AN ABSTRACT OF THE THESIS OF

Vineeth Dharmapalan for the degree of Master of Science in Civil Engineering presented on June 7, 2011.

Title: Risk Factor Quantification of Design Elements for Multistory Commercial Office Buildings.

Abstract approved: ____

John A.Gambatese

Designing for construction safety is part of standard practice in countries such as the UK, Australia, and South Africa. Designing the permanent facility in a manner to eliminate or reduce the risks of injury, illness, or fatality of construction workers is defined as designing for construction safety (DfCS). Although evident through research that design is one of the contributing factors to construction hazards, the US construction industry has been resistant in implementing DfCS. Lack of designers' knowledge about the construction processes and limited availability of DfCS tools are examples of inhibitors to the development and implementation of DfCS.

This thesis describes a research effort to develop a DfCS tool that provides knowledge of the construction processes to the designer and helps the designer evaluate design elements in terms of risk factors. The tool, which focuses on a multistory commercial office building, was developed using results obtained from a comprehensive field survey and analysis program on safety risks associated with constructing different design features.

The field survey program included the accumulation of 89 design elements and 473 construction activities from construction literature. Using survey methodology, the average exposure and average frequency of four severity categories were obtained for each construction activity. The inputs were provided by superintendents and/or safety managers of general contracting and trade contracting firms. Together the respondents provided a total of more than 33,800 ratings. The analytical program included conversion of the ratings obtained from the field survey program into unit risk and cumulative risk factors using appropriate scales and computations. The results of this research include the quantification of the unit risk and cumulative risk factors for the 89 design elements and the 473 construction activities. These were put into a MS Excel® spreadsheet which can be used for designing for construction safety.

The data was also used to analyze comparisons between risk perceptions of the respondent groups. Group comparisons were made between general contractor superintendents vs trade contractors, general contractor safety managers vs trade contractors, and general contractors vs trade contractors. Using cast-in-place concrete column as an example, the activity risk factors, the four severity category risk factors, and the total risk factors were individually compared. The results indicate that there is no evidence of a difference in risk perception between general contractor superintendents and general contractor safety managers in terms of risk ratings for the activity risk, severity categories, and total risk comparisons. The construction and removal of formwork and pouring of concrete show moderate to suggestive evidence of a difference in the sample mean risk perceptions for the three group comparisons. For the four severity levels and total risk comparisons, there is moderate to suggestive evidence of a difference for medium severity, high severity, and total risk for the three group comparisons. There is no evidence of a difference in the way the groups perceive near miss risks.

Additionally, comparison between design elements was analyzed. For steel stud versus concrete masonry unit block partition walls, there is moderate evidence that on an average, the construction of CMU block wall has a larger cumulative risk of medium severity and high severity injuries. There is suggestive evidence that the average near misses are more for CMU block partition walls than for steel stud partition walls. Finally, there is moderate evidence that on an average, the total cumulative risk associated with CMU block wall construction is more than that during steel stud wall construction.

Risk Factor Quantification of Design Elements for Multistory Commercial Office Buildings

by

Vineeth Dharmapalan

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 7, 2011
Commencement June 2012

Master of Science thesis of Vineeth Dharmapalan presented on June 7, 2011

APPROVED:

Major Professor, representing Civil Engineering

Head of the School of Civil and Construction Engineering

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Vineeth Dharmaplan, Author

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to Dr. John Gambatese for being my mentor. Without his support and guidance, this research study would not have been possible. Working with John has been a wonderful experience and he has influenced me in many ways. From his calm and relaxed nature, I understood the true meaning of patience and how to think critically. He is the ideal advisor a student can get.

My teaching assistantship at OSU gave me the opportunity to work closely with Dr. David Rogge. He was always willing to listen and help whenever I stopped by his office. I also admire his energy levels at taking the 8 am class during the cold and wet Winter term.

I am also grateful to Dr. Lisa Madsen for agreeing to be my minor professor. Her ST512 class got me interested in the world of statistics and inspired me to pursue a minor. I would also like to thank Dr. Thomas Plant for being part of my defense committee.

Graduate life is impossible without the encouragement and support of friends. Fortunately, there are too many to name here but special thanks to Radhakrishnan, Chetan, Vaibhav, and Venkatesh for teaching me to drive, which proved instrumental for my data collection. I am also grateful to Raj, Vaibhav, Vishal and Yogitha for accommodating me during my data collection. I am also grateful to my good friend and fellow graduate student Raul for sharing ideas and assisting me during my analysis. Raul, you will be remembered always for the discussions we had on life and statistics during our coffee breaks.

Without my family, I never would have made it this far in life. I offer special thanks to my mother whose love and support has always been my strength. I appreciate the support from my elder brothers, Visakh and Ranjan. Ranjan, I thank you for taking care of me during the last weeks before my defense. Special thanks to Dhanashree Shinde. Her love, support and friendship has enhanced my life tremendously. I love you all from the bottom of my heart.

Finally, I would like to acknowledge the School of Civil and Construction Engineering at Oregon State University for providing me with a tremendous graduate school experience and making me feel at home.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES (Continued)

DEDICATION

To my father, the late V. Dharmapalan

INTRODUCTION

Regardless of the increased efforts over the years, injuries and fatalities continue to be a problem for the construction industry. The industry has started to realize that safety practices of the constructor alone are inadequate and that there is a need for increased involvement by the entire project team. It is evident through research that the designer is one such team member whose decisions influence construction worker safety. Designers typically dictate the components, design features, and their configuration for a facility. However, designers are often oblivious to safety consequences encountered during construction of their design decisions. This lack of designers' knowledge about the construction processes, and limited availability of DfCS tools, are examples of inhibitors that preclude DfCS as an intervention.

The primary objective of this thesis is to educate the designer regarding the construction process related to their design decisions and about the safety hazards during the construction of their designs. To achieve this objective, a tool to evaluate design features of a typical multistory commercial office building is developed. It encompasses all the components that make up the shell of a multistory commercial office building (the foundation, framing, exterior, interior, and roofing), and the different design features that are part of these components. The evaluation of the design features is based on safety risk ratings calculated by obtaining expected risk values associated with the construction process of the design features. The design rating system serves as a DfCS tool for designers and also provides an opportunity to rate projects based on the priority given to designing for construction safety.

0.1 RESEARCH QUESTIONS

The research objective discussed above will be met by answering the research questions presented below.

1. Is there a need for designing for construction safety?
2. What are the typical design features that are used for constructing a multistory commercial office building?
3. What are the major construction activities that are performed on the jobsite during construction of the typical design elements used for multistory commercial office buildings?
4. What are the risk values of the construction activities of the design elements?
5. What are the risk values of the design elements used for multistory commercial office buildings?
6. Are the risk perceptions between different construction field personnel groups the same?
7. Is the construction safety risk of two different design elements that are used for the same system in a building the same?

0.2 ORGANIZATION OF THESIS

This thesis is organized using a section-subsection format. There are seven sections and several subsections within each section. The following is a brief explanation of the various sections in this thesis.

- Section 1(the current section) introduces the research topic and presents the research questions that need to be addressed.
- Section 2 provides a comprehensive review of relevant literature. This section starts with a review of history of US construction industry injuries and fatalities, and the costs associated with them. A review of all of the project team members' contributions towards improving construction safety is then provided. Following

this, the concept of Designing for Construction Safety is reviewed and the need for it is discussed.

- Section 3 presents the gaps or needs in current research and discusses the significance of the research study.
- Section 4 provides the research methodology used in the current study to obtain the information analyzed. The process of questionnaire development and data collection used to gather information is discussed.
- Section 5 presents the results, which show the data obtained as part of the research effort.
- Section 6 presents the analysis and discussion of the data obtained from the survey and quantifies the risks associated with construction activities of design features.
- Section 7 presents conclusions drawn from the research study. It also provides limitations and assumptions associated with the results of the research study.
- Section 8 provides recommendations for future research initiatives based on the research study.

LITERATURE REVIEW

1.1 US CONSTRUCTION INDUSTRY SAFETY STATISTICS

Over the past few decades, safety has been a key area of interest for the construction industry and researchers. Despite the significance given to construction safety, construction is consistently among the major industry sectors in terms of workplace injuries and fatalities. This is clearly evident from the fatality and disabling injuries data accumulated by the National Safety Council. Figure 1.1 provides a graphical representation of the fatality rate for various work industries from 2003 to 2009. At a fatality rate of more than ten per 100,000 workers, the construction sector has steadily been the fourth most hazardous work industry in terms of fatalities over the past six years. Moreover, the fatality and injury rates have been disproportionate as evidenced from Figure 1.2. On an average from 1951-2008, construction has employed 5.6% of the US workforce but accounted for 19.4% of the fatalities and 10.8% of disabling injuries (NSC 2010). In spite of the increased safety and health management adopted on the construction site, the number of fatal injuries does not show any significant decrease over the past 20 years (see Figure 1.3).

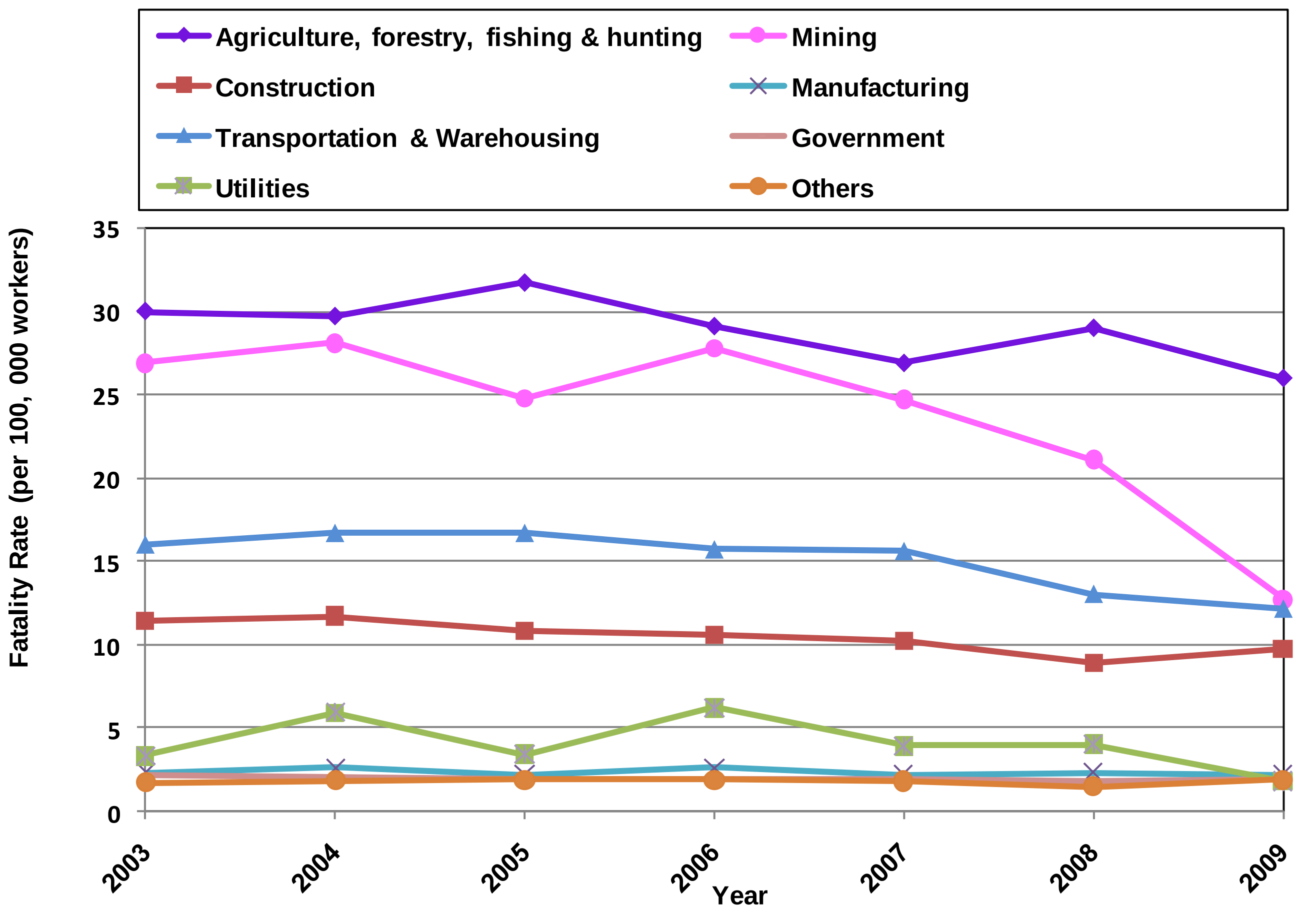

Figure 1.1: Annual Fatality Rate for Various Work Industries (Source: “Injury Facts”, National Safety Council, 2003-2010)

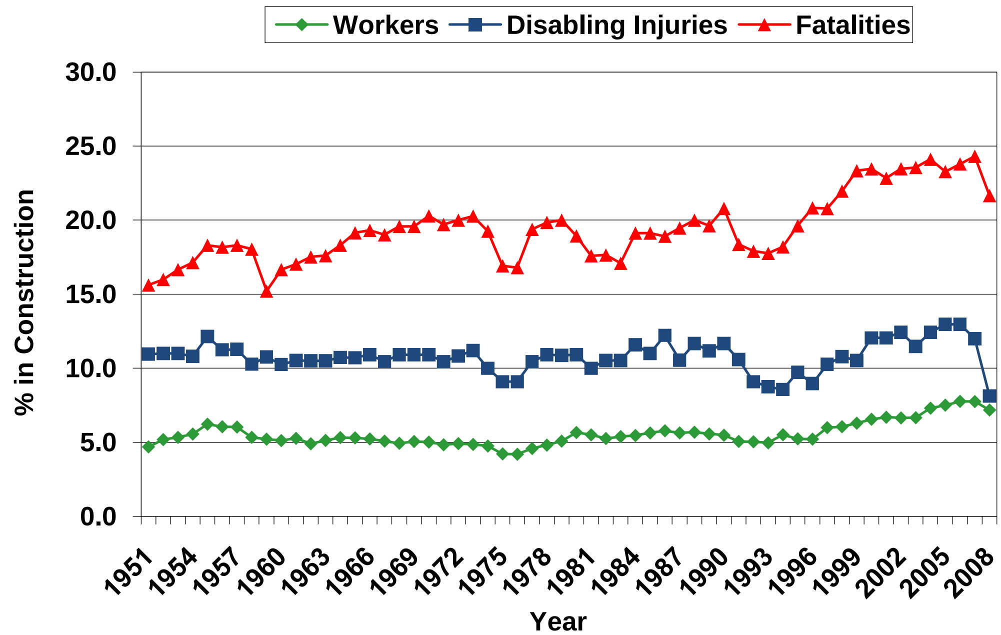

Figure 1.2: Construction Workers, Fatalities, and Disabling Injuries as a Percentage of Total U.S. Workforce (Source: "Injury Facts", National Safety Council, 1952-2010)

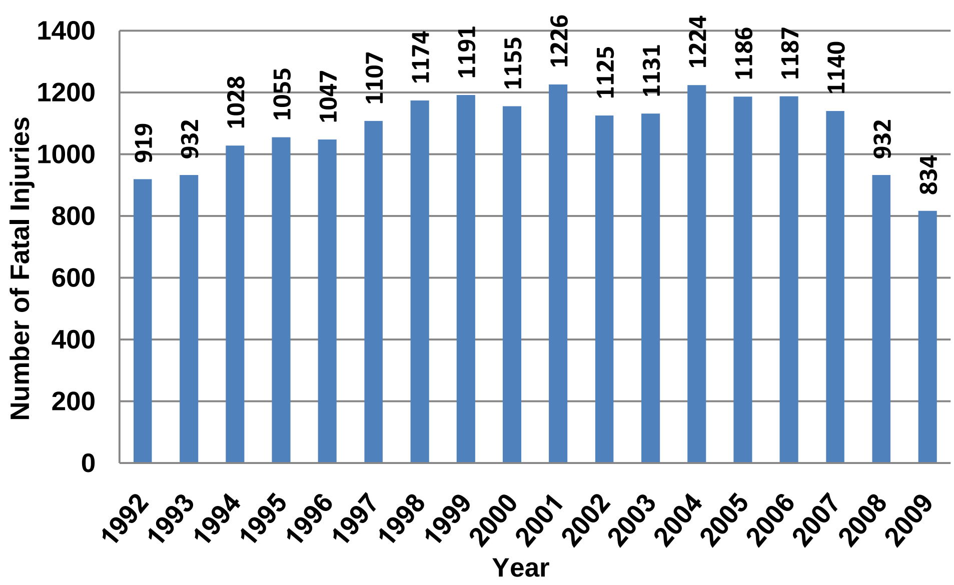

Figure 1.3: Number of Fatal Injuries in Construction, 1992-2009 (BLS 2010)

1.2 COST OF CONSTRUCTION FATALITIES AND INJURIES

A fatality or injury on the jobsite is not just a loss of life or work-time. There is also a dollar value associated with each fatality and injury. One of the earlier studies on costs of injuries by Hinze and Appelgate (1991) investigated the costs due to medical and lost work day injuries Their findings for job and employer costs are summarized in Table 1.1 (as cited in Gambatese 2000).

Table 1.1: Average Cost of Construction Site Injuries

Type of Injury	Job Costs		Estimated Liability	Total Cost to Employer
	Direct	Indirect		
Medical Only	$520	$440	$240	$1,200
Lost Work Day	$6,900	$1,600	$16,500	$25,000

Everett and Frank (1996) examined the total accident and injuries costs to the construction industry. Based on their study, the researchers concluded that costs associated with injuries and fatalities account for 7.9% to 15.0% of construction costs. This cost increased from 6.5% of the construction costs estimated in 1982 (Everett and Frank 1996). Waehrer et al (2007) investigated the 2002 national incidence data and estimated that 15% of the costs for all private industry were contributed by the fatal and nonfatal costs incurred by the construction industry. Table 1.2 was developed using the data accumulated by the National Safety Council, and shows the estimated fatality and injury cost incurred by the US construction industry from 1995-2008.

Table 1.2: Fatality and Injury cost per construction employee, 1996-2008 (Source: "Injury Facts", National Safety Council, 1996-2010)

Year	**Fatalities**	**Disabling Injuries**	**Fatality cost (x1000)**	**Injury cost (x1000)**	**Total Cost (x1000)**	**Cost/ Employee**
1995	1,040	350,000	$821,600	$9,800,000	$10,621,600	$1,634
1996	1,000	350,000	$790,000	$9,100,000	$9,890,000	$1,498
1997	1,060	390,000	$943,400	$10,920,000	$11,863,400	$1,512
1998	1,120	410,000	$1,019,200	$11,480,000	$12,499,200	$1,554
1999	1,190	400,000	$1,118,600	$11,200,000	$12,318,600	$1,453
2000	1,220	470,000	$1,195,600	$13,160,000	$14,355,600	$1,604
2001	1,210	470,000	$1,234,200	$13,630,000	$14,864,200	$1,629
2002	1,150	460,000	$1,230,500	$15,180,000	$16,410,500	$1,791
2003	1,060	390,000	$1,176,600	$14,820,000	$15,996,600	$1,726
2004	1,194	460,000	$1,373,100	$15,640,000	$17,013,100	$1,656
2005	1,155	480,000	$1,374,450	$18,240,000	$19,614,450	$1,826
2006	1,187	480,000	$1,471,880	$18,720,000	$20,191,880	$1,785
2007	1,140	420,000	$1,447,800	$18,060,000	$19,507,800	$1,709
2008	932	260,000	$1,220,920	$12,480,000	$13,700,920	$1,301

The 50% reduction in the number of injuries and fatalities over the past three decades (Hinze 2006) is not entirely due to the altruistic nature of the employer. From an economic standpoint, the employer has to bear the expenses in the event of an accidental injury or fatality. As can be seen from Table 1.2, on an average, $1,620 was spent by the employer every year per employee to address the cost associated with injuries and fatalities. The workers' compensation insurance, which provides coverage for the injured workers, is an escalator in project costs. Coble et al. (2000) estimated the average workers' compensation cost to be 3.5% of the total project cost.

As a result of all the above statistics, the past three decades have witnessed the development of safety standards and legislation and also an extended responsibility for the entire project team towards worker safety. These will be addressed in the following sections.

1.3 OCCUPATIONAL SAFETY AND HEALTH ACT (OSH ACT)

In the late 1960s, Ralph Nader initiated safety legislation to address construction worker safety. The first legislative step achieved was in the form of The Construction Safety Act of 1969. However, it was applicable only to federal and federally-assisted projects. Nader's continued efforts encouraged Congress to pass the Occupational Safety and Health Act (also called the Williams-Steiger Act) in 1970. Three agencies were set up as a result of the OSH Act: Occupational Safety and Health Administration (OSHA), National Institute for Occupational Safety and Health Administration (NIOSH), and Occupational Safety and Health Review Commission (OSHRC). OSHA is responsible for promulgation of all regulations for safety and health, conducting inspections, providing safety training and developing safety statistics. NIOSH is the research body for OSHA and recommends new standards as per its research on safety and health. OSHRC is the judicial agency that consists of three members appointed by the president to oversee cases involving OSHA citations. OSHA requires employers in the construction industry to comply with both the general industry standards promulgated as Title 29, Part 1910 (29 CFR 1910) and the construction industry standards (29 CFR 1926). OSHA officers conduct surprise compliance checks by visiting construction jobsites. Any violation of regulations is cited and the employer is fined accordingly. The employer can contest the citation before the OSHRC. OSHA also provides free of charge consultation services for improving worker safety on jobsite.

Since OSHA regulations became effective, there has been a 60% reduction in workplace fatalities and 40% reduction in injuries and illness rates (OSHA 2010). However, some researchers feel that the OSHA regulations are inconsistent, vague, formidable, non-applicable in every work situation, occasionally contradictory (Hinze 2006; Toole and Gambatese 2002), and do not necessarily provide a safe work environment.

1.4 SAFETY RESPONSIBILITY AND THE PROJECT TEAM

The responsibility for worker safety has gone through a major transition over the past two centuries. During the 19^{th} century, common law defenses held the employee responsible for their own work-related injuries. This changed after the passing of workers' compensation laws in the first half of the 20^{th} century. The laws transferred the responsibility for employee injuries to the employer. This responsibility achieved legal status with the Occupational Health and Safety Act (OSH Act) of 1970. In addition to government association, the late 1900s witnessed the other parties typically working on a project displaying an inclination towards worker safety. This section of the thesis describes the influence and involvement of the owner, contractor, subcontractor, and designer in addressing construction safety.

1.4.1. The Project Team

A construction project team typically consists of four major parties: the owner, designer, contractor, and subcontractors. Since each of these parties individually contributes to the completed project, they affect construction safety in their own way (Rajendran and Gambatese 2006). The influence on construction safety by the owner, contractor, subcontractor, and designer is discussed below.

1.4.1.1. Owner

The owner pays the bills on the project and is the ultimate beneficiary of the finished project. The owner is responsible for the scope, schedule, and cost of the project. Type of contract, contract clauses, and designer and contractor selection are some of the additional duties performed by the owner.

Following the passage of the OSH Act, courts began emphasizing the involvement of multiple parties in construction worker safety. This involved extending the responsibility of worker safety beyond the traditional employee-employer relationship. In some cases, courts held owners accountable for worker injuries on their jobsite, which eventually led to increased liability suits against owners in the mid-1980s. The simultaneous escalation in health care costs during this time made matters worse for owners. These events led to increased voluntary involvement of private owners in construction worker safety (Gambatese 2000; Huang and Hinze 2006). In 1998, the American Society of Civil Engineers (ASCE) issued ASCE's Policy Statement 350 on construction safety. One of the highlights in the policy was the requirement of owners to actively participate in project safety.

Safe contractor selection, project delivery method, addressing safety requirements in contract clauses, cognizance about safety performance and implications, and active involvement during the construction phase are some of the ways in which owners can influence construction safety (Gambatese 2000; Hinze 2006).

Previous research studies (Hinze 1991; 1992; 1994a; 1994b) have shown an increase in the percentage of owner organizations conducting prequalification of contractors on the basis of safety. Active owner involvement in safety management and contractor prequalification has reduced the number of accidents on projects (Coble 1999; Levitt and Samelson 1982). Moreover, the contractual relationship has an influence on project safety with the design-build delivery method resulting in better safety performance compared to other contracting arrangements (Huang and Hinze 2006). Inclusion of safety provisions in the contract is another way of emphasizing safety, and addressing additional safety requirements has resulted in improved safety performance (Huang and Hinze 2006). In addition to preconstruction, owner participation in jobsite safety, specifically safety recognition programs, safety performance monitoring, funding safety initiatives, accident reporting and investigations, participation in safety meetings, safety training and orientation, have resulted in better safety performance (Gambatese 2000; Huang and Hinze 2006).

1.4.1.2. The Contractor

The constructor (prime/general) is the entity responsible for the interpretation of the contract documents and the physical construction of the project within the prescribed budget and schedule. Also, the constructor employs specialty contractors (subcontractors) for the purpose of dividing the work and co-ordinates their entire effort.

The OSHA general (1910) and construction (1926) industry standards place the duty of worker safety on the employer. Though not specifically mentioned by OSHA (Toole 2002), the constructor, being the primary employer on the jobsite (Gambatese 2000) shoulders this responsibility. Industry organizations such as the American Institute of Architects (AIA), Associated General Contractors of America (AGC), American Society of Civil Engineers (ASCE) clearly indicate the contractor as the major entity being responsible for construction safety (Toole 2002). The OSH Act specifies numerous responsibilities to the employer. Maintaining a safe, healthful workplace for the employee, knowledge about applicable OSHA regulations, inspection, warning, and control of workplace hazards, ensuring employees have and use safe tools and equipment (including PPE), paying for PPE for employees when it is required by OSHA standards, providing training, information, monitoring, and medical examinations as required, and maintaining records and posting specified information, are required to be performed by the employer (OSHA 2010). Hinze et al. (2001) recommend nine “zero accident” techniques to be followed by the contractor. These are: demonstrated management commitment, staffing for safety, safety planning, safety training and education, worker participation and involvement, recognition and rewards, subcontractor management, accident/incident reporting and investigations, and drug and alcohol testing (Rajendran and Gambatese 2006).

1.4.1.3. The Subcontractor

Subcontractors (specialty/trade) are hired by the contractor (general/prime) to perform specific tasks as part of the overall project. Subcontractors play a vital role in the construction industry and hence significantly influence the safety performance of projects. However, as per OSHA regulations, a joint responsibility for safety is required to be assumed by the contractor and subcontractor (Hinze 2006). Therefore, even though OSHA standards assign more safety responsibility to subcontractors (Toole 2002), the contractor is indirectly held accountable for every accident caused by a subcontractor.

Research studies have focused on improving subcontractor safety performance. Two such studies (Hinze and Figone 1988; Hinze and Talley 1988) revealed practices that improve subcontractor safety performance as influenced by the contractor or construction manager. Employing a full-time project safety representative, discussing safety at coordination and pre-job meetings, monitoring of project safety performance, complete compliance with safety regulations, and getting top management involved and committed to project safety improved subcontractor safety performance (Hinze and Figone 1988; Hinze and Talley 1988). Hinze and Gambatese (2003) found that minimizing worker turnover, conducting employee drug testing, and training by contractor associations are some factors that have a positive influence on subcontractor safety performance. Also, subcontractors are required to have their own safety policies, general as well as project specific (Hinze and Tracy 1994), which can be effective in reducing accidents (Arditi and Chotibhongs 2005). A recent study (Hallowell and Gambatese 2009a) compared the effectiveness of the different safety program in an effort to quantify their respective abilities in mitigating construction safety and health risks. Strategic subcontractor selection and management, and upper management support, were found to be the most effective in mitigating the construction safety and health risks (Hallowell and Gambatese 2009a).

1.4.1.4. The Designer

The designer (architects/engineers/design consultants) is a licensed professional architect or engineer selected by the owner. The designer's scope of work typically includes assisting the owner with the project's scope, budget, and schedule, and also preparation of the construction documents that will be used by the contractor to build the project. Traditionally, site safety is not part of the designer's job responsibilities. However, the industry has started to realize that the safety practices of the constructor alone are inadequate and there is a need for increased involvement by the entire project team. It is becoming more evident through research that the designer is one such team member whose decisions influence construction worker safety. The best way a designer can supplement safety is by designing for construction safety.

1.5 WHAT IS DESIGN FOR CONSTRUCTION SAFETY

It is common knowledge among safety and health professionals that elimination of hazards by incorporating safety in the design is more effective compared to mitigation of hazards by managing safety during construction. The order of precedence by Mac Collum (1995) and Andres (2002), and the hierarchy of controls by Manuele (2008), illustrate this principle, both having elimination of the hazard (design for safety) as the top priority to address safety. The concept of designing for safety (DfS) has been applied in many industries including aircraft manufacturing, automobile manufacturing, chemical industry, and electronics industry (Christensen and Manuele 1999). The International Labor Office (ILO) initiated the implementation of the concept in the construction industry in 1985 (ILO 1985, as cited in Behm 2004). It is an extension of the design for safety concept (Mroszczyk 2006) and is commonly known as design for construction safety (DfCS). DfCS is defined as the process of elimination of hazards or mitigation of its risks by deliberately addressing construction site safety during the design phase so as to produce a structure that is inherently safe to build. DfCS applies to the design of the permanent facility and the temporary structures, equipment, and facilities. The focus of this research thesis is application of DfCS to the permanent structure.

The time/safety curve (Figure 1.4) developed by Szymberski (1997) illustrates the importance of addressing safety early in a project. It is apparent from the figure that the designer is in the best position to address construction worker safety.

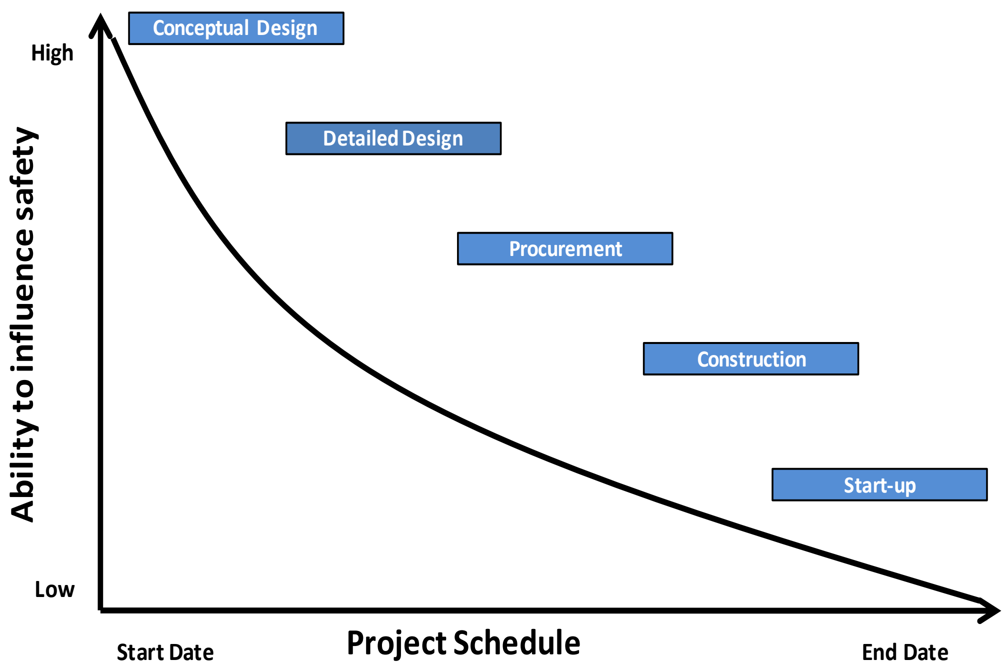

Figure 1.4: Time/Safety Influence Curve (Szymberski 1997)

1.6 WHY DESIGN FOR CONSTRUCTION SAFETY

As the name implies, designing for construction safety is intended to improve safety on the construction jobsite. However, there are numerous reasons as to why it should be implemented. These reasons are discussed below:

1.6.1. Enhances safety

Past research has revealed the contribution of design to construction injuries and fatalities. One of the earlier studies found that decisions made before beginning the work-execution stage caused 63% of the fatal accidents and 80% of the structural damage and defects in construction (Lorent 1991).

A study conducted in the United Kingdom by Haslam et al. (2003) analyzed 100 construction accidents and investigated whether a change in design would have reduced the risk of accidents. It was found that changes in permanent design could have reduced the risks associated with almost half of the accidents (Haslam et al. 2003). The researchers concluded that permanent works design is one of the originating influences in construction accidents and that the site, workers, and the construction materials and equipment are influenced by the design.

Jeffrey and Douglas (1994) contend that design decisions influence construction safety. Based on their study of the safety performance of the United Kingdom's construction industry, the researchers determined that of site fatalities reviewed, 35% were caused by falls and could have been prevented through design decisions.

Hecker et al. (2001) identified antecedents in design, planning, scheduling, and material specifications were most likely responsible for risks of musculoskeletal injuries during the construction process (Hecker et al. 2001).

In a survey of the construction community in South Africa (Smallwood 1996), researchers found that 50% of 71 general contractors identified design as the highest component out of all components identified that negatively affect health and safety.

