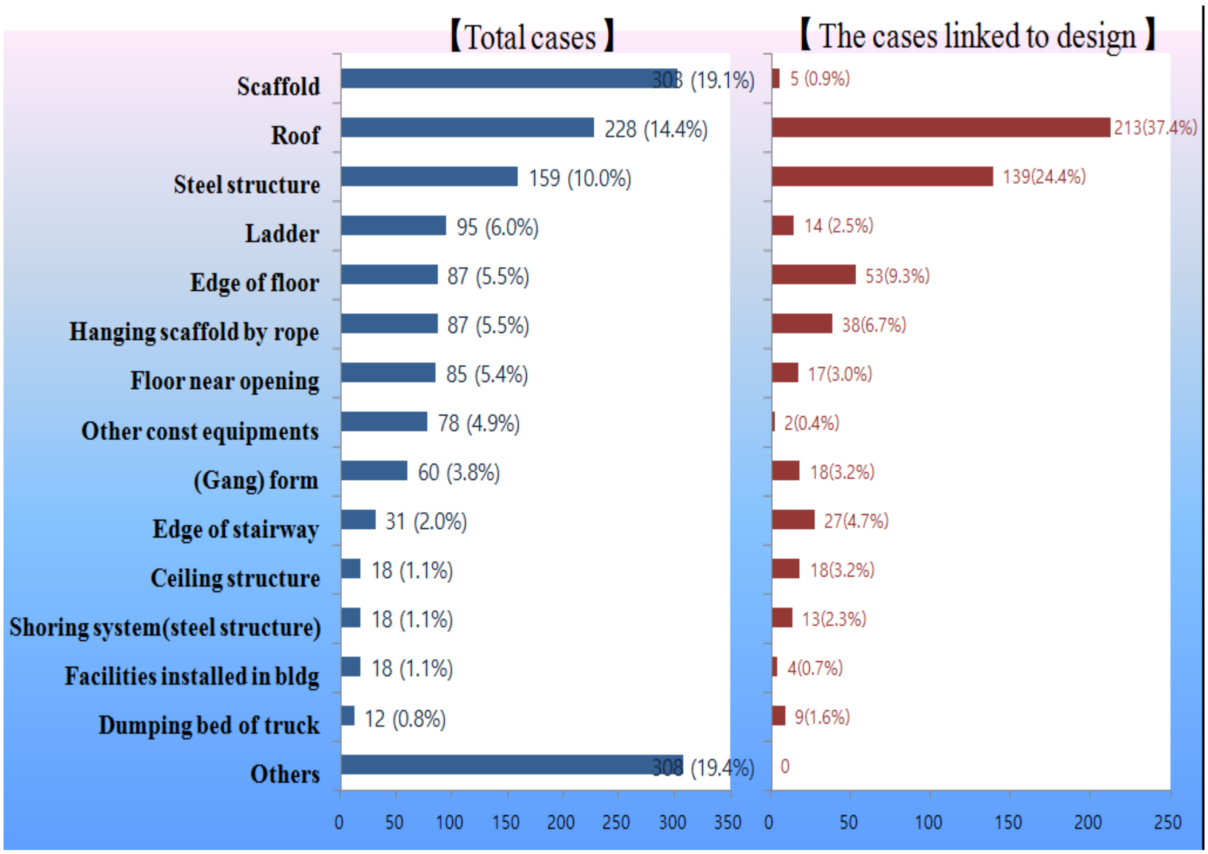



Figure 6 : Frequency of location of falls (total cases vs. the cases linked to design)

With respect to the Standard Industrial Classification (SIC) code, the highest frequency of fatal falls is shown in 1761 (roofing, siding, and sheet metal work) which accounts for 13.5%, and then 1771 (concrete work) and 1791 (structural steel erection) were followed which respectively accounts for 11.7% and 9.4%, while the frequency of the cases linked to design indicates that 1761 and 1791 are the most vulnerable to fatal falls (figure 7).

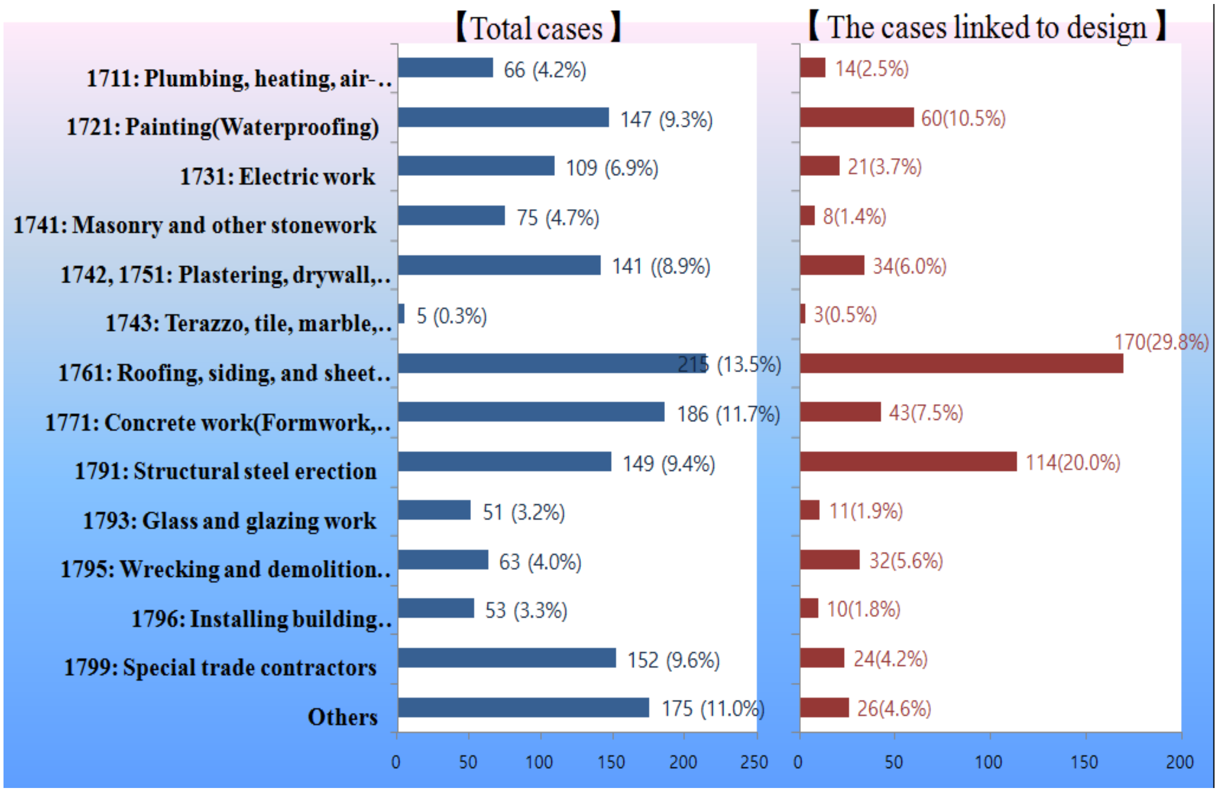



Figure 7 : Frequency of SIC code (total cases vs. the cases linked to design)

### 4.2. CROSS TABULATION ASSOCIATED WITH CHI SQUARE TEST

Cross tabulation methodology was adopted to analyze the relationship between dependent variable (Linkage to Design) and 7 independent variables, and this analysis was associated with Chi-Square test and Phi or Cramer's Value which indicate the significance and strength of the two variable's correlation. In reference to the table 6, it indicates that all the independent variables except the variable of age have significant relationships with design because the p-values for Chi Square test for construction end use, project type, project cost, fall height, location of falls, and SIC code are less than 0.05 rejecting the null hypothesis that the two variables are independent. Phi or Cramer's values shown in the table 5 indicate that location of falls and SIC code have strong relationship with design, and the linkage between the variables of construction end use, project type, and design has moderate strength.

