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Research Paper

Application of the FMEA Method in the Study of Construction Safety Risks in High-Rise Building Projects: A Case Study of the Tower AB Project at the State University of Jakarta

Muhamad Wilfadz [1], Hari Nugraha Nurjaman [2], Dwi Dinariana [3]
[1,2,3] *(Faculty of Civil Engineering, Department of Engineering and Construction Project Management, Persada Indonesia YAI University)*
Corresponding Author: Muhamad Wilfadz

ABSTRACT: *High-rise building construction is a complex process that involves various occupational safety risks, especially in activities performed at height. This study aims to identify, analyze, and evaluate occupational safety risks in high-rise building construction projects, with a case study on the Tower AB construction project of the State University of Jakarta. The Failure Mode and Effect Analysis (FMEA) method was used to determine the Risk Priority Number (RPN) for each potential hazard, based on assessments of severity, occurrence, and detection. The research was conducted through expert validation, questionnaire distribution, and risk ranking based on the RPN values. Nine risks with the highest RPN scores were selected to develop risk response recommendations. Validation was also conducted through interviews with the project's Health, Safety, and Environment (HSE) team to evaluate the alignment between the proposed risk responses and actual field conditions. The results showed that all proposed risk responses were approved by the project team, with additional notes provided on risks X33 and X21 to strengthen mitigation efforts. These findings demonstrate that the FMEA-based risk response framework can be applied and is aligned with practical field implementation.*

KEYWORDS: *Construction safety risk, FMEA, RPN, High-Rise Building, Risk Management*

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I. INTRODUCTION

The construction industry is a strategic sector in national development but also ranks highest in workplace accidents. This is due to its complex processes, involvement of multiple stakeholders, heavy equipment use, and high-risk work environments. Safety management in construction must therefore be treated as a core component of project execution.

In Indonesia, accident data from BPJS Ketenagakerjaan and the Ministry of Manpower show that construction remains the most accident prone sector. This reflects weaknesses in hazard identification, risk evaluation, and structured mitigation planning.

Such challenges are evident in large scale educational projects like the Tower AB Project at the State University of Jakarta, part of a national infrastructure modernization initiative funded by international loans. With high-rise structures and technical works, the project involves significant safety risks requiring compliance with both national and international standards.

To address these risks, this study applies the Failure Mode and Effect Analysis (FMEA) method—an approach that systematically evaluates potential failures based on severity, occurrence, and detection, producing a Risk Priority Number (RPN) to determine mitigation priorities. This research aims to assess construction safety risks in the Tower AB Project using FMEA and provide practical risk-based recommendations for improving safety performance in high-rise building construction.

II. LITERATUR REVIEW

CONSTRUCTION PROJECTS

A construction project is defined as the process of building a structure that is planned in accordance with specific designs and executed within defined time and resource constraints. Its primary purpose is to meet the needs of the client or end user [1]. In execution, construction projects are governed by the "triple constraint" a framework that balances time, cost, and quality objectives to ensure project success [2]. Due to their complex nature, these projects require precise coordination among stakeholders, proper scheduling, and effective management strategies.

Construction activities can be classified into several categories based on their scale and function. These include: (1) Building Construction, such as housing, offices, schools, and hospitals; (2) Heavy Engineering Construction, which involves infrastructure like roads, bridges, dams, and ports; (3) Industrial Construction, including factories, power plants, and processing facilities; (4) Transportation Construction, covering toll roads, tunnels, railways, and terminals; and (5) Specialized Construction, such as underwater tunnels, earthquake-resistant buildings, heritage restorations, and eco-friendly smart buildings. Each type poses unique technical and safety challenges that require specialized approaches in design, execution, and risk management.

BUILDING CONSTRUCTION PROJECTS

Building construction is a complex activity composed of interconnected phases, each carried out with specific objectives within a defined timeframe. In the context of high-rise buildings such as apartments, construction work presents heightened risks due to the involvement of numerous workers and the vertical scale of the structure [3]. These projects typically involve multiple technical stages from design and planning to execution and supervision. Each stage must comply with established technical standards, specifications, and implementation protocols. Given this complexity, the role of supervising consultants becomes critical in ensuring the project meets quality standards, timelines, and safety requirements [4].