In Australia, under the National OHS Strategy 2002-2012, 'Elimination of hazards during the design phase' is considered as one of the top five priorities (NOHSC 2004). Driscoll et al. (2004) investigated the role of design issues in work-related injuries in Australia between 2000 and 2002, and found 27 out of the 43 construction cases (63%) were either definitely or possibly related to the design (Driscoll et al. 2004).

Behm (2005) tested the hypothesis that the design for construction safety concept is linked to construction fatalities and disabling injuries. The author reviewed US fatality investigation reports from the NIOSH FACE website and concluded that 42% of the 224 fatality cases reviewed were linked to the design (Behm 2005). Further, Gambatese et al. (2008) validated this research by using a panel of experts. The expert panel was asked to examine a sample of the 224 cases, and whether they observed any congruency with respect to the previous research findings. Out of the 90 responses given by the panel, 64 were in agreement with the previous research (Gambatese et al. 2008). The fact that 23 out of the 36 fatality cases were linked to the DfCS by the panel further reinforces the importance of DfCS in improving construction site safety.

Various factors contribute to construction injuries and fatalities. The above studies confirm that design is one of the factors and that better design decisions and/or design changes would have benefited construction safety. Although enhancement in safety is difficult to measure, in a recent study on designing for safety (Weinstein et al. 2005), trade contractors identified 14 of the 26 design suggestions as having improved worker safety or reduced risks.

1.6.2. Improves project characteristics

Levitt and Samelson (1993) and Hinze (2006) contend that improvement in health and safety positively influences productivity, quality, time, and activity costs (Toole and Hallowell 2006). Therefore, by addressing construction worker safety, DfCS is indirectly playing a part in improving these project characteristics. DfCS also increases the buildability and constructability of a project (Lam et al. 2006). Better designs, reduced workers' compensation premiums, and reduced environmental damages are some other outcomes of DfCS (ISTD 2003, as cited in Gambatese et al. 2005)

1.6.3. Professional Ethics and Changing Policies

The professional codes of ethics of several national engineering associations (e.g., ASCE, and NSPE) state that engineers have a moral responsibility towards public safety. If we consider construction workers as part of the 'public', then engineers' code of ethics mandate DfCS. Unfortunately, construction workers do not have a place in the definition of 'public' in the engineer's dictionary. However, recent developments in policies and standards are an indication that in the future, designers will actively participate in construction worksite safety (Toole 2005a). The 2001 revised ASCE Policy Statement (PS 350) on construction site safety acknowledges that all project participants (including designers) have site safety responsibility. Also, in 2003, the ASCE-OSHA Alliance was formed so that ASCE members are better informed of safety regulations and increase their safety awareness. The same year saw the implementation of revised steel erection standards (29 CFR 1926, Subpart R) that require the design engineers to be involved in design changes in the field and in planning a safe steel erection process.

1.6.4. Reduced lawsuits

Reviews of court cases by Gambatese (1998) and Behm (2004) show that designers are held liable when negligent in providing the minimum standard of care as part of their professional duty. Gambatese (1998) contends that even though not part of standard practice, implementation of safety knowledge by the designer would be considered as standard of care, and decreases the chances of being involved in third party lawsuits.

1.7 HOW TO DESIGN FOR CONSTRUCTION SAFETY

It is readily apparent from research studies that design does contribute to construction injuries and fatalities. However, unlike other parties in a project, the designer refrains from taking active participation in worker safety. A survey of design firms revealed that "less than one-third of the design firms address construction worker safety in their designs, and less than one-half of the independent constructability reviews conducted address construction worker safety" (Hinze and Wiegand 1992). In studies of owners with large construction budgets, Hinze (1994a, 1994b) found that the majority of designers (45%) never consider construction worker safety in the design. Recently, Gambatese et al. (2005) investigated the feasibility of the design for safety concept in improving construction worker safety and health in the US construction industry. Forty-two percent of the designers interviewed were not ready to accept the concept.

1.7.1. Barriers to DfCS

The designer's minimal consideration and non-acceptance of DfCS can be attributed to numerous barriers to its implementation (Gambatese 1998; Gambatese et al. 1997; Hecker et al. 2005; Hinze and Wiegand 1992; Toole 2005b). Identified barriers to DfCS are as follows:

1.7.1.1. Lack of regulatory mandate

Designers in Australia, South Africa, and in fifteen European Union countries are explicitly required to actively participate in construction worker safety. However, the practice is not part of regulatory requirements in the US.

1.7.1.2. Liability exposure

The designer's role in a typical project team does not involve construction site safety. OSHA places responsibility for health and safety on the employer which for construction workers is the general or trade contractor. Additionally, the contractual language promulgated by the EJCDC and the AIA prohibits the designer from supervising, directing, or controlling the contractor's scope of work. For these reasons, involvement in safety increases designer liability and exposes designers to lawsuits due to injuries and fatalities.

1.7.1.3. Lack of safety expertise

Formal education and training received by the designers typically does not address construction worker safety. This can be attributed to the lack of construction site safety in engineering curricula and minimal safety knowledge of engineering school faculty members. Also, the design codes and manuals used by the designer address the safety of the end product (facility designed) and the end user (facility occupant).

1.7.1.4. Lack of knowledge of the construction process

Designers typically lack knowledge of the construction process since a design profession typically contains only occasional visits to the construction site. In order to gain construction experience, a designer would have to be on the jobsite performing the tasks for an extended period of time (Toole 2005b).

1.7.1.5. Lack of DfCS tools and software

One of the major reasons for the slow dissemination and acceptance of the DfCS concept is due to limited number of resources that can be used by the designers to design for safety (Gambatese 2004). Designers contend that in addition to the lack of construction knowledge and safety expertise, there is limited assistance for them on how to modify their designs from a construction safety viewpoint (Gambatese et al. 1997).

1.7.1.6. Additional costs

Designing for construction safety entails additional time, people, and effort by the design firm, and hence increases the direct and indirect design costs accordingly. Another source of increased overhead costs is additional premiums that have to be paid to insurance companies to get insured against liability exposures. In order to account for these increased costs, design firms would have to increase their professional fees. This in turn would hamper their chances of getting selected when compared to a traditional design firm that does not consider safety in its design.

1.7.1.7. Specialization

Education has divided the construction industry from the master builder system into separate systems of design and construction (Gambatese 1998). The traditional design-bid-build method of delivery reflects such a system. Over the years, further disintegration within these systems has resulted in separate entities, for example, design engineers and trade/subcontractors focusing on specific design disciplines. This narrow specialization of the design and construction hinders the practice of designing for safety and collaboration needed to identify and address safety hazards in the design phase (Hecker et al. 2005).

1.7.2. Overcoming barriers to DfCS

For the successful dissemination of DfCS in the US, it is imperative that the aforementioned barriers are addressed. Gambatese (1998), Gambatese et al. (2005), and Toole (2005b) provide suggestions to overcome these barriers.

The current model contract and bid documents followed by the industry need to be revised for the successful intervention of designing for construction safety in the US (Toole 2005b). This change is viable if DfCS is made part of standard practice (Behm 2005). Countries outside the US have been successful in mandating the concept. Although, imitating similar legislation in the United States is inappropriate (Toole 2005b), some lessons can be learned from them. Over the coming decade, Toole (2007) predicts there will be considerable changes in the current US regulations, customs, and practice.

Construction worker safety is often given the least priority by designers when compared with other project objectives (Gambatese et al. 2005). This attitude can be changed by increasing owner involvement (Gambatese et al. 2005), and realization of the importance of designing for safety. Prequalification of designers and requiring designers to address construction worker safety in the design (Gambatese 2000; Hinze and Wiegand 1992) are active ways in which an owner can help in designing for safety. An owner can also select a delivery method, modify the contract language to facilitate designing for construction safety, and eliminate liability exposures of designers. Designers contend that designing for safety is associated with increased liability and additional costs. However, owners should consider the entire lifecycle of the project which would result in long term savings since the design changes would facilitate operations and maintenance safety (Gambatese et al. 2005; Toole 2005b). Also, by designing for construction safety, Gambatese (1998) claims that the designers are in fact reducing their liability exposure in contrast to their contention.

Toole (2002) recommends that for increasing the safety knowledge of designers, outside safety experts can be hired or formal training on OSHA standards can be given to designers. Additionally, safety-in-design tools, guidelines, and procedures could be used to assist designers in safety and construction expertise (Toole 2005b). Design-for-safety checklists, risk mitigation forms, the “Design for Construction Safety ToolBox”, design visualization tools (CAD), and the CHAIR review process tool are some of the design for safety tools and technologies that are currently available for use (Gambatese 2004).

1.7.3. Improving DfCS through Research

Hinze (2000) recommends a lifecycle approach when considering worker safety during the design. A ‘safety for all’ approach starting from the initial construction process, maintenance, and ultimately demolition of the facility is required by the designer to effectively address safety implications. The design for safety decisions made for construction workers would also facilitate safety of maintenance and demolition workers (Hinze 2000).

The ability to influence safety is highest during the design phase (conceptual and detailed) and decreases as the project nears the construction phase. In a study conducted to assess the impact of design for safety, Weinstein et al. (2005) investigated the Lifecycle Safety (LCS) concept being employed by Intel during the design and construction of their microchip manufacturing facilities. In the construction of one of Intel’s facilities, a majority of 17 design changes (71%) noted during the programming phase were implemented, while only 4 of the 9 design changes (44%) noted during the programming phase but proposed later were implemented (Weinstein et al. 2005). This result is in agreement with the time/safety curve depicted by Figure 1.4. The authors attributed high capital costs, inadequate information regarding impact on worker safety and health, and importance of project schedule as the reasons for non-implementation of late-proposed design changes.

Another method of improving design for construction safety implementation is to increase the collaboration of the design and construction teams (Atkinson and Westall 2010). Designer-contractor collaboration by means of the design/build delivery method has resulted in better safety performances (Huang and Hinze 2006). This improvement can be attributed to the designer's proactive involvement in worker safety, since the designer's decision in this case would impact his/her own employees. However, liability coverage and contracts with the owner and subcontractors are some of the issues faced by a design-build firm (Coble 1999). Also, the aforementioned LCS study (Weinstein et al. 2005) showed an increased likelihood of design changes addressing safety being implemented if they were proposed by trade contractors. The coordination between designers and construction foremen was studied by Coble and Haupt (2000) who contend that construction foremen with excellent safety records can significantly contribute to designing for safety. Even within the traditional design-bid-build arrangement, preconstruction service agreements between designers and constructors (Hecker et al. 2005), and design reviews by engineers having knowledge about safety and health (MacKenzie et al. 2000), can enhance construction safety.

Toole (2005b), based on his professional experience, suggested that by modifying the standard tasks performed by designers, they could potentially increase their roles in construction worker safety. Albeit the barriers aforementioned, incorporation of safety while reviewing designs, while preparing design documents, during the procurement stage, while reviewing submittals, and while performing site inspections, would enhance construction safety (Toole 2005b).

RESEARCH NEEDS AND SIGNIFICANCE OF PROPOSED STUDY

This research study aims to develop a new design rating system (similar to a LEED rating system) to evaluate the construction safety risk associated with a design. It will serve as a tool for architects and engineers to make projects safer to construct. The rating system will address all of the components that make up the shell of a multi-story commercial office building (the foundation, structural framing, exterior enclosure, interior finishes, and roofing), and the different design features that are used for constructing each component. Evaluation of the design features is performed by obtaining inputs about the safety risks associated with constructing different types of design features. The inputs are provided by superintendents and safety personnel in different general contracting and trade contracting firms. The design of the proposed study is in direct response to the recommendations and successes of past research studies.

Past studies outlined the importance of trade contractor input in making safer designs. Figure 2.1 depicts a DfCS process. The dashed lines in the figure illustrate incorporation of trade contractor site safety knowledge into the design decisions. The results of the LCS study (Weinstein et al. 2005) suggest that trade contractors can provide valuable input during design that improves construction safety.

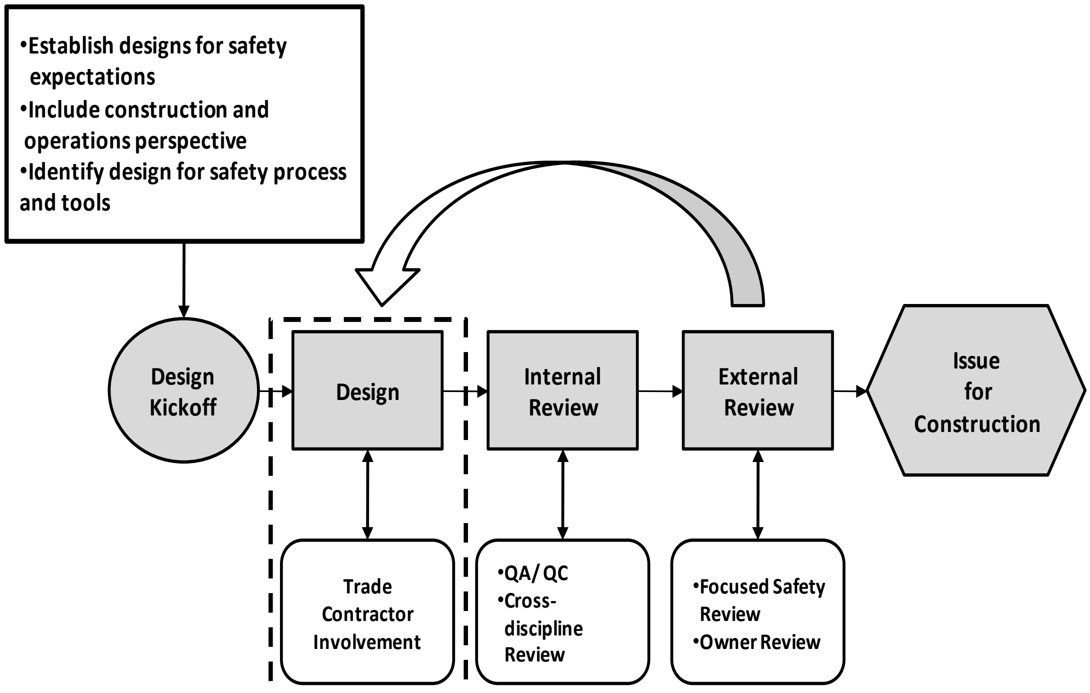

Figure 2.1: Example Design for Construction Safety Process (Gambatese and Hinze 2003)

According to Churcher and Alwani-Starr (1996), in order to fully understand and appreciate the problems and hazards encountered on the construction site, the designer needs to gain site-based experience. This lack of knowledge of the construction process is one of the most significant barriers that must to be addressed (Toole 2005b). The design features and materials influence the construction means and methods to a large extent (Gambatese 2000; Gambatese et al. 2003), and hence knowledge of the individual construction tasks, sequencing between tasks, and coordination of different trades and their processes would help in making designs that are safer to construct (Toole 2005b). The current study addresses this barrier by the construction activity/process level evaluation of the design features.

Further, Gambatese (2008) recommends the need to establish a connection between design features and occupational injuries and illnesses. The tools and technologies currently available are hazard specific, i.e., they teach about construction site hazards as a result of the designs or design decisions. Additionally, most of the current tools and technologies do not make decisions based on risk assessment procedures (Gambatese 1998; 2000). Those that do, focus on a subjective level assessment. Therefore, there is a need for quantification of risks and also comparison of the different design alternatives based on the risk assessment (Hinze et al. 1999; Gambatese 2004). Also, the frequency and severity of injuries and illnesses need to be considered while deciding on design alternatives (Gambatese 2008). This research fills these gaps by considering the quantitative risk assessment of design features based on incident severity and frequency levels.

RESEARCH METHODOLOGY

The current research study aims to integrate construction process knowledge into the design by evaluating the safety risk of the processes used for construction of different design features. The research also builds upon existing research studies and methodologies. Therefore, in order to guide our understanding of construction safety risk and also determine if similar research studies have been published, literature that addresses these topics is explored. Table 3.1 provides a brief overview of key priori and statistical based construction safety risk research. Many of these studies can be grouped based upon the methodology used for the assessment as either expert opinion or statistical data. Researchers have estimated risks by considering different contributing factors, influence factors, and scales of measurement. The scales of measurement used in these studies will be reviewed in section 3.1.2 to develop the scales for the current study.

Table 3.1: Summary of Prior Construction Safety Risk Research

Assessment approach	Risk Assessment Criteria (RAC)	Risk Influence Factor (RIF)	Risk Measure Factors P	S	E	Reference
User input/ Expert opinion	Incident types	Design	X	X	X	Gangolells et al. (2010)
	Fall hazard	Design	X	X	X	Cooke et al. (2008)
	Hazard event	Design	X	X	X	Frijters and Swuste (2008)
	Incident types	Activity	X	X	-	Hallowell and Gambatese (2008)
	Design and construction	Safety impact factors	X	X	-	Seo and Choi (2008)
	Physical attributes, means and methods, work conditions	Activity	-	-	-	Imriyas et al. (2007)
	Hazard event	Activity	X	X	-	Carter and Smith (2006)
	Schedule	Activity	-	-	-	Yi and Langford (2006)
	Means, methods, work type, condition	Activity	X	X	X	Jannadi and Almishari (2003)
	Safety factors	Activity	X	-	-	Lee and Haplin (2003)
	Ergonomics	Activity	-	-	-	Everett (1999)
Statistical data	Site influence factors	Construction trades, construction sites	X	X	-	Kim et al. (2010)
	Claims cost, incident types	Activity	-	-	-	Mitropoulos and Guillama (2010)
	Labor hours, incident types	Project	-	-	-	Wang et al. (2006)
	Fatality, lost work time	Construction trades	X	X	-	Baradan and Usemen (2006)
	Worker's compensation rates	Worker's compensation classifications	-	-	-	Knab (1978)
	Worker's compensation rates	Activity	-	-	-	New York State Divison of Industrial Safety Service (1967)

P = Probability; S = Severity; E = Exposure
RAC = The criteria studied; RAF = The factor influenced
For example Hallowell and Gambatese (2008) quantified the effect of incident types on activities.

The safety risks of construction processes (or activities) have been investigated for some time. The New York State Division of Industrial Service used workers' compensation rates to determine the degree of risk associated with construction activity (Knab 1978).

Using expert opinion and judgment, Jannadi and Almishari (2003) developed a model for risk assessment of major activities. Lee and Haplin (2003) used a fuzzy logic system based on expert input to predict the accident risk of common construction processes. Carter and Smith (2006) created a tool (Total-Safety) for improving the hazard identification of projects using an activity-based risk assessment process. A part of the study by Imriyas et al. (2007) involved estimation of the Project Hazard Index (PHI). The authors focused only on the most hazardous activities and rated the physical characteristics (height, volume, material, type) of each activity. It is interesting to note that most of the physical attributes identified by the authors depended on design decisions. Hallowell (2008) developed a risk-based construction safety and health analytical model for quantification and mitigation of risk for construction processes. Further, it was used to estimate activity risk for the concrete formwork construction process (Hallowell and Gambatese 2009b). Recently, Mitropoulos and Guillama (2010) analyzed construction activities to determine the high risk activities for residential construction using claims cost, incident types (i.e., fall from elevation, struck by, etc.), and data from a large residential framing contractor.

Very few research studies have evaluated the safety risks of constructing design features. Researchers in Australia have developed a tool to assess the risk of fall during maintenance work on roofs (Cooke et al. 2008). The risk, though, is not estimated using activities, but by using the physical characteristics (area, angle, loadings etc.) of the roof design. The assessment of design features based on safety risk of the associated construction processes has also been performed. In the Netherlands, Frijters and Swuste (2008) devised a risk assessment model that assesses the risk of hazard events during the construction activities of design features. The model can be used by designers to compare building systems during the design phase. Likewise, a very recent study in Spain by Gangolells (2010) used risk events to evaluate the safety risk of constructing residential design features. The primary objective of the two studies conducted in Spain and the Netherlands are similar to the current study. However, the literature review identifies differences and inherent limitations in many respects.

Firstly, in the Dutch study, the risk classification used is based on subjective levels such as insignificant, acceptable, moderate, unacceptable, and insignificant. The Spanish study estimates objective values for risk. However, unlike the Dutch study, the Spanish research only uses high risk activities for estimating the risk of design features for residential construction. Also, an expert panel of associate professors, architects, engineers, and project managers was used for assessing the risk of construction activities.

A coupled field survey-analytical research methodology was employed to attain the research objectives in the current study. A schematic showing the field survey and analytical programs of this research is provided in Figure 3.1.

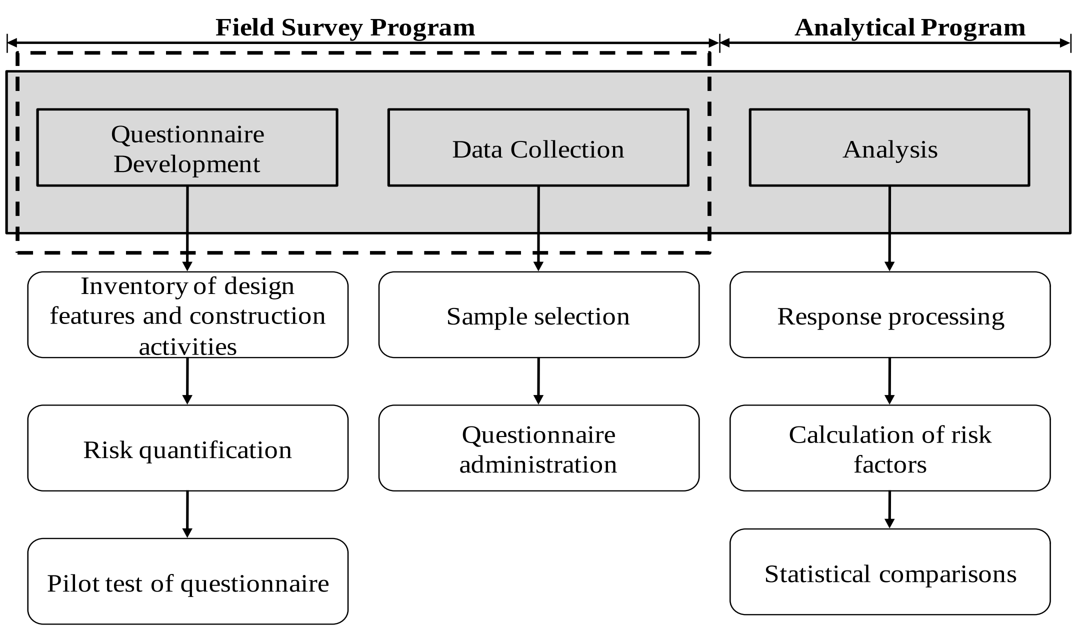

Figure 3.1: Schematic Showing the Elements of Field Survey-Analytical Program

The field survey program in the current study included the development of questionnaires and data collection. Questionnaire development involved reading construction books and reviewing literature on construction risks. The former task was to identify the different design features used for multistory commercial office buildings and determine the major activities that are performed on the jobsite to construct each design feature. The comprehensive review of literature on construction risk was performed to arrive at a suitable risk assessment procedure to quantify the safety risk of the activities. Data collection involved the identification of trade contracting and general contracting companies' contacts, and acquiring their input on the questionnaires. The analytical program included the processing of the responses, calculation of risk factors, and statistical analyses. Each of the activities of the field survey program (shown in dashed lines) is described in further detail below.

3.1 DESIGN OF SURVEY QUESTIONNAIRES

A shell of a multistory commercial building comprises five major systems/components: the footings and foundations, structural frame, roofing, exterior enclosure, and interior construction. Therefore, five survey questionnaires were developed, one for each respective system. The five questionnaires were further organized into eleven questionnaires by trade expertise, namely: piling, concrete, steel, precast, glazing, masonry, cladding, interior ceilings and walls, flooring, roofing, and sheet metal. The general format of all of the questionnaires remained the same despite the divisions based on components and trade expertise. All of the questionnaires started with a similar instruction page that comprised of steps explaining the mechanics for filling out the questionnaire, the scales to be used, and definitions. In addition, general demographic information was solicited. The demographic information consisted of company type, position/title, years of construction experience, and type of work experience. The subsequent fields of the questionnaires are enumerated below and the respective methodologies implemented to design them are explained in each section. The actual questionnaires are provided in Appendix C.

3.1.1. Design Feature and Inventory of Construction Activities

Following the instructions page, each page of every system and trade questionnaire has a design feature followed by the major construction activities that are performed on the jobsite to install the particular design feature. The format was adopted from Hallowell and Gambatese (2009b) where the authors identified the specific worker activities associated with the concrete formwork construction process. The activities were identified by conducting field observation of the formwork construction process followed by review and validation by industry professionals (Hallowell and Gambatese 2009b). Field observation was unrealistic for the current study since it would have entailed observing construction activities of multiple design features for every system. Therefore, owing to time constraints, limited availability of on-going multistory commercial projects, and lack of publications, a different approach was implemented for the documentation of the design features and the construction activities. Construction books are reasonable resources that provide information on the various systems, typical design features used for each system, and major construction activities performed to construct the design features. Creating an inventory of the aforementioned design features and construction activities by reviewing construction books, and further refinement by industry professionals during the data collection phase, was determined as feasible, effective, and the most efficient methodology. The list of the various books that were used for recording the systems, design features, and construction activities are tabulated in Table 3.2.

Table 3.2: Books Referenced

Reference	**Authors**
Building construction: Principles, materials, and systems, 4th edition (2010)	Madan Mehta, Walter Scarborough, Diane Armpriest
Fundamentals of Building Construction, 4th edition (2004)	Allen and Joseph Iano
Principles and Practices of Commercial Construction, 7th edition (2004)	Cameron K. Andres and Ronald C. Smith
Concrete Formwork, 3rdedition (2005)	Leonard Koel

Multiple books were reviewed to get the best and comprehensive information. This process helped in cross checking the information explained in one book with another. Table 3.3 gives the number of systems, design features, and construction activities identified for the study. The names of the design features, the associated construction activities, and descriptions are shown in Appendix C. In addition, the books were also used to compile images of the design features considered in the study.

Table 3.3: Identified number of design elements

NO.	SYSTEM/ COMPONENT	NO. OF DESIGN FEATURES/ COMPONENTS	NO. OF CONSTRUCTION ACTIVITIES
1	Footings and foundations	11	59
2	Structural framing	17	172
3	Roofing	12	42
4	Exterior enclosure	24	114
5	Interior construction	25	86
Total		89	473

3.1.2. Risk quantification

Traditionally, construction safety risk has been defined using different values, namely probability, severity, and exposure. In order to quantify the safety risk of the identified design features and associated construction activities, it was required to define, develop, and quantify risk measurement factors for the current study. The construction safety risk literature reviewed and summarized in Table 3.1 provides a brief overview of the various measurement factors that were used. The literature also helped in selecting a standard and accurate method for quantification of the measurement factors. The definition and scales of measurement of the factors in some of the studies are summarized below.

Frijters and Swuste (2008) determine the risk of construction activities using probability and severity. The exposure to the risk is calculated using man-hours per unit of the design feature and total amount of design feature under consideration. Gangolells et al.

(2010) used probability and severity to determine significance of the risk to shortlist the high risk activities, and the sum of all potential exposures for a project is used to evaluate the risk of a project. Exposure is defined as project dependent and is the measure of the extent of the hazardous situation (unsafe condition). Also, Baradan and Mumtaz (2006) used the statistical injury and fatality data from the BLS website for estimating the risk of the different construction trades. In the study, the frequency was calculated as the annual injury and fatality rate using the annual employment. The cost of lost time due to an injury for a given trade was the measure of severity and it was calculated using the median number of days away from work, hourly wage, and number of hours worked in a day.

Owing to the absence of an appropriate scoring system, most of these studies develop their own probability, severity, and exposure scales. However, these fail to incorporate a complete spectrum of probability and severity levels (Hallowell and Gambatese 2009b). To address these issues, Hallowell and Gambatese (2008a) created objective risk scales that account for all possible probability and severity levels. These scales have been reproduced in Table 3.4. Frequency is defined in terms of worker hours per incident, and severity in terms of impact to the worker. Exposure is defined in worker-hours and is termed as project dependent. For the purpose of risk quantification and interpretation, frequency values need to be inverted. Using the above definitions, units, and procedure, the authors calculated unit risk in terms of severity per worker-hour, and cumulative risk in terms of severity. Equations (3.1) and (3.2) illustrate the calculations:

$$\text{Unit risk(S/w-h)} = \text{Frequency (incident/w-h)} \times \text{Severity (S/incident)} \quad (3.1)$$

$$\text{Cumulative risk(S)} = \text{Frequency (incident/w-h)} \times \text{Severity (S/incident)} \times \text{Exposure (w-h)} \quad (3.2)$$

Table 3.4: Probability and Severity Scales (Hallowell 2008).

Subjective score	Scaled frequency (w-h/incident)	Subjective severity level	Scaled severity (relative impact)
1	>100 million	Temporary discomfort	2
2	10-100 million	Persistent discomfort	4
3	1 to 10 million	Temporary pain	8
4	100,000 to 1 million	Permanent pain	16
5	10,000 to 100,000	Minor first aid	32
6	1,000 to 10,000	Major first aid	64
7	100 to 1,000	Medical case	128
8	10 to 100	Lost work time	256
9	1 to 10	Permanent disablement	1024
10	0.1 to 1	Fatality	26,214

The same probability and severity categories were considered for the current study and the questionnaire was developed. A copy of the questionnaire section for cast-in-place concrete columns from structural framing is provided in Figure 3.2. The entire questionnaire on structural framing and the remaining systems is provided in Appendix C for reference.

SYSTEM/ COMPONENT :**COLUMNS**															
DESIGN FEATURE/ ELEMENT:**CAST IN PLACE CONCRETE COLUMNS**															
ACT NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**											
				Near miss	**Negligible**	**Temporary discomfort**	**Persistent discomfort**	**Temporary pain**	**Persistent pain**	**Minor first aid**	**Major first aid**	**Lost work-time**	**Medical case**	**Permanent disablement**	**Fatality**
1		**Connection of foundation dowels with column rebar**	hoisting of column reinforcement cage over foundation dowels, overlapping/ splicing and tying of the vertical rebar of columns and foundation dowels												
2		**Formwork construction for columns**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity												
3		**Pouring of concrete for columns**	concrete is poured using pumps/ buckets and consolidated using vibrators												
4		**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength												
5		**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar												
6															

NOTE: ***Total of all activity exposures may add up to more than 100%**

Special designs that **increase** risk of injury: ______________________

Special designs that **decrease** risk of injury: ______________________

Figure 3.2: Sample questionnaire design

Respondents were asked to conduct the following tasks to complete the questionnaires: (1) for a design feature being reviewed, refine the list of construction activities; (2) indicate the percentage of time spent on each activity during the construction of the design feature; (3) rate the frequency (i.e., average duration) between accidents for each severity level (e.g., near miss, temporary discomfort, etc.); and (4) for the design feature, specify any designs that increase/decrease the risk.

For filling in the responses, the respondents were provided with the definitions of the injury severity levels and the frequency scale illustrated in Table 3.4. Additionally, a copy of images of the design features was also provided for reference.

3.1.3. Pilot test of the questionnaire

The first draft of the questionnaire was pilot tested by three general contractor superintendents working on major construction projects on the OSU campus. The superintendents were selected for conducting the pilot study since, unlike the trade contractors' superintendents, they were given the entire set of questionnaires (all the systems and design features). Therefore, in addition to improving quality and comprehension (Rea and Parker 1997), it was important for the researchers to get an estimate of the time required to fill out the questionnaires.

In the presence of the researchers, the superintendents were asked to complete one design feature (one page) of a questionnaire. The participants were asked to report their feedback through an informal discussion. Most comments by the superintendents were to reduce the number of severity levels, citing that twelve were too many to evaluate reliably and that it was preventing thoughtful judgment. Also, the frequency scale in terms of worker hours per incident was causing confusion. The researchers too observed a significant amount of time being spent by the superintendents to fill in the responses. All three superintendents had similar opinions about reducing the number of severity levels and to simplify the frequency scale. For example, the superintendents indicated that there is not much of a difference between the two severity levels of 'discomfort' and 'pain'. Other comments included combining the severity levels into general categories that can be defined in terms of workers return to the jobsite after the fact. Also, one of the superintendents pointed out that there might be numerous 'near misses' that occur on the field, but all are seldom reported to the GC superintendents.

In order to generate interest and get an accurate response, it was necessary to revise the frequency and severity scales. It should be noted that selection of the probability and severity categories and description is not an exact science and variations can be observed in their use (Manuele 2008). Keeping in mind the input by the superintendents, two major modifications were made to the frequency and severity scales originally developed by Hallowell (2008b). The frequency scale was simplified by defining average time between incidents in terms of hour, day, week, etc. The revised frequency scale developed for the current study is provided in Table 3.5.

Table 3.5: Revised Frequency Scale

Subjective score	Scaled frequency (Average time/incident)
0	Impossible
1	Negligible
2	50 years
3	10 years
4	5 years
5	1 year
6	6 months
7	1 month
8	1 week
9	1 day
10	1 hour

The number of severity levels was categorized based on the worker's ability to return to regular work. This resulted in combining the severity levels used by Hallowell (2008) into general categories defined by low, medium, and high severity categories. For example, low severity injuries range from temporary discomfort to minor first aid. Low severity is defined as an accident that results in injury, but the worker is able to return to regular work within the same day. The cut-off at minor first aid is also consistent with OSHA's definition of low severity (non-recordable) injuries. OSHA defines high severity injuries ranging from major first aid through fatality. However, for the current study, it was further separated into medium and high severity on the basis of the worker's inability to return to regular work within the same day and inability to return at all. The severity categories and the combined severity levels are illustrated in Table 3.6.

