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Identification and Analysis of Safety Risk Factors in Design for Building Construction

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Abstract

Construction safety is an important aspect that needs to be considered from the design stage to the demolition stage of a building to minimize the risk of accidents and building failures. This study aims to identify, analyze and determine control measures for design safety risk factors that can affect safety during the construction, operation and maintenance stages of building construction. The research approach is a quantitative approach using the Failure Mode and Effects Analysis (FMEA) method. Data were collected through a questionnaire survey sent to 80 respondents consisting of local consultants and contractors domiciled in West Sumatra Province. The results show that critical risks are injury or fatalitis due to fire and emergency condition with an RPN value of 30.95; falling from height with an RPN value of 29.8; injuries due to damage to facilities with an RPN value of 29.4; fatique due to manual handling with an RPN value of 28.3 and slipping due to movement of people and materials with an RPN value of 27.9. Based on the results, it is expected to contribute to the preparation of hazard identification, assessment and control of safety risks in the construction stage by adopting the design for safety concept so that the risk of accidents and building failures can be prevented.

Keywords: *design for safety, safety risks, factors, design, building, FMEA*

1. Introduction

Occupational safety and health are crucial factors in the implementation of construction projects. According to data from the Social Security Agency (BPJS Ketenagakerjaan), in 2023 there were 370,747 cases of workplace accidents in Indonesia, with 2,965 cases occurring in the construction sector. As of October 2024, the number of workplace accidents reached 356,383 [1]. These accidents not only cause injuries and deaths but also damage the environment. Several incidents in the past five years, compiled through social media, indicate that the main causes are structural failure, design errors, and a lack of safety awareness. Construction accidents should not only be focused on their impacts but also on how they occurred. Defects that exist and lead to failures in the pre-construction stage develop, leading to construction accident incidents. Defects as deficiencies in design are caused by failure to meet professional standards in planning and design, design using substandard materials or building components, non-compliance with standards, and failure to meet standards regarding quality and workmanship [2]. Inadequate, inaccurate and fragmented design tolerance information in specifications, failure to convey tolerance information during the tender process and ineffective quality control documents are also significant causes of structural defects [3].

Design plays a crucial role in determining worker safety, as it is the initial stage of project implementation. The Designer must determine the design application based on the project complexity, establish a risk management context by identifying workplace hazards in accordance with regulations and standards, identify required design disciplines and competencies, and establish collaborative relationships with the Project Owner and other parties affected by the design. Hazards that may be influenced, created, or increased by the design of an asset must be assessed for their risk, and consideration must be given to possible ways in which these hazards can be eliminated or minimized. Design errors can lead to workplace accidents, such as building collapses, worker falls from heights, and other workplace accidents. Therefore, it is necessary to conduct a risk analysis of design implementation on construction safety in building construction. The Designer is also required to refer to the Regulation of the Minister of General Works and Public Housing Number 10 of 2021 concerning the Construction Safety Management System with the aim of considering safety aspects from the beginning of both project planning and buildings, infrastructure, and other engineering systems.

Design for safety is an approach that integrates safety aspects to anticipate or handle problems that consider Health and Safety from the early stages of construction project design that aims to eliminate and reduce risks in the workplace before construction begins, considering hazards and risks throughout the life cycle of the structure from the construction, operational, maintenance and demolition stages [4]. Design for safety can reduce the number of work accidents from construction to the operational period of the building, can save costs, ensure regulatory compliance, and improve the company's reputation and project performance because the building is safer for workers and end users.

An aspect of the safety process in design is incorporating risk assessment and hazard management into the design development process. The safety risk management process in design begins with identifying hazards, assessing, and controlling those design hazards. Examples of potential safety and health hazards identified at the design stage are confined work areas, energy sources, hazardous substances, working on tall structures, work procedures, equipment/machinery, the environment, material disposal, and so on. Studies on the identification and assessment of safety risks at the design stage for building construction are still limited and are still being studied. Ran Lv et al (2023), explored the factors that influence the safety risks of construction buildings from the perspective of the relationship between the design and construction phases of pre-fabricated material components, operators, environmental management, and technology [5]. Jeong et al (2022), stated that the risk of falling from heights and the workplace is a priority risk in modular construction in the pre-construction stage [6]. Payungallo et al (2025) concluded that the preparation of Detailed Engineering Design (DED) has the most potential safety hazards [7]. This study aims to identify the risk factors of design activities for the safety of building construction projects from the perspective of Designers and Contractors and determine safety risk control measures at the design stage.