Table 6: Chi Square test between dependent and independent variables

| Independent variable | Chi Square Value | Df. | Significance (p) | Phi or Cramer's V |
|---|---|---|---|---|
| Construction end use | 126.453 | 4 | .000 | .282 |
| Project type | 72.752 | 4 | .000 | .214 |
| Project cost | 42.684 | 5 | .000 | .164 |
| Age | 9.868 | 5 | .079 | .079 |
| Fall height | 45.413 | 4 | .000 | .169 |
| Location of falls | 1071.536 | 14 | .000 | .801 |
| SIC code | 423.076 | 13 | .000 | .516 |

Table 7: Cross tabs between linkage to design and construction end use

| **Linkage to Design** / **Const End Use** | YES | NO | Total |
|---|---|---|---|
| 1. Industrial | 226 (39.6%) | 176 (17.3%) | 402 (25.3%) |
| 2. Residential | 119 (20.9%) | 241 (23.7%) | 360 (22.7%) |
| 3. Commercial | 46 (8.1%) | 102 (10.0%) | 148 (9.3%) |
| 4. Heavy, Highway | 12 (2.1%) | 130 (12.8%) | 142 (8.9%) |
| 0. Others | 167 (29.3%) | 368 (36.2%) | 535 (33.7%) |
| Total | 570 | 1,017 | 1,587 |

The table 7 shows that industrial projects are the leading field of fall fatalities and highly related to design because the p-value of Chi Square test is less than 0.05, and 226 fatal fall cases (39.6%) could have been prevented by design solutions. It was also discovered that the two variables, linkage to design and construction end use, have moderate relationship, base on the Phi or Cramer's value (0.282). It is assumed that industrial buildings are usually composed of steel structure and envelope (roof), and those parts are where many design suggestions and guidelines have been developed: in this study, 20 out of 44 design suggestions and guidelines that had been collected for the statistical analysis are relevant to roof and steel structure.

Table 8: Cross tabs between linkage to design and project type

| **Project Type** \ **Linkage to Design** | YES | NO | Total |
|---|---|---|---|
| 1. New project or new addition | 373<br>(65.4%) | 737<br>(72.5%) | 1,110<br>(69.9%) |
| 2. Maintenance or repair | 144<br>(25.3%) | 121<br>(11.9%) | 265<br>(16.7%) |
| 3. Alteration or rehabilitation | 18<br>(3.2%) | 65<br>(6.4%) | 83<br>(5.2%) |
| 4. Demolition | 23<br>(4.0%) | 20<br>(2.0%) | 43<br>(2.7%) |
| 0. Others | 12<br>(2.1%) | 74<br>(7.3%) | 86<br>(5.4%) |
| Total | 570 | 1,017 | 1,587 |

Shown in the table 8, new projects and new additions are the leading project type linked to design where 373 fatal fall cases could have been prevented by design suggestions and guidelines, accounting for 65.4%. This is probably because most projects where fatal fall accidents happened were new buildings or the extension of the previous ones. Another thing that should be considered is that maintenance or repair projects have relatively strong relationship with design because the percentage of linkage to design (25.3%) is higher than the total percentage (16.7%) in which 265 out of 1,587 fatal falls occurred in the maintenance or repair projects. This is because some design guidelines or suggestions focus on the safety of maintenance or repair work, for instance designing safe access to roof for the future work, and placing electrical control boxes at lower level to reduce working on ladders for repair. The Phi or Cramer's value (0.214) indicates that the two variables have moderate relationship.

Table 9: Cross tabs between linkage to design and project cost

| **Linkage to Design** / **Project Type** | YES | NO | Total |
|---|---|---|---|
| 1. Under $300K | 260 (45.6%) | 330 (32.4%) | 590 (37.2%) |
| 2. $300K - $2M | 119 (20.9%) | 205 (20.2%) | 324 (20.4%) |
| 3. $2M - $12M | 92 (16.1%) | 201 (19.8%) | 293 (18.5%) |
| 4. $12M - $80M | 70 (12.3%) | 156 (15.3%) | 226 (14.2%) |
| 5. $80M - $150M | 13 (2.3%) | 72 (7.1%) | 85 (5.4%) |
| 0. $150M over | 16 (2.8%) | 53 (5.2%) | 69 (4.3%) |
| Total | 570 | 1,017 | 1,587 |

The table 9 shows that the projects whose cost is under $300K are highly related to design because 260 out of 590 fatal falls could have been reduced by the implementation of safe design, accounting for 45.6%. Interestingly, 127 out of 260 fatal falls occurred in maintenance or repair projects; 141 workers (139 cases) fell from roof in the projects under $ 300K, and among them, 74 workers were killed falling from roof while they were doing maintenance or repair work. According to Phi or Cramer's value (0.164), the relationship between linkage to design and project cost has moderate strength.

Table 10: Cross tabs between linkage to design and age

| Age \ Linkage to Design | YES | NO | Total |
|---|---|---|---|
| 1. 19 - 25 | 6 (1.1%) | 9 (0.9%) | 15 (0.9%) |
| 2. 26 - 35 | 49 (8.6%) | 59 (5.8%) | 108 (6.8%) |
| 3. 36 - 45 | 134 (23.5%) | 216 (21.2%) | 350 (22.1%) |
| 4. 46 - 55 | 222 (38.9%) | 391 (38.4%) | 613 (38.6%) |
| 5. 56 - 65 | 131 (23.0%) | 269 (26.5%) | 400 (25.2%) |
| 0. 66 over | 28 (4.9%) | 73 (7.2%) | 101 (6.4%) |
| Total | 570 | 1,017 | 1,587 |

Observed in the table 10, 46 to 55 year old workers are the highest fatality group falling from height, which accounts for 38.6%, and then 56 - 65 (25.2%) and 36 - 45 (22.1%) groups are followed. Over 56 year old workers' fatal fall cases accounts for 31.6%, which were caused partly by the workers' physical limitations. The significance p-value for Chi Square test in the table 6 shows that the relationship between design and age is not significant.

As shown in the table 11, 593 fatal fall cases occurred at the height of more than 30 feet which indicates that workers above 30 feet high are greatly prone to fall accidents, and 213 cases (37.4%) are related to design among them.

Table 11: Cross tabs between linkage to design and fall height

| Age \ Linkage to Design | YES | NO | Total |
|---|---|---|---|
| Less than 6 ft | 15 (2.6%) | 89 (8.8%) | 104 (6.6%) |
| More than 6' less than 10' | 33 (5.8%) | 102 (10.0%) | 135 (8.5%) |
| More than 10' less than 20' | 169 (29.6%) | 290 (28.5%) | 459 (28.9%) |
| More than 20' less than 30 | 140 (24.6%) | 156 (15.3%) | 296 (18.7%) |
| More than 30' | 213 (37.4%) | 380 (37.4%) | 593 (37.4%) |
| Total | 570 | 1,017 | 1,587 |

The Phi or Cramer's value (0.169) in the table 6 indicates that the relationship between linkage to design and fall height has moderate strength even though there is no significant difference between the values (YES and NO) of linkage to design in each level of fall height.

Given in the table 12, the values that are significantly related to design are roof and steel structure, accounting for 61.8% where 387 fatal fall cases (389 workers) could have been prevented if the previously developed design suggestions and guidelines were implemented in the design processes. Among the collected 44 design solutions for the usage of statistical analysis, 13 design suggestions and guidelines are for roofing and 7 for structural steel working. The values of edge of floor, edge of stairway, ceiling structure are also linked to design solutions, which accounts for 17.2%.