Table 3.6: Revised Severity Categories

Injury Severity Categories	**Combined Severity Levels**
Near miss (no impact on work time)	Near miss
	Negligible
Low severity (no impact on work time/ worker returned to regular work within 1 day)	Temporary discomfort
	Persistent discomfort
	Temporary pain
	Permanent pain
	Minor first aid
Medium severity (worker could not return to regular work within 1 day)	Major first aid
	Medical case
	Lost work time
High severity (worker could not return to regular work at all)	Permanent Disablement
	Fatality

Near miss was retained in the study as opposed to the suggestion made by one superintendent since a near miss could be a potential incident that can result in any of the severities mentioned in the table. Therefore, it was considered vital to get a risk estimate for the near misses. The quantification process of the four severity categories and the activity exposure will be discussed in the Analysis section. The revised version of the frequency scale and severity categories was incorporated into all of the questionnaires. The modified copy of the page for cast- in-place concrete columns is provided in Figure 3.3.

SYSTEM/ COMPONENT :**COLUMNS**							
DESIGN FEATURE/ ELEMENT:**CAST IN PLACE CONCRETE COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1		**Connection of foundation dowels with column rebar**	hoisting of column reinforcement cage over foundation dowels, overlapping/ splicing and tying of the vertical rebar of columns and foundation dowels				
2		**Formwork construction for columns**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity				
3		**Pouring of concrete for columns**	concrete is poured using pumps/ buckets and consolidated using vibrators				
4		**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength				
5		**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar				
6							

NOTE: ***Total of all activity exposures may add up to more than 100%**

Special designs that **increase** risk of injury: ____________________

Special designs that **decrease** risk of injury: ____________________

Figure 3.3: Sample modified questionnaire design

3.2 DATA COLLECTION

3.2.1. Sample Selection

A preliminary database of general contracting and trade contracting firms was created by referring to the 2010 Directory of Northwest Construction and the Blue Book of Construction website. Location and financial constraints precluded the inclusion of firms employed outside the Pacific Northwest of the United States. A convenience sample of general contracting and trade contracting firms that have affiliation with Oregon State University was drawn from the database. Only a few trade contracting firms were identified as a result of this selection since mostly GCs participate in OSU activities. The convenience sample for trade contracting firms was selected from the database with the help of the general contracting firms that were currently working on projects on campus. The GCs provided names of trade contractors that were associated with their companies' projects and would be interested in participating. It was ensured that both the general contracting and trade contracting firms satisfied the multistory commercial office building (five stories and above) criteria in terms of expertise resulting in a stratified sample within the convenience samples. Out of the two convenience samples, random samples comprising of five trade contractors from each trade and twenty general contractors were drawn and included in the research study. The selected trade contractor groups and their type of specialty is listed in Table 3.7. Given the nature of the research study, the length of the questionnaires, and the time and budget constraints, the sample sizes and make-up were considered reasonable.

Table 3.7: Trade contractors and area of trade expertise

Trade contractor group	Type of specialty
Piling	Pile driving and deep foundations
Concrete	Concrete foundations and superstructure
Steel	Structural steel and steel decking erection
Masonry	Exterior brick veneer, glass block walls
Glazing	Glass curtain walls
Cladding	Exterior cladding, curtain walls
Flooring	Floor coverings
Interior walls and ceilings	Acoustical, plaster, drywall, stucco, steel studs
Roofing	Membrane roofing, roof openings and specialties
Precast concrete	Structural precast and curtain walls erection

3.2.2. Questionnaire administration

The process of distributing the questionnaires started in approximately mid-June 2010. Initially, the construction firms were contacted via email with the questionnaires attached. The questionnaires for all the systems (footings and foundations, structural framing, roofing, exterior enclosure and interiors finishes) were sent to general contracting firms while the trade contracting firms only received those questionnaires that matched their trade. Fifty trade contractor questionnaires (10 trades x 5 participants/ trade) and twenty general contractor questionnaires were distributed resulting in a total of 70 questionnaires distributed. The document containing design feature images was also attached for reference while filling in the responses. The body of the email briefly explained the objective of the research study and asked for voluntary participation of the company's superintendents and safety managers. The email also assured anonymity of the respondents and confidentiality of responses. A sample of the email is provided in Appendix A. The email correspondence approach proved unsuccessful, resulting in only a few companies displaying interest. Most companies forwarded the questionnaires to either their safety managers or superintendents. The interested superintendents and safety managers were then contacted to explain the process of filling in the questionnaire. During the telephone conversation, the participants were asked to fill in the responses for one of the design features. The lack of response by the other firms was attributed to a lack of interest and time commitment that participation would require to fill in the questionnaires. The low response could also be due to the targeted participants being superintendents; one of the busiest persons on the construction job site. In addition, the research study was conducted during a tough economic time in the US. Most of the companies in business were trying their best to complete their jobs before scheduled to save money and stay competitive.

A different approach was employed for the distribution of the subsequent surveys to those organizations that did not respond. About two weeks after the intial emailing, the organizations were contacted by telephone. Face-to-face meetings with the participants were scheduled and a copy of the questionnaire was emailed for review before the appointment. The researcher personally visited the participants as per their convenience and distributed the questionnaires. The participants were given the option of scanning and emailing back the responses or mailing them back using self-addressed stamped envelopes provided by the researchers. During each visit, the participants were briefly introduced the purpose of the study and the mechanics of the questionnaire. Here too the participants were asked to fill in the responses for one design feature of the questionnaire. This methodology not only increased the interest and response rate but also maximized the quality of the responses.

It should be noted that during both the participants' correspondence via telephone and face-to-face interactions, attention was given to details that might affect response behavior. For example, it was stressed that the participants fill in the responses using experience and judgment and not based on the company's safety record and accidents witnessed by the participant. This ensured the reduction of the effect of Von Restorff and Recency bias (Hallowell 2009).

The follow up process using emails and telephone calls started two months after the distribution of the questionnaires. Upon receipt of the completed questionnaires, the responses were compiled in a Microsoft Excel spreadsheet. Individual tabs on the spreadsheet were designated for each response to aid analysis of the results.

RESULTS

The responses to the questionnaires were analyzed to evaluate the information obtained. This chapter starts with a descriptive statistical analysis of the demographic information of the participants followed by a description of the open-ended question regarding the special designs that increase/decrease the risk of injury. It then delves into the analysis methodology that will be used for processing the responses to the injury severity and activity exposure fields.

4.1 RESPONDENT DEMOGRAPHICS

The instruction page of each questionnaire asked for demographic information about the participant. It solicited information regarding the participant's position, and the type and years of construction experience. Judgment is the primary means of evaluating risk, and it improves with experience (Sillars 2009). Since experience will dictate the results of the study, years of experience was the most important demographic information collected. Descriptive statistics of both the general contracting and trade contracting firm respondents is summarized in Tables 4.1 and 4.2.

Table 4.1: Summary Statistics of General Contractor respondents

Company Type	**Position/ Title**	**No. of respondents**	**Construction Experience**			
			Mean	**Median**	**Min.**	**Max.**
GC	Superintendent	8	25.25	28	12	35
GC	Safety Manager(6); Risk Manager(1)	7	26	32	5	35
All		15	25.60	28	5	35

Out of the 20 questionnaires that were sent to the construction firms (GCs), 15 responded resulting in a response rate of 75 percent. It was intended to get multiple responses from the same firm from both the superintendent and the safety manager/director. However, typically either one or the other provided input.

Table 4.2: Summary statistics of trade contractor respondents

Specialty	**Position/ Title**	**No. of respondents**	**Construction Experience**			
			Mean	**Median**	**Min**	**Max**
Piling & Deep Foundations	Superintendent	5	23	24	15	30
Concrete	Superintendent(3); Safety Manager(2)	5	26	27	12	34
Steel	Superintendent	3	28.67	30	21	35
Masonry	Superintendent	4	25.25	25.25	18	35
Glazing	Superintendent(2); Safety Director(1)	3	30	30	25	35
Stone Cladding	Superintendent	3	20	25	5	30
Flooring	Superintendent	4	39	35.5	25	60
Interior walls and ceilings	Superintendent(3); Safety Manager(2)	5	27.8	30	19	33
Roofing & Sheet metal	Superintendent(3); Safety Manager(1)	4	17.75	18	10	25
Precast concrete	Superintendent	3	26.67	25	20	35
All		39	26.36	25	5	60

In total, 39 out of the 50 individuals contacted, representing ten different trades, responded to the study. The trade contractor's response rate was 78%. The response rate of each trade is shown in Figure 4.1.

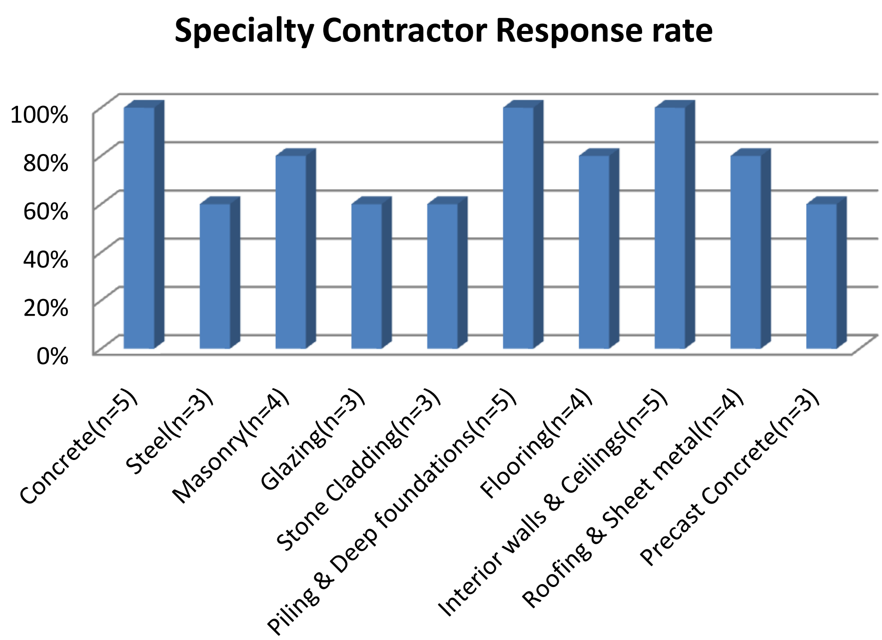

Figure 4.1: Trade contractor survey response rate

The position/title of the respondents in Tables 4.1 and 4.2 reflects their current designation and many respondents have had experience working in other positions. One must also note that construction of a design element involves multiple crews having diverse expertise working independently. Therefore, the ratings provided by the respondents reflect the entire crew constructing the design feature. Also, the respondents provided input only for the design features that they were familiar with. The table in Appendix D shows the number and type of respondents that provided input for each design feature. A total of more than 33,800 ratings were provided by the respondents.

4.2 RESPONSE PROCESSING AND ANALYSIS METHODOLOGY

As mentioned previously, the respondents were asked to focus on four tasks to complete the questionnaires: refinement of construction activities, indicate the time (in percent) spent on each activity, rate the average duration between accidents at the four severity levels for each activity, and answer the open-ended question on designs that increase/decrease the risk of injury. This section describes the response processing and methodology that was adopted to analyze the raw data obtained for each of these tasks. For clarity of explanation of these tasks, an example response from one of the respondents for CIP concrete columns is shown in Figure 4.2.

As shown in the Figure 4.2, cast-in-place concrete column requires five major construction activities to be performed during construction. The activity exposure field has average percentage values of time spent by the worker performing the different activities. For example, as per the respondent, a worker takes thirty percent of the time for formwork construction, ten percent for pouring concrete, and so forth. For the four severity fields, the respondent has provided the average duration between incidents for each activity. For example, for formwork construction, a near miss happens once every year, a low severity once every year, a medium severity once every ten years, and high severity is negligible. For the open ended question, as per the respondent, construction of round columns involved less risk as compared to square columns.

SYSTEM/ COMPONENT :**COLUMNS**							
DESIGN FEATURE/ ELEMENT:**CAST IN PLACE CONCRETE COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	**30%**	**Connection of foundation dowels with column rebar**	hoisting of column reinforcement cage over foundation dowels, overlapping/ splicing and tying of the vertical rebar of columns and foundation dowels	**4**	**5**	**3**	**1**
2	**30%**	**Formwork construction for columns**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity	**5**	**5**	**3**	**1**
3	**10%**	**Pouring of concrete for columns**	concrete is poured using pumps/ buckets and consolidated using vibrators	**5**	**5**	**5**	**1**
4	**20%**	**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength	**4**	**5**	**5**	**1**
5	**20%**	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	**2**	**3**	**2**	**1**
6							

NOTE: ***Total of all activity exposures may add up to more than 100%**

Special designs that **increase** risk of injury:

____

Special designs that **decrease** risk of injury:

Round columns since it minimizes formwork construction

Figure 4.2: Raw data example

4.2.1. Refinement of Construction Activities

The researcher developed the list of construction activities required to construct the various design features by referring to construction literature. While completing the questionnaire, the respondent was asked to verify whether the listed design feature is commonly used, and review and refine the list of activities created for that design feature. The respondents were given the free reign to expand/combine the listed activities or add/remove activities. Typically on a construction job, a tradesperson breaks down each activity further into manageable tasks for convenience and to quantify each detailed activity would be too elaborate. Hence, the respondents were asked to focus only on the major construction activities that are performed on the jobsite.

The respondents made comments and suggested inclusion of activities for some of the design features. The researcher decided to set a criterion that comments and suggestions made by two or more respondents would be considered for inclusion. The list of activities identified as a result of this process is provided in Table 4.3.

Table 4.3: Additional Identified Activities

System	Design Feature	Additional Identified Activities
Structural frame	Steel columns/ beams	Offloading of truck; Shaking out of steel sections
Interior Walls and Ceilings	Suspended acoustical ceilings	Installation of wall angles/ ceiling support angles; Installation of seismic wires and compression posts
Flooring	Terrazzo flooring	Laying of waterproof membrane
Roofing	Single-ply roof membrane(mechanically attached system)	Detailing/ seaming of membrane

4.2.2. Exposure and Severity Fields

The activity exposure and severity fields required numeric responses from the respondents. The activity exposure field required them to indicate percentage of time spent by the workers to perform each activity during the construction of the design feature. One should note that during construction multiple activities are performed simultaneously and hence these percentage values may add up to more than one hundred percent.

For the injury severity field, the respondents were asked to rate the frequency (average duration) between incidents at multiple severity levels (i.e., near miss, low, medium, and high) while performing each construction activity. For example, they were asked to envision themselves in the shoes of the worker and, using judgment, to rate how often a near miss occurs while performing a construction activity. They were asked to do likewise for the low, medium, and high severity levels. The numerical response values in Figure 4.2 correspond to the frequency scale provided to the respondents (introduced and described in section 3.1.3).

The activity exposure and frequency values are provided by multiple respondents having diverse construction knowledge and experience. Various sources of bias may exist in judgment-based research (Hallowell 2008) which may result in outlying response values. Therefore, it is important to account for judgment-based bias and minimize the variation in responses. In statistics, the median is resistant to outliers and hence calculating the median of each activity exposure and frequency responses would result in obtaining their true values. According to Hallowell (2008), reporting median response values minimizes the influence due to myside, recency, and neglect of probability biases. Also, both the samples of general contracting firms and trade contracting firms were convenience samples. With a convenience sample, the respondents are most likely to respond and are not representative of the harder-to-select or non-responding individuals (Lohr 1999). However, despite the convenience samples, the participants had to be given persistent follow-up phone calls and emails in order to get the responses. The respondents, being superintendents and/or safety managers, and the extensiveness of the questionnaires, can be attributed to the initial non-responsiveness. Therefore, even though the bias due to the convenience sampling was not explicitly addressed, the non-responsiveness of the convenience samples accounted for it to some extent.

The analysis section of this thesis presents the estimated median activity exposure and median frequency values of the raw data.

4.2.3. Special designs that increase/decrease the risk of injury field

In addition to the numeric responses for the severity and exposure fields, the questionnaire consisted of open-ended questions (special designs that increase/decrease the risk of injury) for every design feature. The purpose was to get input from the respondents about complicated or simple designs that they might have come across during their construction careers. The responses to some of the design features are summarized below.

The comments to the open-ended question were varied in nature. Some stressed substitution or modification of the existing design feature. For example, one suggested the substitution of square cast-in-place concrete columns with circular columns. Formwork construction and removal are two of the high risk activities for cast-in-place design features. Since circular columns typically require fewer formwork components, the risk of incidents during their construction is also less. Skylights reinforced with wire mesh or domed skylights are examples of design modifications that were suggested by the roofing trade contractors. Other comments focused on the physical attributes of the design feature. Use of very tall (size) steel columns and heavy (weight) floor panels for raised access flooring are some examples. The basic idea of all the comments though remained the same, i.e., to reduce the probability and/or magnitude of the high risk activities. A summary of the remaining responses can be found in Appendix E.

ANALYSIS AND DISCUSSION

This section presents the analysis of the raw data introduced and described in the Results section. Before commencing the risk analysis, the relative weights of the four severity categories are quantified. Following this, the median frequency and median percentage activity exposure values are calculated and converted into usable units for the estimation of construction safety risk. These calculations are followed by the risk analysis where the unit risk and cumulative risk of design elements are calculated. The risk perceptions between respondents and risk scores between design elements are then statistically compared.

5.1 QUANTIFICATION OF PROPOSED SEVERITY CATEGORIES

Hallowell (2008), in his study on formwork construction risk quantification, used a linear scale (1-10 scale) to rate the severity of the various injury types. The author later hypothesized that the true impacts between the different severity levels is better represented by a geometric scale and recommends its use in future studies. Both the linear and geometric scales and the corresponding severity categories (injury types) are reproduced in Table 5.1.

Table 5.1: Linear and Geometric Scale Values for Injury Types (Hallowell 2008)

Severity Categories (Injury types)	**Linear scale value**	**Geometric scale value**
Near miss	0	0
Negligible	0	1
Temporary discomfort	1	2
Persistent discomfort	2	4
Temporary pain	3	8
Permanent pain	4	16
Minor first aid	5	32
Major first aid	6	64
Medical case	7	128
Lost work time	8	256
Permanent disablement	9	1024
Fatality	10	26,214

The adjusted severity impact values are visually depicted in Figure 5.1. The noticeable spike in value from medical case to permanent disablement is because the impact due to a permanent disablement is four times that of a medical case. Even more noticeable is the increase from permanent disablement to fatality; a fatality is 256 times that of a permanent disablement (Hallowell 2008). The other severity categories (negligible to medical case) have a common ratio of two between them.

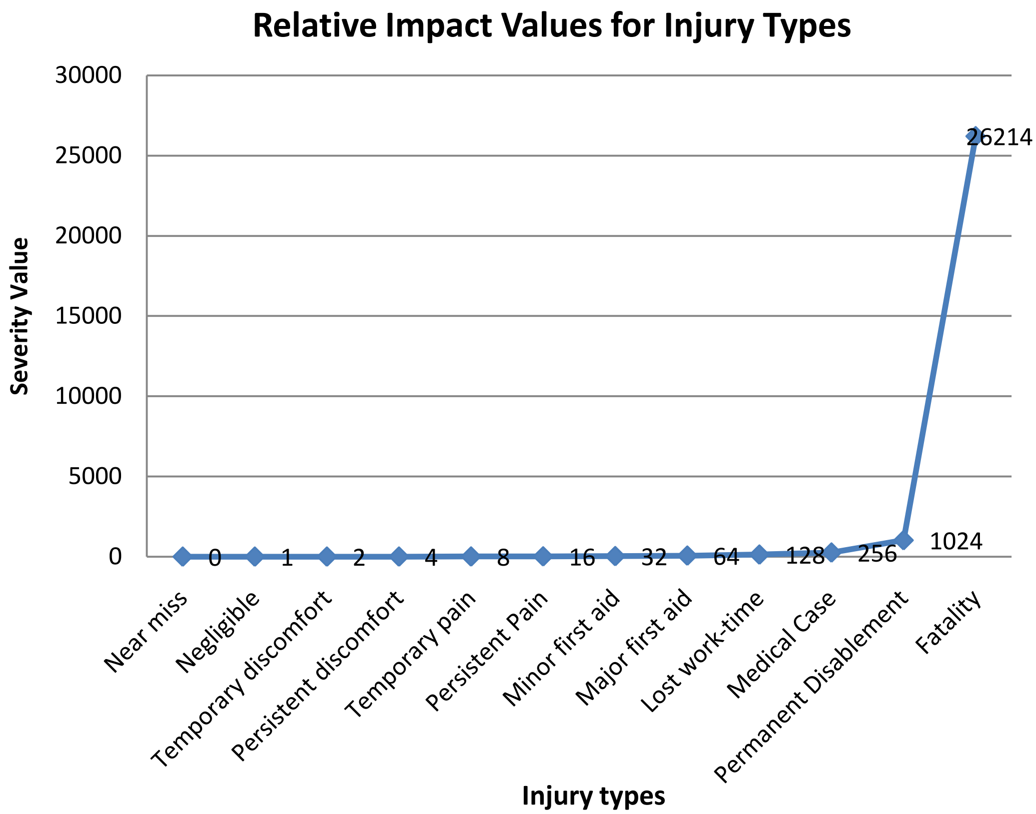

Figure 5.1: Graphical representation of severity impact values

The current study consisted of four severity categories after combining the relevant injury types. In order to rate the relative impacts of these severity categories, it was required to come up with values that are representative of each severity category as well as reflective of the geometric progression.

For clarity of explanation, the injury types combined for the low severity (coded as diamonds) and medium severity (coded as squares) categories are represented in Figure 5.2. The figure is developed using the linear scale values on the X-axis and the corresponding geometric impact values on the Y-axis.

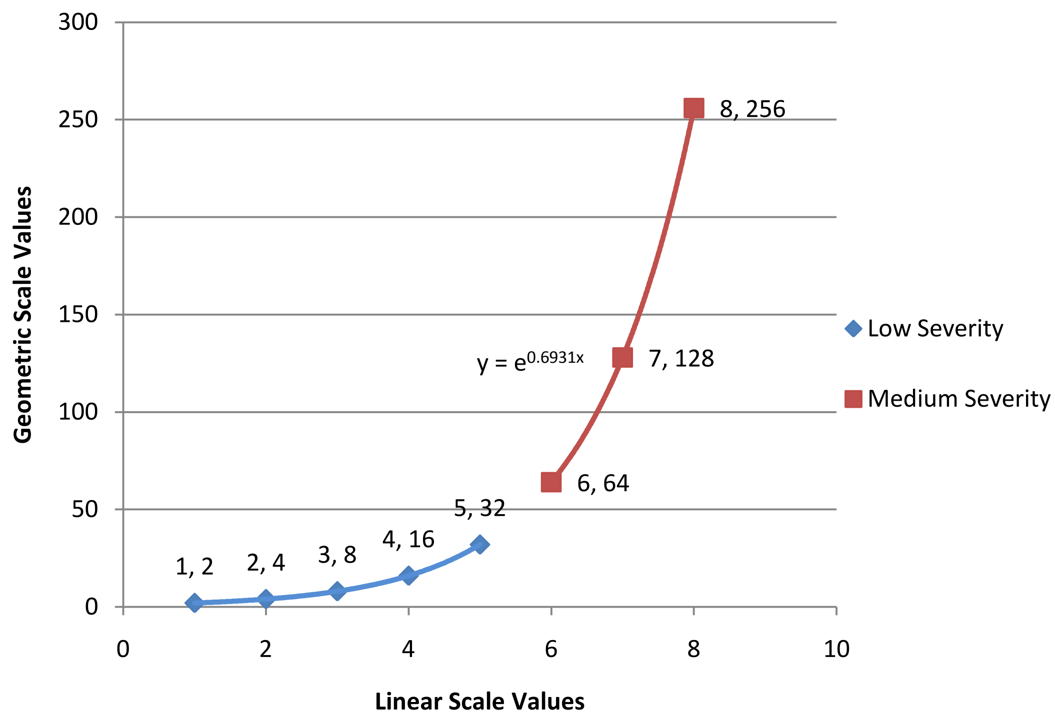

Figure 5.2: Low severity and medium severity category values

The trendline passing through these points represents an exponential curve with an equation $y=e^{0.6931x}$. Initially, the y-coordinate of the centroid of the area under the curve was thought to be a reasonable estimate for each severity category (i.e., y-coordinate of the centroid of the area between (1,2) and (5,32) for low severity, and between (6,64) and (8,256) for medium severity respectively. The y-coordinate values are of interest as the geometric scale values are plotted along the y-axis.

In general, if $\bar{X}$ and $\bar{Y}$ denote the centroid of an area, we can say:

$$\bar{X}=\frac{\text{total moments(x direction)}}{\text{total area}};\ \bar{Y}=\frac{\text{total moments(y direction)}}{\text{total area}}$$

Therefore, for an area under the curve depicted in the Figure 5.2, the centroid can be calculated using definite integrals illustrated by equations (5.1) and (5.2).

$$\bar{X}=\frac{\int_{x_1}^{x_2} x.f(x).dx}{\int_{x_1}^{x_2} dx}.....................(5.1)$$

$$\bar{Y}=\frac{\int_{y_1}^{y_2} y.f(y).dy}{\int_{y_1}^{y_2} dy}......................(5.2)$$

However, after close examination it was apparent that the X-axis (linear scale) is discrete while the Y-axis (geometric scale) is continuous. Hence, calculating the centroid of the area under the curve is not the best fitting approach given these variables. With the number of elements being finite, a better estimate would be to re-express the integrals as a finite summation using equation (5.3).

$$Y_1=\frac{\sum_1^n x_i y_i \vartriangle x}{\sum_1^n x_i \vartriangle x}......................(5.3)$$

Dividing the numerator and the denominator of the above equation by $\vartriangle X$ results in an equation equivalent to weighted averages given by equation (5.4):

$$Y_1 = \frac{\sum_{1}^{n} x_i y_i}{\sum_{1}^{n} x_i} \text{....................(5.4)}$$

For example, the above equation can be used to compute the impact value for the low severity (LS) category as follows:

$$Y_{LS} = \frac{(1x2)+(2x4)+(3x8)+(4x16)+(5x32)}{1+2+3+4+5} = 17$$

Using a similar approach, the weighted averages of the impact values for the medium and high severity categories were also calculated and are shown in Table 5.2.

Table 5.2: Severity category impact values

Severity Categories	**Geometric impact values**
Near miss	0 and 1
Low severity	17
Medium Severity	158
High Severity	14282

As one can see, the near miss category has been assigned two values, 0 and 1. A near miss by definition is an accident that does not result in injury or damage. However, it is important to document near misses to reduce reoccurrence and prevent bigger accidents (Hinze 2006). In addition, the focus of the risk evaluation is on hazards, not just injuries and fatalities. Therefore, it can be considered as a hazard, and the severity impact is given a value of 1 while performing a hazard assessment, and 0 for solely an injury assessment.

5.2 CALCULATION OF MEDIANS AND CONVERSION INTO APPROPRIATE UNITS

For a design feature, raw data obtained from the various respondents comprised of frequency and activity exposure values. As discussed in the analysis methodology section, in order to account for the variability and potential biases, the median frequency values and the median percentage activity exposure values are calculated. The frequency and activity exposure values are then converted into useable units for the risk analysis.

The median frequency values included values corresponding to the frequency scale provided to the survey participants. This scale is reproduced in Figure 5.3. These frequency values are converted to useable units of incident per worker-hour.

Frequency Scale: Average duration between incidents										
Impossible	**Negligible**	**50 years**	**10 years**	**5 years**	**1 year**	**6 months**	**1 month**	**1 week**	**1 day**	**1 hr**
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Figure 5.3: Frequency scale provided to participants

As can be seen in Figure 5.3, each frequency value corresponds to time periods in either hours, days, months, or years. The median frequency responses were converted to worker hours assuming an average of 45 worker-hours per week for 50 weeks a year. This assumption of the amount of time worked in a year is consistent with the past study by Hallowell (2008). Hallowell adopted a similar methodology for the probability conversion. These frequency estimates are defined in terms of worker-hours per incident. By finding the inverse of these frequency values, the actual frequency values in incidents per worker-hour is calculated. The frequency values (incidents per worker-hour) can also be interpreted as probabilities, and are denoted by F in the equation below. For example, if f_{lsx}, f_{lsy}, and f_{lsz} are the frequency values (in worker-hours/incident) given by three respondents for the low severity (LS) category for activity A1, then the median frequency value F_{LS1} (in incidents/worker-hour) is calculated as shown by equation 5.5:

$$F_{LS1} = \frac{1}{\text{median}(f_{lsx} \times f_{lsy} \times f_{lsz})} \dots\dots\dots\dots\dots\dots\dots (5.5)$$

For design features that had an even number of the responses, the median frequency calculations resulted in non-integer values (i.e., values in between the scaled values from 0 to 10). In such cases, the average between the two integer frequencies was calculated. Table 5.3 indicates both the conversion from recognizable work durations to worker-hours and the probability values in terms of incidents per worker-hour.

Table 5.3: Frequency conversions

Frequency Scale value	**Original Range**	**Worker-hours per incident**	**Incidents per worker-hour**
10	1hr	1	1.0E+00
9	1day	9	1.1E-01
8	1week	45	2.2E-02
7	1month	189	5.3E-03
6	6months	1,134	8.8E-04
5	1year	2,250	4.4E-04
4	5years	11,250	8.9E-05
3	10years	22,500	4.4E-05
2	50years	112,500	8.9E-06
1	Negligible	Negligible	0.0E+00

In addition to the median calculations, frequency values in incidents per worker-hour were also calculated for each individual response (or design feature) for analytical comparisons.

The activity exposure field of the survey questionnaires asked the respondents to indicate the percentage of time spent on each activity during the construction of the design feature. Again, the median activity exposure values were calculated. For the cumulative risk calculations, it was required to quantify these percentage values into usable units. The study conducted in the Netherlands by Frijters and Swuste (2008) defined exposure in terms of man-hours. In the Netherlands study, a building costs catalogue was used to determine the man-hours per unit. The total units can be indentified using the project drawings and multiplied by the man-hours per unit to get the exposure in man-hours. A similar approach was employed for converting the percentage exposure values in the current study. The RS Means "Building Construction Cost Data" (RS Means 2011) lists the man-hours required per unit for the construction of all the design elements used for building construction. The man-hours per unit for the design features selected for the study were documented. These values were verified for reliability from a few individuals who participated in the study. The participants affirmed that the numbers were a reasonable estimate to be used for calculation of activity exposure. The median percentage exposure values for each activity of a design feature were used to distribute the worker-hours per unit to each activity. For example, x%, y%, and z% are the activity exposure values given by three respondents for activity A1, and E is the worker-hours/unit required for the design feature from RS Means. The exposure for activity A1 in worker-hours/unit for the design feature is given by ε_1 and calculated as follows:

$\varepsilon_1 = \mu\% \times E$....................(5.6)

where

$\mu\ (\%) = \text{median}(x\%, y\%, z\%)$

5.3 CALCULATION OF RISK FACTORS

The converted frequency values in terms of incident per worker-hour, the four severity values defined in terms of impact to the worker, and the activity exposure values defined in terms of worker-hours per unit, were used to quantify the risk values for the activities. Equations (5.7) and (5.8) were used for computing the risk values.

Unit risk(S/w-h) = Frequency (incident/ w-h) × Severity (S/incident)..........(5.7)

Cumulative risk(S/unit) = Frequency (incident/ w-h) × Severity (S/incident) × Exposure (w-h/unit).. (5.8)

Unit risk is calculated by multiplying the frequency values of each severity category by the corresponding severity impact value. The summation of the unit risks corresponding to each severity category for an activity (i.e., horizontally along an activity in the risk matrix in Figure 5.4) gives the total unit risk associated with the activity for the design feature. The summation of the unit risks vertically (in Figure 5.4) along a severity category gives the total unit risk of the severity level for the design feature. The total unit risk (TUR) associated with constructing a design feature is the summation of the calculated activities' unit risks for the design feature, or the summation of the calculated severity categories' unit risks. The unit risk values are defined in terms of severity per worker-hour. For example, if α_{LS} denotes the impact value of 17 for low severity (LS) category, then the unit risk for low severity category for activity A1 is calculated using the equation 5.9 below:

$$UR_1 = F_{LS1} \text{ x } \alpha_{LS} \text{....................(5.9)}$$

where:

$$F_{LS1} = \frac{1}{\text{median}(f_{lsx} \text{ x } f_{lsy} \text{ x } f_{lsz})}$$

The total unit risk for activity A1 and severity category low severity (LS) are calculated using the following expressions:

$$\sum TUR_{A1} = \sum_{i=NM}^{HS} UR_1 \text{ ....(5.10)}$$

$$\sum TUR_{LS} = \sum_{i=LS_{A1}}^{LS_{AN}} UR\text{....................(5.11)}$$

The total unit risk (TUR) for the design feature A is given by the expression:

$$TUR_A = \sum_{i=A_1}^{A_n} TUR = \sum_{i=NM}^{HS} TUR\text{....................(5.12)}$$

For computing the cumulative risk values, each calculated unit risk value is multiplied by the activity exposure value defined in terms of worker-hours per unit of the design feature. The summation of the cumulative risks corresponding to each severity category for an activity (i.e., horizontally in Figure 5.5 along an activity) gives the total cumulative risk associated with the activity for the design feature. The summation of the cumulative risks vertically along a severity category gives the total cumulative risk of the severity level for the design feature. The total cumulative risk (TCR) associated with constructing a design feature is the summation of the calculated activities' cumulative risks for the design feature, or the summation of the calculated severity categories' cumulative risks.