Comprehensive planning is essential in building construction projects, incorporating considerations such as local building regulations, technological efficiency, and occupational health and safety. These projects go beyond residential and commercial buildings, extending to public infrastructure such as hospitals, places of worship, and educational facilities like university buildings. In the initial phase, civil engineers and architects are responsible for project planning, which is then implemented on site under strict technical supervision. Due to the inherent risks associated with multi-story building construction, safety management must be treated as a fundamental component of project management. This includes systematic hazard identification, risk evaluation, and the implementation of mitigation strategies to prevent accidents, project delays, financial losses, and reputational damage.

CONSTRUCTION SAFETY

Construction safety encompasses all engineering efforts aimed at ensuring security, occupational health, and sustainability throughout the implementation of construction projects. According to the Ministry of Public Works and Public Housing Regulation No. 10 of 2021, construction safety involves protecting not only construction workers but also nearby communities and the surrounding environment from potential hazards that may arise during project execution [5]. In high-rise building projects, safety risks are particularly diverse and complex, including hazards such as falls from height, collisions with heavy equipment, collapse of temporary structures, and unsafe working conditions. Consequently, a structured and systematic risk management approach is essential to prevent accidents, injuries, and project related losses.

As part of the government's commitment to improving safety standards, the regulation mandates the implementation of a Construction Safety Management System (SMKK). SMKK is an integral component of project management that ensures safety throughout all project phases from planning to supervision. Project implementers are required to prepare safety documents such as the Construction Safety Plan (RKK) and conduct quantitative risk assessments using methods appropriate to the complexity of the work [5]. One effective method for assessing and prioritizing safety risks is the Failure Mode and Effect Analysis (FMEA), which evaluates risk based on severity, likelihood of occurrence, and detectability. The resulting Risk Priority Number (RPN) serves as a guide in determining which risks should be addressed first through mitigation strategies.

RISK

Risk can be defined as the potential danger or negative outcome that may result from an ongoing or forthcoming process. Risk is an uncertain event that could cause harm or loss. In the context of construction projects, the presence of multiple stakeholders such as contractors, consultants, suppliers, and clients introduces a wide range of uncertainties. This makes effective communication and coordination among project participants essential. When communication fails, it can significantly disrupt coordination and lead to operational inefficiencies in the field [6].

In risk management theory, project risk is often understood as a combination of the likelihood of an uncertain event and the impact it may cause. These risks have the potential to interfere with the achievement of project objectives and expected outcomes. Proper identification and analysis of risks enable project teams to minimize their adverse effects through appropriate mitigation strategies, ensuring that the project stays on track in terms of scope, cost, and timeline.

RISK MANAGEMENT

Risk management is a comprehensive process aimed at identifying, evaluating, and addressing potential risks using appropriate methods and tools. Primary goal of risk management is to reduce the adverse effects of unexpected events through prevention, planning, and structured mitigation efforts. This process ensures that organizations are better prepared to deal with uncertainties that may impact performance, resources, or project objectives.

Based on the SNI ISO 31000:2018 standard, risk management involves a systematic and effective approach to identifying, assessing, monitoring, and managing risks associated with activities, processes, or organizational structures. It helps minimize potential losses while enhancing opportunities. This framework can be applied across all types of organizations with defined goals and operational structures. The general stages of risk management typically include: risk identification, risk analysis, risk evaluation, risk treatment or mitigation, communication and consultation, and continuous monitoring and review. These stages are interrelated and are essential for creating a dynamic and adaptive risk management strategy suitable for complex construction environments.

FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Failure Mode and Effect Analysis (FMEA) is a structured method used to identify potential failure modes in a process or system and to assess their consequences in order to reduce or eliminate the likelihood of failure [7]. According to [8], FMEA integrates expert knowledge and experience to evaluate the severity, causes, and effects of potential failures, enabling corrective or preventive actions. The FMEA process involves several key steps:

1. Identifying potential failure modes in each stage of the work process.
2. Assessing the impact of each failure (Severity), using a scale from 1 (minor) to 5 (critical).
3. Determining the likelihood of failure occurrence (Occurrence), also rated from 1 (rare) to 5 (frequent).
4. Evaluating the effectiveness of existing controls (Detection), with a rating from 1 (highly effective) to 5 (ineffective).
5. Calculating the Risk Priority Number (RPN) by multiplying Severity, Occurrence, and Detection (RPN = S × O × D).
6. Ranking risks based on RPN values to prioritize mitigation strategies.

FMEA provides a systematic and quantitative basis for risk assessment and is widely used in safety-critical industries, including construction, to support proactive decision-making.

Table 1 - Severity Rating Scale in the FMEA Method

Severity Level / Impact Description	Score
Fatal or causes permanent life-changing injury	5
Serious impact (individual is unable to perform any activity)	4
Moderate impact (individual is unable to work for 1–2 days)	3
Minor impact (individual can still perform activities with mild discomfort)	2
No impact (individual experiences no effect from the incident)	1

Source: [9]

Table 2 - Occurrence Rating Scale in the FMEA Method

Probability of Occurrence	Frequency Estimate	Score
Very high and unavoidable	>1 in 2	5
High and occurs frequently	1 in 8	4
Moderate and occurs occasionally	1 in 80	3
Low and rarely occurs	1 in 2,000	2
Very low and almost impossible to occur	1 in 150,000	1

Source: [9]

Table 3 - Detection Rating Scale in the FMEA Method

Detectability	Detection Level	Score
Very low detection. The risk can be completely prevented because the preventive actions are highly effective and routinely implemented, such as regular inspections and mandatory PPE usage	Very Rare	5
Low detection. Risks are easily identified, and prevention is fairly effective through standard procedures such as equipment checks and PPE usage.	Very Low	4
Moderate detection. Risks are sometimes detected; preventive actions are applied but not consistently.	Moderate	3
High detection. Risks are difficult to identify; supervision and preventive actions are not optimal or are not conducted routinely.	High	2
Very high detection. Control tools can accurately detect the form and causes of failure.	Almost Certain	1

Source: [10]

III. RESEARCH METHODS

This study uses a descriptive qualitative approach, focusing on the Tower AB Project located at Campus A, State University of Jakarta. Data collection was carried out in three phases: literature review, expert validation, and questionnaire distribution.

The data used in this study are as follows:

- Primary Data: Expert-based questionnaire using FMEA parameters (S, O, D)
- Secondary Data: Project documentation, regulations (ISO 31000, Permen PUPR 10/2021), and previous studies

Risk assessment process:

- Risk Identification: Derived from expert interviews and document analysis
- Risk Analysis: Severity, occurrence, and detection values were assigned for each risk
- Risk Evaluation: RPN values calculated and ranked to identify critical risks
- Critical Risk Threshold: The average RPN score was used to set the minimum value for critical risks
- Risk Mitigation: Recommendations proposed for top-ranked risks
- Validation: Field validation was conducted with the HSE team

DATA COLLECTION

The data used in this study were construction safety risks identified in the Tower AB Construction Project at Universitas Negeri Jakarta. The first stage of data collection involved literature review and expert validation through interviews with project stakeholders, particularly the Health, Safety, and Environment (HSE) team. The purpose was to identify potential hazards during high-risk activities, especially those related to working at heights.

The second stage involved the distribution of a structured questionnaire based on the Failure Mode and Effect Analysis (FMEA) method. The questionnaire assessed three main variables: severity, occurrence, and detection. It was completed by 20 certified HSE practitioners working on the project, selected based on their direct involvement and expertise in construction safety management.

Each identified risk was evaluated according to its severity level (impact of failure), likelihood of occurrence, and the ability of existing systems to detect or prevent the failure. The results were used to calculate the Risk Priority Number (RPN) for each risk, which served as the basis for prioritizing safety responses and determining mitigation strategies.