Table 12: Cross tabs between linkage to design and location of falls

| Location of Falls \ Linkage to Design | YES | NO | Total |
|---|---|---|---|
| Roof | 213 (37.4%) | 15 (1.5%) | 228 (14.4%) |
| Steel structure | 139 (24.4%) | 20 (2.0%) | 159 (10.0%) |
| Edge of floor | 53 (9.3%) | 34 (3.3%) | 87 (5.5%) |
| Hanging scaffold by rope | 38 (6.7%) | 49 (4.8%) | 87 (5.5%) |
| Edge of stairway | 27 (4.7%) | 4 (0.4%) | 31 (2.0%) |
| (Gang) form | 18 (3.2%) | 42 (4.1%) | 60 (3.8%) |
| Ceiling structure | 18 (3.2%) | 0 (0.0%) | 18 (1.1%) |
| Floor near opening | 17 (3.0%) | 68 (6.7%) | 85 (5.4%) |
| Ladder | 14 (2.5%) | 81 (8.0%) | 95 (6.0%) |
| Shoring system(steel structure) | 13 (2.3%) | 5 (0.5%) | 18 (1.1%) |
| Dumping bed of truck | 9 (1.6%) | 3 (0.3%) | 12 (0.8%) |
| Scaffold | 5 (0.9%) | 298 (29.3%) | 303 (19.1%) |
| Facilities installed in building | 4 (0.7%) | 14 (1.4%) | 18 (1.1%) |
| Other construction equipments | 2 (0.4%) | 76 (7.5%) | 78 (4.9%) |
| Others | 0 (0.0%) | 308 (30.3%) | 308 (19.4%) |
| Total | 570 | 1,017 | 1,587 |

Interestingly, 102 out of 228 fatal fall cases falling from roof and 97 out of 157 cases from steel structure had occurred in industrial buildings, which means industrial projects can obtain the highest benefits from the application of the design for construction safety concept in Korea. The significance p-value and Phi or Cramer's value (0.801) shown in the table 5 indicate that the linkage between linkage to design and location of falls has strong correlation. Consequently, the variable of location of falls can provide designers with important indications when they apply the design for construction safety to their projects. This is because it can specify which factors should be concentrated on, in regard to designers' identification of potential fall hazards and how those hazards can be eliminated or reduced through design optimization. This variable can also point out on which locations of construction projects new design solutions have to be created for fall prevention.

In addition, although it was pre-determined that the design solutions related to temporary structures were left out on determining each fatal fall case's linkage to design, the table 11 shows that some cases of falls from hanging scaffold by rope, ladder, and scaffold are related to design. This is because if those cases could have been prevented by other design solutions, such as prefabrication, designing gutters inside building or service routes for maintenance, then it was concluded that the case was linked to design. The table 11 also indicates that the existing design suggestions and guidelines for fall prevention were developed in limited areas, such as roof, steel structure, and edge of floor. This finding is also supported by the fact that only 40.7% of values are related to the collected 44 design suggestions and guidelines among the 54 values of location of falls that were defined at the first stage. This observation can lead to a hypothesis that there are numerous parts needed to develop new design suggestions or guidelines in terms of fall prevention.

Table 13: Cross tabs between linkage to design and SIC code

| Location of Falls \ Linkage to Design | YES | NO | Total |
|---|---|---|---|
| 1711: Plumbing, heating, air-conditioning | 14 (2.5%) | 52 (5.1%) | 66 (4.2%) |
| 1721: Painting(Waterproofing) | 60 (10.5%) | 87 (8.6%) | 147 (9.3%) |
| 1731: Electric work | 21 (3.7%) | 88 (8.7%) | 109 (6.9%) |
| 1741: Masonry and other stonework | 8 (1.4%) | 67 (6.6%) | 75 (4.7%) |
| 1742, 1751: Plastering, drywall, insulation and carpentry work | 34 (6.0%) | 107 (10.5%) | 141 (8.9%) |
| 1743: Terazzo, tile, marble, mosaic work | 3 (0.5%) | 2 (0.2%) | 5 (0.3%) |
| 1761: Roofing, siding, and sheet metal work | 170 (29.8%) | 45 (4.4%) | 215 (13.5%) |
| 1771: Concrete work(Formwork, Reinforcing) | 43 (7.5%) | 143 (14.1%) | 186 (11.7%) |
| 1791: Structural steel erection | 114 (20.0%) | 35 (3.4%) | 149 (9.4%) |
| 1793: Glass and glazing work | 11 (1.9%) | 40 (3.9%) | 51 (3.2%) |
| 1795: Wrecking and demolition work | 32 (5.6%) | 31 (3.0%) | 63 (4.0%) |
| 1796: Installing building equipment, nec | 10 (1.8%) | 43 (4.2%) | 53 (3.3%) |
| 1799: Special trade contractors | 24 (4.2%) | 128 (12.6%) | 152 (9.6%) |
| Others | 26 (4.6%) | 149 (14.7%) | 175 (11.0%) |
| Total | 570 | 1017 | 1587 |

Cross tabulation between linkage to design and SIC code (Table 13) shows that the two values, which are 1761 (roofing, siding, and sheet metal work) and 1791 (structural steel erection), have significant relationship with design solutions, accounting for 49.8%. Furthermore, among 284 fatal fall cases of 1761 and 1791, which are linked to design solutions, 282 cases are related to roof and steel structure in the variable of location of falls. 1761 and 1791 are also related to industrial projects in the variable of construction end use probably because most industrial buildings are composed of steel structure and envelope including sloping roof. As shown in the table 6, The significance p-value for Chi Square test indicates that there is a significant relationship between design and SIC code because p-value is less than 0.05, and Phi or Cramer's value (0.516) shows that their relationship is strong.

## 4.3. SUMMARY OF CROSS TABULATION ANALYSIS

The results of cross tabulation analysis associated with Chi Square test show that there are significant relationships between linkage to design and 6 independent variables: construction end use, project type, project cost, fall height, location of falls, and SIC code, based on the significance p-values for Chi Square test that are below 0.05. Only the variable of age's relationship with design is not significant. Importantly, the relationships between design and the two independent variables, location of falls and SIC code, are strong pointing out that the Phi or Cramer's values are more than o.5.

From the secondary analysis of factors (values) in each variable, several values are highly related to design solutions, which include industrial buildings in the construction end use, maintenance or repair projects in the project type, projects under $300K in the project cost, fall heights between 20 and 30 feet in the fall height, roof and steel structure in the location of falls, and 1761 and 1791 in the SIC code.

With respect to the application of the design for construction safety concept, designers can obtain benefits from the variable of location of falls. This is because the values provide designers with significant indications in terms of hazard identification and design solution integration, and the table 12 also shows on which areas new design suggestions and guidelines should be created for fall prevention.

### 4.4. LOGISTIC REGRESSION ANALYSIS

Because the dependent variable (Linkage to Design) has a binary nature, which means the variable has two values of YES and NO, logistic regression methodology was adopted in this study. This logistic regression model aims at the evaluation on which factors in the 1,587 fatal fall cases are highly connected to the collected design solutions. For this analysis, six independent variables were chosen based on the results of the previous cross tabulation analysis indicating their relationships with the design solutions are significant. The selected variables include construction end use, project type, project cost, fall height, location of falls, and Standard Industrial Classification (SIC) code, as shown in the table 14.