2. Research Method

This research is a quantitative study that identifies and analyzes safety factors in design of building construction projects. The research respondents were local consultants and contractors, numbering 80 out of 402 people who are members of the Consultant and Contractor Association in West Sumatra Province. The research sample was determined using a purposive sampling technique, namely respondents who are considered to have understanding and experience related to design and construction safety. The research began by determining the problem formulation and research objectives and then conducting a literature study, compiling instruments to collect primary data. The primary data collection instrument used a questionnaire form that tested the validity and reliability of the causal factors analyzed using Failure Mode and Effect Analysis (FMEA). FMEA is a methodical process to determine the root cause of a problem used to determine how an item, facility, or system can fail and the consequences of that failure [8]. Several phases that need to be considered before conducting an FMEA analysis are first identifying design safety risk factors, identifying the probability assessment scale of occurrence, severity and detection. Priority risks require control and mitigation efforts. The severity, occurrence and detection assessment scales can be shown in Table 1, Table 2, and Table 3.

Table 1. The Level of Severity

Rating Scale	Item of Severity
1	Negligible design deviation error
2	Error level with deviation requiring design changes
3	Structural component damage
4	Significant structural failure has occurred
5	Potential construction accident (injury and death)

Table 2. Level of Occurrence

Rating Scale	Item of Occurrence
1	Very rarely occurs in more than 10 years
2	Rarely occurs in 5-10 years
3	Sometimes occurs in 3-4 years
4	Frequently occurs in less than 1 year

Table 3. The Level of Detection

Rating Scale	Item of Detection
1	The cause of the design error is very easy to detect and preventive action can be taken quickly.
2	The design error is easy to detect and preventive action can be taken.
3	Somewhat easy to detect and sometimes preventive action can be taken.
4	Difficult to detect and nonconformity prevention methods are less effective.
5	Very difficult to detect and preventive action is ineffective.

Next, calculate the RPN for each design safety risk factor and its average RPN. Priority risks are those with RPN values exceeding the average RPN. The RPN calculation can be formulated as follows:

Risk Priority Number (RPN) = S (Severity) x O (Occurrence) x D (Detection) (1)

Then, to calculate the RPN, the risk factors and the average RPN are calculated respectively. The most critical risk factors are seen from the values that exceed the average RPN displayed through the histogram diagram which can be seen in Figure 1. The average RPN can be formulated as follows.
The Average of RPN = Total RPN value / Number of risk factor (2)

Critical RPN = RPN > The Average of RPN (3)

3. Result

3.1 Validity and Reliability Test

Validity testing was conducted on 80 respondents with 25 safety risk factors in the design, and showed that all statements in the questionnaire were declared valid and reliable. The validity test in the study used a significance level of 5%, with an r-table value of 0.220. Each statement item was declared valid if the calculated r-value was greater than the r-table (R-Calculation > 0.220). A variable can be said to be reliable when it has a Cronbach's Alpha value of more than 0.6 and the total variance value of all risk factors is 0.957 where it is > the Conbrach's Alpha value of 0.6. The results of the validity and reliability tests are shown in Table 4 and Table 5.

Table 4. Results of the validity test of safety risk factors in design

No	The Components of Design	Hazard/Safety Risk		R-Calculation	R-Table	Valid or Invalid
1	Electrical installation	Short circuit	(R1)	0,428	0,220	Valid
		Fire	(R2)	0,565	0,220	Valid
		Electrical shock	(R3)	0,654	0,220	Valid
2	Fire and emergency systems	Evacuation failure	(R4)	0,724	0,220	Valid
		Injury or Fatalities	(R5)	0,569	0,220	Valid
3	Movement of people and materials	Collision	(R6)	0,633	0,220	Valid
		Slipping	(R7)	0,685	0,220	Valid
		Injury	(R8)	0,663	0,220	Valid
4	Workplace	Heat stress	(R9)	0,791	0,220	Valid
		Visual disturbances	(R10)	0,725	0,220	Valid
		Fatigue	(R11)	0,786	0,220	Valid
5	Lay out	Evacuation route disruption	(R12)	0,786	0,220	Valid
		Utility damage	(R13)	0,734	0,220	Valid
6	Facilities and Utilities	Injuries due to damage to facilities	(R14)	0,783	0,220	Valid
7	Earthworks	Landslide	(R15)	0,775	0,220	Valid
		Structure collapse	(R16)	0,780	0,220	Valid
		worker accident	(R17)	0,606	0,220	Valid
8	Structural reliability	Building collapse	(R18)	0,676	0,220	Valid
9	Manual handling	Back injury	(R19)	0,683	0,220	Valid
		Fatique	(R20)	0,689	0,220	Valid
10	Hazardous Substances	Exposure to hazardous materials	(R21)	0,734	0,220	Valid
11	Fall prevention system	Falling from height	(R22)	0,808	0,220	Valid
12	Special risks	Offshore project risks	(R23)	0,790	0,220	Valid
		Underground project risks	(R24)	0,717	0,220	Valid
13	Noise exposure	Hearing disorders	(R25)	0,816	0,220	Valid