For example, if ε_1 denotes the activity exposure value (in worker-hours/unit) for activity A1, the cumulative risk for low severity (LS) category for activity A1 is calculated using the expression below

$$CR_1 = f_{LS1} \times \alpha_{LS} \times \varepsilon_1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.13)$$

The cumulative risks for activity A1 and for severity category low severity (LS) are calculated using the following expressions:

$$\sum TCR_{A1} = \sum_{i=NM}^{HS} CR_1 \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.14)$$

$$\sum TCR_{LS} = \sum_{i=LS_{A1}}^{LS_{AN}} CR \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.15)$$

The total cumulative risk (TCR) for the design feature A is given by the expression:

$$TCR_A = \sum_{i=A_1}^{A_n} TCR = \sum_{i=NM}^{HS} TCR \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.16)$$

The entire process of calculating the unit risk factors and cumulative risk factors is illustrated in Figure 5.4 and Figure 5.5, respectively.

Table 5.4: List of symbols used in Figures 5.4 and 5.5

Symbols	Description	Source
α_{NM}, α_{LS}, α_{MS}, α_{HS}	Severity impact values for the four severity categories	Calculated
F_{NM1} , F_{LS1}, F_{MS1}, F_{HS1}	Median frequency (incident/ w-h) for the four severity categories for activity A_1	Survey
A_1 ...A_n	Activities	Identified
TUR_{NM}, TUR_{LS}, TUR_{MS}, TUR_{HS}	Total unit risk factors for the four severity categories	Calculated
TUR_{A1}...TUR_{An}	Total unit risk factors for activities A_1 to A_n	Calculated
TUR_A	Total unit risk factor for design feature A	Calculated
E	Exposure (worker-h/unit)	RS Means
ε_1	Exposure(worker-h/unit) for A_1	Calculated
μ_1%.......μ_n%	Activity exposure in percentages for A_1 to A_n	Survey
TCR_{A1}...TCR_{An}	Total cumulative risk factors for activities A_1 to A_n	Calculated
TCR_{NM}, TCR_{LS}, TCR_{MS}, TCR_{HS}	Total cumulative risk factors for the four severity categories	Calculated
TCR_A	Total cumulative risk factor for design feature A	Calculated

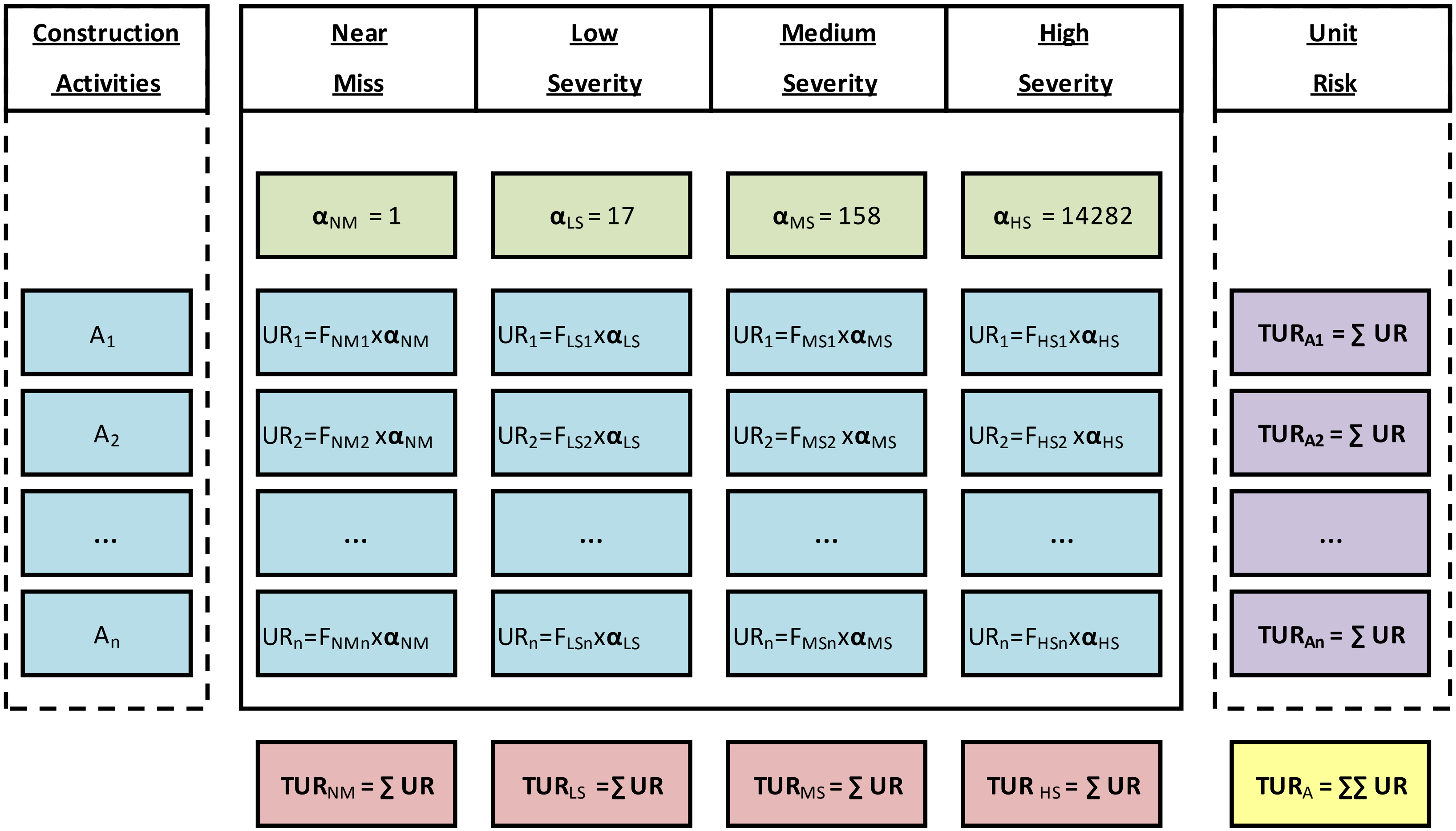

Figure 5.4: Unit risk calculations

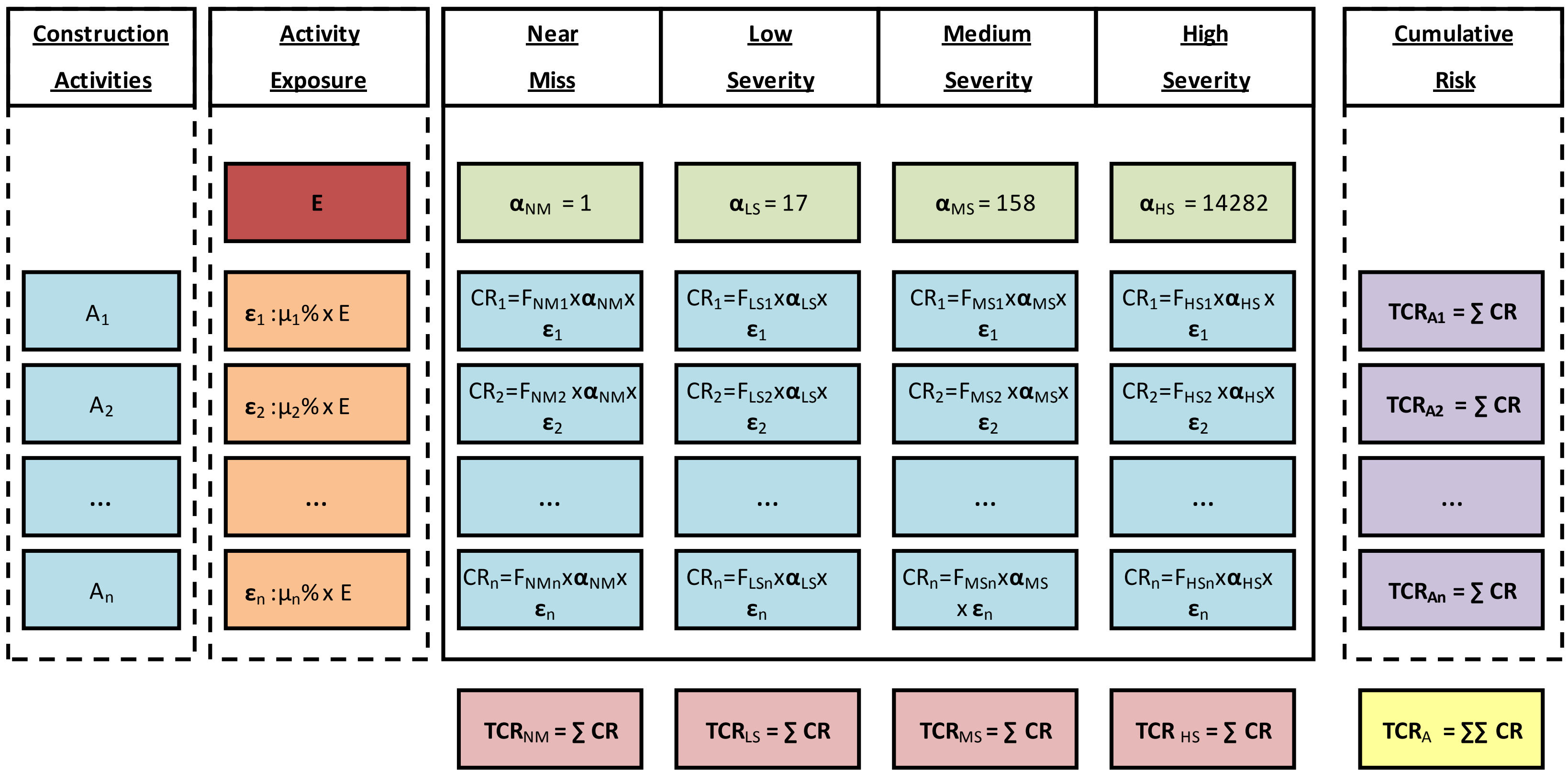

Figure 5.5: Cumulative risk calculations

An example risk matrix for unit risk and cumulative risk for cast-in-place concrete columns is represented by Table 5.5 and Table 5.7. Cast-in-place concrete columns require five major activities during construction. A total of nineteen individuals (5 TCs, 7 GC superinterndents, 7 GC safety managers) responded for CIP concrete columns. The median frequency values based on the nineteen responses are converted to incidents per worker-hour using Table 5.3 and multiplied by the corresponding severity category value from Table 5.2 to give the unit risk factors. The resulting unit risk matrix is represented in Table 5.5. The activity unit risk factor field represents the summation of the unit risk factors along each row of activity. The severity unit risk factors field represents the summation of the unit risk factors along each column of severity category. The summation of the activity unit risk factor field, or the summation of the severity unit risk factor field, results in the total unit risk (0.916) for CIP concrete columns.

In order to describe the variation in the data, the average absolute deviation of each data point was calculated. Since, each data point in the unit risk matrix in Table 5.5 is a median value, the average absolute deviation was used to quantify variation (Hallowell 2008). These are given in Table 5.6.

Table 5.5: Unit risk matrix for CIP concrete columns

	UNIT RISK: SEVERITY PER WORKER HOURS				
	Severity Categories				
Cast In Place Concrete Columns	Near Miss	Low Severity	Medium Severity	High Severity	Activity Unit Risk Factors
Connection of foundation dowels with column rebar	0.001	0.008	0.014	0.127	**0.149**
Formwork construction for columns	0.001	0.008	0.070	0.127	**0.206**
Pouring of concrete for columns	0.001	0.008	0.070	0.127	**0.206**
Stripping of formwork	0.001	0.015	0.070	0.127	**0.213**
Repair and patching work after stripping of formwork	0.000	0.008	0.007	0.127	**0.142**
Severity Unit Risk Factors	**0.004**	**0.045**	**0.232**	**0.635**	**0.916**

Table 5.6: Average absolute deviation of CIP concrete column unit risk factors

	AVERAGE ABSOLUTE DEVIATION OF UNIT RISK FACTORS			
Cast In Place Concrete Columns	Near Miss	Low Severity	Medium Severity	High Severity
Connection of foundation dowels with column rebar	0.010	0.027	0.027	0.343
Formwork construction for columns	0.004	0.030	0.073	1.188
Pouring of concrete for columns	0.004	0.012	0.038	0.889
Stripping of formwork	0.006	0.038	0.038	0.870
Repair and patching work after stripping of formwork	0.002	0.004	0.017	0.273

In the cumulative risk matrix represented by Table 5.7, the activity exposure values in worker-hours per cubic yard are obtained by multiplying the median percentage exposure values of the nineteen respondents for each activity by the worker-hours per cubic yard for CIP concrete columns obtained from the RS Means manual. The RS Means has two values for CIP concrete columns: 13.832w-h/cy for square columns and 8.958w-h/cy for round columns, representing different exposure times required for the two types (RS Means 2011). The cumulative risk matrix in Table 5.7 is calculated for square CIP concrete columns. The unit risk matrix factors calculated above are multiplied by the corresponding activity exposure values. The activity cumulative risk factor field represents the summation of the cumulative risk factors along each row of activity. The severity cumulative risk factor field represents the summation of the cumulative risk scores along each column of severity category. The summation of the activity cumulative risk factor field, or the summation of the severity cumulative risk factor field, results in the total cumulative risk (2.665) for CIP concrete columns.

The variation in the cumulative risk factors is also represented by calculating the average absolute deviation. The average absolute deviation of each data point (risk factor) can be found in Table 5.8.

Table 5.7: Cumulative risk matrix of CIP concrete columns

		CUMULATIVE RISK: SEVERITY PER CUBIC YARD				
		Severity Categories				
Cast In Place Concrete Square Columns	Activity Exposure	Near Miss	Low Severity	Medium Severity	High Severity	Activity Cumulative Risk Factors
Connection of foundation dowels with column rebar	2.075	0.002	0.016	0.029	0.263	**0.310**
Formwork construction for columns	4.150	0.004	0.031	0.291	0.527	**0.853**
Pouring of concrete for columns	2.766	0.002	0.021	0.194	0.351	**0.569**
Stripping of formwork	3.458	0.003	0.052	0.243	0.439	**0.737**
Repair and patching work after stripping of formwork	1.383	0.001	0.010	0.010	0.176	**0.196**
Severity Cumulative Risk Factors		**0.012**	**0.130**	**0.767**	**1.756**	**2.665**

Table 5.8: Average absolute deviation of CIP concrete column cumulative risk scores

	AVERAGE ABSOLUTE DEVIATION OF CUMULATIVE RISK FACTORS			
Cast In Place Concrete Square Columns	Near Miss	Low Severity	Medium Severity	High Severity
Connection of foundation dowels with column rebar	0.019	0.054	0.057	0.773
Formwork construction for columns	0.024	0.183	0.449	7.367
Pouring of concrete for columns	0.011	0.032	0.091	2.476
Stripping of formwork	0.020	0.081	0.126	2.608
Repair and patching work after stripping of formwork	0.002	0.007	0.024	0.421

The unit risk matrix and cumulative risk matrix for precast concrete columns are represented by Tables 5.9 and 5.10 respectively. It is important to note that the total cumulative risk of precast concrete columns (0.108 S/L.F.) is less compared to the total cumulative risk of cast-in-place concrete columns (2.665 S/C.Y.). However, these are absolute values, since both the values have different units and are project specific. Comparing cast-in-place concrete columns to precast columns requires information regarding how much of each type is on the project.

Using a similar process, risk factors for all the 89 design features were calculated. The resulting risk factors represent the ultimate objective of the research study which was to quantify the construction safety risk value of design elements. The analysis also quantified the construction safety risk value for the four severity categories and for each construction activity of design elements.

Table 5.9: Unit risk matrix for Precast concrete columns

	UNIT RISK: SEVERITY PER WORKER HOURS				
	Severity Categories				
Precast Concrete Columns	Near Miss	Low Severity	Medium Severity	High Severity	Activity Unit Risk Factors
Loading the column section from crane	4.44E-04	0.005	0.007	0.127	**0.139**
Hoisting of column section using crane	8.82E-04	0.008	0.007	0.127	**0.142**
Accepting, guiding and placing of column section from crane	3.09E-03	0.008	0.011	0.381	**0.402**
Plumb, leveling and connecting column section with foundation	4.44E-04	0.002	0.007	0.127	**0.136**
Grouting of space between column section and footing	2.67E-04	0.001	0.001	0.063	**0.066**
Splicing of precast column sections for the subsequent tiers	4.44E-04	0.008	0.007	0.127	**0.142**
Severity Unit Risk Factors	**0.006**	**0.030**	**0.040**	**0.952**	**1.028**

Table 5.10: Cumulative risk matrix for Precast concrete columns

Precast Concrete Columns	Activity Exposure	CUMULATIVE RISK: SEVERITY LINEAR FEET Severity Categories Near Miss	Low Severity	Medium Severity	High Severity	Activity Cumulative Risk Factors
Loading the column section from crane	0.056	2.47E-05	2.52E-04	3.90E-04	0.007	**0.008**
Hoisting of column section using crane	0.083	7.35E-05	6.30E-04	5.86E-04	0.011	**0.012**
Accepting, guiding and placing of column section from crane	0.139	4.29E-04	1.05E-03	1.46E-03	0.053	**0.056**
Plumb, leveling and connecting column section with foundation	0.083	3.71E-05	1.26E-04	5.86E-04	0.011	**0.011**
Grouting of space between column section and footing	0.083	2.22E-05	9.45E-05	1.17E-04	0.005	**0.006**
Splicing of precast column sections for the subsequent tiers	0.111	4.94E-05	8.40E-04	7.81E-04	0.014	**0.016**
Severity Cumulative Risk Factors		**0.001**	**0.003**	**0.004**	**0.101**	**0.108**

5.4 APPLICATION

A designer can use this tool to evaluate the safety risk of an entire project. While contemplating the type of design features to be used for the different systems, the designer can use the cumulative risk matrices and project information to calculate the risk scores. To illustrate the methodology, an example will be provided.

For this example, the design features assumed for the five systems are given in Table 5.11. The cumulative risk factors for the design features are also provided. Multiplying the cumulative risk factors of each design feature with the estimated quantity of each design feature for the project will result in the cumulative risk of the design feature for the project. For example, multiplying the cumulative risk factor of skylights (2.9E-01 S/EA) by the number of skylights designed for the project will give the safety risk of skylights for the project in terms of severity. The addition of all the safety risks of all the design features (in severity) will give the total cumulative risk for the project.

Table 5.11: Example project design features

System/ Components	**Design feature/ Elements**	**Cumulative risk factors (Severity/ unit)**
Footings and foundations	Steel H-piles	1.6E-02 S/V.L.F
	Slab on grade	5.4E-04 S/S.F.
Structural framing	Steel columns	2.0E-02 S/L.F.
	Steel beams	3.0E-02 S/L.F.
	Composite decks with concrete	9.7E-03 S/S.F.
	Steel roof decks	2.6E-03 S/S.F.
	Steel stairs with concrete filled metal pans	1.0E-01 S/S.F.
Roof covering and specialties	Modified bitumen roof membrane	4.5E-03 S/S.F.
	Skylights	2.9E-01 S/EA
	Edge guard	3.7E-03S/L.F.
Exterior enclosure	Steel stud back-up wall	2.3E-04 S/S.F.
	Brick veneer without exterior insulation	3.9E-02 S/S.F.
	Entrance/ exterior doors	1.3E+00 S/EA
	Aluminum windows	4.7E-01 S/EA
Interior construction	CMU partition walls	9.4E-03 S/S.F.
	Drywall finish	9.2E-04 S/S.F.
	Suspended gypsum board ceilings	1.6E-03 S/S.F.
	Carpet flooring	5.9E-05 S/S.F.
	Aluminum doors	5.4E-02 S/S.F.

The designer can try alternative design features (for example steel stud partition walls instead of CMU partition walls) and several combinations to reduce the safety risk of the project.

The following section explains how the data collected can be further analyzed to determine the differences in risk perception between the respondents and for comparison between design features.

5.5 STATISTICAL COMPARISONS

An exploration of the data using pivot tables in MS Excel® reveals differences in the mean unit risk and cumulative risk matrices between the respondent groups. Also, differences were observed in the mean cumulative risk matrices between the design elements. In order to check if these differences are statistically significant, the calculated risk values were analyzed using the statistical analysis software R. The following sections introduce and describe these comparisons. The results of the statistical tests are also summarized in each section.

5.5.1. Comparison of Risk Perceptions

According to Hallowell (2010), construction risk perception is the subjective judgment made by construction crews regarding the frequency of the various severity types given a risk scenario. For the current study, opinions were given by general contracting and trade contracting companies. The risk matrices that were developed in the previous section were further analyzed to compare the risk perception between the different respondent groups. Opinions were provided by superintendents and safety managers of general contracting firms. The trade contracting respondents had safety managers and superintendents for some of the trades. For the analysis, these were combined together into one group designated as trade contractors. This section provides a comparison of the risk perception between the three groups of respondents.

Safety risk perception studies of various industries are prominent in the existing body of literature. Several studies (Bailey 1997; Findley et al. 2007; Harvey et al. 1999; T. Lee 1998; McDonald et al. 2000; Zohar 2000) focusing on differences in risk perceptions between work groups have been conducted. Recently, Hallowell (2010) quantified and compared the safety risk perception between construction workers and managers. The study found no evidence of a difference (p-value > 0.20 using Wilcoxon rank sum test) between the upper level managers and workers/lower level managers. In the study, superintendent, project manager, safety manager, and vice president of operations were classified as upper-level managers while foremen, crew leaders, tradesmen, journeymen, laborer were classified as lower-level managers (Hallowell 2010).

The current study involved superintendents, safety managers, and trade contractors. The data collected can be analyzed to investigate if there is a difference in risk perception between these three groups. The responses provided to the same risk scenario had to be compared. The design element was held constant to meet this objective, i.e., for the same design element, the activity risk factors, the four severity category risk factors, and the total risk factors were individually compared. These comparisons were performed on both the unit risk and the cumulative risk matrices.

An example comparison between the groups for the cast-in-place concrete columns design element is analyzed. Owing to the relatively larger number of individual respondents (5 TCs, 7 GC superintendents, 7 GC safety managers) for CIP columns, it was selected for the analysis. Risk perception analyses for any design feature can be performed using a similar procedure.

5.5.1.1. Analysis of Data

The small sample size of each group restricts the equal variance and normal distribution assumptions. These assumptions are required to use traditional statistical tests based on the t-student family of distributions. Therefore, the permutation test for two group comparisons was used to analyze the data.

A summary of the statistical test conducted for unit and cumulative risk values for activities is shown by Table 5.12 and for severity categories and total risk is shown in Table 5.13. As can be seen from the two tables, comparison between two groups were analyzed for general contractor superintendents and general contractor safety managers, general contractor superintendents and trade contractors, general contractor safety managers and trade contractors, and between general contractors and trade contractors. There is no evidence of a difference in risk perception between general contractor superintendents and general contractor safety managers for the activity risk, severity categories, and total risk comparisons. As one can see from Table 5.12, except for connecting foundation dowels with column rebar and repair and patch work, the remaining three activities show moderate to suggestive evidence of a difference in the sample mean risk perceptions for the three comparisons (i.e., GCsuperintendents vs TC, GCsafety vs TC and GCs vs TCs). Table 5.13 also shows moderate to suggestive evidence of a difference for medium severity, high severity, and total risk for these three comparisons. There is no evidence of a difference in the way the groups perceive near miss risks.

The non-difference in risk perception between general contractor superintendents and general contractor safety managers is consistent with the study by Zohar (2000). Zohar found that there is homogeneity between risk perceptions within the same organization level. Safety managers and superintendents are grouped as upper level management as confirmed by Hallowell (2010).

A trade contractor specializes in his/her own trade and has the complete knowledge of it. A general contractor on the other hand supervises the entire project and a trade contractor's work is part of his/her supervision. This may have been a factor that contributed to the differences in risk perceptions between general contractor's field personnel (superintendent and safety managers) and trade contractor's field personnel. The small number of responses might also have been a factor that contributed to the difference between risk perceptions (i.e., one or two individuals having outlying risk perceptions for a group).

Even with the moderate and suggestive differences between the trade contractors and general contractors, there is no literature that can support one group's risk perception as being closer to the actual risk compared to the other. Also, the number of responses for each group was small to be considered individually for calculating the risk. Therefore, the responses were aggregated by calculating the medians to compute the risk factors for the study.

Table 5.12: CIP concrete column activity comparisons between respondent groups

Comparisons	Unit risk		Cumulative risk	
	Statistical strength	Statistical Conclusion	Statistical strength	Statistical Conclusion
Connection of foundation dowels with column rebar				
GC Superintendents vs GC Safety Managers	p = 0.897	No evidence	p = 0.663	No evidence
GC Superintendents vs TCs	p = 0.354	No evidence	p = 0.48	No evidence
GC Safety Managers vs TCs	p = 0.418	No evidence	p = 0.401	No evidence
GCsvsTCs	p = 0.333	No evidence	p = 0.392	No evidence
Formwork construction for columns				
GC Superintendents vs GC Safety Managers	p = 0.964	No evidence	p = 0.613	No evidence
GC Superintendents vs TCs	p = 0.038	Moderate evidence	p = 0.011	Moderate evidence
GC Safety Managers vs TCs	p = 0.057	Suggestive evidence	p = 0.048	Moderate evidence
GCsvsTCs	p = 0.018	Moderate evidence	p = 0.01	Moderate evidence
Pouring of concrete for columns				
GC Superintendents vs GC Safety Managers	p = 0.854	No evidence	p = 0.931	No evidence
GC Superintendents vs TCs	p = 0.042	Moderate evidence	p = 0.053	Suggestive evidence
GC Safety Managers vs TCs	p = 0.074	Suggestive evidence	p = 0.073	Suggestive evidence
GCsvsTCs	p = 0.023	Moderate evidence	p = 0.024	Moderate evidence
Stripping of formwork				
GC Superintendents vs GC Safety Managers	p = 0.886	No evidence	p = 0.431	No evidence
GC Superintendents vs TCs	p = 0.038	Moderate evidence	p = 0.056	Suggestive evidence
GC Safety Managers vs TCs	p = 0.053	Suggestive evidence	p = 0.056	Suggestive evidence
GCsvsTCs	p = 0.017	Moderate evidence	p = 0.02	Moderate evidence
Repair and patching work after stripping of formwork				
GC Superintendents vs GC Safety Managers	p = 0.488	No evidence	p = 0.443	No evidence
GC Superintendents vs TCs	p = 0.576	No evidence	p = 0.987	No evidence
GC Safety Managers vs TCs	p = 0.143	No evidence	p = 0.098	Suggestive evidence
GCsvsTCs	p = 0.237	No evidence	p = 0.724	No evidence

Table 5.13: CIP concrete columns severity level and total risk comparisons between respondent groups

Comparisons	Unit risk		Cumulative risk	
	Statistical strength	Statistical Conclusion	Statistical strength	Statistical Conclusion
Near miss total				
GC Superintendents vs GC Safety Managers	p = 0.703	No evidence	p = 0.723	No evidence
GC Superintendents vs TCs	p = 0.948	No evidence	p = 0.885	No evidence
GC Safety Managers vs TCs	p = 0.803	No evidence	p = 0.871	No evidence
GCsvsTCs	p = 0.792	No evidence	p = 0.929	No evidence
Low severity total				
GC Superintendents vs GC Safety Managers	p = 0.338	No evidence	p = 0.337	No evidence
GC Superintendents vs TCs	p = 0.072	Suggestive evidence	p = 0.063	Suggestive evidence
GC Safety Managers vs TCs	p = 0.948	No evidence	p = 0.882	No evidence
GCsvsTCs	p = 0.726	No evidence	p = 0.938	No evidence
Medium Severity total				
GC Superintendents vs GC Safety Managers	p = 0.498	No evidence	p = 0.52	No evidence
GC Superintendents vs TCs	p = 0.034	Moderate evidence	p = 0.02	Moderate evidence
GC Safety Managers vs TCs	p = 0.094	Suggestive evidence	p = 0.051	Suggestive evidence
GCsvsTCs	p = 0.018	Moderate evidence	p = 0.01	Moderate evidence
High severity total				
GC Superintendents vs GC Safety Managers	p = 0.699	No evidence	p = 0.686	No evidence
GC Superintendents vs TCs	p = 0.057	Suggestive evidence	p = 0.039	Moderate evidence
GC Safety Managers vs TCs	p = 0.054	Suggestive evidence	p = 0.048	Moderate evidence
GCsvsTCs	p = 0.022	Moderate evidence	p = 0.015	Moderate evidence
Total risk				
GC Superintendents vs GC Safety Managers	p = 0.847	No evidence	p = 0.85	No evidence
GC Superintendents vs TCs	p = 0.044	Moderate evidence	p = 0.035	Moderate evidence
GC Safety Managers vs TCs	p = 0.065	Suggestive evidence	p = 0.052	Suggestive evidence
GCsvsTCs	p = 0.022	Moderate evidence	p = 0.014	Moderate evidence

5.5.2. Comparison of Design Elements

The cumulative risk matrices can be effectively used to make comparisons between design elements that are structurally used for the same purpose. For example, steel studs (framed partitions) or concrete masonry units (wall partitions) can be used as interior partition walls. Likewise, the structural frame of a multistory building can be designed as a steel frame or cast-in-place concrete frame structure. The design elements are compared for the total near miss, total low severity, total medium severity, total high severity, and total risk factor values. The comparisons were made to check if there is a difference between the risk factors of the design elements. Activity comparisons between design elements are not analyzed since there might be a difference in the number and type of activities that are performed to construct the design features. Also, one must note that comparisons are possible for design elements that have the same exposure units and also the exposure is not project specific. For example, the structural use of steel columns and cast-in-place concrete columns is the same. However, both have different exposure units. Also, a mat foundation and isolated column footings have the same exposure units (worker-hrs/cy), but the exposure units are project dependent. The amount of concrete used for each design feature varies for the same project. Interior partition walls and ceilings, flooring, exterior walls, and roof coverings are examples of systems that have common exposure units (worker-hrs/sf) and are also comparable irrespective of the project.

5.5.2.1. Analysis of Data

Statistical comparisons between a framed steel stud partition wall and a CMU partition wall are summarized in Table 5.14. The permutation test was used while evaluating the differences in the risk scores between the two design elements because the samples were:

- small (n=16 for framed, n=10 for CMU wall);
- non-normal;
- did not have equal sample variance; and

- had a lot of zeroes.

As one can see from Table 5.14, there is suggestive evidence of a difference in cumulative near miss risk factors for the steel stud partition wall and the CMU block partition wall (two-sided p-value=0.049 from a permutation test). Also, there is moderate evidence that the cumulative medium severity (two-sided p-value=0.01), cumulative high severity (two-sided p-value=0.035), and cumulative total risk factors (two-sided p-value=0.029) are different for the two interior partition wall types. For the sample responses obtained for the two design elements, the cumulative near miss risks, medium severity risks, high severity risks, and total risks associated with CMU block wall partition construction are on average greater than that during steel stud wall partition construction. CMU block walls are heavier to work with and their installation is also much more demanding compared to steel studs. Steel studs are much lighter in weight, and requires simple tools for installation. These might be possible reasons as to the higher risk factors for CMU block walls compared to steel studs.

Table 5.14: Interior partition wall comparisons

Steel stud partition v. CMU block partion	**Cumulative risk**		**Statistical test**
	Statistical strength	**Statistical Conclusion**	
Near miss total	p = 0.049	Suggestive evidence	Permutation test
Low severity total	p = 0.138	No evidence	Permutation test
Medium Severity total	p = 0.01	Moderate evidence	Permutation test
High severity total	p = 0.035	Moderate evidence	Permutation test
Cumulative risk total	p = 0.029	Moderate evidence	Permutation test

Suspended acoustical and suspended gypsum board ceilings were similarly compared and the statistical tests are summarized in Table 5.15. As one can see, there is no evidence of a difference between the cumulative risk factor values associated with the construction of the two ceiling types.

One must note that even though there is no statistical evidence of a difference between gypsum board ceilings and acoustical ceilings, the computed risk factor values show otherwise. The majority of the activities for both the design elements are the same, except for installation of acoustical panels for acoustical ceilings and installation and finishing of gypsum boards for gypsum board ceilings. Also, the installation of acoustical panels and gypsum boards are similar in nature except for finishing work required for gypsum boards. This might have contributed to the results shown in Table 5.15.

Table 5.15: Interior ceiling comparisons

Suspended acoustical ceilings v. Suspended gypsum board ceilings	**Cumulative risk**		**Statistical test**
	Statistical strength	**Statistical Conclusion**	
Near miss total	p = 0.539	No evidence	Permutation test
Low severity total	p = 0.531	No evidence	Permutation test
Medium Severity total	p = 0.228	No evidence	Permutation test
High severity total	p = 0.389	No evidence	Permutation test
Cumulative risk total	p = 0.342	No evidence	Permutation test

Similar comparisons can be performed for other design elements, and the author encourages the reader to use the data provided in the Appendix C and D to perform such analyses.