Table 14: Variables for logistic regression analysis

| Variables | Values | Type of variable |
|---|---|---|
| Linkage to Design (Dependent variable) | 1. YES<br>0. NO | Categorical<br>Dichotomous |
| Construction End Use | 1. Industrial<br>2. Residential<br>3. Commercial<br>4. Heavy, Highway<br>0. Others | Categorical |
| Project Type | 1. New project or new addition<br>2. Maintenance or repair<br>3. Alteration or rehabilitation | Categorical |

| | | |
|---|---|---|
| | 4. Demolition<br>0. Others | |
| Project Cost | 1. Under $300K<br>2. $300K - $2M<br>3. $2M - $12M<br>4. $12M - $80M<br>5. $80M - $150M<br>0. $150M over | Categorical |
| Fall Height | 1. Less than 6 ft<br>2. More than 6' less than 10'<br>3. More than 10' less than 20'<br>4. More than 20' less than 30'<br>0. More than 30' | Categorical |
| Location of Falls | 1. Scaffold<br>2. Roof<br>3. Steel structure<br>4. Ladder<br>5. Edge of floor<br>6. Hanging scaffold by rope<br>7. Floor near opening<br>8. Other construction equipments<br>9. (Gang) form<br>10. Edge of stairway<br>11. Ceiling structure<br>12. Facilities installed in bldg<br>13. Shoring system(steel structure)<br>14. Dumping bed of truck<br>0. Others | Categorical |
| SIC code | 1. 1711: Plumbing, heating, air-conditioning<br>2. 1721: Painting(Waterproofing) | Categorical |

| | | |
|---|---|---|
| | 3. 1731: Electric work<br>4. 1741: Masonry and other stonework<br>5. 1742, 1751: Plastering, drywall, insulation, and carpentry work<br>6. 1743: Terazzo, tile, marble, mosaic work<br>7. 1761: Roofing, siding, and sheet metal work<br>8.1771: Concrete work(Formwork, Reinforcing)<br>9. 1791: Structural steel erection<br>10. 1793: Glass and glazing work<br>11. 1795: Wrecking and demolition work<br>12. 1796: Installing building equipment, nec<br>13. 1799: Special trade contractors<br>14. Others | |

The Hosmer and Lemeshow test indicates that this model is a poor fit because the significance p-value is less than 0.05. This inappropriate fit for the model was mainly caused by the improper distribution of values in dependent variable (linkage to design); the collected 44 design suggestions and guidelines have been developed in limited areas, such as roof, steel structure, and edge of floor. Another reason that can be mentioned for this poor fit is that the relationship between the dependent and independent variables are inconsistent: for instance, even though workers fell from the same location such as edge of floor, or they belong to the same trade (SIC code), they are not coherently related to the design solutions.

The results of logistic regression analysis using SPSS program show that each fatal fall case's linkage to design could be predicted in 62.8%, by comparing the observed and predicted results from the model.

Given in the table 15, the significance p-value for all the variables are less than 0.05, which means those variables are significantly related to dependent variable (linkage to design) in the model; especially the significance p-values of the two variables, location of falls and SIC code, indicate 0.000.

Table 15: The results of logistic regression analysis

| Variables | B | S.E. | Wald | df | P | Exp(β) | 95% C.I. for Exp(β) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Lower | Upper |
| Const. end use | -.151 | .047 | 10.405 | 1 | .001 | .860 | .784 | .942 |
| Project type | .186 | .072 | 6.721 | 1 | .010 | 1.204 | 1.046 | 1.386 |
| Project cost | -.150 | .045 | 11.249 | 1 | .001 | .860 | .788 | .939 |
| Fall height | .092 | .035 | 7.158 | 1 | .007 | 1.097 | 1.025 | 1.174 |
| Location of falls | .143 | .017 | 75.028 | 1 | .000 | 1.154 | 1.117 | 1.192 |
| SIC code | .050 | .014 | 12.340 | 1 | .000 | 1.051 | 1.022 | 1.081 |
| Constant | -1.321 | .216 | 37.503 | 1 | .000 | .267 | | |

# CHAPTER 5

# CONCLUSION

The starting point of this study was the fact that although the previous researches have discussed the concept of design for construction safety is the most effective approach to occupational accident prevention in the construction industry, and there is no disagreement in regard to the benefits of the concept, many professionals working for construction safety still consider the concept as impractical, pointing to several realistic barriers. One of the major barriers is designers' lack of knowledge and experience to carry out safe design process; surveys done in the United States indicate that designers have difficulties on hazard identification and design solution integration when applying the design for safety concept to their design process.

One of the lessons learned from the history of the CDM regulations, established in 1994 in the United Kingdom, is that the effectiveness of the design for construction safety highly depends on designers' competence, which can be evaluated by the criteria of knowledge and experience. With respect to the competence of designers, it is noteworthy that it takes time and cost for designers to progress from just awareness to active involvement in the safe design process.

In this respect, this study aimed to provide designers with stepping stone to the application of the design for safety concept, especially in terms of how to identify potential hazards in their projects and resolve those hazards with design solutions. The assumption of this study was that the statistical relationship between design and several independent variables, such as location of falls, construction end use, and project type, might provide designers with significant indications regarding the design for construction safety concept. The variables in the data of 1,587 fatal fall cases were analyzed by statistical tools and SPSS program in terms of their relationship with design.

The major finding of this research is that construction end use, project type, project cost, fall height, location of falls, and Standard Industrial Classification (SIC) code are significantly related to design in terms of fall prevention; especially the design solutions' linkage to two variables, which are location of falls and SIC code, is strong. In the secondary analysis, the results of cross tabulation analysis shows that industrial buildings, maintenance or repair projects, projects under $300K, fall height between 20 and 30 feet, roof and steel structure, and 1761 (roofing, siding, and steel metal work) and 1791 (structural steel erection) are highly linked to design. These findings are connected to the fact that among the collected 44 design suggestions and guidelines, 20 solutions are for roofing and steel working, and 7 design suggestions are for the future work.

The results can provide designers with useful information in terms of hazard identification and design solution integration:

(1) From the variables of 'Construction End Use and Project Type', designers can recognize what sort of projects they can benefit from in terms of the application of design for construction safety concept, for example industrial buildings and maintenance or repair projects are highly connected to safe design.

(2) From 'Location of Falls', designers can identify potential hazards, such as falls from roof or steel structure, and the existing design suggestions and guidelines used to determine each fatal fall case's linkage to design can contribute to design solution integration for those identified hazards (table 4).

(3) Experienced designers can also identify on which areas new design solutions are needed from the values of 'Location of Falls', for instance bridge and concrete structure, construction

equipments, utility poles, and form shoring structures are the areas where design solutions have not been developed.

Consequently, this finding can contribute to time and cost saving required for designers to become competent enough to deal with the concept of design for construction safety.

