International Journal of Scientific Engineering and Research (IJSER)
www.ijser.in
ISSN (Online): 2347-3878, Impact Factor (2014): 3.05

Analysis of Safety Risk in the Design of Multistorey Buildings

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Abstract: ***The design of the permanent structure being constructed is influenced by construction worker safety and health. Architects and design engineers affect construction worker safety and health through the decision they make in the design process. Inhibitors to implementation of the design for construction safety (DfCS) concept can be considered as lack of designer knowledge about construction processes and limited availability of tools to assist in assessing the safety risk associated with a design. This research involves the quantification of the construction safety risk of each of the design elements present in typical multistory buildings. Absolute safety risks were quantified for all design elements and construction activities using the survey-analytical research method. A Risk Analyzing Tool (RAT) will be designed which will assist building designers to assess the level of construction safety risk associated with their designs and is intended for use by designers during the design phase to create buildings that are safer to construct. The research will contribute to the construction industry body of knowledge by providing quantitative values that link specific design features to construction safety.***

Keywords: Risk, DfCS concept, Risk factors, Risk Analyzing Tool, Quantification

1. Introduction

The risk associated with constructing multistory buildings can take many forms involving significant risk associated with construction site safety hazards. The type and magnitude of risk present on construction sites depends to a great extent on the permanent design features. Construction projects typically engage multiple employers and a variety of trades which carry on a diversity of tasks on project sites. A project's design formed is the basis for the means and methods used during construction. Risk management can take place during the design stage to select design alternatives if the risk factors associated with design features are known, which minimize construction safety risk. The design for construction safety concept is defined as the consideration of construction site safety in the design of a project. It includes modifications to the permanent features of the construction project in such a way that construction site safety is considered; attention during the preparation of plans and specifications for construction in such a way that construction site safety is considered; the utilization of specific design for construction safety suggestions; and the communication of risks regarding the designing relation to the site and the work to be performed. Risk quantification process in construction is important and includes risk level determination of each objective and the risk analysis estimation by applying various approaches and technologies which evaluates performance of risk control.

1.1. METHODOLOGY

Literature survey was done about risk analysis. Data were collected in form of questionnaire survey for identification of the typical building design elements and associated construction activities. In analysis process, it involved the calculation of unit risk and cumulative risk factors of all the design elements and the associated construction activities. As a first step of analysis, the relative weights of the four severity categories were quantified. Finally, the risk factors developed were analyzed for assessing the level of construction safety risk associated. Methodology of the project is shown in figure 1.1.

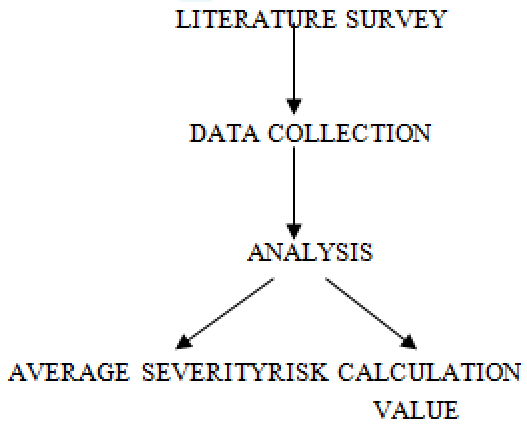

Figure 1.1: Methodology

2. Literature Review

Risk is defined as the combination of the probability (frequency) of a defined hazard and the consequences of its occurrence. Literature survey was focused on construction safety risk and risk quantification was explored and used to guide the development of the survey and the risk quantification process. Vineeth Dharmapalan has discussed the risk associated with constructing multistory commercial buildings which can take many forms. The type and magnitude of risk present on construction sites depends to a great extent on the permanent design features. [1]Jennifer Whyte has explored the relationships between construction safety and digital design practices with the aim of fostering and directing further research. [2]Matthew Hallowell has discussed the holistic quantification of risks for the activities associated with the construction of concrete formwork. Three major research efforts were discussed such as identification of activities required to construct concrete formwork,