Table 5. Results of reliability testing of safety risk factors in design

No	The Components of Design	Hazard/Safety Risk		Variance	Reliable or Unrealiable
1	Electrical installation	Short circuit	(R1)	0,602	Reliable
		Fire	(R2)	0,542	Reliable
		Electrical shock	(R3)	0,569	Reliable
2	Fire and emergency systems	Evacuation failure	(R4)	0,759	Reliable
		Injury or Fatalities	(R5)	0,547	Reliable
3	Movement of people and materials	Collision	(R6)	0,554	Reliable
		Slipping	(R7)	0,540	Reliable
		Injury	(R8)	0,638	Reliable
4	Workplace	Heat stress	(R9)	0,391	Reliable
		Visual disturbances	(R10)	0,556	Reliable
		Fatigue	(R11)	0,759	Reliable
5	Plant Lay out	Evacuation route disruption	(R12)	0,829	Reliable

6	Facilities and Utilities	Utility damage	(R13)	0,962	Reliable
		Injuries due to damage to facilities	(R14)	0,576	Reliable
7	Earthworks	Landslide	(R15)	0,855	Reliable
		Structure collapse	(R16)	0,728	Reliable
		Worker accident	(R17)	0,695	Reliable
8	Structural reliability	Building collapse	(R18)	0,490	Reliable
9	Manual handling	Back injury	(R19)	0,794	Reliable
		Fatique	(R20)	0,891	Reliable
10	Hazardous Substances	Exposure to hazardous materials	(R21)	0,703	Reliable
11	Fall prevention system	Falling from height	(R22)	0,650	Reliable
12	Special risks	Offshore project risks	(R23)	0,549	Reliable
		Underground project risks	(R24)	0,478	Reliable
13	Noise exposure	Hearing disorders	(R25)	0,619	Reliable

3.2 RPN calculation of safety risk in design

By using the RPN calculation formula in equation (1), the RPN value is obtained for each risk factor as shown in Table 6.

Table 6. RPN Calculation of Safety Risk in Design

No	The Components of Design	Hazard/Safety Risk		Severity	Occurrence	Detection	RPN
1	Electrical installation	Short circuit	(R1)	2,89	2,84	2,61	21,40
		Fire	(R2)	2,86	3,10	2,59	22,96
		Electrical shock	(R3)	2,83	2,94	2,93	24,27
2	Fire and emergency systems	Evacuation failure	(R4)	3,18	2,65	3,01	25,35
		Injury or Fatalities	(R5)	3,30	3,10	3,03	30,95
3	Movement of people and materials	Collision	(R6)	2,85	2,94	3,08	25,74
		Slipping	(R7)	3,11	3,03	2,96	27,89
		Injury	(R8)	2,98	2,89	3,11	26,74
4	Workplace	Heat stress	(R9)	2,86	2,63	2,84	21,32
		Visual disturbances	(R10)	2,85	2,70	3,06	23,57
		Fatigue	(R11)	3,08	2,79	2,66	22,82
5	Plant Lay out	Evacuation route disruption	(R12)	2,69	2,65	3,19	22,70
6	Facilities and Utilities	Utility damage	(R13)	3,18	2,93	3,16	29,37
		Injuries due to damage to facilities	(R14)	2,88	2,85	3,04	24,89
7	Earthworks	Landslide	(R15)	3,08	2,71	2,93	24,40
		Structure collapse	(R16)	3,09	2,88	2,98	26,41
		Worker accident	(R17)	2,94	2,78	2,85	23,23
8	Structural reliability	Building collapse	(R18)	3,01	2,70	2,59	21,05
9	Manual handling	Back injury	(R19)	2,83	2,73	3,04	23,38
		Fatique	(R20)	3,40	2,93	2,85	28,34
10	Hazardous Substances	Exposure to hazardous materials	(R21)	2,88	2,79	2,73	21,84
11	Fall prevention system	Falling from height	(R22)	2,98	3,18	3,15	29,75
12	Special risks	Offshore project risks	(R23)	2,84	2,90	2,90	23,86
		Underground project risks	(R24)	2,61	3,04	2,86	22,72
13	Noise exposure	Hearing disorders	(R25)	2,86	2,89	3,16	26,14
	Total RPN Value						**621,09**
	Average RPN						**24,84**