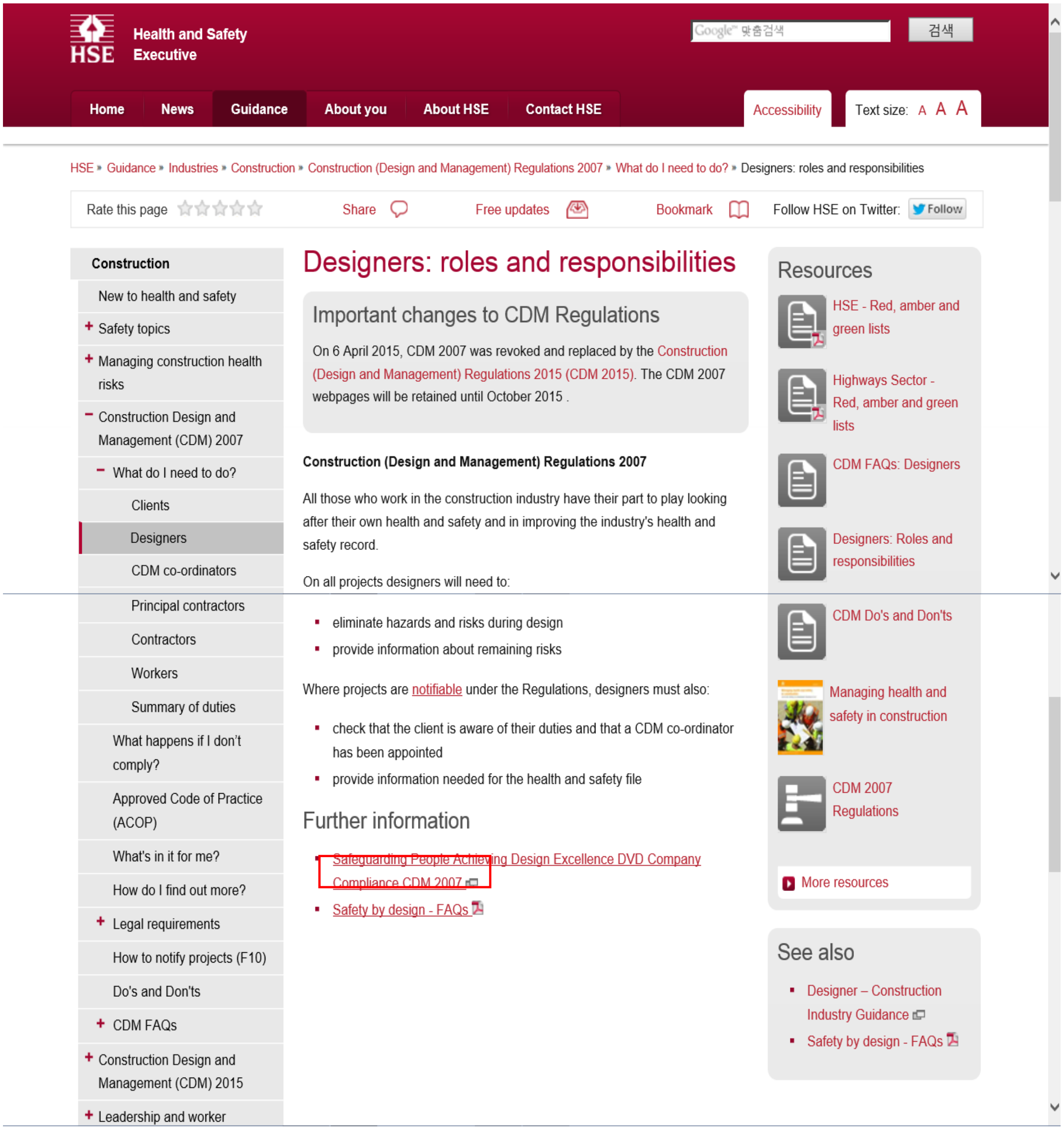
With respect to further research, designing temporary structures and the consideration of constructability at the design phase remain as controversial issues for construction safety because numerous accidents have occurred from or by scaffolds, form shoring structures, or other temporary facilities, and designers do not regard those tasks as their responsibility. A few researchers discussed that designers would be encouraged to get involved in designing temporary structures and construction engineering, and some of the existing design solutions already dealt with those issues. However the trials were at the beginning stage. In regard to designers' role in temporary work, further studies are needed, and collaboration with temporary works designers and suppliers of prefabricated materials should be considered in the further study.

## APPENDIX - A: THE LIST OF DESIGN SUGGESTIONS AND GUIDELINES

| No. | Type | Title | Target | Source |
|---|---|---|---|---|
| 1 | DS | Fall prevention from floor | Edge of floor | The OSHA alliance program's construction round table in the US |
| 2 | DS | Fall prevention from roof | Roof | |
| 3 | DS | Parapet wall on roof edge | Roof | |
| 4 | DS | Fall prevention through skylights | Roof | |
| 5 | DS | Roof anchors | Roof | |
| 6 | DS | Fall prevention from steel structure | Steel structure | |
| 7 | DS | Fall prevention from non-moving Vehicle | Vehicle | |
| 8 | DS | Fixed ladder | Ladder | |
| 9 | DS | Prefabrication and assembly at ground level | Prefabrication (Modular const.) | |
| 10 | DS | Permanent features for suspended Scaffold | Scaffold | |
| 11 | DS | Roof parapet | Roof | NIOSH in the US |
| 12 | DG | Fall protection | Fall arrest Systems | Safety In Design(SID) in the UK |
| 13 | DG | Guide for roofing | Roof | |
| 14 | DG | Guide for steel work | Steel structure | |
| 15 | DG | Suspended access equipment | Maintenance or Repair | |
| 16 | DG | Temporary structures | Temporary structures | |
| 17 | DG | Decision for mass and form | Envelope | Designers' Initiative On Health And Safety (DIOHAS) in the UK |
| 18 | DS | Roof maintenance access options | Maintenance on Roof | |
| 19 | DS | Rainwater outlet maintenance on roof | Maintenance on Roof | |
| 20 | DG | Ceiling closure | Ceiling | Design Best Practice (DBP) in the UK |
| 21 | DS | Access into ceilings | Ceiling | |
| 22 | DS | Secondary grid for work within Ceiling | Ceiling | |
| 23 | DS | Access to ducts for maintenance | Maintenance of Duct | |
| 24 | DS | Sockets for guardrail | Edge of floor | |
| 25 | DS | Mechanical envelope maintenance | Envelope | |
| 26 | DS | Off-site manufacture | Prefabrication | |

| | | | | |
|---|---|---|---|---|
| | | | (Modular const.) | |
| 27 | DS | Construction top section at ground level | Prefabrication (Modular const.) | |
| 28 | DS | Pre-installed supports for M&E | Maintenance or Repair | |
| 29 | DS | Roof-lights and fragile roofing Materials | Roof | |
| 30 | DS | Parapet wall detailing | Roof | |
| 31 | DS | Parapet(folding balustrade) | Roof | |
| 32 | DS | Large span roofing sheets | Roof | |
| 33 | DS | Designated service routes | Roof | |
| 34 | DS | Steel plates for pipe shaft | Opening | |
| 35 | DS | Staircase framing | Steel structure | |
| 36 | DS | Handrails designed into staircase | Steel structure | |
| 37 | DS | Modular pipe-racks | Modular | |
| 38 | DS | Towel rail in steel structure | Steel structure | |
| 39 | DS | Modular plant rooms | Modular | |
| 40 | DS | Trailer access platforms | Vehicle | |
| 41 | DG | CDM Red, Amber and Green lists | All-round | Health and Safety Executive(HSE) in the UK |
| 42 | DG | Designing for safety | All-round | Architects' Council of Europe(ACE) |
| 43 | DG | Safe design practice | All-round | Safe Design Australia |
| 44 | DG | Guidelines on design for safety in buildings and structures | All-round | WSH Council in Singapore |

## APPENDIX - B: THE SOURCE OF DESIGN SOLUTIONS ON THE HSE WEBSITE



HSE Health and Safety Executive

Google™ 맞춤검색 | 검색

Home | News | Guidance | About you | About HSE | Contact HSE | Accessibility | Text size: A A A

HSE » Guidance » Industries » Construction » Construction (Design and Management) Regulations 2007 » What do I need to do? » Designers: roles and responsibilities

Rate this page | Share | Free updates | Bookmark | Follow HSE on Twitter: Follow

Construction
- New to health and safety
- + Safety topics
- + Managing construction health risks
- − Construction Design and Management (CDM) 2007
  - − What do I need to do?
    - Clients
    - Designers
    - CDM co-ordinators
    - Principal contractors
    - Contractors
    - Workers
    - Summary of duties
  - What happens if I don't comply?
  - Approved Code of Practice (ACOP)
  - What's in it for me?
  - How do I find out more?
  - + Legal requirements
  - How to notify projects (F10)
  - Do's and Don'ts
  - + CDM FAQs
- + Construction Design and Management (CDM) 2015
- + Leadership and worker

# Designers: roles and responsibilities

### Important changes to CDM Regulations

On 6 April 2015, CDM 2007 was revoked and replaced by the Construction (Design and Management) Regulations 2015 (CDM 2015). The CDM 2007 webpages will be retained until October 2015 .

**Construction (Design and Management) Regulations 2007**

All those who work in the construction industry have their part to play looking after their own health and safety and in improving the industry's health and safety record.

On all projects designers will need to:

- eliminate hazards and risks during design
- provide information about remaining risks

Where projects are notifiable under the Regulations, designers must also:

- check that the client is aware of their duties and that a CDM co-ordinator has been appointed
- provide information needed for the health and safety file

### Further information

- Safeguarding People Achieving Design Excellence DVD Company Compliance CDM 2007
- Safety by design - FAQs

### Resources

- HSE - Red, amber and green lists
- Highways Sector - Red, amber and green lists
- CDM FAQs: Designers
- Designers: Roles and responsibilities
- CDM Do's and Don'ts
- Managing health and safety in construction
- CDM 2007 Regulations
- More resources

### See also

- Designer – Construction Industry Guidance
- Safety by design - FAQs


## Q17:

### Where can I find practical examples of how Safe by Design has been applied?

The following websites provide practical examples which may be useful.