DATA ANALYSIS

Referring to the methodological procedures applied in this study, the data analysis includes several stages: identification of construction safety risks, risk assessment using the FMEA method, and validation of mitigation responses. These stages were used to evaluate the level of construction safety risks in the Tower AB Construction Project at Universitas Negeri Jakarta.

1. Risk Identification

The identification of safety risks was carried out through a combination of field observations, interviews, and literature studies. A total of 20 certified HSE practitioners were selected as respondents to assess risk variables: severity (S), occurrence (O), and detection (D). Each risk was reviewed based on potential work hazards occurring in high-risk activities, such as working at heights, lifting operations, and material handling. The identified risks were then compiled and ranked to determine the most critical ones.

2. Risk Priority Number (RPN)
The FMEA method was applied to calculate the Risk Priority Number (RPN), integrating three key aspects: severity, occurrence, and detection. Each variable was scored on a scale of 1 to 5. The RPN was calculated using the formula:

$$RPN = S \times O \times D$$

With description:
S : Severity
O : Occurrence
D : Detection

The higher the RPN, the more critical the risk is considered. This prioritization aids in determining which risks require immediate control or mitigation strategies.

3. Validation of Risk Responses
After the risk response strategies were formulated based on the highest RPN scores, a validation phase was conducted with the project's HSE team. This step aimed to review and confirm whether the proposed mitigation actions were consistent with actual field practices and HSE standards. The validation involved structured interviews and feedback sessions focusing on the practicality and relevance of each proposed response.

4. Risk Response Evaluation
The final response strategies were adjusted based on the input from the HSE team to ensure both technical relevance and practical applicability in the field. These updated responses are used as the final recommendations for managing high-risk safety hazards on-site.

IV. FINDING AND DISCUSSION

PROJECT OVERVIEW

The Tower AB Construction Project is part of the Phase II Civil Works under the Development and Upgrading Program of the State University of Jakarta. The project aims to enhance the quality and capacity of campus infrastructure to support academic, administrative, and institutional service activities comprehensively. Located at Campus A of Universitas Negeri Jakarta in Rawamangun, East Jakarta, the project falls under the category of high-rise building construction with considerable technical complexity. The construction scope includes structural works, architectural finishes, mechanical and electrical systems, and supporting facilities, all carried out in multiple phases.

The nature of this project involves intensive construction activities, heavy equipment operation, and extensive work at height, which presents significant safety challenges. These factors necessitate a structured and preventive safety risk assessment approach to ensure that construction operations are conducted safely, efficiently, and with minimal disruption to the surrounding academic environment. By applying Failure Mode and Effect Analysis (FMEA), this study aims to identify and evaluate potential construction safety risks, allowing for the development of appropriate mitigation strategies tailored to the specific conditions of the Tower AB project.

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Figure 1 – Site Plan Area

THE RESULT OF RISK IDENTIFICATION

The risk identification process in this study was conducted exclusively through a comprehensive literature review focusing on construction safety risks commonly found in high-rise building projects. This review resulted in the identification of 47 potential safety risk variables, covering various hazards such as falls from height, struck by objects, electrical incidents, and material handling failures. Subsequently, the list of identified risks was validated by three experts in construction safety, leading to a refined list of 43 relevant risk variables deemed applicable to the Tower AB Construction Project at Universitas Negeri Jakarta.

To assess these risks, the Failure Mode and Effect Analysis (FMEA) method was employed, evaluating each risk based on three parameters: occurrence (O), severity (S), and detection (D). A structured questionnaire was then distributed to 20 HSE professionals working in building construction projects, selected based on their experience and role in managing on-site safety. This validation ensured that the risk identification was both academically grounded and practically relevant to real world construction environments.