The results of risk perception comparisons and design feature comparisons cannot be extended beyond the data collected and analyzed for the current study. However, since the author used a sample including a mix of general contractor's superintendents, general contractor's safety managers, and trade contractors for the design feature risk comparisons, and accounted for potential biases, it is expected that the observed trends in the design feature analyses would provide a useful insight of the differences.

The author recommends a bigger sample size and a formal probability sampling procedure to further investigate the significance and extent of the relevant trends found in this study.

CONCLUSIONS

The main objective of this thesis was to quantify the construction safety risks associated with the construction of design elements used for multistory commercial office buildings. Currently, there is no tool in the US construction industry that rates the design elements on how safe they are to construct in the field or on the basis of construction safety. In order to develop this DfCS tool, the commonly used design features and the corresponding major construction activities needed to be identified. Using construction literature, a database consisting of systems, design features, and construction activities was created.

Once the design features and activities were identified, survey questionnaires were developed to get input from field personnel. The field personnel included general contracting superintendents, general contracting safety managers, and trade contracting superintendents. Field personnel were selected as they are closest to the construction processes of the design elements and hence have better judgment of the construction safety risk. The participants were asked to rate average frequency of incidents for four severity categories associated with each activity for each design feature.

The data collected and processed from the survey was presented and converted to useable units of frequency, severity, and exposure. The subsequent analysis resulted in unit risk and cumulative risk matrices for the design feature selected for the study. The unit risk and cumulative risk matrix for a design feature quantified the risk associated with the activities and risk of the four severity categories for the design feature. Further analyses were performed on these matrices to statistically compare between design elements and to compare risk perceptions between the three field personnel groups.

The data presented in this report can be used by the construction industry to improve construction safety. While designing a particular system in a building, the designer can use the risk matrices created and compare between all the possible design elements applicable to the system in terms of construction safety. For example, while designing the exterior cladding, a designer can evaluate between brick veneer, glazing, prefabricated panels, and so forth. The designer will also be cognizant about the construction process and relative safety risks of the activities of their selection. This knowledge may help them to design-in construction safety features into the design element selected in an effort to reduce the activity and/or severity risks.

A contractor may utilize this data during pre-task safety plan meetings of the construction process. Contractors may caution the workers regarding the high risk activities and the type of injury severities during construction of a design element. Also, they can train the crews on high risk activities. Contractors may also evaluate alternate means and methods of construction for the high risk tasks to reduce the risks.

LIMITATIONS AND ASSUMPTIONS

The limitations and assumptions associated with the research study include:

- Design elements are constructed/prefabricated in all shapes and sizes depending on the characteristics of the project. The study is limited as the risk factors are representative of design elements used only in a typical multistory commercial office building. The results of the study may not be applicable to all building types, and to all types of multistory commercial office buildings.
- The design element risk factors are assumed to remain the same if the element is rated based on major construction activities and if it is rated based on a further breakdown of the major activities into smaller tasks. For example, five major construction activities were identified for cast-in-place concrete columns. It is assumed that even if these five major activities are divided into ten smaller tasks,

the respondents would have rated these ten tasks in such a way that the final risk factor of the design element would be the same in either case.

- The design element risk factors apply to the construction activities as identified, defined, and provided to the respondents. In construction, multiple means and methods can be used to perform the same task and hence the risk factors may change if alternate methods are employed.
- The frequency ratings obtained for the study are based on the judgment of construction personnel.
- The frequency ratings obtained represent the average duration between incidents when typical safety program elements are used.
- Both the samples of general contracting firms and trade contracting firms were convenience samples. Therefore, the scope of the study cannot be statistically extended to a greater population.
- The risk factors of design elements apply to the construction industry in the United States.

RECOMMENDATIONS

Information about construction worker safety on the jobsite must ultimately be drawn from the construction personnel and transferred to the designers. This study makes a preliminary attempt to achieve this objective. It provides the designer with the knowledge of the safety risks while constructing their designs. However, as with any research, this study can be extended and improved upon. Since DfCS is an emerging area of research, it can be widely explored using the analysis and information in this research as groundwork. The current study was designed using scales, methodologies, and ideas from past research studies. The author recommends future research in this area to be consistent at least in terms of analysis assumptions and frequency and severity scales. This consistency would help in developing a database which will ultimately lead to improved construction safety. The subsequent sections provide several suggestions for future research.

7.1 VALIDATION OF THE RESEARCH STUDY

One of the major subsequent research efforts required is to validate the results of this study by collecting secondary data. This is vital to confirm the results obtained in the study and also for its real life applicability. The author attempted to validate the results using archival data from the National Institute for Occupational Safety and Health (NIOSH) and the Bureau of Labor Statistics websites. NIOSH conducts investigations of fatal occupational injuries through the Fatality Assessment and Control Evaluation (FACE) program. BLS records the accident investigation summaries after OSHA conducts an inspection. Both fatalities and injuries are recorded by the BLS. The reports from both the sources were reviewed to extract information if the accidents resulted while constructing specific design features. However, no such information could be solicited since a majority of the reports do not record information on the design feature being constructed.

The author recommends using the results of the study to rate the design features on an actual construction project. The project superintendents and safety managers then can provide their input regarding congruency of the research results with what they perceived on the jobsite. Another method of validation would be to have an expert panel review the results of the study to confirm its accuracy.

7.2 EVALUATION OF DESIGN FEATURES BASED ON THE DIFFERENT DEGREES OF CONNECTIVITY

An injury can occur depending on the level of interaction of the worker with a design element. This interaction level can be defined as the 'degree of connectivity' (DOC). Four scenarios can be considered where a worker can get injured. These scenarios and corresponding DOC are described as follows:

DOC1: Worker is injured while working to construct the design element i.e. direct interface with the design element during all phases of its construction. The current study evaluated the design features based on this scenario.

DOC2: Worker is injured while working to construct other design elements that attach to or interface with the design element under consideration. The interaction with the design element is in its final form. For example, attaching hanger wires for suspended ceilings to the underside of steel decks as compared to the underside of a concrete slab. The design elements under consideration are the steel deck and concrete slab which are in their final forms.

DOC3: Worker is injured while working to construct other design elements that are not attached to or interface with the design element under consideration. The design element is in its final form during the exposure. For example, a worker walks past the design element and is injured after tripping on an object protruding from the design element.

DOC4: Worker does not have any interaction with or exposure to the design element under consideration, but is injured as a result of other workers constructing the design element or interfacing with the design element. For example, a worker gets injured while walking underneath the work being conducted and is struck by an object dropped by another worker who is constructing the design element. Conflicting trades during construction is one of the major issues that needs special attention. The trade contracting companies that participated in the current study too confirmed to this problem. With schedule being vital in construction, it is unlikely that this scenario can be avoided. However, pre-task planning helps address the issue, and simple and safe design can supplement it.

The author recommends subsequent research efforts that address the issues due to DOC 2, 3 and 4.

7.3 QUANTIFICATION OF SAFETY RISKS WHILE CONSTRUCTING OTHER NON-STRUCTURAL SYSTEMS

In addition to the structural components of a building, the safety risks of constructing other systems should be evaluated. These systems include the site work and excavation supporting systems, mechanical, electrical, plumbing, temporary structures, and other systems. These should also be evaluated for the four degrees of connectivity explained above.

7.4 CALCULATION OF MODIFIED TOTAL UNIT RISK AND CUMULATIVE RISK FACTORS OF DESIGN ELEMENTS

One of the subsequent research efforts could be to address the very first limitation in the current study. The current study quantified unit risk factors and cumulative risk factors of typical design elements. The author suggests a research topic to modify the risk factors based on site-specific designs or construction conditions. Modification factors will have to be defined for each condition and the values of the modification factors will have to be quantified for the different possible designs or construction conditions. These modification factors, once defined and quantified, will be multiplied by the risk factor values to get the modified risk factor values.

7.5 DESIGN FOR SAFETY RISK MITIGATION

The current research quantified the safety risk of constructing the design features. In simple words, it enlightens the designers about the difficulty faced by construction workers building their designs. Conversely, a research study should be conducted that mitigates the safety risk of constructing the design features. This can be done by assessing each activity using the elimination and/or substitution strategy of the hierarchy of controls. Design suggestions compiled in the CII Toolbox and by other sources should also be used. Additional design modifications should be compiled by interviewing or surveying experts.

7.6 DESIGN FOR SAFETY HAZARD ASSESSMENT

Finally, the risk quantification for the current study was based on the severity levels of accidents. The author suggests a study focusing on the risk of hazards (struck by object, fall on same level, etc.) while constructing design features. Although a similar study has been conducted, it focuses on residential construction (Gangolells et al. 2010). Also, the scales used for the quantification of the risks are different. The author recommends the use of scales developed by Hallowell (2008) for the formwork construction study for consistency. This study can be very detailed by incorporating the materials, equipment, tools, etc. that are used while constructing design features. The hazard types as a result of these factors can be identified and quantified for each activity of the design feature.

BIBLIOGRAPHY

Allen, E., and Iano, J. (2004). *Fundamentals of Building Construction*. Fourth edition, John Wiley and Sons, Inc. New York.

Andres, C. K., and Smith, R. C. (2004). *Principles and Practices of Commercial Construction*. Seventh edition, Prentice Hall.

Andres, R. N. (2002). "Risk Assessment & Risk Reduction: A Look at the Impact of ANSI B11.TR3." *Professional Safety - The Journal of American Society of Safety Engineers*, 20-26.

Arditi, D., and Chotibhongs, R. (2005). "Issues in subcontracting practice." *Journal of Construction Engineering and Management*, 131, 866.

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

Bailey, C. (1997). "Managerial Factors Related to Safety Program Effectiveness: An Update on the Minnesota Perception Survey." *Professional Safety,* 8, 33-35.

Baradan, S., and Mumtaz, A. U. (2006). "Comparative Injury and Fatality Risk Analysis of Building Trades." *Journal of Construction Engineering and Management*, 132(5), 533-539.

Behm, M. (2004). "Establishing the Link between Construction Fatalities and Disabling Injuries and the Design for Construction Safety Concept." Oregon State University, Corvallis, Oregon.

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

BLS. (2010). "Bureau of Labor Statistics." Accessed December 2010.

Carter, G., and Smith, S. D. (2006). "Safety hazard identification on construction projects." *Journal of Construction Engineering and Management*, 132, 197.

Christensen, W. C., and Manuele, F. A. (1999). *Safety through Design*. National Safety Council, United States of America.

Churcher, D. W., and Alwani-Starr, G. M. (1996). “Incorporating construction health and safety into the design process, implementation of safety and health on construction sites.” *First International Conference,* Lisbon, 29-39.

Coble, R. J., and Blatter Jr., R., L. (1999). “Concerns with safety in Design/Build Process.” *Journal of Architectural Engineering*, 5(2), 44-48.

Coble, R. J., Hinze, J. W., and Haupt, T. C. (2000). *Construction Safety and Health Management*. Prentice Hall, Upper Saddle River, New Jersey.

Cooke, T., Lingard, H., and Blismas, N. (2008). “ToolSHeD: The development and evaluation of a decision support tool for health and safety in construction design.” *Engineering, Construction and Architecture Management*, 15(4), 336-351.

Driscoll, T., Harrison, J. E., and Bradley, C. (2004). *National Occupational Health and Safety Commission: The role of design issues in work-related injuries in Australia 1997-2002*. National Occupational Health and Safety Commission, Canberra.

Everett, J. G., and Frank, P. B. (1996). “Costs of Accidents and Injuries to the Construction Industry.” *Journal of Construction Engineering and Management*, 122(2), 158-164.

Findley, M., Smith, S., Gorski, J., and O’Neil, M. (2007). “Safety climate differences among job positions in a nuclear decommissioning and demolition industry: Employee’s self-reported safety attitudes and perceptions.” *Safety Science*, 45, 875-889.

Frijters, A. C. P., and Swuste, P. H. J. J. (2008). “Safety Assessment in design and preparation phase.” *Safety Science*, 46(2), 272-281.

Gambatese, J. A. (1998). “Liability in Designing for Construction Worker Safety.” *Journal of Architectural Engineering*, 4(3), 107-112.

Gambatese, J. A. (2000). “Safety Constructability: Designer Involvement in Construction Site Safety.” *Building Together for a Better Tomorrow in an Increasingly Complex World*, Orlando, FL.

Gambatese, J. A. (2004). “An Overview of Design-for-Safety Tools and Technologies.” *Proceedings of the Designing for Safety and Health in Construction Research and Practice Symposium*, University of Oregon Press, Eugene, OR, 109-117.

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

Gambatese, J. A., Behm, M., and Hinze, J. W. (2005). "Viability of designing for construction worker safety." 131(9), 1029-1036.

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

Gambatese, J. A., and Hinze, J. W. (2003). "Engineer's role in Designing for Safety." Nashville, TN.

Gambatese, J. A., Hinze, J. W., and Haas, C. T. (1997). "Tool to design for constructon worker safety." *Journal of Architectural Engineering*, 3(1), 32-41.

Gambatese, J. A. (2000). "Owner Involvement in Construction Site Safety." *Construction Congress VI*, 661-670.

Gambatese, J. A., Behm, M., and Hinze, J. W. (2003). "Engineering Mandates Stipulated in OSHA Regulations." *Construction Research Congress*, Reston, Va.

Gangolells, M., Casals, M., Forcada, N., Roca, X., and Fuertes, A. (2010). "Mitigating construction safety risks using prevention through design." *Journal of Safety Research*, 41(2), 107–122.

Hallowell, M. R. (2008). "A formal model of construction safety and health risk management." Oregon State University, Oregon State.

Hallowell, M. R., and Gambatese, J. A. (2009a). "Construction safety risk mitigation." *Journal of Construction Engineering and Management*, 135, 1316.

Hallowell, M. R., and Gambatese, J. A. (2009b). "Activity-Based Safety Risk Quantification for Concrete Formwork Construction." *Journal of Construction Engineering and Management*, 135, 990.

Hallowell, M. R. (2009). "Techniques to minimize bias when using the delphi method to quantify construction safety and health risks." *2009 Construction Research Congress*.

Hallowell, M. R. (2010). "Safety Risk Perception in Construction companies in the Pacific Northwest of the USA." *Construction Management and Economics*, 28(4), 403.

Harvey, J., Bolam, H., and Gregory, D. (1999). "How many safety cultures are there?" *The Safety and Health Practitioner*, 17(12), 9-12.

Haslam, R. A., Hide, S. A., Gibb, A. G. F., Gyi, D. E., Pavitt, T., Atkinson, S., and Duff, A. R. (2003). "Contributing factors in construction accidents." *Applied Ergonomics*, 36(4), 401–415.

Hecker, S., Gambatese, J., and Weinstein, M. (2005). "Designing for Worker Safety: Moving the Construction Safety Process Upstream." *Safety,* 32.

Hecker, S., Gibbons, B., and Barsotti, A. (2001). "Making Ergonomic Changes In Construction." *Applied Ergonomics,* D. Alexander and R. Rabourn, London, 162-189.

Hinze, Coble, R. J., and Elliott, B. R. (1999). "Integrating Construction Worker Protection into Project Design." Balkema, Rotterdam.

Hinze, J. W. (1991). *A Study of Construction activity and procurement policies of major consumers of construction services*. Merit Shop Foundation, Washington, D.C.

Hinze, J. W. (1992). *A Study of Construction Activity and Procurement Policies of Major Consumers of Construction Services (Study 2)*. Merit Shop Foundation, Washington, D.C.

Hinze, J. W. (1994a). *A Study of the Construction Activity Projections for 1994*. Associated Builders and Contractors (ABC), Rosslyn, VA.

Hinze, J. W. (1994b). *A Study of the Construction Activity Projections for 1995*. Associated Builders and Contractors (ABC), Rosslyn, VA.

Hinze, J. W. (2006). *Construction Safety*. Pearson Education, Inc., FL.

Hinze, J. W., and Appelgate, L. L. (1991). "Costs of Construction Injuries." *Journal of Construction Engineering and Management*, 117(3), 537.

Hinze, J. W., and Figone, L. (1988). *Subcontractor safety as influenced by general contractors on small and medium sized projects*. The Construction Industry Institute, Austin, Texas.

Hinze, J. W., Mathis, J., Frey, P. D., Wilson, G., DeForge, P., Cobb, M., and Marconnet, G. (2001). "Making Zero Accidents a Reality." San Francisco, CA.

Hinze, J. W., and Talley, D. (1988). *Subcontractor safety as influenced by general contractors on large projects*. The Construction Industry Institute, Austin, Texas.

Hinze, J. W. (2000). "Designing for the Lifecycle Safety of Facilities." 121-127.

Hinze, J. W., and Gambatese, J. A. (2003). “Factors that influence safety performance of specialty contractors.” *Journal of construction engineering and management*, 129, 159.

Hinze, J. W., and Tracy, A. (1994). “The Contractor-Subcontractor relationships: the subcontractor’s view.” *Journal of Construction Engineering and Management*, 120(2), 274-287.

Hinze, J. W., and Wiegand, F. (1992). “Role of designers in construction worker safety.” *Journal of Construction Engineering and Management*, 118(4), 677.

Huang, X., and Hinze, J. W. (2006). “Owner’s role in construction safety.” *Journal of construction engineering and management*, 132, 164.

Imriyas, K., Pheng, L., and Lin, T. (2007). “A Decision Support System for Predicting Accident Risks in Building Projects.” *Architectural Science Review*, 50(2), 149-162.

Jannadi, O. A., and Almishari, S. (2003). “Risk assessment in construction.” *Journal of construction engineering and management*, 129, 492.

Jeffrey, J., and Douglas, I. (1994). “Safety Performance of the United Kingdom Construction Industry.” *Fifth Annual Rinker International Conference*, Gainesville, Florida.

Koel, L. (2005). *Concrete Formwork*. Third Edition, American Technical Publishers.

Knab, L. (1978). “Numerical Aid to Reduce Construction Injury Losses.” *Journal of Construction Division*, 104(CO4), 437445.

Lam, P. T. I., Wong, F. W. H., and Chan, A. P. C. (2006). “Contributions of designers to improving buildability and constructability.” *Design Studies*, 27(4), 457–479.

Lee, S., and Haplin, W. (2003). “Predictive tool for estimating accident risk.” *Journal of Construction Engineering and Management*, 129, 431.

Lee, T. (1998). “Assessment of safety culture at a nuclear reprocessing plant.” *Work and Safety*, 12(3), 217-237.

Levitt, R. E., and Samelson, N. M. (1982). “Owners’ Guidelines for Selecting Safe Contractors.” *ASCE Journal of the Construction Division*, 108(CO4), 617-623.

Levitt, R. E., and Samelson, N. M. (1993). *Construction Safety Management*. John Wiley & Sons, New York.

Lohr, S.L. (1999). *Sampling: Design and Analysis*. Pacific Grove CA: Brooks/Cole Publishing Company.

Lorent, P. (1991). "From drawing board to building site: Working conditions, quality and economic performance." Office of Official Publications of the European Community, Luxembourg.

MacCollum, D. V. (1995). *Construction Safety Planning*. John Wiley & Sons, USA.

MacKenzie, J., Gibb, A. G., and Bouchlaghem, N. M. (2000). "Communication: The key to designing safely." *CIB Working Commission W99 and the European Construction Institute (ECI)*, London, 77-84.

Manuele, F. A. (2008). "Prevention through Design: Addressing occupational risks in the design and redesign processes." *Professional Safety*, 888, 28.

McDonald, N., Corrigan, S., Daly, C., and Cromie, S. (2000). "Safety management systems and safety culture in aircraft maintenance organizations." *Safety Science*, 34(1), 151-176.

Mehta, M., Armpriest, D., and Scarborough, W. (2010) *Building Construction: Principles, materials, and systems*. Fourth edition, Prentice Hall.

Mitropoulos, P., and Guillama, V. (2010). "Analysis of Residential Framing Accidents, Activities, and Task Demands." *Journal of Construction Engineering and Management*, 136, 260.

Mroszczyk, J. W. (2006). "Designing for Construction Worker Safety." *American Society of Safety Engineers*, 5(3), 3.

NSC. (2010). *Injury Facts*. National Safety Council, Itasca, IL.

OSHA. (2010). *Occupational Health and Safety Website*. Accessed December 2010.

Rajendran, S. (2006). "Sustainable Construction Safety and Health Rating System." Oregon State University, Oregon.

Rea, L. M., and Parker, R. A. (1997). *Designing and conducting survey research: A comprehensive guide*. San Francisco.

RS Means. (2011). *Building Construction Cost Data*. RS Means Co., Kingston, MA, USA.

Sillars, D. (2009). "Risk Management in Construction." Corvallis, Oregon, OSU.

Smallwood, J. (1996). "The Influence of Designers On Occupational Safety And Health. *Implementation of Safety and Health on Construction Sites*, Lisbon, Portugal.

Szymberski, R. (1997). "Construction Project Safety Planning." *TAPPI Journal*, 80(11), 69-74.

The R Development Core Team (2009). *R: A language and Environment for Statistical Computing*. Retrieved from http://www.R-project.org.

NOHSC. (2004). "The Role of Design Issues in Work Related Injuries in Australia 1997-2002." NOHSC, Canberra, Australia.

Toole, T. M. (2002). "Comparison of Site Safety Policies of Construction Industry Trade Groups." *Practice Periodical on Structural Design and Construction*, 7(2), 90-95.

Toole, T. M. (2005a). "A New Era for Engineers and Construction Safety."

Toole, T. M. (2005b). "Increasing Engineers' Role in Construction Safety: Opportunities and Barriers." *Journal of Professional Issues in Engineering Education and Practice*, 131, 199.

Toole, T. M. (2007). "Design Engineers' Responses to Safety Situations." *Journal of Professional Issues in Engineering Education and Practice*, 133, 126.

Toole, T. M., and Gambatese, J. A. (2002). "Primer on Federal Occupational Safety and Health Administration Standards." *Primer on Federal Occupational Safety and Health Administration Standards*, 7(2), 56-60.

Waehrer, G. M., Dong, X. S., Miller, T., Haile, E., and Men, Y. (2007). "Costs of occupational injuries in construction in the United States." *Accident Analysis & Prevention*, 39(6), 1258–1266.

Weinstein, M., Gambatese, J. A., and Hecker, S. (2005). "Can Design Improve Construction Safety?: Assessing the Impact of a Collaborative Safety-in-Design Process." *Journal of Construction Engineering and Management*, 131(10), 1125-1134.

Zohar, D. (2000). "A group-level model of safety climate: testing the effect of group climate on micro-accidents in manufacturing jobs." *Journal of Applied Psychology*, 85(4), 587-596.

APPENDIX

Appendix A: Sample E-mail

Dear Sir/Madam:

OSU Construction Engineering Management is conducting a research study to develop a design rating system (similar to a LEED rating system).

To develop the rating system, we need inputs from superintendents and/ or safety personnel in different general contracting and trade contracting firms. We would very much appreciate getting your input for the study by completing the attached questionnaire. The questionnaire requires input about the safety risks associated with constructing different design features. The input that you will provide will remain confidential and will only be used for aggregated statistical analysis.

We would appreciate your contribution and at the end of the study, we would be glad to provide you the results. We believe the rating system will be a useful tool for architects and engineers to make projects safer to construct.

If you have any questions, please do not hesitate to contact me or my advisor, John Gambatese, at:

Vineeth Dharmapalan
M.S. Candidate
Construction Engineering Management
Dept. of Civil, Construction and
Environmental Engineering
Oregon State University
dharmapv@engr.orst.edu
Ph.: 205-239-1637

John Gambatese, Ph.D., P.E.
Associate Professor
Construction Engineering Management
Dept. of Civil, Construction and
Environmental Engineering
Oregon State University
john.gambatese@oregonstate.edu
Ph.: 541-737-8913;
Fax: 541-737-3052;

Sincerely,

Mr. Vineeth Dharmapalan

Appendix B: Sample Instruction page of Questionnaires

DESIGN FOR CONSTRUCTION SAFETY RISK ASSESSMENT QUESTIONNAIRE

The purpose of this study is to assess the safety risk of constructing different design features. The scope of the study is limited to multistory commercial office buildings (**five stories and above**).

INSTRUCTIONS: PLEASE READ

This questionnaire focuses on the different types of '**system/component name'** used on commercial office buildings (e.g. design feature/ design element name). It addresses major construction activities that are performed to construct each design feature. The fields that require a response have been highlighted.

Steps for completing the questionnaire:

1. Based on your construction knowledge and experience, please check if the listed activities are commonly performed when constructing the design feature. Modify the list (e.g., combine or expand activities) or add additional activities in the spaces provided at the bottom of the table wherever applicable.
2. For the 'Activity Exposure' field, please indicate the percentage of time spent on each activity during the construction of the design feature. The different percentage values may add up to more than 100%.
3. For the 'Injury Severity Level' field, using your experience and judgment, rate 'how frequently an injury occurs at each severity level while performing each construction activity'. Use the following frequency scale for filling in your responses:

Frequency Scale: Average amount of time between incidents										
Impossible	**Negligible**	**50 years**	**10 years**	**5 years**	**1 year**	**6 months**	**1 month**	**1 week**	**1 day**	**1 hr**
0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

The definitions of the severity levels are given as follows:

Severity	Description**
Near Miss	Incident that does not result in harm to the worker (No impact on work time)
Low Severity	Incident that results in pain, discomfort, or requires first aid treatment (worker returns to regular work within 1 day)
Medium Severity	Incident that results in lost work time or hospitalized injury (worker does not return to regular work within 1 day)
High Severity	Incident that results in permanent disablement or death (worker does not return to work at all)

NOTE: **An incident refers to a worker may or may not getting injured while working to construct the design element, i.e., direct interface with the design element during all phases of its construction.

DEMOGRAPHIC INFORMATION:

Company Type	☐ **General contractor**	☐ **Trade Contractor**
Your Position/Title		
No. of years of construction experience		
Type of work experience		

Appendix C: Survey Questionnaires

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **STEEL PILES**							
TYPE : **STEEL H-PILES**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.35	**Loading, hoisting, placing, plumbing the steel H-pile from crane**	whole process of vertically aligning the H-pile for the driving operation	6.6E-04	7.6E-03	1.1E-02	1.3E-01
2	0.65	**Driving steel H-pile using hammer**	the whole process of H-pile driving using the hammer that is applicable	6.6E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **STEEL PILES**							
TYPE : **STEEL PIPE PILES**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Loading, hoisting, placing, plumbing the steel pipe pile from crane**	whole process of vertically aligning the pipe pile for the driving operation	4.4E-04	4.5E-03	7.0E-03	1.3E-01
2	0.60	**Driving steel pipe pile using hammer**	the whole process of pipe pile driving using the hammer that is applicable	4.4E-04	4.5E-03	7.0E-03	1.3E-01
3	0.15	**Removal of soil, cleaning of pipe before concreting**	open pipe pile requires removal of soil, cleaning before being filled with concrete	4.4E-04	1.5E-03	7.0E-03	1.3E-01
4	0.10	**Pouring concrete inside pipe piles**	Concreting work of pipe piles	4.4E-04	4.5E-03	7.0E-03	6.3E-02
5	0.05	**Insertion of dowels for pile cap reinforcement connection**	Steel dowels are placed before finishing the fresh concrete at the top for connecting to pile cap	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **PRECAST CONCRETE PILES**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.21	**Loading, hoisting, placing, plumbing the precast pile from crane**	whole process of vertically aligning the precast pile for the driving operation	6.6E-04	7.6E-03	1.1E-02	3.8E-01
2	0.61	**Driving precast concrete pile using hammer**	the whole process of precast pile driving using the hammer applicable	6.6E-04	1.5E-03	7.0E-03	1.3E-01
3	0.19	**Cutting of precast pile top for pile cap reinforcement connection**	Removal of concrete at top to expose rebar for connecting to pile cap	6.6E-04	7.6E-03	1.1E-02	1.3E-01

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **CONCRETE PILES**							
TYPE : **BORED CONCRETE PILES**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.40	**Drilling of hole for pile**	hole is drilled using auger	4.4E-04	4.5E-03	7.0E-03	6.3E-02
2	0.20	**Insertion of casing for pile**	a temporary steel pipe is inserted in the bore hole	6.6E-04	1.5E-03	7.0E-03	6.3E-02
3	0.18	**Insertion of reinforcement cage**	Rebar cage is assembled, hoisted and lowered into the bored hole	8.8E-04	7.6E-03	1.1E-02	6.3E-02
4	0.18	**Concreting of pile and removal of steel casing**	Concrete is poured in the bored hole and the steel pipe is withdrawn simultaneously	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.10	**Insertion of dowels for pile cap reinforcement connection**	Steel dowels are placed before finishing the fresh concrete at the top for connecting to pile cap	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **CONCRETE PILES**							
TYPE : **DRIVEN CONCRETE PILES**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.45	**Driving of steel casing into the ground using hammer**	a permanent steel pipe is driven using hammer	6.6E-04	1.5E-03	7.0E-03	6.3E-02
2	0.20	**Insertion of reinforcement cage**	Rebar cage is assembled, hoisted and lowered into the driven steel casing	8.8E-04	7.6E-03	4.2E-03	0.0E+00
3	0.20	**Concreting of pile**	Concrete is poured into the steel casing	4.4E-04	7.6E-03	7.0E-03	6.3E-02
4	0.15	**Insertion of dowels for pile cap reinforcement connection**	Steel dowels are placed before finishing the fresh concrete at the top for connecting to pile cap	2.7E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **PILE CAP**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.30	**Formwork construction for pile cap**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling formwork	8.8E-04	1.5E-02	4.2E-02	6.3E-02
2	0.25	**Reinforcement work for pile cap**	Placement and tying of rebar in pile cap, vertical dowels of columns using tie wires	4.4E-04	7.6E-03	1.4E-02	1.3E-01
3	0.20	**Concreting of pile cap**	concrete is poured using pumps/ buckets and compacted using vibrators	4.4E-04	7.6E-03	7.0E-03	6.3E-02
4	0.05	**Insertion of dowels/ anchor bolts for superstructure**	steel dowels/ steel anchor bolts are placed before finishing the fresh concrete at the top	4.4E-04	4.5E-03	1.4E-03	0.0E+00
5	0.15	**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength	8.8E-04	1.1E-02	4.2E-02	1.3E-01
6	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **DRILLED SHAFT/ DRILLED PIER FOUNDATION**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.30	**Drilling operation**	drilling hole using rotary drilling equipment such as auger drill	4.4E-04	7.6E-03	7.0E-03	0.0E+00
2	0.20	**Insertion of steel casing**	temporary/ permanent steel casing is sometimes inserted depending on the soil type	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Drilling with slurry**	bentonite slurry is sometimes used depending on the soil type	8.8E-04	1.5E-03	7.0E-03	0.0E+00
4	0.15	**Insertion of rebar cage**	rebar cage is assembled, hoisted and lowered into the drilled hole	8.8E-04	7.6E-03	1.4E-02	0.0E+00
5	0.15	**Concreting of caisson**	concrete is poured into the caisson and steel casing(if temporary) is withdrawn	8.8E-04	7.6E-03	7.0E-03	0.0E+00
6	0.05	**Insertion of dowels/ anchor bolts for superstructure**	steel dowels/ steel anchor bolts are placed before finishing the fresh concrete at the top	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **DRILLED CAISSON**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.30	**Drilling operation**	drilling hole using rotary drilling equipment such as auger drill	4.4E-04	7.6E-03	7.0E-03	0.0E+00
2	0.20	**Insertion of steel casing**	temporary/ permanent steel casing is sometimes inserted depending on the soil type	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Drilling with slurry**	bentonite slurry is sometimes used depending on the soil type	8.8E-04	1.5E-03	7.0E-03	0.0E+00
4	0.15	**Insertion of rebar cage**	rebar cage is assembled, hoisted and lowered into the drilled hole	8.8E-04	7.6E-03	1.4E-02	0.0E+00
5	0.15	**Concreting of caisson**	concrete is poured into the caisson and steel casing(if temporary) is withdrawn	8.8E-04	7.6E-03	7.0E-03	0.0E+00
6	0.05	**Insertion of dowels/ anchor bolts for superstructure**	steel dowels/ steel anchor bolts are placed before finishing the fresh concrete at the top	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**

DESIGN FEATURE/ ELEMENT: **ISOLATED COLUMN FOOTING/ SPREAD FOOTING**

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	INJURY SEVERITY LEVEL			
				Near Miss	Low Severity	Medium Severity	High Severity
1	0.20	**Excavation work for spread footing**	Excavation process for spread footing	4.4E-04	4.5E-03	7.0E-03	0.0E+00
2	0.28	**Formwork construction of isolated column footing**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling formwork	8.8E-04	1.5E-02	7.0E-02	0.0E+00
3	0.20	**Reinforcement work of isolated column footing**	placement and tying of top, bottom rebar in footing, vertical dowels of columns using tie wires	6.6E-04	7.6E-03	7.0E-03	0.0E+00
4	0.13	**Concreting of footing**	concrete is poured using pumps/ buckets, compacted using vibrators, and surface-finished; anchor bolts(for steel columns) are inserted in fresh concrete	8.8E-04	7.6E-03	1.1E-02	0.0E+00
5	0.15	**Stripping of formwork**	stripping of the footing formwork after it gains sufficient strength	8.8E-04	1.5E-02	4.2E-02	0.0E+00
6	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast footing such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **MAT FOUNDATION**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Excavation work for mat foundation**	Excavation process for mat foundation	4.4E-04	7.6E-03	1.1E-02	6.3E-02
2	0.20	**Formwork construction for mat foundation**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling formwork	8.8E-04	1.1E-02	4.2E-02	1.3E-01
3	0.28	**Reinforcement work for foundation mat**	Hoisting, placement, connection of mat foundation rebar, vertical dowels for columns using tie wires	3.1E-03	7.6E-03	4.2E-02	1.3E-01
4	0.23	**Concreting of mat foundation**	concrete is continuously poured using pumps, compacted using vibrators, and surface-finished; anchor bolts(for steel columns) are inserted in fresh concrete	8.8E-04	7.6E-03	7.0E-02	1.3E-01
5	0.10	**Stripping of mat footing formwork**	stripping of the footing formwork after it gains sufficient strength	8.8E-04	7.6E-03	1.4E-02	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**