**In the UK:**

- Safe by Design (SID) www.sid.org.uk
- Designers Initiative on health and safety (DIOHAS) www.diohas.org.uk
- Design best practice (dbp) www.dbp.org.uk
- UK Olympic Delivery Authority (ODA) http://learninglegacy.london2012.com/themes/design-and-engineering-innovation/index.php

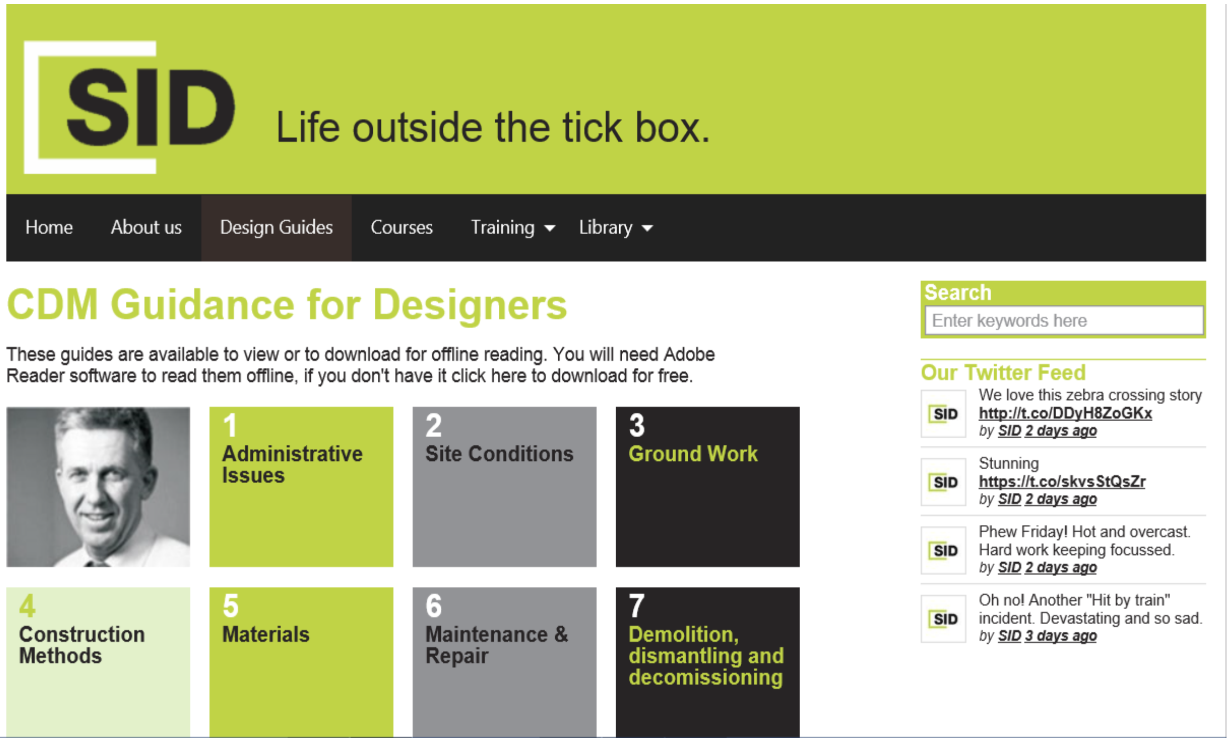
**In Singapore:**

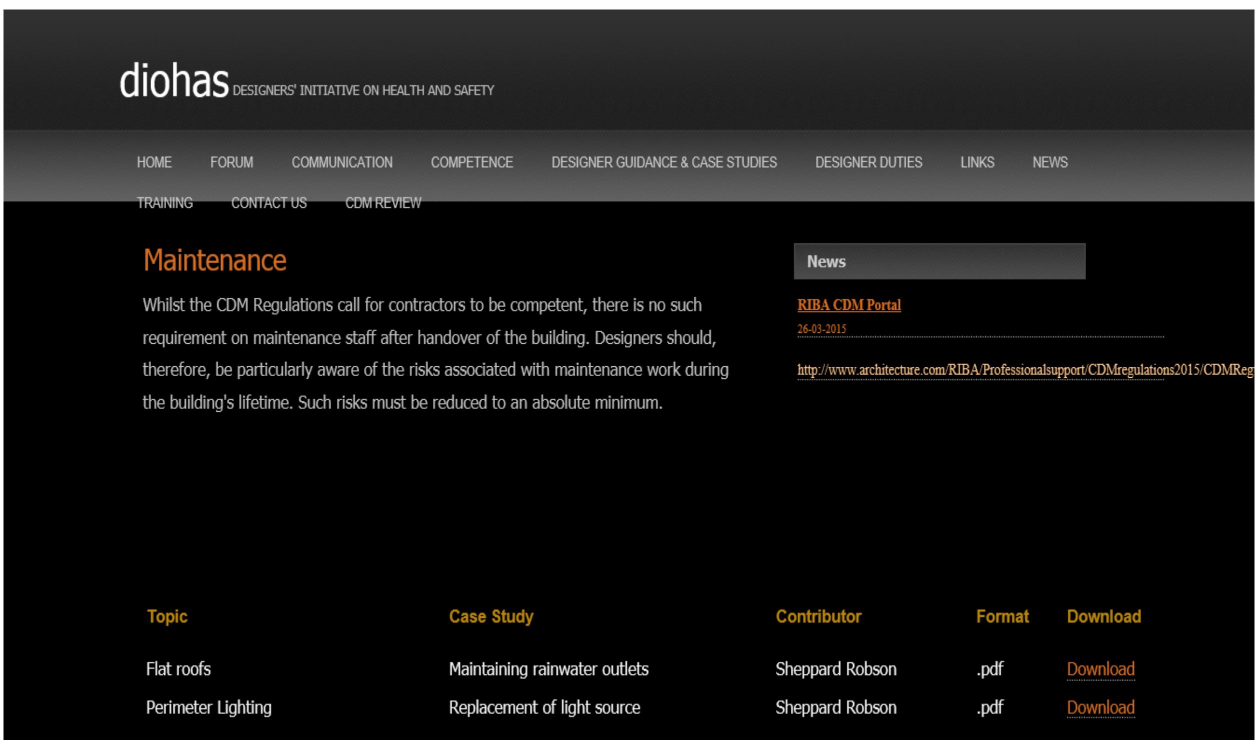
- https://www.wshc.sg/wps/portal/resources?action=detailedInfoStop&fInfoStopID=IS2010012500120