Table 4 – Identification Risk

Variable	Failure Mode
X1	Worker scratched by scattered material objects
X2	Worker struck by collapsed and unstable materials
X3	Worker's foot punctured by sharp scattered materials
X4	Collision or accident involving heavy equipment
X5	Excavator falls into soil excavation pit
X6	Heavy equipment collides with tools and materials
X7	Worker suffers respiratory issues (shortness of breath) due to dust and vehicle exhaust
X8	Worker's foot run over by heavy equipment (excavator, dump truck)
X9	Worker falls or slips into excavation pit
X10	Worker buried by landslide during excavation
X11	Worker struck by materials or manual tools during piling
X12	Worker scratched by reinforcing steel bars
X13	Worker punctured by sharp scattered materials left from piling activities
X14	Worker struck by rebar while lifting it
X15	Worker's fingers or hands cut by bar cutter during rebar fabrication
X16	Worker's hand scratched by steel bars
X17	Worker's eyes exposed to fine steel dust
X18	Worker's fingers or hands lacerated by cut rebar edges
X19	Worker exposed to sparks during welding
X20	Worker's foot punctured by scattered rebar wire or steel rods
X21	Steel material falls from height and hits worker
X22	Worker electrocuted due to electrical short circuit
X23	Worker's hand punctured by nails, wood, or hit by hammer
X24	Worker's hand pinched by formwork

Variable	Failure Mode
X25	Worker's hand injured by sharp saw blade
X26	Worker struck by brittle formwork material during installation
X27	Worker trips over dismantled formwork debris
X28	Worker's head hits formwork
X29	Worker falls during formwork installation
X30	Formwork material falls from height and hits worker
X31	Heavy equipment hits tools, materials, or workers near the site
X32	Worker sprayed by concrete
X33	Worker struck by falling concrete bucket
X34	Wet concrete spills and hits worker below
X35	Worker bumps into concrete bucket
X36	Worker falls from height during scaffolding installation
X37	Worker struck by unsecured scaffolding material
X38	Worker struck by collapsing brick wall
X39	Worker's eyes exposed to mortar splashes
X40	Worker splashed with paint
X41	Skin irritation due to paint exposure
X42	Worker suffers respiratory problems due to ceramic dust from cutting
X43	Worker struck by flying ceramic shards

Source: Processed results Alone, 2025

THE RESULTS OF RISK ANALYSIS AND EVALUATION

Table 5 - Risk Priority Number

Variabel	Failure Mode	S	O	D	RPN
X1	Worker scratched by scattered material objects	2,35	3,60	2,70	23
X2	Worker struck by collapsed and unstable materials	3,80	2,65	2,70	27
X3	Worker's foot punctured by sharp scattered materials	2,90	3,20	2,75	26
X4	Collision or accident involving heavy equipment	4,35	2,30	2,80	28
X5	Excavator falls into soil excavation pit	3,95	2,30	2,30	21
X6	Heavy equipment collides with tools and materials	3,20	2,50	2,55	20
X7	Worker suffers respiratory issues (shortness of breath) due to dust and vehicle exhaust	2,85	2,80	3,00	24
X8	Worker's foot run over by heavy equipment (excavator, dump truck)	3,90	2,15	2,60	22
X9	Worker falls or slips into excavation pit	3,40	2,60	2,70	24
X10	Worker buried by landslide during excavation	3,75	2,30	2,80	24
X11	Worker struck by materials or manual tools during piling	3,45	2,50	2,80	24
X12	Worker scratched by reinforcing steel bars	2,40	3,10	2,65	20
X13	Worker punctured by sharp scattered materials left from piling activities	2,75	2,70	2,55	19
X14	Worker struck by rebar while lifting it	3,00	2,50	2,65	20
X15	Worker's fingers or hands cut by bar cutter during rebar fabrication	3,80	2,85	3,00	32
X16	Worker's hand scratched by steel bars	2,45	3,45	2,65	22
X17	Worker's eyes exposed to fine steel dust	2,65	3,25	2,75	24
X18	Worker's fingers or hands lacerated by cut rebar edges	3,10	3,10	2,60	25
X19	Worker exposed to sparks during welding	2,80	3,05	2,90	25
X20	Worker's foot punctured by scattered rebar	2,70	3,30	2,65	24

