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Research Paper

Applying FMEA and FTA in Construction Safety Risk Mitigation: A Preventive Approach of the Situ Rempoa Project

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ABSTRACT: *The situ normalization project carries a high level of safety risk due to working conditions in open areas, deep excavations, and constant interaction with water. Common occupational accidents include incidents such as falling, slipping, being struck by objects, being buried, and drowning. This study aims to identify and analyze construction safety risks in the Situ Rempoa Normalization Project and formulate appropriate preventive measures. The Failure Mode and Effect Analysis (FMEA) method is used to assess the severity, occurrence, and detection of each risk, which are then calculated into a Risk Priority Number (RPN) to determine mitigation priorities. Meanwhile, Fault Tree Analysis (FTA) is conducted qualitatively to trace the root causes of the prioritized risks. Data were collected through questionnaires distributed to expert respondents with experience in similar projects under the Public Works and Spatial Planning Agency (PUPR) of Banten Province. The analysis identified 13 major risks, which were classified into five categories: (1) falling workers, (2) slipping workers, (3) workers struck by objects, (4) workers buried in soil, and (5) drowning incidents. The highest RPN was found in the risk of workers falling into excavations without adequate protection. FTA revealed that the dominant root causes included inadequate safety design, hazardous site conditions, and poor implementation of personal protective equipment (PPE). Based on these findings, preventive strategies were formulated, including improvements in protective system design, strengthened HSE supervision, and enhanced safety training. The study demonstrates that an incident-based approach is effective in mapping construction risks and designing structured preventive actions, especially for water infrastructure projects that have not yet entered the execution phase.*

KEYWORDS: *Construction safety risk, FMEA, FTA, Incident-Based Approach, Preventive Measures, Situ Normalization*

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I. INTRODUCTION

The normalization of urban lakes (known as situ in Indonesia) plays a vital role in flood control, water resource conservation, and ecological restoration. These projects, typically conducted in wet and unstable environments, often require deep excavation, slope stabilization, and heavy equipment operation—conditions that pose substantial risks to construction workers. Such high-risk conditions demand rigorous safety management, especially considering that many construction-related accidents stem from inadequate hazard recognition, unsafe work practices, and limited protective measures [1].

Despite existing regulatory frameworks, including Indonesia's Construction Safety Management System (SMKK) mandated by the Ministry of Public Works [2], safety implementation in situ normalization projects remains inconsistent. Previous studies have shown that systematic safety planning can significantly reduce worksite accidents and improve productivity [3]. However, the majority of prior research focuses on general construction hazards, without emphasizing the specific risks associated with water-infrastructure environments such as situ projects.

To address this gap, the present study analyzes construction safety risks in the Situ Rempoa Normalization Project using a combination of Failure Mode and Effect Analysis (FMEA) and Fault Tree

Analysis (FTA). The FMEA method enables prioritization of risks based on severity, occurrence, and detection, resulting in a Risk Priority Number (RPN), while FTA is used to qualitatively trace the root causes of critical hazards. Through expert-based assessments, this study aims to offer a comprehensive safety risk map and preventive strategies tailored to the unique challenges of normalizing water bodies in Indonesia's urban infrastructure projects.

II. LITERATUR REVIEW

RISK MANAGEMENT

Risk management is a structured and systematic process aimed at identifying, analyzing, evaluating, and mitigating risks that could affect project objectives. In construction projects, especially those involving uncertain environmental conditions and complex field operations, risk management serves as a fundamental strategy to reduce the probability and impact of potential failures [4]. According to ISO 31000:2018, the risk management process consists of several key steps: establishing context, risk identification, risk analysis, risk evaluation, risk treatment, monitoring, and review. These stages are interlinked and should be implemented continuously throughout the project lifecycle.

In the context of civil engineering, effective risk management allows stakeholders to anticipate safety-related hazards, optimize resource allocation, and develop responsive strategies. Projects involving water infrastructure—such as dams, lakes, and urban drainage systems—are particularly exposed to environmental uncertainties, mechanical failures, and human errors. Therefore, understanding the full risk landscape and integrating risk-based decision-making into planning and execution is essential. As emphasized by [5] PMBOK Guide (7th edition), managing risk also involves seizing positive opportunities that may arise from proactive preparation and planning.

CONSTRUCTION SAFETY MANAGEMENT SYSTEM (SMKK)

In Indonesia, the Construction Safety Management was formally introduced as a regulatory mandate under the Ministerial Regulation of Public Works and Housing No. 10 of 2021. This regulation requires all construction service providers to implement a structured system to manage occupational safety risks in accordance with national law. The core of SMKK includes the preparation of a Construction Safety Plan, the establishment of a Construction Safety Unit, and the documentation of safety supervision across all project stages.