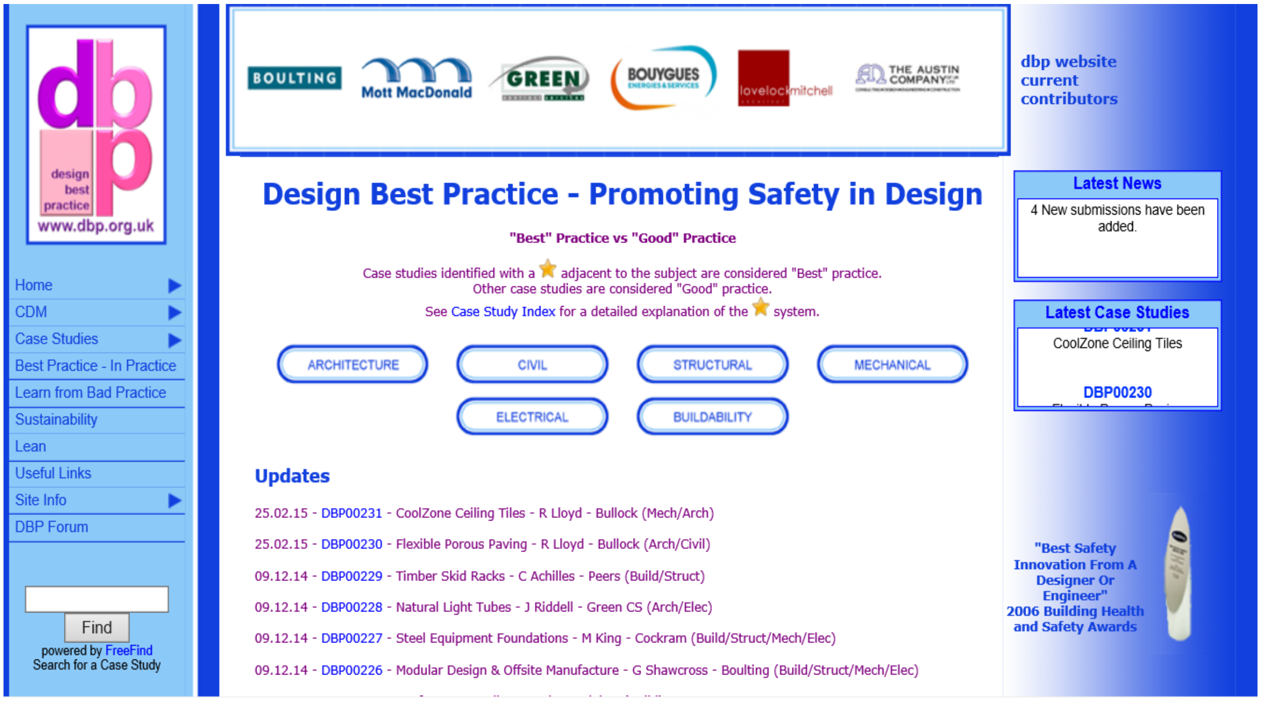
**In Australia:**

- www.safeworkaustralia.gov.au/safetyinyourworkplace/safedesign/pages/safedesign.aspx
- http://www.workcover.nsw.gov.au/formspublications/publications/pages/wc00976_chairsafetyindesigntool.aspx

## APPENDIX - C: THE OTHER SOURCES OF DESIGN SOLUTIONS

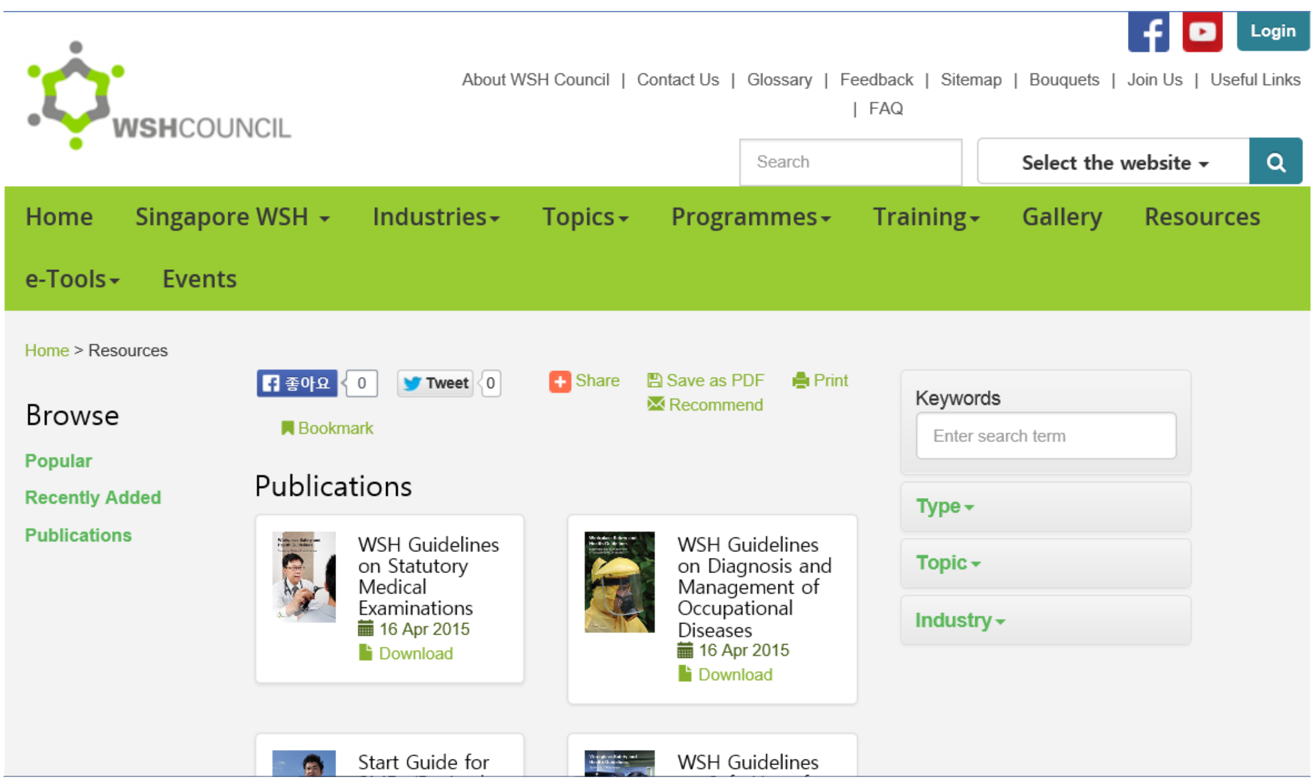



dbp design best practice www.dbp.org.uk
Home
CDM
Case Studies
Best Practice - In Practice
Learn from Bad Practice
Sustainability
Lean
Useful Links
Site Info
DBP Forum
Find
powered by FreeFind
Search for a Case Study
BOULTING
Mott MacDonald
GREEN
BOUYGUES
lovelockmitchell
THE AUSTIN COMPANY
dbp website current contributors
Design Best Practice - Promoting Safety in Design
"Best" Practice vs "Good" Practice
Case studies identified with a adjacent to the subject are considered "Best" practice.
Other case studies are considered "Good" practice.
See Case Study Index for a detailed explanation of the system.
ARCHITECTURE
CIVIL
STRUCTURAL
MECHANICAL
ELECTRICAL
BUILDABILITY
Latest News
4 New submissions have been added.
Latest Case Studies
CoolZone Ceiling Tiles
DBP00230
Updates
25.02.15 - DBP00231 - CoolZone Ceiling Tiles - R Lloyd - Bullock (Mech/Arch)
25.02.15 - DBP00230 - Flexible Porous Paving - R Lloyd - Bullock (Arch/Civil)
09.12.14 - DBP00229 - Timber Skid Racks - C Achilles - Peers (Build/Struct)
09.12.14 - DBP00228 - Natural Light Tubes - J Riddell - Green CS (Arch/Elec)
09.12.14 - DBP00227 - Steel Equipment Foundations - M King - Cockram (Build/Struct/Mech/Elec)
09.12.14 - DBP00226 - Modular Design & Offsite Manufacture - G Shawcross - Boulting (Build/Struct/Mech/Elec)
"Best Safety Innovation From A Designer Or Engineer" 2006 Building Health and Safety Awards


Prevention through Design
Design for Construction Safety
PtD
Home | Concept | Process | History & Future | Challenges | Resources | Links | Contacts
Design Tools
SliDeRulE (Safety in Design Risk Evaluator) assists building designers with assessing the construction safety risk associated with their designs. Use SliDeRulE for buildings to:
1) Determine the level of safety risk associated with an entire building, a specific building system, or each of the many design features within a building
2) Compare prospective designs based on construction safety risk
3) Learn about design features that increase and decrease the risk of injury
OSHA's hazard identification training tool may prove helpful for education design engineers and other non-safety professionals about common construction site hazards.
Safe Design Guidelines distributed by the San Francisco Public Utilities Commission.
1600+ PtD list compiled by Alan Speegle (The Southern Company). Note: This spreadsheet is most helpful for process (i.e., industrial) construction. The attached file was posted