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selection of an appropriate risk classification system and the quantification of the average frequency and severity levels for each risk classification associated with each activity. [3] Edmundas Kazimieras Zavadskas, has discussed the risk assessment of construction projects which is based on the multi-attribute decision-making methods. [4] Mumtaz A. Usmen has discussed about occupational injury and fatality risk analysis which was performed on 16 building trades. The approach was based on defining risk fundamentally as the product of probability (frequency) and severity, and using the risk plane concept to evaluate and rank the trades in terms of nonfatal injury rates.[5] Michael Behm has discussed about the link between construction fatalities and the design for construction safety concept.[6]

3. Survey and Analysis

This thesis addresses two main research questions: (1) what are the major constructions activities undertaken for the typical design elements of a multistory building; and (2) what are the safety risk values associated with the design elements when constructed using the major construction activities. A coupled field survey-analytical research methodology is employed to attain the research objectives. The field survey program included the development of survey questionnaires followed by data collection. The analysis includes the quantification of the relative weights of the four severity categories considered for the survey. These calculations are followed by a risk analysis where the unit risk and cumulative risk of design elements are calculated.

3.1 Questionnaire Survey

Questionnaire development began with an inventory of design features and construction activities for multistory buildings. This initial task entailed identifying all of the different design features present within a typical commercial office building, including all of the different design options for each feature, and the major activities performed on a jobsite to construct each design option. Based on the review of the literature, a total of 7 design elements and 55 construction activities were identified and documented. To develop frequency and severity scales for calculating safety risk, the frequency and severity categories were considered for the study. The frequency scale ranges from 1 incident every 6 min (0.1 worker hours) to 1 incident every 100 million or more worker hours. The severity scale includes a spectrum of 12 possible injury categories from negligible injury (severity = 1) to fatal injury (severity =26,214). The questionnaires were developed using these scales along with the inventory of design elements and construction activities. The injury severity levels were categorized based on the worker's ability to return to regular work. Severity categories were identified as: near miss, low severity, medium severity, and high severity. The severity categories used in this study are shown in Table 3.1. The frequency scale was defined as the average time between incidents in terms of hours, days, and weeks and is shown in Table 3.2.

Table 3.1: Severity Categories

Injury Severity Categories	Severity Levels
Near miss (no injury or 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

All of the questionnaires started with a similar instruction page describing how to complete the survey, the frequency scale to be used, and the severity categories and definitions. General demographic information about the participant was solicited. Respondents were asked to conduct the following tasks to complete the questionnaires: (1) for each design feature being reviewed, refine the list of construction activities if needed; (2) indicate the typical percentage of time required on each activity within the overall process to construct the design feature; (3) for each construction activity, identify the frequency (i.e., average amount of time) with which injuries at each severity level (near miss, low severity, medium severity, and high severity) occur on a project; and (4) for each design feature, indicate any special design features that increase or decrease the safety risk.

Table 3.2: Frequency Scale

Frequency Scale: Average Amount of Time Between Incidents	
Impossible	0
Negligible	1
50 years	2
10 years	3
5 years	4
1 year	5
6 months	6
1 month	7
1 week	8
1 day	9
1 hour	10

3.2 Analysis

The analytical program for the research involved the calculation of unit risk and cumulative risk factors of all the design elements and the associated construction activities. As a first step, the relative weights of the four severity categories were quantified. Following this step, the median frequency and median percentage activity exposure values were converted into usable units. These calculations were followed by a risk analysis where the unit risk and cumulative risk of design elements are calculated. The weighted averages were calculated using the formula given by:-

$$Y = \left(\sum_{1}^{n} x_i y_i\right) / \left(\sum_{1}^{n} x_i\right) \rightarrow \text{Equation (1)}$$

Where x_i represents the linear scale value and y_i represents the corresponding geometric scale value. Table 3.3 shows the linear scale and geometric scale values for each severity category. 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. It is important to document near misses to reduce reoccurrence and prevent more severe accidents. Near misses can be considered as indicators of hazards, and the severity impact is given a value of 1 while performing a hazard assessment and 0 for solely an injury assessment.