DESIGN FEATURE/ ELEMENT: **WALL/ STRIP FOOTING**

ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Excavation work for strip footing**	Excavation process for wall footing	4.4E-04	4.5E-03	1.1E-02	0.0E+00
2	0.30	**Formwork construction of wall footing**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling formwork	8.8E-04	1.5E-02	7.0E-02	6.3E-02
3	0.20	**Reinforcement work of wall footing**	placement and tying of top, bottom rebar in footing, vertical rebars of wall using tie wires	8.8E-04	1.5E-02	4.2E-02	0.0E+00
4	0.10	**Concreting of wall footing**	concrete is poured using pumps, compacted using vibrators, and surface-finished	6.6E-04	7.6E-03	4.2E-02	6.3E-02
5	0.15	**Stripping of wall footing formwork**	stripping of the wall footing formwork after it gains sufficient strength	8.8E-04	1.5E-02	4.2E-02	6.3E-02
6	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast footing such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FOOTINGS AND FOUNDATIONS**							
DESIGN FEATURE/ ELEMENT: **SLAB ON GRADE**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Laying and compaction of crushed stone**	¾ inch. dia. crushed stone at least 4" deep is laid and compacted over the subsoil	4.4E-04	4.5E-03	7.0E-03	0.0E+00
2	0.25	**Formwork construction for slab**	installation of edge forms using stakes; application of form release compound	8.8E-04	7.6E-03	7.0E-03	0.0E+00
3	0.10	**Laying moisture barrier**	water-proof membrane is laid over the crushed stone layer	4.4E-04	4.5E-03	4.2E-03	0.0E+00
4	0.20	**Reinforcement work for slab**	rebar/ welded wire reinforcement is installed over high chairs	8.8E-04	1.1E-02	1.4E-02	0.0E+00
5	0.25	**Concreting and finishing of slab**	concrete is poured using pumps/ chute/ bucket, compacted using vibrators, and surface-finished	6.6E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **COLUMNS**							
DESIGN FEATURE/ ELEMENT: **CAST IN PLACE CONCRETE SQUARE COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low severity**	**Medium severity**	**High severity**
1	0.15	**Connection of foundation dowels with column rebar**	hoisting of column reinforcement cage over foundation dowels, overlapping/ splicing and tying of the vertical rebar of columns and foundation dowels	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.30	**Formwork construction for columns**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity	8.8E-04	7.6E-03	7.0E-02	1.3E-01
3	0.20	**Pouring of concrete for columns**	concrete is poured using pumps/ buckets and consolidated using vibrators	8.8E-04	7.6E-03	7.0E-02	1.3E-01
4	0.25	**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength	8.8E-04	1.5E-02	7.0E-02	1.3E-01
5	0.10	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **COLUMNS**							
DESIGN FEATURE/ ELEMENT: **CAST IN PLACE CONCRETE ROUND COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low severity**	**Medium severity**	**High severity**
1	0.15	**Connection of foundation dowels with column rebar**	hoisting of column reinforcement cage over foundation dowels, overlapping/ splicing and tying of the vertical rebar of columns and foundation dowels	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.30	**Formwork construction for columns**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity	8.8E-04	1.1E-02	7.0E-02	1.3E-01
3	0.20	**Pouring of concrete for columns**	concrete is poured using pumps/ buckets and consolidated using vibrators	8.8E-04	7.6E-03	7.0E-02	1.3E-01
4	0.25	**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength	3.1E-03	1.5E-02	7.0E-02	1.3E-01
5	0.10	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **COLUMNS**							
DESIGN FEATURE/ ELEMENT: **STRUCTURAL STEEL COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Offload truck**	offloading steel columns from truck	8.8E-04	7.6E-03	1.4E-02	6.3E-01
2	0.15	**Shake out steel columns**	shaking out steel column sections	8.8E-04	7.6E-03	1.4E-02	6.3E-01
3	0.10	**Loading the column section from crane**	manually loading the crane with steel column sections that are going to be lifted for placement	8.8E-04	1.5E-03	7.0E-03	1.3E-01
4	0.10	**Hoisting of column section using crane**	lifting and lowering of the steel column sections by the crane operator as directed by workers	8.8E-04	1.5E-03	7.0E-03	1.3E-01
5	0.20	**Accepting, guiding and placing of column section from crane**	workers physically accept, guide and place the column section from the crane on the protruding anchor bolts as it is being lowered	5.3E-03	7.6E-03	1.4E-02	6.3E-01
6	0.10	**Checking plumb and leveling**	leveling of the column sections using leveling nuts below the base plate or adjusting the plastic shims below the base plate/ leveling plate	8.9E-05	7.6E-04	1.4E-03	0.0E+00
7	0.10	**Anchoring the column section with foundation**	tightening of anchor bolts, grouting of space between the bottom of the base plate and top of the footing	4.4E-04	7.6E-04	1.4E-03	0.0E+00
8	0.15	**Splicing of column sections for the subsequent tiers**	hoisting of column sections into position and connecting using splice plates to the previous tier columns	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **COLUMNS**							
DESIGN FEATURE/ ELEMENT: **BUILT-UP STEEL COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Offload truck**	offloading built-up steel columns from truck	8.8E-04	7.6E-03	1.4E-02	6.3E-01
2	0.20	**Shake out built-up steel columns**	shaking out built-up steel column sections	5.3E-03	7.6E-03	1.4E-02	6.3E-01
3	0.10	**Loading the built-up column section from crane**	manually loading the crane with built-up column sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	1.3E-01
4	0.15	**Hoisting of built-up column section using crane**	lifting and lowering of the built-up column sections by the crane operator as directed by workers	5.3E-03	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Accepting, guiding and placing of built-up column section from crane**	workers physically accept, guide and place the built-up column section from the crane on the protruding anchor bolts as it is being lowered	5.3E-03	7.6E-03	1.4E-02	6.3E-01
6	0.10	**Checking plumb and leveling**	leveling of the built-up column sections using leveling nuts below the base plate or adjusting the plastic shims below the base plate/ leveling plate	8.9E-05	1.5E-03	1.4E-03	0.0E+00
7	0.10	**Anchoring the built-up column section with foundation**	tightening of anchor bolts, grouting of space between the bottom of the base plate and top of the footing	4.4E-04	1.5E-03	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **COLUMNS**							
DESIGN FEATURE/ ELEMENT: **PRECAST CONCRETE COLUMNS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading the column section from crane**	manually loading the crane with precast column sections that are going to be lifted for placement	4.4E-04	4.5E-03	7.0E-03	1.3E-01
2	0.15	**Hoisting of column section using crane**	lifting and lowering of the precast column sections by the crane operator as directed by workers	8.8E-04	7.6E-03	7.0E-03	1.3E-01
3	0.25	**Accepting guiding and placing of column section from crane**	workers physically accept, guide and place the precast column section from the crane on the protruding anchor bolts as it is being lowered	3.1E-03	7.6E-03	1.1E-02	3.8E-01
4	0.15	**Plumb, leveling and connecting column section with foundation**	making connections using washers, nuts after the sections are leveled and plumbed	4.4E-04	1.5E-03	7.0E-03	1.3E-01
5	0.15	**Grouting of space between column section and footing**	the gap between the column section and footing is dry packed using a stiff grout	2.7E-04	1.1E-03	1.4E-03	6.3E-02
6	0.20	**Splicing of precast column sections for the subsequent tiers**	hoisting of column sections into position and connecting using shims, washers and nuts to the previous tier columns. The gap between the column sections is dry packed using a stiff grout	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **SHEAR WALLS**							
DESIGN FEATURE/ ELEMENT: **CAST IN PLACE CONCRETE WALLS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low severity**	**Medium severity**	**High severity**
1	0.15	**Connection of foundation dowels with wall reinforcement**	overlapping/ splicing and tying of the rebar of walls and foundation dowels	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.35	**Formwork construction for walls**	cutting, lubricating, hoisting, placing, bracing, connecting and leveling are some of the sub-activities performed during this activity	8.8E-04	1.5E-02	7.0E-02	1.3E-01
3	0.20	**Pouring of concrete for walls**	concrete is poured using pumps/ buckets and consolidated using vibrators	8.8E-04	1.5E-02	1.4E-02	6.3E-01
4	0.25	**Stripping of formwork**	stripping of the column formwork after it gains sufficient strength	8.8E-04	1.5E-02	1.4E-02	1.3E-01
5	0.10	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast walls such as honey-combing or segregation using mortar	4.4E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **FLOOR FRAME BEAMS**							
DESIGN FEATURE/ ELEMENT: **STRUCTURAL STEEL BEAMS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.05	**Offload truck**	Offloading of steel beams from truck	8.8E-04	7.6E-03	7.0E-02	6.3E-01
2	0.10	**Shake out steel beams**	Shaking out of steel beam sections	5.3E-03	1.5E-02	1.4E-02	1.3E-01
3	0.05	**Loading beam sections from crane**	manually loading the crane with steel beam sections that are going to be lifted for placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01
4	0.10	**Lifting and lowering of beam sections from crane**	lifting and lowering of the steel beam sections by the crane operator as directed by workers	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Accepting, guiding, aligning and placing of beam sections from crane**	workers accept and guide the beam sections from the crane initially using a tagline and then physically. The placement and alignment of the beam section may involve workers using crowbars, hammers, drift pins, etc	5.3E-03	7.6E-03	1.4E-02	6.3E-01
6	0.15	**Making connections (beam-to-beam and beam-to-column)**	insertion and partial tightening of bolts to hold the sections together temporarily. The primary beams are connected with the column while the secondary beams are connected with the primary beams	5.3E-03	1.5E-02	1.4E-02	6.3E-01
7	0.10	**Checking plumb and leveling**	on-going activity throughout the process using diagonal cables and turnbuckles, plumb bobs, transits, etc	4.4E-04	1.5E-03	7.0E-03	1.3E-01
8	0.15	**Tightening connections/ welding**	tightening of bolts (if bolted connection)	8.8E-04	7.6E-03	7.0E-03	1.3E-01
			welding (if welded connection)	8.8E-04	7.6E-03	7.0E-03	1.3E-01
9	0.10	**Bracing of floor and roof frames**	installing K-brace (for heavy loading) or eccentric K-brace (for seismic) in between floor fames and/or roof frames	8.8E-04	7.6E-03	1.4E-02	6.3E-01

SYSTEM/ COMPONENT : **FLOOR FRAME BEAMS**

DESIGN FEATURE/ ELEMENT: **PLATE GIRDERS/ BUILT-UP GIRDERS**

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	INJURY SEVERITY LEVEL			
				Near Miss	Low Severity	Medium Severity	High Severity
1	0.05	**Offload truck**	Offloading of girder sections from truck	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.10	**Shake out girders**	Shaking out of girder sections	5.3E-03	1.5E-02	1.4E-02	1.3E-01
3	0.05	**Loading girder sections from crane**	manually loading the crane with steel girder sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	1.3E-01
4	0.10	**Lifting and lowering of girder sections from crane**	lifting and lowering of the girder sections by the crane operator as directed by workers	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Accepting, guiding, aligning and placing of girder sections from crane**	workers accept and guide the girder sections from the crane initially using a tagline and then physically. The placement and alignment of the girder section may involve workers using crowbars, hammers, drift pins, etc	8.8E-04	7.6E-03	1.4E-02	1.3E-01
6	0.15	**Making connections (girder-to-column)**	insertion and partial tightening of bolts to hold the sections together temporarily.	5.3E-03	7.6E-03	1.4E-02	1.3E-01
7	0.10	**Checking plumb and leveling**	on-going activity throughout the process using diagonal cables and turnbuckles, plumb bobs, transits, etc	4.4E-04	1.5E-03	7.0E-03	0.0E+00
8	0.15	**Tightening connections/ welding**	tightening of bolts (if bolted connection)	8.8E-04	7.6E-03	7.0E-03	1.3E-01
			Welding (if welded connection)	8.8E-04	7.6E-03	7.0E-03	1.3E-01
9	0.10	**Bracing of floor and roof frames**	installing K-brace (for heavy loading) or eccentric K-brace (for seismic) in between floor fames and/or roof frames	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **MONOLITHIC FRAME AND FLOOR SLABS**							
DESIGN FEATURE/ ELEMENT: **ONE WAY SOLID SLAB**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Formwork construction for beams/ girders**	beam/ girder forms are cut, lubricated, hoisted, placed, braced, connected, shored and leveled	5.3E-03	1.1E-02	4.2E-02	1.3E-01
2	0.20	**Formwork construction for slabs**	slab bottom and edge(perimeter) forms are cut, lubricated, erected, connected, and shored	8.8E-04	7.6E-03	4.2E-02	1.3E-01
3	0.10	**Installation of beam/ girder reinforcement**	top, bottom bars and stirrups in beams/ girders are installed	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.10	**Installation of slab reinforcement**	top, bottom, shrinkage-temperature bars are placed using bolsters	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.10	**Pouring of concrete for beams and slab**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	4.2E-02	1.3E-01
6	0.10	**Finishing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.15	**Stripping of formwork**	stripping of the beam and slab formwork including pans/domes after they gain sufficient strength	3.1E-03	1.5E-02	7.0E-02	1.3E-01
8	0.08	**Re-shoring of cast slabs and beams**	the beams and slabs are re-shored using vertical props	8.8E-04	7.6E-03	1.4E-02	1.3E-01
9	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	4.5E-03	1.1E-02	6.3E-02

SYSTEM/ COMPONENT : **MONOLITHIC FRAME AND FLOOR SLABS**							
DESIGN FEATURE/ ELEMENT: **TWO WAY SOLID SLAB**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Formwork construction for beams/ girders**	beam/ girder forms are cut, lubricated, hoisted, placed, braced, connected, shored and leveled	5.3E-03	1.1E-02	4.2E-02	1.3E-01
2	0.20	**Formwork construction for slabs**	slab bottom and edge(perimeter) forms are cut, lubricated, erected, connected, and shored	8.8E-04	7.6E-03	4.2E-02	1.3E-01
3	0.10	**Installation of beam/ girder reinforcement**	top, bottom bars and stirrups in beams/ girders are installed	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.10	**Installation of slab reinforcement**	top, bottom, shrinkage-temperature bars are placed using bolsters	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.10	**Pouring of concrete for beams and slab**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	4.2E-02	1.3E-01
6	0.10	**Finishing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.15	**Stripping of formwork**	stripping of the beam and slab formwork including pans/domes after they gain sufficient strength	3.1E-03	1.5E-02	7.0E-02	1.3E-01
8	0.08	**Re-shoring of cast slabs and beams**	the beams and slabs are re-shored using vertical props	8.8E-04	7.6E-03	1.4E-02	1.3E-01
9	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	4.5E-03	1.1E-02	6.3E-02

SYSTEM/ COMPONENT : **MONOLITHIC FRAME AND FLOOR SLABS**							
DESIGN FEATURE/ ELEMENT: **FLAT PLATE SLAB**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Formwork construction for slabs**	slab bottom and edge(perimeter) forms are cut, lubricated, erected, connected, and shored	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.20	**Installation of slab reinforcement**	top, bottom, shrinkage-temperature bars are placed using bolsters	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.10	**Pouring of concrete for slab**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.10	**Finishing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	4.4E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Stripping of formwork**	stripping of the beam and slab formwork including pans/domes after they gain sufficient strength	8.8E-04	1.5E-02	1.4E-02	1.3E-01
6	0.10	**Re-shoring of cast slabs**	the beams and slabs are re-shored using vertical props	4.4E-04	1.5E-03	7.0E-03	1.3E-01
7	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **MONOLITHIC FRAME AND FLOOR SLABS**							
DESIGN FEATURE/ ELEMENT: **ONE WAY JOIST FLOOR SLAB**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Formwork construction for beams/ girders**	beam/ girder forms are cut, lubricated, hoisted, placed, braced, connected, shored and leveled	5.3E-03	1.5E-02	1.4E-02	1.3E-01
2	0.15	**Placing flat form deck for one way/ two way joist floor slab**	flat form deck is installed for supporting the pans or domes. It involves cutting, erection, connection and shoring of the decks	5.3E-03	1.5E-02	1.4E-02	1.3E-01
3	0.15	**Placing U-shaped pans (for one way joist slab) or domes (for two way joist slab) over the flat form deck**	U-shaped pans or domes are manually placed over the flat form deck	8.8E-04	1.5E-02	1.4E-02	1.3E-01
4	0.10	**Installation of beam/ girder reinforcement**	top, bottom bars and stirrups in beams/ girders are installed in the gaps between the pans/ domes	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.08	**Installation of slab reinforcement**	top, bottom, shrinkage-temperature bars are placed using bolsters on the top of the pans/ domes	8.8E-04	7.6E-03	1.4E-02	1.3E-01
6	0.07	**Pouring of concrete**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.07	**Finishing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	8.8E-04	7.6E-03	1.4E-02	1.3E-01
8	0.15	**Stripping of formwork**	stripping of the beam and slab formwork including pans/domes after they gain sufficient strength	5.3E-03	1.5E-02	7.0E-02	1.3E-01
9	0.06	**Re-shoring of cast slabs and beams**	the beams and slabs are re-shored using vertical props	4.4E-04	7.6E-03	7.0E-03	1.3E-01
10	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **MONOLITHIC FRAME AND FLOOR SLABS**							
DESIGN FEATURE/ ELEMENT: **TWO WAY JOIST FLOOR SLAB (WAFFLE SLAB)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Formwork construction for beams/ girders**	beam/ girder forms are cut, lubricated, hoisted, placed, braced, connected, shored and leveled	5.3E-03	1.5E-02	1.4E-02	1.3E-01
2	0.15	**Placing flat form deck for one way/ two way joist floor slab**	flat form deck is installed for supporting the pans or domes. It involves cutting, erection, connection and shoring of the decks	5.3E-03	1.5E-02	1.4E-02	1.3E-01
3	0.15	**Placing U-shaped pans (for one way joist slab) or domes (for two way joist slab) over the flat form deck**	U-shaped pans or domes are manually placed over the flat form deck	8.8E-04	1.5E-02	1.4E-02	1.3E-01
4	0.10	**Installation of beam/ girder reinforcement**	top, bottom bars and stirrups in beams/ girders are installed in the gaps between the pans/ domes	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.08	**Installation of slab reinforcement**	top, bottom, shrinkage-temperature bars are placed using bolsters on the top of the pans/ domes	8.8E-04	7.6E-03	1.4E-02	1.3E-01
6	0.07	**Pouring of concrete**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.07	**Finishing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	8.8E-04	7.6E-03	1.4E-02	1.3E-01
8	0.15	**Stripping of formwork**	stripping of the beam and slab formwork including pans/domes after they gain sufficient strength	5.3E-03	1.5E-02	7.0E-02	1.3E-01
9	0.06	**Re-shoring of cast slabs and beams**	the beams and slabs are re-shored using vertical props	4.4E-04	7.6E-03	7.0E-03	1.3E-01
10	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **FLOOR FRAME BEAMS**							
DESIGN FEATURE/ ELEMENT: **POST-TENSIONED BEAM AND SLAB**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Formwork construction for beams/ girders**	beam/ girder bottom forms are cut, lubricated, hoisted, placed, braced, connected, shored and leveled	5.3E-03	1.1E-02	1.4E-02	1.3E-01
2	0.20	**Formwork construction for slabs**	slab bottom forms and edge (perimeter) forms are cut, lubricated, erected, connected and shored	5.3E-03	7.6E-03	1.4E-02	1.3E-01
3	0.13	**Installation of reinforcement for beams including pre stressing tendons**	top, bottom bars and stirrups in beams/ girders are installed in the forms. Also the pre-stressing tendons are installed	8.8E-04	7.6E-03	1.1E-02	1.3E-01
4	0.11	**Installation of reinforcement for slab including pre stressing tendons**	top, bottom, shrinkage-temperature bars are placed using bolsters on the slab bottom forms. Also, the pre-stressing tendons are installed	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.10	**Pouring of concrete**	concreting work of beams and slabs is performed in a single operation using pumps, bucket and vibrators	8.8E-04	7.6E-03	1.1E-02	1.3E-01
6	0.05	**Finishing and curing operations**	striking off surface of concrete slab, smoothening of surface by floating operation	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.10	**Post-tensioning process**	stripping of edge forms, stressing of tendons in beams and/or slabs using hydraulic pump and jack, cutting of excess length of tendons and surface finishing	8.8E-04	7.6E-03	1.4E-02	1.3E-01
8	0.10	**Stripping of remaining formwork**	stripping of the beam and slab bottom formwork after it gains sufficient strength	3.1E-03	7.6E-03	4.2E-02	1.3E-01
9	0.05	**Re-shoring of cast beams and slabs**	beams and slabs are re-shored using vertical props	8.8E-04	7.6E-03	1.4E-02	1.3E-01
10	0.05	**Repair and patching work after stripping of formwork**	repairing of irregularities or defects in the cast columns such as honey-combing or segregation using mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **FLOOR FRAME BEAMS**							
DESIGN FEATURE/ ELEMENT: **PRECAST BEAMS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Loading the beam section from crane**	manually loading the crane with precast beam sections that are going to be lifted for placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.20	**Hoisting of beam section using crane**	lifting and lowering of the precast beam sections by the crane operator as directed by workers	4.4E-04	7.6E-03	1.4E-02	1.3E-01
3	0.35	**Accepting, guiding, placing, and connecting precast beam section from crane onto columns**	workers physically accept, guide and place the precast beam section from the crane on the bearing pads/ reinforcing bars of columns. These are then fastened together using weld plate/ weld angle connectors	5.3E-03	7.6E-03	1.4E-02	6.3E-01
4	0.20	**Post-tensioning beam-column connection**	post-tensioning process may be required at column-beam connections to make it continuous. This activity involves passing tendons from pocket in the top of one beam, through the column, to a pocket in the top of the other beam. The tendons are then stressed using jacks and the pockets are grouted	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.10	**Shoring of beams if required**	beams are sometimes shored using vertical props	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOOR FRAME SLABS**							
DESIGN FEATURE/ ELEMENT: **HOLLOW-CORE PLANK SLABS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading the slab section from crane**	manually loading the crane with precast slab sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	1.3E-01
2	0.10	**Hoisting of slab section from crane**	lifting and lowering of the precast slab sections by the crane operator as directed by workers	4.4E-04	7.6E-03	7.0E-03	1.3E-01
3	0.30	**Accepting guiding and placing of slab section from crane onto beams**	workers physically accept, guide and place the precast slab section from the crane on the bearing pads installed on the beams	5.3E-03	7.6E-03	1.4E-02	6.3E-01
4	0.10	**Reinforcement work in keyways and grouting operations for continuity**	reinforcing tie bars are inserted in the keyways between adjacent slab elements and grouted during this activity	8.8E-04	1.5E-03	7.0E-03	0.0E+00
5	0.10	**Welded wire reinforcement work over slabs**	installation of welded wire reinforcing fabric over the plank slabs	4.4E-04	1.5E-03	7.0E-03	1.3E-01
6	0.20	**Pouring of site cast concrete topping over slabs**	concreting of slab tops using pumps/bucket, vibrators; finishing operations such as striking off surface of concrete slab; smoothening of surface by floating operation	8.8E-04	7.6E-03	7.0E-03	1.3E-01
7	0.10	**Temporary shoring of slabs**	slabs are sometimes shored using vertical props	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOOR FRAME SLABS**							
DESIGN FEATURE/ ELEMENT: **CELLULAR DECKS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading the deck section from crane**	manually loading the crane with deck sections that are going to be lifted for placement	8.8E-04	1.5E-03	7.0E-03	1.3E-01
2	0.10	**Lifting and lowering of deck section from crane**	lifting and lowering of the deck sections by the crane operator as directed by workers	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.20	**Accepting, guiding, carrying of deck section to the point of placement**	workers accept, guide and carry the deck sections from the crane to the point of placement	5.3E-03	7.6E-03	1.4E-02	6.3E-01
4	0.10	**Anchoring of deck sections to the supporting elements**	spot welding the deck section with the underlying supporting elements (wide flange beam) or joist. Power actuated fasteners or screws may be used as an alternative for making the connections	8.8E-04	1.5E-03	7.0E-03	1.3E-01
5	0.10	**Lapping longitudinal edges of decks with screws**	lapping and screwing of longitudinal edges of the decks at intervals	4.4E-04	1.5E-03	7.0E-03	1.3E-01
6	0.10	**Laying reinforcement over the deck**	placement and tying of reinforcement (wire fabric or rebars) on the deck section	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.10	**Installation of pour stops and closure plates**	installation of a pour stop and closure plates near the edges of the floor deck to terminate the concrete pour	8.8E-04	7.6E-03	1.4E-02	1.3E-01
8	0.15	**Concreting pouring and finishing operations of the cellular deck**	pouring concrete over the reinforced deck section, the finishing and curing operations of the poured concrete	8.8E-04	7.6E-03	1.4E-02	1.3E-01
9	0.10	**Shoring of cast cellular deck**	erection of temporary shores used to support the weight of cast cellular deck if required	8.8E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **FLOOR FRAME SLABS**

DESIGN FEATURE/ ELEMENT: **COMPOSITE DECK**

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	INJURY SEVERITY LEVEL			
				Near Miss	Low Severity	Medium Severity	High Severity
1	0.05	**Loading the deck section from crane**	manually loading the crane with deck sections that are going to be lifted for placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.10	**Hoisting of deck section from crane**	lifting and lowering of the deck sections by the crane operator as directed by workers	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.20	**Accepting, guiding, carrying of deck section to the point of placement**	workers accept, guide and carry the deck sections from the crane to the point of placement	5.3E-03	7.6E-03	7.0E-02	6.3E-01
4	0.10	**Anchoring of deck sections to the supporting elements**	spot welding the deck section with the underlying supporting elements (wide flange beam) or joist using puddle welds. Power actuated fasteners or screws may be used as an alternative for making the connections	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.10	**Lapping longitudinal edges of decks with screws**	lapping and screwing of longitudinal edges of the decks at intervals	8.8E-04	7.6E-03	7.0E-03	1.3E-01
6	0.10	**Installation of shear studs over supporting beams**	shear studs (3/4 in. dia.) are installed for composite action of the deck and the beam	8.8E-04	7.6E-03	1.1E-02	1.3E-01
7	0.10	**Reinforcement work of composite decks**	placement and tying of reinforcement (wire fabric or rebars) on the deck section	8.8E-04	7.6E-03	7.0E-03	1.3E-01
8	0.10	**Installation of pour stops and closure plates**	installation of a pour stop and closure plates near the edges of the floor deck to terminate the concrete pour	8.8E-04	7.6E-03	1.4E-02	1.3E-01
9	0.15	**Concreting pouring and finishing operations of the composite deck**	pouring concrete over the reinforced deck section, the finishing and curing operations of the poured concrete	8.8E-04	7.6E-03	1.4E-02	0.0E+00
10	0.07	**Shoring of cast composite deck**	erection of temporary shores used to support the weight of cast composite deck if required	8.8E-04	7.6E-03	1.4E-02	0.0E+00

SYSTEM/ COMPONENT : **FLOOR FRAME SLABS**							
DESIGN FEATURE/ ELEMENT: **FORM DECKS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading the deck section from crane**	manually loading the crane with deck sections that are going to be lifted for placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.10	**Hoisting of deck section from crane**	lifting and lowering of the deck sections by the crane operator as directed by workers	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.20	**Accepting, guiding, carrying of deck section to the point of placement**	workers accept, guide and carry the deck sections from the crane physically to the point of placement	5.3E-03	7.6E-03	7.0E-02	6.3E-01
4	0.10	**Anchoring of deck sections to the supporting elements**	welding the deck section with the underlying supporting elements (wide flange beam) or joist using puddle welds. Power actuated fasteners or screws may be used as an alternative for making the connections	8.8E-04	1.5E-03	7.0E-03	1.3E-01
5	0.10	**Lapping longitudinal edges of decks with screws**	lapping and screwing of longitudinal edges of the decks at intervals	4.4E-04	7.6E-03	7.0E-03	1.3E-01
6	0.10	**Laying conventional reinforcement over deck**	placement and tying of conventional reinforcement on the deck section	8.8E-04	7.6E-03	1.4E-02	1.3E-01
7	0.10	**Installation of pour stops and closure plates**	installation of a pour stop and closure plates near the edges of the floor deck to terminate the concrete pour	8.8E-04	7.6E-03	1.4E-02	1.3E-01
8	0.15	**Concreting pouring and finishing operations of the composite deck**	pouring concrete over the reinforced deck section, the finishing and curing operations of the poured concrete	8.8E-04	7.6E-03	1.4E-02	0.0E+00
	0.10	**Shoring of cast form deck**	erection of temporary shores used to support the weight of cast form deck if required	8.8E-04	7.6E-03	1.4E-02	0.0E+00

SYSTEM/ COMPONENT : **ROOF FRAME SLABS**							
DESIGN FEATURE/ ELEMENT: **STEEL ROOF DECK**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading the deck section from crane**	manually loading the crane with deck sections that are going to be lifted for placement	8.8E-04	4.5E-03	7.0E-03	1.3E-01
2	0.15	**Hoisting of deck section from crane**	lifting and lowering of the deck sections by the crane operator as directed by workers	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.35	**Accepting, guiding, carrying of deck section to the point of placement**	workers accept, guide and carry the deck sections from the crane to the point of placement	5.3E-03	7.6E-03	7.0E-02	3.8E-01
4	0.23	**Anchoring of deck sections to the supporting elements**	welding the deck section with the underlying supporting elements (wide flange beam) or joist using puddle welds. Power actuated fasteners or screws may be used as an alternative for making the connections	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Lapping longitudinal edges of decks with screws**	lapping and screwing of longitudinal edges of the decks at intervals	8.8E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **ROOFING**							
DESIGN FEATURE/ ELEMENT: **LOW SLOPE (BUILT-UP ROOF MEMBRANE)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.20	**Mopping of bitumen**	application of bitumen using mops or a bitumen dispenser (large roofs). This process is repeated depending upon the number of felt layers (plies)	8.8E-04	7.6E-03	7.0E-02	1.3E-01
4	0.15	**Installation of felt layer over bitumen**	unrolling of the felt layers and pressing down using a squeegee. This process is repeated depending on the number of felt layers (plies)	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.10	**Application of flood coat of bitumen**	pouring of bitumen to form a coat to receive the aggregate cover. A bitumen dispenser is usually used for the purpose	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.05	**Laying stone aggregate cover**	the flood coat is covered with stone aggregate. This activity involves spreading of aggregate using shovels or aggregate spreader	4.4E-04	1.5E-03	7.0E-03	0.0E+00
6	0.10	**Installation of cap sheet layer**	cap sheet layer of mineral granules or metal foil is asphalt mopped	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOFING**							
DESIGN FEATURE/ ELEMENT: **LOW SLOPE (MODIFIED BITUMEN ROOF MEMBRANE)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.15	**Application of coating of modified bitumen**	applying a layer of modified bitumen over the cover board	8.8E-04	7.6E-03	7.0E-02	1.3E-01
4	0.20	**Installation of fiberglass and/or polyester reinforcement layer**	layer of fiberglass or polyester reinforcement or both are installed	8.8E-04	7.6E-03	1.4E-02	0.0E+00
5	0.15	**Application of coating of modified bitumen**	applying a layer of modified bitumen over the reinforcement layer	8.8E-04	7.6E-03	7.0E-02	1.3E-01
6	0.10	**Installation of cap sheet layer**	cap sheet layer of mineral granules or metal foil is asphalt mopped	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOFING**							
DESIGN FEATURE/ ELEMENT: **LOW SLOPE (SBS MODIFIED BITUMEN MEMBRANE)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.23	**Installation of base sheet of SBS**	hot mopping or screw attaching of base SBS modified sheets over the cover boards	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.22	**Installation of smooth surfaced SBS sheet over the base sheet**	2-ply or 3-ply of smooth surfaced SBS sheets are hot mopped using bitumen	5.3E-03	7.6E-03	1.4E-02	1.3E-01
5	0.15	**Installation of cap sheet layer**	SBS cap sheet of mineral granules or metal foil is asphalt mopped	5.3E-03	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOFING**							
DESIGN FEATURE/ ELEMENT: **LOW SLOPE (APP MODIFIED BITUMEN MEMBRANE)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.20	**Installation of APP base sheets**	screw attaching of base APP modified sheets over the cover boards	8.8E-04	7.6E-03	7.0E-03	0.0E+00
4	0.45	**Installation of APP modified bitumen cap sheet layer using propane torch**	simultaneous application of flame torch/ dragon wagon and unrolling and pressing of the APP cap sheets to the base sheet layer	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOFING**							
DESIGN FEATURE/ ELEMENT: **LOW SLOPE [SINGLE –PLY ROOF MEMBRANE (Fully adhered system)]**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.25	**Application of adhesive on the underside of the membrane**	manufacturer-provided adhesive is applied to the underside of the entire membrane	4.4E-04	1.5E-03	1.4E-03	0.0E+00
4	0.40	**Installing the membrane with the adhesive over the cover board**	placement and seam welding of joints of the single-ply membrane over the cover board	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **ROOFING**								
DESIGN FEATURE/ ELEMENT: **LOW SLOPE [SINGLE –PLY ROOF MEMBRANE (Mechanically fastened attachment system)]**								
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**				
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Attaching rigid board insulation over the roof decks**	using cap and screw over the steel decks	8.9E-05	1.5E-03	7.0E-03	0.0E+00
			using bitumen mopping over the concrete decks	8.8E-04	7.6E-03	7.0E-02	1.3E-01
2	0.15	**Attaching cover boards over the rigid board insulation**	installation of cover board over the rigid insulation board using bitumen mopping	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.15	**Laying the single ply membranes over the cover board**	placement and lapping of the membrane over the cover board	8.9E-05	1.5E-03	1.4E-03	0.0E+00
4	0.20	**Fastening of the membrane to the substrate**	mechanically fastening the membrane to the cover board using a system of batten bars, screws and double-sided tape	4.4E-04	1.5E-03	7.0E-03	0.0E+00
	0.30	**Detailing/ seaming membrane**	Detail work of membrane	8.9E-05	1.5E-03	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **ROOF OPENINGS AND SPECIALTIES**							
DESIGN FEATURE/ ELEMENT: **ROOF HATCH**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of roof hatch**	The entire process of installation of a roof hatch	8.8E-04	7.6E-03	1.1E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOF OPENINGS AND SPECIALTIES**							
DESIGN FEATURE/ ELEMENT: **SMOKE HATCH**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of smoke hatch**	The entire process of installation of a smoke hatch	6.6E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **ROOF OPENINGS AND SPECIALTIES**							
DESIGN FEATURE/ ELEMENT: **SKYLIGHTS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of skylights**	The entire process of installation of skylight	6.6E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **ROOF EDGES AND EXPANSION JOINTS**							
DESIGN FEATURE/ ELEMENT: **BUILDING SEPARATION JOINT**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Building separation joint construction**	the entire construction process of building separation joint on the roof. It comprises of installation of the cants, wood curbs, curb flashing, metal cleats, metal expansion joint covers, etc	4.4E-04	1.5E-03	4.2E-03	6.3E-02