Safe Design Australia
Login/Sign up
Australia-wide service | info@safedesignaustralia.com.au | 1300 732 732
Home | Services | Projects | Safe Design | WHS Legislation | Resources | FAQs | Contact
RESOURCES
Safe Design Australia have developed a number of resources for our clients and the design community. Our Safe Design in Practice eBook provides information on the WHS legislation and how designers can best practice safe design. Our fact sheets explain the WHS legislation and designer and client duties. You can also fnd some valuable links and resources in Australia and overseas.
Providing specialist services in safety and design.
EBOOK
SAFE DESIGN IN PRACTICE
DOWNLOAD NOW
Safe design in practice: For designers of structures
Safe Design Australia's eBook provides information to assist designers in meeting their safe design obligations at each stage of the design process from pre design to design completion, and


Login
WSHCOUNCIL
About WSH Council | Contact Us | Glossary | Feedback | Sitemap | Bouquets | Join Us | Useful Links | FAQ
Search
Select the website
Home
Singapore WSH
Industries
Topics
Programmes
Training
Gallery
Resources
e-Tools
Events
Home > Resources
좋아요 0
Tweet 0
Share
Save as PDF
Recommend
Print
Bookmark
Browse
Popular
Recently Added
Publications
Publications
WSH Guidelines on Statutory Medical Examinations
16 Apr 2015
Download
WSH Guidelines on Diagnosis and Management of Occupational Diseases
16 Apr 2015
Download
Start Guide for
WSH Guidelines
Keywords
Enter search term
Type
Topic
Industry

**REFERENCES**

1. John A. Gambatese, 2005, "Viability of Designing for Construction Worker Safety"

2. Jorgensen K. et al.(Denmark), 2010, "Integration of Safety in the Building Delivery System.

3. John W. Mroszczyk, 2006, "Designing for Construction Worker Safety"

4. R.A. Haslam, S.A. Hide, A.G.F. Gibb, D.E. Gyi, T. Pavitt, S. Atkinson, A.R. Duff, 2004, "Contributing factors in construction accidents"

5. Marc Weinstein, John Gambatese, Steven Hecker, 2005, "Can Design Improve Construction Safety?: Assessing the Impact of a Collaborative Safety-in-Design Process"

6. Michael Behm, 2005, "Linking construction fatalities to the design for construction safety concept"

7. Xinyu Huang and Jimmie Hinze, 2003, "Analysis of Construction Worker Fall Accidents"

8. Chia-Fen Chi, Tin-Chang Chang, Hsin-I Ting, 2004, "Accident patterns and prevention measures for fatal occupational falls in the construction industry"

9. Alasdair N. Beal, 2007, "CDM Regulations: 12 years of pain but little gain"

10. The Council of the European Communities, 1992(amended in 2007), "The Temporary or Mobile Construction Site Directive"

11. Health and Safety Executive (HSE), CDM Regulations 2007 (www.hse.gov.uk)

12. Health and Safety Executive (HSE), 2007, "Managing health and safety in construction: CDM Regulations 2007 Approved Code of Practice(ACoP)"

13. Frontline Consultants for HSE, 2011, "Evaluations of CDM Regulations 2007(Pilot study)"

14. John A. Gambatese, Michael Behm, Sathyanarayanan Rajendran, 2008, "Design's role in construction accident causality and prevention: Perspectives from an expert panel"

15. Lew, J.J. et al, 2010, "Designing for Safety - Applications for the Construction Industry"

16. Hulya Cakan, 2012, "Analysis and Modeling of Roofer and Steel Worker Fall Accidents"

17. Marta Gangolells, Miquel Casals, Núria Forcada, Xavier Roca, Alba Fuerteset, 2010, "Mitigating construction safety risks using prevention through design"

18. Dolores Martinez Aires, Carmen Rubio Gamez, Alistair Gibb, 2009, "Prevention through design: The effect of European Directives on construction workplace accidents"

19. John. A. Gambatese, 2008, "Research Issues in Prevention through Design"

20. T. Michael Toole, John Gambatese, 2008, "The Trajectories of Prevention through Design in Construction"

21. Sijie Zhang, Jochen Teizer, Jin-Kook Lee, Charles M. Eastman, Manu Venugopal, 2012, "Building Information Modeling (BIM) and Safety: Automatic Safety Checking of Construction Models and Schedules"

22. Korea Occupational Safety and Health Agency (KOSHA) website, http://www.kosha.or.kr

23. Safety In Design (SID) website, http://www.safetyindesign.org.uk

24. Designers Initiatives On Health And Safety (DIOHAS) website, http://www.diohas.org.uk

25. Design Best Practice (DBP) website, http://www.dbp.org.uk

26. Prevention through Design, Design for Construction Safety (DfCS) website, http://www.designforconstructionsafety.org

27. The National Institute for Occupational Safety and Health (NIOSH) website, http://www.cdc.gov/niosh

28. Safe Design Australia, 2014, "Safe Design in Practice for Designers of Structures"

29. Architects' Council of Europe (ACE), 2006, "Designing for Safety in Construction"

30. The Workplace Safety and Health (WSH) council in Singapore, 2008, "Guidelines on Design for Safety in Buildings and Structures"

## ABSTRACT

**STATISTICAL APPROACH TO**
**DESIGN FOR FALL PREVENTION IN CONSTRUCTION**

by

**KYUNGHWAN KIM**

**May 2015**

**Advisor :** Dr. Mumtaz Usmen

**Major :** Civil Engineering

**Degree :** Master of Science

During the past decades, the construction industry has been considered as one of the most vulnerable field to work-related injuries and fatalities, and fall accidents are the leading causes accounting for about one-third of the total fatal injuries happened in construction. Furthermore, more than 30% of fall fatal cases occurred in the projects under $ 300K in Korea where construction workers' safety and health are not usually considered as top priorities because the contractors, who are normally small sized construction firms or self-employed, do not have safety budget to deal with construction workers' safety.

In this respect, this study focused on designers' role in terms of fall prevention in the construction industry because the previous researchers have discussed the effectiveness of the design for construction safety concept and publishes it as a major issue in famous journals. However, from designers' perspective, the concept has been considered as an impractical approach mainly due to their shortage of required knowledge and ability to deal with. This study found that sufficient time and cost are required for designers to progress from the awareness of

design's role on construction safety to competent professionals from the history of the CDM regulations established in the United Kingdom.

This study first identified the relationship between design and 1,587 fatal fall cases occurred in Korea partly adopting the methodology of previous research, and then analyzed the dependent variable (linkage to design)'s relationship with 7 independent variables using statistical tools, which include construction end use, project type, project cost, age, fall height, location of falls, and SIC code. The author assumed that these independent variables' relationship with design would provide designers with significant indications in regard to hazard identification and design solution integration on which less-experienced designers have difficulties when applying the design for construction safety concept.

The outcomes of the statistical analysis show 6 independent variables except age have significant linkage to design, and especially design's relationships with location of falls and SIC code are strong. Designers can obtain great benefits from these results because some variables, such as construction end use, project type, and location of falls, can provide designers with practical approach to hazard identification and design solution integration..

## AUTOBIOGRAPHICAL STATEMENT

Kyunghwan Kim had worked as an inspector and manager in Korea Occupational Safety and Health Agency (KOSHA), which is the public agency established to prevent work-related injuries, fatalities, and illnesses, for more than 12 years. Since his graduation from Yeungnam University, Daegu, Korea, he immediately entered into the KOSHA and started to work for construction safety.

While he was working in branch offices of the KOSHA, he inspected construction sites regarding safety management, educated construction workers and safety personnel, and investigated construction accidents whenever those cases happened. When he took service with the headquarter of his company, he analyzed the statistics of construction periodically and announced the accident rate of each construction firm, which was applied to the Pre-Qualification of bidding. He also published the casebooks of construction fatalities on a regular basis and contributed partially to establishing construction safety policy and developing educational resources.