Table 3.3: Linear and Geometric Scale Values

Severity Levels	*Linear Scale Values*	*Geometric Scale Values*	*Injury Severity Category*
Near miss Negligible	0 0	0 1	Near miss
Temporary discomfort Persistent discomfort Temporary pain Permanent pain Minor first aid	1 2 3 4 5	2 4 8 16 32	Low severity
Major first aid Medical case Lost work time	6 7 8	64 128 256	Medium severity
Permanent disablement Fatality	9 10	1,024 26,214	High severity

The median frequency value aggregated for each activity and severity category were converted from units of worker-hours per incident to units of incidents per worker-hour. Each frequency value on the scale used for the survey corresponds to time periods in either hours, days, months, or years. The median frequency responses were converted to worker-hours and by finding the inverse of these frequency values, the actual frequency values in incidents per worker-hour is calculated. The median activity exposure values aggregated for each activity from the participant responses were converted to worker-hours per unit of design element. The converted frequency values in terms of incidents 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 then used to calculate the risk values for each activity and each severity category. Unit risk and cumulative risk values corresponding to each activity and each severity category were calculated using the formula as given below:

Unit Risk=Frequency× Severity → Equation (2)
Cumulative Risk = Frequency× Severity× Exposure → Equation (3)

The summation of the unit risks corresponding to each severity category for an activity (i.e., horizontally along an activity) gives the total unit risk (TUR) associated with the activity for the design feature. The summation of the cumulative risks corresponding to each severity category for an activity gives the total cumulative risk associated with the activity 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. Using the calculation procedures, the unit risk and cumulative risk factors for all of the design features were calculated. For each of the design elements, the construction safety risk values were quantified for each of the four severity categories and for each construction activity.

4. Result

The analytical program for the research involved the calculation of unit risk and cumulative risk factors of all the design elements and the associated construction activities. The unit risk and cumulative risk factors for all of the design features were calculated. For each of the design elements, the construction safety risk values were quantified for each of the four severity categories and for each construction activity along with its activity exposure. The activity exposure field shows the average percentage values of time spent by a crew performing the different activities. For example, as per the respondent, a crew takes 30% of the time for formwork construction, 10% for pouring concrete, and so forth. For the four severity fields, the respondent has provided the average duration between incidents (using the frequency scale) for each activity. For example, for stripping of formwork, a near miss happens approximately once every five years, low severity and medium severity incidents occur once every year and high severity is negligible. Similar numerical responses were received from the survey respondents for all the design elements to calculate the risk factors.

5. Risk Analysing Tool

In addition to quantifying the risk factors, the research included the development of a Risk Analyzing Tool (RAT).The tool acts as a calculator to calculate the risk values for every design element of the building. The tool is structured in a simple format that allows designers to focus on their designs and on the safety risk associated with their designs. For each project being designed, the tool prompts users to input the quantities of each of the different design features included in the project. After all of the design quantities are input, or just those which are of interest to the designer, the tool calculates the risk factor values associated with the design elements of the specific building.

6. Conclusion

Risk factors relating each individual design element within a building to the safety of those who construct the design elements can be quantified. To do so, relevant experiential input is required that addresses frequency, severity, and exposure associated with each of the activities required to construct the design elements. Lacking such input will not allow for determining comprehensive risk factors that account for different levels of severity and for different amounts of exposure. In addition, representative frequency and severity scales are needed to convert the input received to the risk factors. Risk factors are different from one design element to another. Additionally, depending on the design element, the risk factor may vary between the possible options for each design element .The calculated risk factors are impacted by the risk perceptions of those surveyed. The analyses reveal that risk perceptions vary between different project personnel. This impact on the final risk values should be taken into consideration when conducting the research and applicable controls should be implemented. For future research, it is suggested that the assessment tool can be created to allow designers to quantitatively assess the common safety risk value for the entire project associated with constructing a design and to compare the safety risk between alternative designs.

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