SYSTEM/ COMPONENT : **ROOF EDGES AND EXPANSION JOINTS**							
DESIGN FEATURE/ ELEMENT: **EDGE GUARD**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Edge guard construction**	the entire construction process of edge guard on the roof. It comprises of installation of sheet metal edge guard, flange flashing, metal cleats, etc	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **ROOF EDGES AND EXPANSION JOINTS**							
DESIGN FEATURE/ ELEMENT: **PARAPET WALL**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Parapet wall construction**	the entire construction process of parapet wall. It comprises of installation of the cants, counter-flashing, base flashing, metal cleats, parapet coping, etc	4.4E-04	1.5E-03	4.2E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE [Back-up/ Infill wall]**							
DESIGN FEATURE/ ELEMENT:							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Steel stud back-up wall**	Installation of bottom, top tracks and steel studs between the tracks	8.8E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR CARPENTRY**							
DESIGN FEATURE/ ELEMENT:							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**CMU back-up wall**	Installation and finishing work of CMU blocks using vertical reinforcement, mortar	8.8E-04	7.6E-03	1.4E-02	3.8E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT : **SHEET METAL PANELS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Installation of U-shaped clips to back up wall**	metal U-shaped clips are bolted to the constructed back-up wall	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.10	**Installation of air barrier**	installation of a coating of airtight mastic on the back up wall as an airtight barrier	4.4E-04	1.5E-03	7.0E-03	1.3E-01
3	0.10	**Installation of insulation layer to the backup wall**	adhesion of rigid insulation panels to the back-up wall	4.4E-04	1.5E-03	7.0E-03	1.3E-01
4	0.30	**Installation of vertical metal channels**	bolting of vertical metal channels with the projecting U-shaped clips. Also, horizontal metal angles are installed at two-story intervals to act as a barrier	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.30	**Installation of sheet metal panels**	metal panels are hung on the horizontal rods that are supported by the vertical channels	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT : **INSULATED METAL PANELS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
2	0.10	**Loading insulated metal panel sections from crane**	manually loading the crane with metal panel sections that are going to be lifted for placement	4.4E-04	4.5E-03	7.0E-03	6.3E-02
3	0.25	**Hoisting of panel sections from crane**	lifting and lowering of the metal panel sections by the crane operator as directed by workers	4.4E-04	1.5E-03	7.0E-03	6.3E-02
4	0.35	**Accepting, guiding, aligning and placing of metal panel sections from crane**	workers accept and guide the panel sections from the crane physically near the point of placement to make the connections with the stud wall	8.8E-04	7.6E-03	1.4E-02	1.3E-01
5	0.30	**Making connections**	the insulated metal panels are fastened to the metal stud wall using concealed fasteners and other accessories	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**

DESIGN FEATURE/ ELEMENT: **BRICK VENEER CURTAIN WALL [**Backup wall-**steel studs with exterior insulation**]

ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Installation of exterior sheathing**	fastening of exterior sheathing to the steel stud assembly	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.10	**Bolting of steel shelf angle to spandrel beam**	steel shelf angles are connected to the spandrel beams using bolts and wedge inserts. Wedge inserts are already cast into the concrete spandrel beam during concreting work of beams	5.3E-03	7.6E-03	1.4E-02	1.3E-01
3	0.15	**Installation of scaffold**	setting of tube steel scaffold	8.8E-04	7.6E-03	7.0E-03	1.3E-01
			setting of platform scaffold	5.3E-03	7.6E-03	1.4E-02	1.3E-01
4	0.05	**Installation of flashing**	installation of flashing over the exterior sheathing near the bottom and around the shelf angle	8.8E-04	1.5E-03	7.0E-03	0.0E+00
5	0.05	**Installation of air/ moisture/ vapor barrier**	application of coating or tapping of building wrap to the exterior sheathing of back-up wall	4.4E-04	1.5E-03	7.0E-03	0.0E+00
6	0.05	**Installation of rigid insulation**	rigid foam insulation is sometimes used in the air space between the brick veneer and back-up wall	4.4E-04	1.5E-03	1.4E-03	0.0E+00
7	0.05	**Installation of anchors for brick veneer and back-up wall connection**	fastening of anchors to the steel studs through the exterior sheathing. These anchors are used for connecting the brick veneer to the back-up wall	4.4E-04	1.5E-03	7.0E-03	0.0E+00
8	0.30	**Construction of brick veneer**	laying of brick courses with mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01
9	0.05	**Sealing of joints**	sealing of vertical and horizontal expansion joints in the brick veneer construction with backer rod and sealant	8.9E-05	7.6E-04	1.4E-03	0.0E+00
10	0.10	**Brick washing**	washing of brick veneer wall using chemicals etc.	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**

DESIGN FEATURE/ ELEMENT: **BRICK VENEER CURTAIN WALL [**Backup wall-**steel studs without exterior insulation**]

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	INJURY SEVERITY LEVEL			
				Near Miss	Low Severity	Medium Severity	High Severity
1	0.10	**Installation of exterior sheathing**	fastening of exterior sheathing to the steel stud assembly	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.10	**Bolting of steel shelf angle to spandrel beam**	steel shelf angles are connected to the spandrel beams using bolts and wedge inserts. Wedge inserts are already cast into the concrete spandrel beam during concreting work of beams	5.3E-03	7.6E-03	1.4E-02	1.3E-01
3	0.15	**Installation of scaffold**	setting of tube steel scaffold	8.8E-04	7.6E-03	7.0E-03	1.3E-01
			setting of platform scaffold	5.3E-03	7.6E-03	1.4E-02	1.3E-01
4	0.10	**Installation of flashing**	installation of flashing over the exterior sheathing near the bottom and around the shelf angle	8.8E-04	1.5E-03	7.0E-03	0.0E+00
5	0.05	**Installation of air/ moisture/ vapor barrier**	application of coating or tapping of building wrap to the exterior sheathing of back-up wall	4.4E-04	1.5E-03	7.0E-03	0.0E+00
6	0.05	**Installation of anchors for brick veneer and back-up wall connection**	fastening of anchors to the steel studs through the exterior sheathing. These anchors are used for connecting the brick veneer to the back-up wall	4.4E-04	1.5E-03	7.0E-03	0.0E+00
7	0.30	**Construction of brick veneer**	laying of brick courses with mortar	4.4E-04	1.5E-03	7.0E-03	1.3E-01
8	0.05	**Sealing of joints**	sealing of vertical and horizontal expansion joints in the brick veneer construction with backer rod and sealant	8.9E-05	7.6E-04	1.4E-03	0.0E+00
9	0.10	**Brick washing**	washing of brick veneer wall using chemicals etc.	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **BRICK VENEER CURTAIN WALL [**Backup wall-**CMU**]							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Bolting of steel shelf angle to spandrel beam**	steel shelf angles are connected to the concrete spandrel beams using bolts and wedge inserts. Wedge inserts are already cast into the concrete spandrel beam during concreting work of beams	5.3E-03	7.6E-03	1.4E-02	1.3E-01
2	0.15	**Installation of scaffold**	setting of platform scaffold	8.8E-04	7.6E-03	7.0E-03	1.3E-01
			setting of tube steel scaffold	5.3E-03	7.6E-03	1.4E-02	1.3E-01
3	0.15	**Installation of flashing**	installation of continuous flashing over the shelf angle and to the CMU backup wall using termination bar	8.8E-04	1.5E-03	7.0E-03	0.0E+00
4	0.15	**Placement of rigid insulation**	placing rigid foam insulation between the CMU backup and brick veneer	4.4E-04	1.5E-03	1.4E-03	0.0E+00
5	0.30	**Construction of brick veneer**	laying of brick courses with mortar and to the wire anchors projecting from the CMU backup wall	4.4E-04	1.5E-03	7.0E-03	1.3E-01
6	0.05	**Sealing of joints**	sealing of vertical and horizontal expansion joints in CMU back up wall, brick veneer wall; construction with backer rod, sealant and compressible filler material	8.9E-05	1.5E-03	7.0E-03	1.3E-01
7	0.10	**Brick washing**	washing of brick veneer wall using chemicals etc.	4.4E-04	1.5E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **PREFABRICATED BRICK PANEL CURTAIN WALLS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Loading brick panel sections from crane**	manually loading the crane with brick panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	6.3E-02
2	0.20	**Hoisting of brick panel sections from crane**	lifting and lowering of the brick panel sections by the crane operator as directed by workers	4.4E-04	7.6E-03	7.0E-03	1.3E-01
3	0.40	**Accepting, guiding, aligning and placing of brick panel sections from crane**	workers accept and guide the panel sections from the crane	3.1E-03	7.6E-03	7.0E-03	1.3E-01
4	0.20	**Making field connections**	connecting the brick panel sections with the structural frame using field connections and inserts cast into/connected with the structural frames	3.1E-03	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **STONE PANELS MOUNTED ON STEEL SUB FRAME**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Erection of vertical members of the sub frame**	erection and connection of vertical members to the structural frame	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.15	**Erection of horizontal members of sub frame**	erection and connection of horizontal aluminum support members to the vertical members erected previously	8.8E-04	7.6E-03	7.0E-03	1.3E-01
3	0.10	**Loading stone panel sections from crane**	manually loading the crane with stone panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	0.0E+00
4	0.20	**Hoisting of stone panel sections from crane**	lifting and lowering of the stone panel sections by the crane operator as directed by workers	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.30	**Accepting, guiding, aligning and placing of stone panel sections from crane**	workers accept and guide the stone panel sections onto the horizontal aluminum members	5.3E-03	1.5E-02	7.0E-03	1.3E-01
6	0.10	**Sealing of space between panels**	filling of gaps between panels using backer rod and sealant	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **MONOLITHIC STONE CLADDING PANELS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.30	**Installation of connections to the backup wall for holding the stone panels**	anchoring the dead load support, tie-back anchors, and flashing supports to the backup wall. Shelf angle clips, clip angles or vertical support channels, combined dead load supports and tie-back anchors, channel supports etc. are some examples of connections that are made to the backup wall	8.8E-04	7.6E-03	7.0E-03	0.0E+00
2	0.10	**Loading panel sections from crane**	manually loading the crane with stone panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Hoisting of panel sections from crane**	lifting and lowering of the stone panel sections by the crane operator as directed by workers	4.4E-04	7.6E-03	1.4E-02	1.3E-01
4	0.30	**Accepting, guiding, aligning and connection of stone panel sections from crane**	workers accept and guide the panel sections from the crane near the point of placement over the dead load supports and tieback connections anchored to the backup wall. The shop bolted connections on the stone panels are set on the backup wall connections	5.3E-03	1.5E-02	7.0E-03	1.3E-01
5	0.10	**Sealing of joints between stone wall panels**	joints in between the stone wall sections are sealed with backer rod and sealant	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **STONE CLADDING ON STEEL TRUSSES/ PREFABRICATED STONE CURTAIN WALLS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Installing brackets on the structural frame to support the panels**	brackets are welded to the steel columns of the building frame. These brackets would be the supporting members for the panels	8.8E-04	7.6E-03	7.0E-03	1.3E-01
2	0.10	**Loading panel sections from crane**	manually loading the crane with stone panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Hoisting of panel sections from crane**	lifting and lowering of the stone panel sections by the crane operator as directed by workers	4.4E-04	7.6E-03	7.0E-03	1.3E-01
4	0.30	**Accepting, guiding, aligning and placing of stone panel sections from crane**	workers accept and guide the panel sections from the crane near the point of placement over brackets	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Making connection of the panel**	steel angle clips on the upper corners of the truss side of the stone panels are connected with the brackets on the columns of the building frame. Also, the tieback for the panel is connected with the spandrel beams	8.8E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **STONE-HONEYCOMB PANELS (THIN STONE CLADDING)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Installation of interlocking channel to backup wall**	anchoring of interlocking channel which would hold the interlocking channel on the panel	8.8E-04	7.6E-03	7.0E-03	0.0E+00
2	0.15	**Loading panel sections from crane**	manually loading the crane with panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Hoisting of panel sections from crane**	lifting and lowering of the panel sections by the crane operator as directed by workers	4.4E-04	7.6E-03	7.0E-03	1.3E-01
4	0.40	**Accepting, guiding, aligning and attaching of panel sections from crane**	workers accept, guide and attach the panel sections from the crane near the point of placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **PREFABRICATED STONE HONEYCOMB CURTAIN WALL**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Installation of connections to building frame for holding prefabricated panels**	panel supporting connections are installed to the building frame	4.4E-04	7.6E-03	7.0E-03	0.0E+00
2	0.10	**Loading panel sections from crane**	manually loading the crane with panel sections that are going to be lifted for placement	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Hoisting of panel sections from crane**	lifting and lowering of the panel sections by the crane operator as directed by workers	8.8E-04	7.6E-03	7.0E-03	1.3E-01
4	0.30	**Accepting, guiding, aligning and placing of panel sections from crane**	workers accept and guide the panel sections from the crane near the point of placement	8.8E-04	7.6E-03	7.0E-03	1.3E-01
5	0.20	**Making connection of the panel**	the panels are connected with the installed supports	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **PRECAST CONCRETE CURTAIN WALLS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Loading PC wall sections on crane**	manually loading the crane with PC wall sections that are going to be lifted for placement	4.4E-04	7.6E-03	7.0E-03	1.3E-01
2	0.18	**Hoisting of PC wall sections from crane**	lifting and lowering of the PC wall sections by the crane operator as directed by workers	4.4E-04	7.6E-03	7.0E-03	1.3E-01
3	0.30	**Accepting, guiding, aligning and placing of the PC wall sections from crane**	workers accept and guide the panel sections from the crane near the point of placement over the embeds in the spandrel beam of the building frame	8.8E-04	7.6E-03	1.4E-02	6.3E-01
4	0.23	**Connecting the PC wall section with the embeds in the members of the building frame and leveling**	connecting the bearing supports (steel tubes/ steel angles/ wide flange sections) with the bearing plates embedded in the structural members of the building frame. Shims are used for leveling the placed PC wall section	8.8E-04	7.6E-03	1.4E-02	6.3E-01
5	0.10	**Welding of bearing supports on bearing plate**	welding operation is performed after the leveling of the PC wall section	8.8E-04	7.6E-03	1.4E-02	1.3E-01
6	0.10	**Sealing of joints between PC wall panels**	filling of gaps between panels using backer rod and sealant	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **GLASS FIBER-REINFORCED CONCRETE (GFRC) CURTAIN WALL**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.18	**Loading GFRC sections on crane**	manually loading the crane with GFRC sections that are going to be lifted for placement	3.1E-03	1.5E-02	7.0E-03	6.3E-02
2	0.15	**Hoisting of GFRC sections from crane**	lifting and lowering of the GFRC sections by the crane operator as directed by workers	4.4E-04	4.5E-03	7.0E-03	1.3E-01
3	0.30	**Accepting, guiding, aligning and placing of the GFRC sections from crane**	workers accept and guide the panel sections from the crane near the point of placement next to the embeds in the spandrel beam of the building frame	3.1E-03	1.5E-02	7.0E-03	1.3E-01
4	0.27	**Connecting the GFRC section with the embeds in the members of the building frame and leveling**	connecting the bearing supports (steel tubes/ steel angles) with the bearing plates embedded in the structural members of the building frame. Shims are used for leveling the GFRC section	4.4E-04	7.6E-03	7.0E-03	1.3E-01
5	0.10	**Sealing of joints between GFRC sections**	filling of gaps between panels using backer rod and sealant	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **STUCCO FINISH [**Backup wall-**steel studs]**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Installation of exterior sheathing**	fastening of exterior sheathing to the steel stud assembly	4.4E-04	7.6E-03	7.0E-03	1.3E-01
2	0.10	**Installation of building paper, metal flashing and joint accessories**	installation of building paper on the exterior sheathing; provision of metal flashings, corner beads, casings beads; installation of expansion and control joint accessories	8.9E-05	1.5E-03	7.0E-03	0.0E+00
3	0.20	**Installation of metal lath**	self furring metal lath is fastened using screws which acts as the base for the stucco coats	4.4E-04	1.5E-03	7.0E-03	0.0E+00
4	0.20	**Application of scratch coat of stucco**	application of base coat 3/8 to ½ in. thick	4.4E-04	1.5E-03	7.0E-03	0.0E+00
5	0.20	**Application of brown coat of stucco**	application of base coat 3/8 to ½ in. thick	4.4E-04	1.5E-03	7.0E-03	0.0E+00
6	0.18	**Application of finish coat of stucco**	finish coat, nearly 1/8 in. thick is applied	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **STUCCO FINISH [**Backup wall- **CMU]**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Cleaning, repairing, wetting of masonry wall**	masonry surface made clean and free from defects. It is also prewetted prior to the application of stucco	8.9E-05	1.5E-03	1.4E-03	0.0E+00
2	0.20	**Installing control joints and expansion joints accessories and trims**	fastening of accessories and trims for providing control and expansion joints in stucco wall. Masonry nails are used for the purpose	4.4E-04	7.6E-03	7.0E-03	0.0E+00
3	0.30	**Application of base coat of stucco**	application of base coat 1/2 to 5/8 in. thick. This may be applied in two coats	4.4E-04	7.6E-03	7.0E-03	0.0E+00
4	0.30	**Application of finish coat of stucco**	finish coat, nearly 1/8 in. thick is applied	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **EXTERIOR INSULATION AND FINISH SYSTEM (EIFS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Application of liquid-applied air-weather retarder**	liquid applied air weather retarder is applied to the backup wall	8.9E-05	7.6E-04	7.0E-03	1.3E-01
2	0.20	**Installation of metal flashing/ drainage accessories**	metal flashing/ perforated drainage tracks (drainable EIFS) are installed around openings	4.4E-04	7.6E-03	7.0E-03	1.3E-01
3	0.15	**Application of adhesive and attachment of insulation board**	adhesive is applied to back of insulation boards and the boards are pressed against the substrate	8.9E-05	7.6E-03	7.0E-03	1.3E-01
4	0.15	**Rasping of insulation boards**	the insulation boards are sanded smooth for surface irregularities	4.4E-04	7.6E-03	7.0E-03	1.3E-01
5	0.30	**Application of EIFS lamina**	involves the back wrapping process, application of the base coat, the reinforcement mesh and the finish coat. In back wrapping, the terminal edges of the insulation boards around openings are wrapped with reinforcing mesh. The base coat is applied followed by unrolling of the mesh over the base coat. A second base coat is applied to fully embed the mesh followed by the finish coat	4.4E-04	7.6E-03	7.0E-03	1.3E-01
6	0.10	**Sealing of expansion joints between EIFS sections**	expansion joints in the EIFS wall sections are filled with backer rod and sealant	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **GLASS CURTAIN WALLS/ GLASS ALUMINUM CURTAIN WALLS**							
TYPE : **STICK-BUILT SYSTEM**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.19	**Installation of mullion anchors to building frame**	installation of expansion and dead load anchors to the spandrel beam of reinforced concrete frame or pour stop in slab of steel building frame. These anchors hold the mullions in place	8.8E-04	7.6E-03	1.1E-02	1.3E-01
2	0.24	**Installation of vertical mullion members, expansion splice and accessories**	connecting of vertical members (mullions) to the anchors; splicing of mullion members by inserting, fastening expansion splices to the lower mullion members and sliding the upper mullion over the splice; fastening of shear blocks to the mullions using screws for holding the rails	8.8E-04	7.6E-03	1.1E-02	1.3E-01
3	0.20	**Installation of horizontal rails between the mullions**	horizontal rails are installed (2 to 3 rails per floor) to hold the spandrel and/or vision members. These rails are snapped onto the shear blocks on the mullions	4.4E-04	1.5E-03	7.0E-03	1.3E-01
4	0.20	**Installation of spandrel glass/panels to the mullion framework**	spandrel panels made of metal or glass is installed on the spandrel area of the structure	8.8E-04	1.1E-02	1.1E-02	1.3E-01
5	0.20	**Installation of vision glass panes to the mullion frame work**	installation of glass panels on the vision area of the structure	8.8E-04	1.1E-02	1.1E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **GLASS CURTAIN WALLS/ GLASS ALUMINUM CURTAIN WALLS**							
TYPE : **UNITIZED SYSTEM**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.35	**Installation of anchors to building frame**	installation of expansion and dead load anchors to the spandrel beam of reinforced concrete frame or pour stop in slab of steel building frame	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.65	**Installation of preassembled units**	pre-assembled units are erected and connected with the anchors as well as interlocked with adjacent units during this activity	8.8E-04	1.1E-02	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**								
DESIGN FEATURE/ ELEMENT: **GLASS CURTAIN WALLS/ GLASS ALUMINUM CURTAIN WALLS**								
TYPE : **UNIT AND MULLION SYSTEM**								
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**				
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Installation of mullion anchors to building frame**	installation of expansion and dead load anchors to the spandrel beam of reinforced concrete frame or pour stop in slab of steel building frame. These anchors hold the mullions in place	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.25	**Installation of vertical mullion members**	connecting vertical members (mullions) to the anchors; splicing of mullion members by inserting, fastening expansion splices to the lower mullion members and sliding the upper mullion over the splice	8.8E-04	7.6E-03	1.4E-02	1.3E-01
3	0.50	**Installation of preassembled units**	pre-assembled units are erected and lowered in between the vertical mullions from the floor above	8.8E-04	1.1E-02	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **GLASS CURTAIN WALLS/ GLASS ALUMINUM CURTAIN WALLS**							
TYPE : **PANEL SYSTEM**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.30	**Installation of anchors to building frame**	installation of expansion and dead load anchors to the spandrel beam of reinforced concrete frame or pour stop in slab of steel building frame	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.70	**Installation of preassembled panels**	pre-assembled units are erected and connected with the anchors during this activity	8.8E-04	1.1E-02	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR ENCLOSURE**							
DESIGN FEATURE/ ELEMENT: **GLASS CURTAIN WALLS/ GLASS ALUMINUM CURTAIN WALLS**							
TYPE : **COLUMN COVER AND SPANDREL SYSTEM**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.40	**Installation of spandrel panels**	spandrel panels are installed that span from column to column	6.6E-04	7.6E-03	1.4E-02	1.3E-01
2	0.30	**Installation of column cover sections**	column covers are connected to spandrel covers	6.6E-04	7.6E-03	1.4E-02	6.3E-02
3	0.30	**Installation of glazing infill**	glazing is installed in between the column and spandrel panels	8.8E-04	7.6E-03	1.4E-02	6.3E-02

SYSTEM/ COMPONENT : **EXTERIOR CARPENTRY**							
DESIGN FEATURE/ ELEMENT: **EXTERIOR DOORS**							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Erection and installation of exterior doors/entrance doors**	installation of the door frame in the rough opening; installation of the door and the typical hardware	4.4E-04	7.6E-03	1.4E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR CARPENTRY**							
DESIGN FEATURE/ ELEMENT: **ALUMINUM WINDOWS**							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Erection and installation of windows**	installation of the window frame in the rough opening/ masonry opening; installation of the window	8.8E-04	1.5E-02	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **EXTERIOR CARPENTRY**							
DESIGN FEATURE/ ELEMENT: **PLASTIC CLAD/ METAL CLAD WINDOWS**							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Erection and installation of windows**	installation of the window frame in the rough opening/ masonry opening; installation of the window	1.4E-02	5.2E-02	1.4E-02	3.8E-01

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Partition walls]**							
DESIGN FEATURE/ ELEMENT: **FRAMED PARTITIONS (Steel stud wall)**							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of steel stud assembly**	the assembly consists of steel studs, bottom track, and top track. The process involves placement and connection of the stud assembly within the interior frame of the building	8.8E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Partition walls]**							
DESIGN FEATURE/ ELEMENT: **WALL PARTITIONS (CMU wall)**							
ACT. NO.	**ACTIVITY EXPOSURE**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Construction of concrete masonry walls between structural frame**	laying CMU blocks with mortar, installation of vertical and joint reinforcement, grouting of vertically reinforced cells, finishing work and so forth	8.8E-04	1.1E-02	7.0E-03	6.3E-02

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Partition walls]**							
DESIGN FEATURE/ ELEMENT: **GLASS MASONRY WALL**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Construction of glass masonry wall**	Installation of glass block units using mortar, metal anchors and compressible foam gaskets	4.4E-04	1.5E-03	0.0E+00	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Partition walls]**							
DESIGN FEATURE/ ELEMENT: **FOLDING ACCORDIAN**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of folding accordion**	Installation of folding accordian and accessories	8.9E-05	7.6E-04	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Partition walls]**							
DESIGN FEATURE/ ELEMENT: **MOVABLE AND BORROW LITES (DEMOUNTABLE)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Installation of demountable lites**	Installation of demountable partitions and accessories	2.7E-04	4.5E-03	1.4E-03	6.3E-02

SYSTEM/ COMPONENT : **CEILINGS**							
DESIGN FEATURE/ ELEMENT : **SUSPENDED ACOUSTICAL CEILINGS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Installation of wall angles**	attaching wall angle to all perimeter walls at finished ceiling height	4.4E-04	7.6E-03	7.0E-03	0.0E+00
2	0.18	**Installation of hanger wires**	attaching of hanger wires to the underside of the structure above	2.7E-04	7.6E-03	4.2E-03	0.0E+00
3	0.18	**Installation of main runner tees**	tying of the main runner tees with the hanger wires	4.4E-04	7.6E-03	7.0E-03	0.0E+00
4	0.15	**Installation of cross runner tees**	the cross runner tees are snapped into and interlocked with the main runners	4.4E-04	7.6E-03	7.0E-03	0.0E+00
5	0.15	**Installation of seismic wires and compression posts**	Seismic wires are attached to underside of structure above and strung at 45 degree angle then attached to main runners. Compression posts are installed between main runners and structure above	8.9E-05	7.6E-04	1.4E-03	0.0E+00
6	0.28	**Installation of acoustical lay-in panels**	acoustical lay-in panels are laid in each opening to create the finished ceiling	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **CEILINGS**							
DESIGN FEATURE/ ELEMENT : **SUSPENDED GYPSUM BOARD CEILINGS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Installation of ceiling support angles to the wall**	horizontal metal angles are installed at perimeter walls to support ceiling framing	4.4E-04	7.6E-03	7.0E-03	0.0E+00
2	0.10	**Installation of hanger wires**	attaching the hanger wires to the underside of the structure above	2.7E-04	7.6E-03	4.2E-03	0.0E+00
3	0.10	**Installation of main runner tees**	tying of the main runner tees with the hanger wires	4.4E-04	7.6E-03	7.0E-03	0.0E+00
4	0.10	**Installation of cross runner tees**	the cross runner tees are snapped into and interlocked with the main runners	4.4E-04	7.6E-03	7.0E-03	0.0E+00
5	0.15	**Installation of seismic wires and compression posts**	Seismic wires are attached to underside of structure above and strung at 45 degree angle then attached to main runners. Compression posts are installed between main runners and structure above	8.9E-05	7.6E-04	1.4E-03	0.0E+00
6	0.23	**Attaching gypsum board sheets**	screw-attaching gypsum board sheets to the grid structure	4.4E-04	1.1E-02	1.4E-02	6.3E-02
7	0.23	**Finishing work of gypsum boards**	application of joint compound and joint tape to make a finish surface	4.4E-04	7.6E-03	1.1E-02	0.0E+00

SYSTEM/ COMPONENT : **CEILINGS**							
DESIGN FEATURE/ ELEMENT : **SUSPENDED GYPSUM PLASTER CEILINGS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Installation of hanger wires**	attaching the hanger wires to the underside of the structure above	8.9E-05	1.5E-03	4.2E-03	0.0E+00
2	0.13	**Installation of steel carrying (runner) channels**	carrying channels are tied to the hanger wires	2.7E-04	4.5E-03	7.0E-03	0.0E+00
3	0.15	**Installation of steel furring channels to the carrying channels**	wire-tying of furring channels to the carrying channels	4.4E-04	4.5E-03	7.0E-03	0.0E+00
4	0.20	**Installation of lath to the furring and carrying channel frame**	the lath is tied to the carrying and furring channel framework. Gypsum board lath is tied for gypsum plaster, while wire mesh lath is tied for Portland cement plaster	4.4E-04	1.5E-03	7.0E-03	0.0E+00
5	0.25	**Application of plaster to the lath**	Portland cement plaster is applied over the wire mesh lath while gypsum plaster is applied over the gypsum board lath	4.4E-04	7.6E-03	7.0E-03	0.0E+00
6	0.20	**Finishing work and painting**	Application of paint and finishing of plastered surface	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **CEILINGS**							
DESIGN FEATURE/ ELEMENT : **SUSPENDED PORTLAND CEMENT PLASTER CEILINGS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Installation of hanger wires**	attaching the hanger wires to the underside of the structure above	8.9E-05	1.5E-03	4.2E-03	0.0E+00
2	0.13	**Installation of steel carrying (runner) channels**	carrying channels are tied to the hanger wires	2.7E-04	4.5E-03	7.0E-03	0.0E+00
3	0.15	**Installation of steel furring channels to the carrying channels**	wire-tying of furring channels to the carrying channels	4.4E-04	4.5E-03	7.0E-03	0.0E+00
4	0.20	**Installation of lath to the furring and carrying channel frame**	the lath is tied to the carrying and furring channel framework. Gypsum board lath is tied for gypsum plaster, while wire mesh lath is tied for Portland cement plaster	4.4E-04	1.5E-03	7.0E-03	0.0E+00
5	0.25	**Application of plaster to the lath**	Portland cement plaster is applied over the wire mesh lath while gypsum plaster is applied over the gypsum board lath	4.4E-04	7.6E-03	7.0E-03	0.0E+00
6	0.20	**Finishing work and painting**	Application of paint and finishing of plastered surface	4.4E-04	7.6E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**							
DESIGN FEATURE/ ELEMENT : **CERAMIC TILE FLOORING**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Laying waterproof membrane**	a layer of waterproofing membrane is laid over the subfloor	8.9E-05	7.6E-04	0.0E+00	0.0E+00
2	0.15	**Laying mortar bed on subfloor**	mortar is spread on the subfloor using notched trowel or other similar accessory covering the waterproof membrane	8.9E-05	7.6E-04	0.0E+00	0.0E+00
3	0.15	**Laying reinforcement**	expanded metal lath or reinforcement mesh is sometimes laid over the waterproofing membrane and in the mortar	4.4E-04	1.5E-03	1.4E-03	0.0E+00
4	0.10	**Application of cleavage bond coat**	application of cleavage bond coat over the mortar bed	8.9E-05	7.6E-04	0.0E+00	0.0E+00
5	0.33	**Placement of ceramic tiles**	laying the ceramic tiles as required	2.7E-04	1.5E-03	1.4E-03	0.0E+00
6	0.18	**Grouting of joints**	voids between the tiles are filled with Portland cement and sand grout	4.4E-05	7.6E-04	0.0E+00	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**							
DESIGN FEATURE/ ELEMENT : **STONE PANEL FLOORING**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Laying waterproof membrane**	a layer of waterproofing membrane is laid over the subfloor	8.9E-05	7.6E-04	0.0E+00	0.0E+00
2	0.20	**Placing of Portland cement and sand mix**	a damp mix of Portland cement and sand is placed and leveled on the subfloor covering the waterproof membrane	8.9E-05	7.6E-04	0.0E+00	0.0E+00
3	0.15	**Laying reinforcement**	expanded metal lath or reinforcement mesh is sometimes laid over the waterproofing membrane and in the mix	8.9E-05	4.5E-03	7.0E-04	0.0E+00
4	0.40	**Placement of stone panels**	application of bond coat of cementitious material on the backs of the panels and setting them in place	4.4E-04	4.5E-03	1.4E-03	0.0E+00
5	0.15	**Grouting of joints**	voids between the panels are filled with Portland cement and sand grout	4.4E-05	7.6E-04	0.0E+00	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**							
DESIGN FEATURE/ ELEMENT : **TERRAZZO FLOORING**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.10	**Laying waterproofing membrane**	a layer of waterproofing membrane is laid over the subfloor	8.9E-05	7.6E-04	0.0E+00	0.0E+00
1	0.13	**Laying dry sand bed**	clean, dry sand is used to cover the entire slab surface	4.4E-05	7.6E-04	0.0E+00	0.0E+00
2	0.10	**Laying isolation membrane**	isolation membrane is laid over the subfloor and edges	8.9E-05	7.6E-04	0.0E+00	0.0E+00
3	0.10	**Install welded wire reinforcement**	welded wire reinforcement is placed over the membrane and sand bed	4.4E-04	1.5E-03	1.4E-03	0.0E+00
4	0.20	**Laying concrete under-bed**	a bed of cementitious material is placed and prepared for receiving the terrazzo topping	8.9E-05	7.6E-04	0.0E+00	0.0E+00
5	0.15	**Installation of divider strips and joint strips**	divider and control joint strips are installed to the under-bed using an adhesive	8.9E-05	7.6E-04	0.0E+00	0.0E+00
6	0.25	**Placing terrazzo topping and finishing**	terrazzo topping is placed in a wet, plastic condition; leveled, rolled, compacted, and toweled; ground using a grinding machine, grouted and polished	8.9E-05	1.5E-03	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**							
DESIGN FEATURE/ ELEMENT : **RAISED ACCESS FLOORING**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.33	**Installation of pedestals**	installation process of pedestals that would hold the tiles. This is done after the ductwork, piping, and wiring is complete on the floor below	8.9E-05	1.5E-03	1.4E-03	0.0E+00
2	0.35	**Installation of frame on the pedestals to hold the tiles**	connection of metal rods to the pedestal to form a grid for receiving the tiles	8.9E-05	1.5E-03	1.4E-03	0.0E+00
3	0.35	**Installation of the tiles**	solid, perforated or grating tiles are placed and screwed to the grid installed	8.9E-05	1.5E-03	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**							
DESIGN FEATURE/ ELEMENT : **CARPET FLOORING**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Floor preparation prior to carpet placement**	removal of ridges, high spots, and other imperfections	8.9E-05	1.5E-03	1.4E-03	0.0E+00
2	0.75	**Installation of carpet**	carpet is attached to the subfloor using an adhesive	4.4E-04	1.5E-03	1.4E-03	0.0E+00