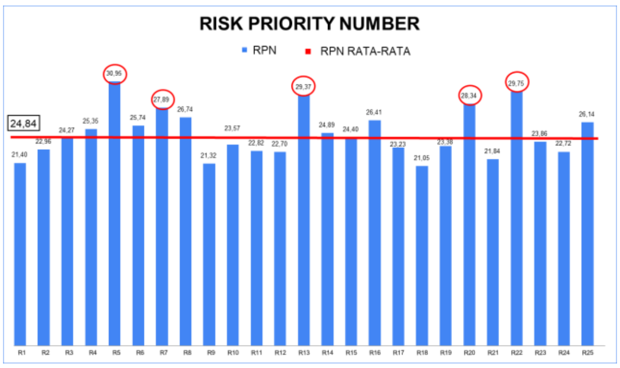

Figure 1. The Histogram of Risk Priority Number (RPN)

3.3 Priority safety risks in design

Based on the calculation of the Risk Priority Number (RPN), the average RPN value was 24.84. RPN values exceeding the average RPN value are considered critical, and risks with critical RPN values are considered priority risks. The following 5 priority risks with critical RPN values and their recommended control measures are shown in Table 7.

Table 7. Critical RPN

Safety Risk in Design	Code	RPN	Ranking	The Control Measures
Injury or fatalitis due to fire and emergency condition	(R5)	30,95	1	▪ Integrate fire protection systems (sprinklers, alarms, extinguishers) from the design stage. ▪ Provide adequate emergency exits and evacuation routes in compliance with building codes. ▪ Design for redundant power supply and fire-resistant materials to reduce ignition risk.
Falling from height	(R22)	29,8	2	▪ Incorporate fall prevention systems (guardrails, safety nets, anchor points) directly into building design. ▪ Ensure safe access routes (stairs, ladders, platforms) with ergonomic layout. ▪ Plan maintenance access points (e.g., façade cleaning, roof inspection) with integrated safety harness points.
Injuries due to damage to facilities	(R13)	29,4	3	▪ Design for structural redundancy to minimize collapse risk if one component fails. ▪ Use quality materials and ensure compliance with SNI & ISO standards. ▪ Integrate preventive maintenance planning into the design (durable finishes, replaceable elements).
Fatique due to manual handling	(R20)	28,3	4	▪ Apply ergonomic design (layout to minimize excessive manual lifting). ▪ Include mechanical handling aids (elevators, hoists, conveyors). ▪ Plan workspaces to reduce repetitive strain (adjustable height, proper clearances).
Slipping due to movement of people and materials	(R7)	27,9	5	▪ Provide separate pathways for pedestrian and material movement. ▪ Ensure spacious circulation areas to reduce congestion. ▪ Design with traffic flow analysis to prevent collision and slipping hazards.

4. Conclusion

Based on the research stages that have been conducted, several points can be concluded from the results of this study, including the following:

1. There are 25 safety risk factors in building construction design, with validity and reliability tests declared valid (R-Calculation > 0.220) and reliable (Cronbach's Alpha value > 0.6), enabling a risk assessment using the FMEA method.
2. The safety risks in the design categorized as priority risks are injury or fatality due to fire and emergency conditions (R5) with an RPN value of 30.95; falling from a height (R22) with an RPN value of 29.8; injuries due to damage to facilities (R13) with an RPN value of 29.4; fatigue due to manual handling (R20) with an RPN value of 28.3; and slipping due to the movement of people and materials (R7) with an RPN value of 27.9.
3. Safety risk control measures in design include eliminating or minimizing design hazards for construction, operation, maintenance and demolition safety such as in planning project layouts, designing structural reliability, considering ergonomic aspects of work methods, and integrating safety factors into the design of fire protection systems, fall prevention and material movement.
4. Based on the results, it is expected to contribute to the preparation of hazard identification, assessment and control of safety risks in the construction stage by adopting the design for safety concept so that the risk of accidents and building failures can be prevented.

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