Variabel	Failure Mode	S	O	D	RPN
	wire or steel rods				
X21	Steel material falls from height and hits worker	3,95	2,85	2,90	33
X22	Worker electrocuted due to electrical short circuit	3,85	2,60	2,85	29
X23	Worker's hand punctured by nails, wood, or hit by hammer	2,65	3,30	2,55	22
X24	Worker's hand pinched by formwork	2,95	2,90	2,45	21
X25	Worker's hand injured by sharp saw blade	3,10	2,30	2,30	16
X26	Worker struck by brittle formwork material during installation	3,30	2,35	2,60	20
X27	Worker trips over dismantled formwork debris	2,30	3,25	2,30	17
X28	Worker's head hits formwork	2,35	2,55	2,35	14
X29	Worker falls during formwork installation	3,95	2,65	2,75	29
X30	Formwork material falls from height and hits worker	3,80	2,60	2,85	28
X31	Heavy equipment hits tools, materials, or workers near the site	3,55	2,30	2,75	22
X32	Worker sprayed by concrete	2,65	2,35	2,50	16
X33	Worker struck by falling concrete bucket	4,10	2,90	2,90	34
X34	Wet concrete spills and hits worker below	3,15	2,60	2,50	20
X35	Worker bumps into concrete bucket	2,80	2,25	2,30	14
X36	Worker falls from height during scaffolding installation	4,45	2,90	3,05	39
X37	Worker struck by unsecured scaffolding material	3,80	2,95	3,05	34
X38	Worker struck by collapsing brick wall	2,90	2,25	2,40	16
X39	Worker's eyes exposed to mortar splashes	2,65	2,80	2,45	18
X40	Worker splashed with paint	2,25	2,60	2,55	15
X41	Skin irritation due to paint exposure	2,40	2,50	2,30	14
X42	Worker suffers respiratory problems due to ceramic dust from cutting	2,70	3,25	2,75	24
X43	Worker struck by flying ceramic shards	2,75	2,90	2,50	20

Source: Processed results Alone, 2025

Based on the results of weighting and ranking using the severity, occurrence, and detection scales for each failure mode, the next step is to determine the critical RPN value to classify the risk levels accordingly. In this study, the maximum value for each scale Severity, Occurrence, and Detection is 3, resulting in a maximum medium category RPN score of 27. Therefore, risks with RPN values greater than 27 are classified as priority risks and require appropriate response actions. A total of 9 variables exceeded the score of 27, as shown in the following table:

Table 6 - Critical RPN Value

Variabel	Failure Mode	RPN
X36	Worker falls from height during scaffolding installation	39
X33	Worker struck by falling concrete bucket	34
X37	Worker struck by unsecured scaffolding material	34
X21	Steel material falls from height and hits worker	33
X15	Worker's fingers or hands cut by bar cutter during rebar fabrication	32
X29	Worker falls during formwork installation	29
X22	Worker electrocuted due to electrical short circuit	29
X30	Formwork material falls from height and hits worker	28

Variabel	Failure Mode	RPN
X4	Collision or accident involving heavy equipment	28

Source: Processed results Alone, 2025

DEVELOPMENT OF RISK RESPONSES

Risk responses were developed for the nine priority risks using four main strategies: avoid, accept, transfer, and mitigation. The formulation of these responses considered best practices in high-rise construction and literature studies. The mitigation plans focused on technical aspects such as proper use of personal protective equipment (PPE), routine training, engineering controls, and scheduled visual inspections.