SYSTEM/ COMPONENT : **FLOORING**

DESIGN FEATURE/ ELEMENT : **RESILIENT FLOORING**

ACT. NO.	ACTIVITY EXPOSURE* (%)	ACTIVITIES	ACTIVITY DESCRIPTION	INJURY SEVERITY LEVEL			
				Near Miss	Low Severity	Medium Severity	High Severity
1	0.20	**Floor preparation**	removal of ridges, high spots, and other imperfections	8.9E-05	1.5E-03	1.4E-03	0.0E+00
2	0.25	**Installation of moisture retardant barrier**	installing a layer of moisture retardant barrier	8.9E-05	7.6E-04	0.0E+00	0.0E+00
3	0.40	**Installation of vinyl composition tiles/ sheets over the subfloor**	resilient flooring (vinyl tiles/ sheets) is applied by full-spreading of adhesive using a notched trowel	4.4E-04	1.5E-03	1.4E-03	0.0E+00
4	0.20	**Installation of resilient flooring accessories**	wall base and moldings are installed around corners and gaps	8.9E-05	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **DRYWALL FOR FRAMED PARTITIONS (STEEL STUDS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Installation of rigid insulation between the studs**	rigid foam insulation is sometimes installed between the studs	6.7E-05	1.1E-03	1.4E-03	0.0E+00
2	0.40	**Installation of drywalls**	drywall (gypsum) boards are installed on either side of the steel stud assembly using screws	6.6E-04	1.1E-02	1.1E-02	6.3E-02
3	0.40	**Application of joint tape, gypsum board accessories, joint compound and painting**	covering of joints between drywall panels using joint tape, installation of L-shaped trim on corners and application of joint compound in these areas to make a smooth surface. After the joints and corners are finished, interior painting is performed	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **DRYWALL FOR WALL PARTITIONS (CONCRETE MASONARY)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Installation of furring strips**	metal furring channels are fastened to the masonry to provide a concealed space for utilities, insulation etc	8.9E-05	1.5E-03	7.0E-03	0.0E+00
2	0.15	**Installation of rigid insulation between furring strips**	rigid foam insulation is sometimes installed between the furring channels	8.9E-05	1.5E-03	4.2E-03	0.0E+00
3	0.35	**Installation of drywall over the furring strips**	drywall (gypsum) boards are screwed to the furring channels	4.4E-04	7.6E-03	1.4E-02	0.0E+00
4	0.35	**Application of joint tape, gypsum board accessories, joint compound and painting**	covering of joints between drywall panels using joint tape, installation of L-shaped trim on corners and application of joint compound in these areas to make a smooth surface. After the joints and corners are finished, interior painting is performed	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **GYPSUM PLASTER FOR FRAMED PARTITIONS (STEEL STUDS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Installation of insulation between studs**	the assembly consists of steel studs, bottom track, top track, exterior sheathing. The process involves erection, placement and connection of the stud assembly with the building frame and fastening of exterior sheathing to the steel stud assembly	4.4E-05	1.1E-03	1.4E-03	0.0E+00
2	0.20	**Installation of gypsum lath**	the lath is attached to the steel studs with self-drilling screws or wire clips and sheet metal clips. Gypsum board lath is tied for gypsum plaster	4.4E-04	4.5E-03	7.0E-03	0.0E+00
3	0.13	**Corner treatments**	corner treatments using casing beads, corner beads, etc	4.4E-04	4.5E-03	7.0E-03	0.0E+00
4	0.35	**Application of plaster coats**	application of scratch, brown and finish coats for Portland cement plaster, or brown coat and finish coats for gypsum plaster. The coats are applied over the respective laths	4.4E-04	4.5E-03	7.0E-03	0.0E+00
5	0.20	**Finishing and painting**	Application of paint and finishing of plastered surface	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **GYPSUM PLASTER FOR WALL PARTITIONS (CMU WALLS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Masonry insulation**	Pouring masonry insulation into the CMU block walls	4.4E-04	1.5E-03	4.2E-03	0.0E+00
2	0.15	**CMU wall surface treatment**	pre-wetting of wall surface with water and application of bonding agent	8.9E-05	7.6E-04	1.4E-03	0.0E+00
3	0.40	**Application of plaster coats**	application of base and finish coats of plaster over the CMU walls	4.4E-04	1.5E-03	7.0E-03	0.0E+00
4	0.25	**Finishing and painting**	Application of paint and finishing of plastered surface	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **PORTLAND CEMENT PLASTER FOR FRAMED PARTITIONS (STEEL STUDS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.15	**Installation of insulation between studs**	the assembly consists of steel studs, bottom track, top track, exterior sheathing. The process involves erection, placement and connection of the stud assembly with the building frame and fastening of exterior sheathing to the steel stud assembly	4.4E-05	1.1E-03	1.4E-03	0.0E+00
2	0.20	**Installation of metal lath**	the lath is attached to the steel studs with self-drilling screws or wire clips and sheet metal clips. Metal lath is tied for cement plaster	4.4E-04	4.5E-03	7.0E-03	0.0E+00
3	0.13	**Corner treatments**	corner treatments using casing beads, corner beads, etc	4.4E-04	4.5E-03	7.0E-03	0.0E+00
4	0.35	**Application of plaster coats**	application of scratch, brown and finish coats for Portland cement plaster, or brown coat and finish coats for gypsum plaster. The coats are applied over the respective laths	4.4E-04	4.5E-03	7.0E-03	0.0E+00
5	0.20	**Finishing and painting**	Application of paint and finishing of plastered surface	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR CONSTRUCTION [Interior wall finishing]**							
DESIGN FEATURE/ ELEMENT: **PORTLAND CEMENT PLASTER FOR WALL PARTITIONS (CMU WALLS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Masonry insulation**	Pouring masonry insulation into the CMU block walls	4.4E-04	1.5E-03	4.2E-03	0.0E+00
2	0.15	**CMU wall surface treatment**	pre-wetting of wall surface with water and application of bonding agent	8.9E-05	7.6E-04	1.4E-03	0.0E+00
3	0.40	**Application of plaster coats**	application of base and finish coats of plaster over the CMU walls	4.4E-04	1.5E-03	7.0E-03	0.0E+00
4	0.25	**Finishing and painting**	Application of paint and finishing of plastered surface	4.4E-04	1.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **INTERIOR WALLS AND PARTITIONS**							
DESIGN FEATURE/ ELEMENT: **VENEER PLASTER OVER VENEER BASE**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.35	**Installation of veneer plaster base**	veneer plaster base is attached to the steel stud assembly using screws	4.4E-04	4.5E-03	7.0E-03	0.0E+00
2	0.25	**Corner and joint treatments**	corners are treated by installing corner beads and joints between panels are treated using tapes	4.4E-04	1.5E-03	7.0E-03	0.0E+00
3	0.40	**Application of veneer plaster**	veneer plaster is applied to the veneer base using hawk and trowel	4.4E-04	4.5E-03	7.0E-03	0.0E+00

SYSTEM/ COMPONENT : **STAIRS**							
DESIGN FEATURE/ ELEMENT: **PRECAST STAIRS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.20	**Loading the precast stair section from crane**	manually loading the crane with precast stair section that is going to be lifted for placement	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.20	**Hoisting of precast stair section from crane**	lifting, lowering of the precast stair sections by the crane operator as directed by workers	4.4E-04	1.5E-03	7.0E-03	1.3E-01
3	0.30	**Accepting, guiding and placing of precast stair section from crane**	workers physically accept, guide and place the column section from the crane on the point of placement	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.30	**Making connections with structural frame**	precast stair section is fastened/ welded to the building frame	8.8E-04	7.6E-03	1.4E-02	1.3E-01

SYSTEM/ COMPONENT : **STAIRS**							
DESIGN FEATURE/ ELEMENT: **REINFORCED CONCRETE STAIRS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.40	**Construction of formwork for stairs**	process of cutting, placement, connection and lubrication of formwork to cast the stair flights and the landing	5.3E-03	1.1E-02	1.4E-02	1.3E-01
2	0.20	**Reinforcement work for stairs**	rebar in stairs is laid and tied with the beam rebar at floor level and with landing rebar/ wall rebar using tie wires	6.6E-04	1.1E-02	4.2E-02	1.3E-01
3	0.25	**Pouring concrete**	concreting work of stairs is performed	3.1E-03	1.1E-02	1.4E-02	1.3E-01
4	0.18	**Installation of guard units and handrails**	erection and connection of guardrails and handrails for the stairs	4.4E-04	7.6E-03	1.1E-02	1.3E-01

SYSTEM/ COMPONENT : **STAIRS**							
DESIGN FEATURE/ ELEMENT: **STEEL STAIRS (CONCRETE FILLED TREAD PANS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Erection and connection of landing frame**	landing frame made of structural steel members is erected and supported by suspending it from upper-level floor beams with hanger bars	6.6E-04	7.6E-03	1.4E-02	1.3E-01
2	0.25	**Erection, placement and connection of stringers**	structural steel sections, steel plates are used as stringers. These are erected and placed to position near structural steel beams/ reinforced concrete beams. Using steel angle sections, the stringers are welded with the beams. In case of stair well meeting landing frame, stringers are welded to steel channel sections that act as front header of the landing frame	3.1E-03	1.5E-02	4.2E-02	1.3E-01
3	0.25	**Installation of tread-riser units**	bent sheet steel members are used as tread-riser units and are welded to the insides of the stringers	6.6E-04	1.5E-03	7.0E-03	6.3E-02
4	0.15	**Pouring of concrete in tread pan**	site-filling of concrete in the tread pans to cast concrete treads	8.8E-04	7.6E-03	1.4E-02	0.0E+00
5	0.15	**Installation of guard units and handrails**	erection and connection of guardrails and handrails for the stairs	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **STAIRS**							
DESIGN FEATURE/ ELEMENT: **STEEL STAIRS (PRECAST CONCRETE TREADS)**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	0.25	**Erection and connection of landing frame**	landing frame made of structural steel members is erected and supported by suspending it from upper-level floor beams with hanger bars	8.8E-04	7.6E-03	1.4E-02	1.3E-01
2	0.30	**Erection, placement and connection of stringers**	structural steel sections, steel plates are used as stringers. These are erected and placed to position near structural steel beams/ reinforced concrete beams. Using steel angle sections, the stringers are welded with the beams. In case of stair well meeting landing frame, stringers are welded to steel channel sections that act as front header of the landing frame	8.8E-04	1.5E-02	1.4E-02	1.3E-01
3	0.10	**Installation of tread-riser units**	bent sheet steel members are used as tread-riser units and are welded to the insides of the stringers	8.8E-04	7.6E-03	1.4E-02	1.3E-01
4	0.10	**Attaching reinforcing wire mesh to the steel treads**	wire mesh is attached to the tread pans using epoxy cement. This is done for slip resistance of the precast concrete treads	4.4E-04	7.6E-03	1.4E-02	0.0E+00
5	0.20	**Installation of precast concrete treads**	installation process of precast concrete treads in the tread pans	8.8E-04	1.5E-02	7.0E-02	1.3E-01
6	0.10	**Installation of guard units and handrails**	erection and connection of guardrails and handrails for the stairs	4.4E-04	7.6E-03	7.0E-03	1.3E-01

SYSTEM/ COMPONENT : **INTERIOR CARPENTRY**							
DESIGN FEATURE/ ELEMENT: **INTERIOR DOORS**							
ACT. NO.	**ACTIVITY EXPOSURE* (%)**	**ACTIVITIES**	**ACTIVITY DESCRIPTION**	**INJURY SEVERITY LEVEL**			
				Near Miss	**Low Severity**	**Medium Severity**	**High Severity**
1	1.00	**Erection and installation of interior aluminum doors**	installation of the door frame in the rough opening; installation of the door and the typical hardware	4.4E-04	7.6E-03	1.4E-03	0.0E+00

Appendix D: Worker-hours/unit, Total unit risk, and Total cumulative risk factors of design features

FOOTINGS AND FOUNDATIONS							
RESPONDENT TYPE AND NUMBER			DESIGN FEATURE/ ELEMENT	UNITS	WORKER HOURS/ UNIT	TOTAL UNIT RISK (S/WH)	TOTAL CUMULATIVE RISK (S/UNIT)
TC	SU	SA					
5	6	7	Steel H-pile	V.L.F.	0.113	2.9E-01	1.6E-02
5	6	7	Steel pipe pile	V.L.F.	0.094	5.0E-01	1.2E-02
5	6	3	Precast concrete pile	V.L.F	0.110	6.8E-01	2.1E-02
5	7	3	Bored concrete pile	V.L.F.	0.133	3.9E-01	1.1E-02
5	6	3	Driven concrete pile	V.L.F.	0.169	1.7E-01	8.8E-03
5	7	5	Pile cap	C.Y.	1.748	5.5E-01	2.1E-01
5	6	2	Drilled shaft/ drilled pier	V.L.F.	0.120	8.0E-02	1.7E-03
5	6	2	Drilled Caisson	V.L.F.	3.542	8.0E-02	5.1E-02
5	7	5	Isolated column/ spread footing	C.Y.	2.699	2.0E-01	1.1E-01
5	7	5	Wall/ strip footing	C.Y.	2.550	4.7E-01	2.3E-01
5	7	5	Mat foundation	C.Y.	2.441	6.7E-01	3.7E-01
5	7	5	Slab on ground/ Slab on grade	S.F.	0.033	7.8E-02	5.4E-04

TC = Trade Contractor; SU = General Contractor Superintendent; SA = General Contractor Safety Manager

STRUCTURAL FRAME							
RESPONDENT TYPE AND NUMBER			DESIGN FEATURE/ ELEMENT	UNITS	MAN HOURS/ UNIT	TOTAL UNIT RISK (S/WH)	TOTAL CUMULATIVE RISK (S/UNIT)
TC	SU	SA					
3	7	7	Structural steel column	L.F.	0.057	2.4E+00	2.0E-02
3	7	7	Steel built-up column	L.F.	0.057	2.3E+00	2.5E-02
5	7	7	CIP concrete square column	C.Y.	13.832	9.2E-01	2.7E+00
5	7	7	CIP concrete round column	C.Y.	8.958	9.2E-01	1.7E+00
3	7	6	Precast concrete column	L.F.	0.556	1.0E+00	1.1E-01
5	7	5	CIP concrete shear walls		4.327	1.3E+00	1.2E+00
3	7	7	Structural steel beam	L.F.	0.074	3.4E+00	3.0E-02
3	7	7	Steel plate girder	L.F.	0.074	1.2E+00	1.0E-02
3	7	5	Precast beam	EA.	3.668	1.1E+00	1.1E+00
5	7	6	One way solid slab	C.Y.	8.718	1.4E+00	1.6E+00
5	7	6	Two way solid slab	C.Y.	7.226	1.4E+00	1.3E+00
5	7	5	Flat plate slab	C.Y.	5.140	1.0E+00	7.6E-01
5	7	5	One way joist slab	C.Y.	7.167	1.6E+00	1.3E+00
5	7	5	Two way joist (waffle) slab	C.Y.	5.166	1.6E+00	9.1E-01

STRUCTURAL FRAME (Contd.)							
5	7	6	Post-tensioned beam and slab	C.Y.	8.924	1.5E+00	1.5E+00
3	7	5	Hollow-core plank slab	S.F.	0.023	1.2E+00	6.2E-03
8	5	6	Cellular deck	S.F.	0.056	1.8E+00	1.4E-02
8	5	6	Composite deck	S.F.	0.040	1.8E+00	9.7E-03
8	5	6	Open Floor deck	S.F.	0.035	1.6E+00	8.3E-03
8	5	6	Steel form deck	S.F.	0.038	1.6E+00	9.0E-03
3	5	6	Steel roof deck	S.F.	0.011	9.0E-01	2.6E-03

LOW SLOPE ROOFING							
RESPONDENT TYPE AND NUMBER			DESIGN FEATURE/ ELEMENT	UNITS	MAN HOURS/ UNIT	TOTAL UNIT RISK (S/WH)	TOTAL CUMULATIVE RISK (S/UNIT)
TC	SU	SA					
4	4	5	Built-up roof membrane[over steel decks]	S.F.	0.047	6.8E-01	4.6E-03
4	4	5	Built-up roof membrane[over concrete decks]	S.F.	0.047	8.8E-01	7.0E-03
4	4	5	Modified bitumen roof membrane[over steel decks]	S.F.	0.052	6.1E-01	4.5E-03
4	4	5	Modified bitumen roof membrane[over concrete decks]	S.F.	0.052	8.0E-01	7.2E-03
4	4	5	SBS modified bitumen membrane[over steel decks]	S.F.	0.057	4.8E-01	5.4E-03
4	4	5	SBS modified bitumen membrane[over concrete decks]	S.F.	0.057	6.8E-01	8.2E-03
4	4	5	APP modified bitumen membrane[over steel decks]	S.F.	0.047	1.9E-01	3.5E-03
4	4	5	APP modified bitumen membrane[over concrete decks]	S.F.	0.047	3.9E-01	5.8E-03
4	4	5	Single–ply roof membrane (Fully adhered system)[over steel decks]	S.F.	0.031	3.6E-02	2.8E-04
4	4	5	Single–ply roof membrane (Fully adhered system)[over concrete decks]	S.F.	0.031	2.3E-01	1.9E-03
4	4	5	Single–ply roof membrane (Mechanically fastened attachment system)[over steel decks]	S.F.	0.027	3.9E-02	2.1E-04

LOW SLOPE ROOFING (Contd.)							
4	4	5	Single–ply roof membrane (Mechanically fastened attachment system)[over concrete decks]	S.F.	0.027	2.4E-01	1.6E-03
4	3	5	Roof hatch	E.A.	3.901	1.5E-01	5.7E-01
4	3	5	Smoke hatch	E.A.	3.901	1.4E-01	5.5E-01
4	3	5	Skylight	E.A.	1.921	1.5E-01	2.9E-01
4	3	5	Parapet wall	S.F.	0.058	1.3E-01	7.7E-03
4	3	5	Building separation joint	L.F.	0.056	7.0E-02	3.9E-03
4	3	5	Edge guard	L.F.	0.026	1.4E-01	3.7E-03

EXTERIOR ENCLOSURE							
RESPONDENT TYPE AND NUMBER			DESIGN FEATURE/ ELEMENT	UNITS	MAN HOURS/ UNIT	TOTAL UNIT RISK (S/WH)	TOTAL CUMULATIVE RISK (S/UNIT)
TC	SU	SA					
0	5	4	Steel stud back-up wall	S.F.	0.015	1.5E-02	2.3E-04
0	5	4	CMU back-up wall	S.F.	0.114	4.0E-01	4.6E-02
0	3	4	Sheet metal panels	S.F.	0.138	7.1E-01	2.0E-02
0	4	4	Insulated metal panels	S.F.	0.138	4.5E-01	1.7E-02
4	5	4	Brick veneer curtain wall [Backup wall-steel studs w/ exterior insulation]	S.F.	0.362	7.5E-01	3.9E-02
4	5	4	Brick veneer curtain wall [Backup wall-steel studs w/o exterior insulation]	S.F.	0.352	7.5E-01	3.8E-02
4	5	4	Brick veneer curtain wall [Backup wall-CMU]	S.F.	0.274	7.2E-01	2.7E-02
0	5	3	Prefabricated brick panel curtain walls	S.F.	0.119	5.0E-01	1.5E-02
3	5	3	Stone panel mounted on steel sub-frame	S.F.	0.271	6.1E-01	3.2E-02
3	5	3	Monolithic stone cladding	S.F.	0.271	3.4E-01	2.3E-02
3	5	3	Prefabricated stone curtain walls/ Stone cladding on steel trusses	S.F.	0.271	5.8E-01	3.5E-02
3	5	3	Stone honeycomb panel(thin stone cladding)	S.F.	0.138	3.1E-01	1.2E-02
3	5	3	Prefabricated stone honeycomb curtain wall	S.F.	0.271	4.5E-01	2.8E-02
3	5	4	Precast concrete curtain wall	C.Y.	0.137	1.9E+00	1.1E-01
0	5	1	Glass fiber-reinforced concrete curtain wall	S.F.	0.084	5.3E-01	1.0E-02
3	5	3	Stucco finish[framed partitions]	S.F.	0.165	1.9E-01	4.8E-03

EXTERIOR ENCLOSURE (Contd.)							
2	5	3	Stucco finish[CMU wall partitions]	S.F.	0.084	4.8E-02	2.3E-03
3	3	1	Exterior insulation and finish system	S.F.	0.182	8.4E-01	2.7E-02
3	5	4	Stick-built system	S.F.	0.175	7.3E-01	2.6E-02
3	5	4	Unitized system	S.F.	0.175	3.0E-01	2.7E-02
3	5	4	Unit and mullion system	S.F.	0.175	4.5E-01	2.6E-02
3	5	4	Panel system	S.F.	0.175	3.0E-01	2.7E-02
3	5	4	Column cover and spandrel system	S.F.	0.133	3.2E-01	1.5E-02
0	2	4	entrance/ exterior doors	E.A	9.281	1.4E-01	1.3E+00
0	2	4	aluminum window systems	E.A.	3.152	1.5E-01	4.7E-01
0	2	4	plastic clad/ metal clad windows	E.A.	3.509	4.6E-01	1.6E+00

INTERIOR CONSTRUCTION							
RESPONDENT TYPE AND NUMBER			DESIGN FEATURE/ ELEMENT	UNITS	MAN HOURS/ UNIT	TOTAL UNIT RISK (S/WH)	TOTAL CUMULATIVE RISK (S/UNIT)
TC	SU	SA					
5	6	5	Framed partitions(Steel stud wall)	S.F.	0.015	1.5E-02	2.3E-04
0	6	4	Wall partitions(CMU wall)	S.F.	0.114	8.3E-02	9.4E-03
3	3	3	Glass masonry wall	S.F.	0.226	2.0E-03	4.4E-04
1	2	2	Folding accordion	S.F.	0.120	2.2E-03	2.7E-04
1	2	1	Movable and borrow lites (demountable)	L.F.	0.320	7.0E-02	2.2E-02
5	6	5	Drywall[frame partitions]	S.F.	0.037	1.0E-01	1.5E-03
5	6	5	Drywall[wall partitions]	S.F.	0.065	4.8E-02	9.2E-04
5	6	3	Portland cement plaster[frame partitions]	S.F.	0.105	5.1E-02	9.8E-04
5	6	3	Portland cement plaster[wall partitions]	S.F.	0.092	2.6E-02	6.8E-04
5	6	3	Gypsum plaster [framed partitions]	S.F.	0.117	5.1E-02	1.1E-03
5	6	3	Gypsum plaster [wall partitions]	S.F.	0.104	2.9E-02	8.5E-04
5	6	3	Veneer plaster	S.F.	0.049	3.3E-02	5.5E-04
5	6	5	Suspended acoustical ceilings	S.F.	0.029	7.4E-02	3.8E-04
5	6	5	Suspended gypsum board ceilings	S.F.	0.052	1.7E-01	1.6E-03
5	6	5	Suspended plaster ceilings [gypsum plaster]	S.F.	0.125	6.9E-02	1.6E-03
5	6	5	Suspended plaster ceilings [cement plaster]	S.F.	0.105	6.9E-02	1.3E-03

INTERIOR CONSTRUCTION (Contd.)							
4	6	4	Ceramic tile flooring	S.F.	0.063	9.9E-03	1.2E-04
4	6	4	Stone panel flooring	S.F.	0.267	1.4E-02	9.9E-04
4	6	3	Terrazzo flooring	S.F.	0.190	1.1E-02	3.1E-04
4	6	5	Raised access flooring	S.F.	0.365	9.0E-03	1.1E-03
4	6	5	Carpet flooring	S.F.	0.018	6.4E-03	5.9E-05
4	6	5	Resilient flooring	S.F.	0.016	1.6E-02	6.2E-05
3	4	3	Precast stairs	S.F.	0.807	5.8E-01	1.2E-01
5	4	5	Reinforced concrete stairs	L.F. Nose	0.481	6.4E-01	7.9E-02
2	4	5	Concrete filled tread pans	S.F.	0.827	5.7E-01	1.0E-01
2	4	3	Precast concrete treads	S.F.	0.640	8.3E-01	1.0E-01
0	3	4	Aluminum doors	E.A	5.689	9.4E-03	5.4E-02

Appendix E: Special Designs that Increase and/or Decrease the risk of injury

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
Bored concrete piles	Depth, size and weight	
Post-tensioned beam and slab	Fast tract schedule	clear workers from area during stressing of tendons
CIP concrete columns	Tall columns that require workers to climb instead of using a lift	Round columns since less form pieces; adequate places on the forming system to tie off and to allow lifts to access
CIP walls	Design that requires piece forming	design that allows use of forming systems (less components); form panel system
One way/ two way solid slab	Complex design	European deck system since light in weight; fewer beams and more post tension cables
Flat plate slab	Double mats of rebar	post tension cables instead of rebar; flyer tables decrease the amount of time exposed to fall hazards
Pile cap	Heavy steel forms used without lifting mechanisms like forklift or crane	rebar caps; any system that utilizes forklift or crane to position formwork

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
One way/ two way joist floor slab	Pan system awkward and heavy to work, lot of back injuries as a result of the system	
Stone panels mounted on steel sub-frame	Leading edge exposure due to larger panels	make connections away from leaning edge of building
Structural steel columns	weak narrow gauge anchor bolts, non symmetric columns; type of column connection at the splice, poorly detailed column splice	larger and wide set anchor bolts; getting involved early during fabrication and requesting specific erection aids; easy column splice connections
structural steel beam	nested connections; trapped connections-no access for bolting; welding coated steel	alternate sided connection plates; location of C.G. of beams for erection on the design
plate girders/built-up girder	tall with narrow flanges	easy temporary connections
cellular decks, composite decks	single span, short landing, edges	Concrete mix that passes a 3" hose to save on back injuries
cellular decks, composite decks	single span, short landing, edges	multiple spans(3 or more); stickers between sheets(keeps from packing/ nesting)

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
precast concrete columns	minimal splice connections; eccentric column shapes	connections for temporary bracing
precast beams	gravity connections; reinforcement bar interference	positive temporary connections; safety tie offs; attachments for bracing
hollow-core plank slabs	small landing areas; eccentric cut slabs	deep connection pockets
PC curtain walls	need for rolling frames for lifting; smaller rigging attachments; having to rig with slings	heavy lifting inserts; positive temporary connections not requiring welding before release of crane; clutch inserts
column and spandrel system	eccentric panels; lack of adjustable connections; need for rolling table for lifting; odd shaped panels with no erection aids	fascia lifting points; flexible moment and gravity connections that do not require welding prior to crane release; clutch inserts, simple shaped panels
Roofing	Hot air welding required by systems like PVC/ TPO use of hot asphalt(risk of being burns) bending over	EPDM systems since glued have less chances of burns; eliminate hot asphalt from system

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
parapets	lower parapet	PFAS needs to be used if wall is less than 39"; Make parapet walls 39" and above
Smoke hatch, roof hatch-	greater distance between hatches and lower level	personal fall arrest system during installation in fall restraint mode; covers over hatch to prevent fall through
Skylights	size of hole increases risk	Smaller holes; Reinforced with wire mesh if bigger skylights or covers over skylight
Suspended gypsum board ceilings	access/ heights; working over head creates strain on muscles and joints especially when lifting drywall	having a clean work area; use of eye protection, flex-n-stretch
Suspended plaster ceilings	access/ heights; working overhead greater risk of musculoskeletal injury	one coat systems, direct apply

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
Suspended acoustical ceiling	Floating ceilings; Shooting wires into concrete is the biggest risk when installing ceilings. If stilts are used falls becomes a bigger risk; cutting too many border tiles; ceilings over atriums, stair shafts	cleaning the area before installation; using a larger but lighter ceiling tile would reduce the amount of working over head;
Drywall for framed partitions	Height/ access/ sharp edges; Where the upper track is installed after HVAC, piping is installed; metal stud work leads to lacerations; Reaching too high or pressing too hard while screwing of gypsum panels creates extra strain	Use of gloves, job hazard analysis and pre-job planning; Short walls
Drywall for wall partitions	using table saw for cutting rigid insulation; power actuated fasteners	Short walls

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
Plaster for framed partitions	metal lath is very sharp and hard to handle; plaster packages are bagged in 80lbs bags; always risk of cuts working with metal; reaching increases shoulder injuries	Proper PPE; Shorter walls
Plaster for wall partitions	Access/ heights; working in stairwells because you are working from elevated platforms over the stairs	Proper PPE; Use of back brace, but used frequently makes back weaker
Raised access flooring	moving with heavy floor panel(approx 90lbs); always bend to install them; use of standard tools to perform the work	flex-n-stretch
Veneer plaster over veneer base	using scaffold tat's improperly set up	
Stucco finish	height of work creating the need to work from elevated platforms; Cannot unstack work without reaching stucco materials are very heavy, requires bending and lifting to get mixed.	exterior graded level to be able to move in closer to our work

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
Carpet flooring	arch building design-difficulty in accessing the installation area; Use of knifes and scrapers can result in injury	Carpet tiles instead of rolled carpets
Ceramic tile flooring	high detail; porcelain glazed material; package, heavy material(large units); very heavy, back injuries due to movement and placement	low detail; smaller units/ packaging(less weight per package); hand trucks, pallet jacks and elevators to position materials on fllros and job site
Stone panel flooring	More the size of the panels, more labor required to perform the task; Heavy panels	Smaller size and/ or lighter weight stone panels
Resilient flooring	Knives and scrapers used during installation of these materials; more thick the material, more difficult to cut it.	
steel stairs	more parts, more risk	stringers with treads attached

Design Element	Special Designs That Increase Risk Of Injury	Special Designs That Decrease Risk Of Injury
Brick veneer	Tube scaffold; Chemical during brick washing Heavy shelf angle sections	prefabricated brick panels since factory assembled but prone to finger injuries; Hydraulic scaffold as it reduces risk of falls during continuous masonry operation and improves ergonomics
Slab on grade		Rebar spacing to allow shoe size to step between bar. Increase bar size
Doors	Tall and heavy doors	
Precast concrete stairs	Loading in through tall buildings	
Reinforced concrete stairs	Complex floor plan	Open floor plan
CMU backup walls	Large rebar diameter makes lap length of CMU big; Lifting blocks high over rebar causes shoulder injury	