Table 7 – Risk Response

X Variable	Failure Mode	Risk Response			
		Avoid	Accept	Transfer	Mitigation
X36	Worker falls from height during scaffolding installation	Avoidance is not possible as working at height is mandatory.	Not recommended due to high RPN.	Delegate to certified scaffolding subcontractor with proper insurance.	Use inspected full-body harness, install safety line connected to anchor points, consistently use hooks at all stages, conduct scaffolding checklist, and ensure workers are medically fit and not afraid of heights.
X33	Worker struck by falling concrete bucket	Avoid concreting activities without a clear lifting SOP.	Not recommended due to fatal risk.	Transfer equipment control and procedure to certified operators and lifting supervisors.	Ensure no workers are below the bucket, inspect slings used for lifting, have certified riggers for securing loads, use crane according to lifting chart, strategically position operators and flagmen, and verify crane permits (SIA & SIO) are valid.
X37	Worker struck by unsecured scaffolding material	Avoid using non-standard scaffolding materials.	Acceptable if risks are minimized with strict controls.	Delegate work to certified scaffolding subcontractor.	Use standard clamps/clips and inspect scaffolding materials, ensure certified workers install scaffolding, conduct stage-by-stage installation with inspection at each level, mark incomplete scaffolds with red/yellow tags, and limit number of workers in tight or lifting zones.
X21	Steel material falls from height and hits worker	Avoid rebar work during extreme weather or in confined spaces.	Not recommended due to high risk of serious injury.	Transfer lifting of heavy materials to licensed equipment or winch.	Use complete PPE (helmet, gloves, safety shoes), workers at height must wear full body harness, tight supervision by foremen or HSE officers, consistently follow lifting SOP, place warning tape/signs in hazardous zones, and install perimeter railings or safety decks for small materials.
X15	Worker's fingers or hands cut by bar cutter during rebar fabrication	Avoid rebar cutting without full PPE and proper tool training.	Not recommended due to high injury risk from cutting tools.	Delegate cutting to workshop with strict safety procedures.	Use complete PPE (cut-resistant gloves, face shield, safety glasses), train workers before using cutting tools, display SOPs at work site, and separate cutting area using safety lines.
X29	Worker falls	Avoid	Not	Assign high-	Install safe and stable

X Variable	Failure Mode	Risk Response			
		Avoid	Accept	Transfer	Mitigation
	during formwork installation	formwork work without scaffolding and fall protection.	recommended due to potential for height-related falls.	level formwork installation to licensed team or use man lift.	scaffolding in formwork area, use full body harness and lanyard, conduct safety training on vertical work, install guardrails, and regularly inspect joints and materials.
X22	Worker electrocuted due to electrical short circuit	Avoid using electrical tools without daily inspection and grounding.	Not recommended due to potentially fatal electric shock.	Assign electrical monitoring to certified project electrician.	Daily inspection of cables, plugs, and cutting tools by technicians, ensure grounding on all tools, provide fire extinguishers and warning signs, wear insulating rubber gloves, and prohibit use of non-standard cable joints.
X30	Formwork material falls from height and hits worker	Avoid lifting formwork materials without securing lower areas.	Not recommended due to high potential for injury from falling materials.	Shift lifting to less crowded hours or assign to dedicated operator.	Instruct workers to avoid being under lifting zones, use extra slings and safety locks when lifting, place warning signs and barrier tape, inspect locks and material conditions before lifting, and conduct toolbox meetings before lifting.
X4	Collision or accident involving heavy equipment	Avoid excavator operation during peak traffic hours.	Acceptable with strict coordination and site supervision.	Assign heavy equipment supervision to certified flagman.	Install visual warnings, flashing lights, and banners in equipment zones, assign certified flagmen for supervision, provide communication training, use full PPE and bright safety vests, define and enforce safe zones, and conduct morning briefings to align understanding among teams.

Source: Processed results Alone, 2025

FIELD OCCURRENCE OF PRIORITIZED RISK

Based on interviews conducted with the HSE Manager and two project staff, it was confirmed that several of the prioritized risks identified by the researcher had occurred in the field during the construction process. Two of the nine prioritized risk variables X15 (Fingers and hands injured by bar cutter during rebar fabrication) and X30 (Formwork material falling from height and hitting workers) were reported to have actually happened on site. The incident associated with X15 involved a minor injury caused by negligence in using personal protective equipment (PPE), while the X30 incident occurred due to improper handling of formwork during lifting. Both cases were addressed promptly and did not lead to significant consequences or project delays.

The remaining prioritized risks X36, X33, X37, X21, X29, X22, and X4 although not observed during the study period, were acknowledged by the HSE team as having high potential for occurrence if not properly mitigated. This field validation supports the relevance of the FMEA-based risk prioritization conducted by the researcher and underscores the importance of preventive measures for high-risk construction activities.

VALIDATION BY PROJECT HSE TEAM

To ensure that the proposed risk responses aligned with actual site conditions, a validation process was carried out through interviews with the HSE Manager and two HSE staff members. The HSE team confirmed that all risk responses were relevant and appropriate, with two additional notes:

1. X33 (Workers struck by falling concrete bucket)

The HSE team noted that in the avoid category, this risk cannot be eliminated as concrete pouring is a necessary construction activity. Therefore, control measures must proceed to the next steps. For the accept category, the risk is tolerable with the condition that work methods and HSE procedures are implemented correctly. In the transfer category, the risk is not delegated entirely, but handled in cooperation with certified teams, such as licensed crane operators.

2. X21 (Rebar falling from height and hitting workers)
   For the *mitigation* category, the HSE team recommended the addition of perimeter railings and safety decks, especially in areas prone to falling small rebar materials, such as narrow or open work zones.

Table 7 - Preventive Measures

Risk Type	Description of Risk	Preventive Measures
Falling	Workers fall into excavation holes, slopes, or edges	Install safety fences, fall protection (harness), conduct training, use clear signage
Slipping	Workers slip on muddy or sloped surfaces	Improve drainage, clean surfaces regularly, provide anti-slip footwear
Struck by	Workers are hit by falling materials (e.g., stones)	Implement material stacking SOPs, use lifting tools, assign supervisors
Buried	Workers are buried due to excavation collapse	Use trench shoring, inspect soil condition, avoid work during heavy rain
Drowning	Workers fall into the water near situ area	Install guardrails, provide life vests and rescue ropes, assess swimming ability

Source: Processed results Alone, 2025

These comments were incorporated to enhance the risk response strategies, ensuring they are not only theoretically sound but also grounded in real site practices. Thus, the final adjusted responses based on validation feedback are considered more robust and implementable in similar construction settings.

CONCLUSION

This research applied the Failure Mode and Effect Analysis (FMEA) method to identify, assess, and prioritize occupational safety risks in the Tower AB construction project at the State University of Jakarta. A total of 43 risk variables were identified through literature review and refined by expert validation. Based on the RPN calculation (Severity × Occurrence × Detection), nine prioritized risks were found to exceed the threshold value and therefore required immediate mitigation actions. The study classified and recommended risk responses based on four strategies: avoidance, acceptance, transfer, and mitigation. Each risk was analyzed to determine the most appropriate response, with mitigation strategies being emphasized due to the high-risk nature of most failure modes.

Field occurrence analysis confirmed that some of the prioritized risks had manifested during project execution, highlighting the relevance of the risk identification process. Furthermore, validation by the project's HSE team showed full agreement with all nine risk responses proposed by the researcher, with additional feedback used to refine two variables: X33 (concrete bucket incident) and X21 (falling rebar). In conclusion, the implementation of FMEA in this study has proven effective in systematically identifying critical construction risks and generating practical, field-validated mitigation strategies. The findings are expected to serve as a reference for safety planning in similar high-rise construction projects and contribute to the development of more structured and proactive safety management systems in the construction sector.

LIMITATION & FURTHER RESEARCH

This study is limited to a single high-rise building project and focuses solely on potential safety risks to workers during the construction phase. Risk identification was based only on literature review without real-time observation or incident data. The use of the FMEA method was limited to semi-quantitative analysis and excluded cost, time, and quality risks.

Future research is recommended to integrate other risk analysis methods, such as Bowtie or Monte Carlo simulation, and to expand the scope to include multiple project types and construction phases for broader validation.

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