SMKK emphasizes five key pillars: planning, implementation, supervision, reporting, and evaluation of safety practices. It is applicable to all types of infrastructure projects, including water infrastructure, where risk exposures are higher due to unstable terrain and interaction with natural water bodies. According to [6], the adoption of SMKK significantly improves project performance and reduces accident rates by enforcing structured safety management. Furthermore, it aligns with international best practices by promoting a culture of safety, ensuring worker protection, and fostering stakeholder accountability in achieving zero-accident goals.

FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Failure Mode and Effect Analysis (FMEA) is a structured and proactive approach used to identify potential failure modes in a process or system, evaluate their impact, and prioritize them based on risk. Each risk is assessed using three parameters: Severity (S), Occurrence (O), and Detection (D), which are multiplied to generate the Risk Priority Number (RPN). The higher the RPN, the more critical the failure mode is considered. In construction safety, FMEA enables early identification of hazards that could cause injury, delays, or system failure, helping project teams implement preventive measures before work begins [6].

FMEA is particularly relevant in complex construction environments like situ normalization projects, where workers are exposed to unstable ground, water accumulation, and the use of heavy machinery. These conditions increase the likelihood of hazards such as falling, slipping, or equipment-related injuries. By applying FMEA, safety planners can prioritize these risks and take early action—such as improving site layout, installing guardrails, or enhancing PPE enforcement—to reduce the potential for accidents and ensure safe project execution [7] & [8].

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 Frequent	>10 times during the project or ≥1 time per week	5
Frequent	5–10 times during the project or 1–3 times per month	4
Occasional	2–4 times throughout the project duration	3
Rare	Once during the project or ≤1 time per year	2
Very Rare / Almost Impossible	Has not occurred in >5 years of similar projects	1

Source: [10]

Table 3 - Detection Rating Scale in the FMEA Method

Detectability	Detection Level	Score
No detection system; no training or clear safety procedures	Very Difficult	5
No permanent supervision; inspections are only done weekly	Difficult	4
SOPs are available, but implementation depends on individual awareness	Moderate	3
Supervisors conduct routine patrols; daily checklist for tools and site	Easy	2
Workers are closely supervised; PPE is checked every time they enter site	Very Easy	1

Source: [10]

FAULT TREE ANALYSIS (FTA)

Fault Tree Analysis (FTA) is a deductive, top-down method used to analyze the logical relationships among events that may lead to a specific undesired outcome or system failure, referred to as the "top event." FTA trace how combinations of failures—whether technical, environmental, or human—can collectively cause critical incidents. This makes FTA a valuable tool for identifying the root causes of accidents and designing specific, targeted risk control strategies [11].

In construction safety, FTA is particularly effective for analyzing complex scenarios where multiple factors contribute to incidents, such as a worker falling into an excavation due to both inadequate barriers and poor lighting. By modeling these contributing factors, project managers gain insights into how failures interact and where interventions should be focused. FTA not only supports corrective actions but also strengthens the planning of preventive systems in high-risk activities such as excavation, structural reinforcement, or work near water bodies—common in situ normalization projects [11] & [12].

III. RESEARCH METHODS

This research was conducted using a qualitative descriptive method by collecting data and information to identify potential safety risks, determine the most dominant hazards, and formulate appropriate preventive actions for the Situ Rempoa Normalization Project, located in South Tangerang, Banten Province.

The data used in this study are as follows:

1. Primary Data

   Primary data were obtained directly by distributing questionnaires to respondents who are construction experts and practitioners with experience in similar projects under the Department of Public Works and Spatial Planning (PUPR) of Banten Province. The questionnaire was designed to assess each identified risk based on the Severity (S), Occurrence (O), and Detection (D) criteria in the FMEA method.

2. Secondary Data.
   Secondary data were gathered from supporting literature, safety regulations, previous research, and technical documents related to FMEA, FTA, and construction safety practices in water infrastructure projects.

This integrated approach aims not only to identify and analyze potential risks but also to guide the development of preventive safety measures that can reduce the likelihood and severity of construction-related accidents before project implementation begins.

DATA COLLECTION

The first data used in this study were construction safety risks that may occur in the Situ normalization project, obtained through interviews with service providers and a literature review. The second set of data was collected through the completion of a risk assessment questionnaire, which included factors of occurrence, severity, and detection, by three experts (three specialists in construction safety). The interviews related to safety risks in situ normalization projects initially identified 25 risk types, which were then validated by the experts, resulting in 22 primary risks.

The questionnaire consisted of three risk variables: probability, impact, and detection. It was completed by 39 construction safety practitioners, selected based on their position, level of expertise, type of work, or length of service. Each identified risk was assessed based on the likelihood of its occurrence, the potential impact if the risk materializes, and the level of detectability of the failure.

DATA ANALYSIS

Referring to the methodological procedures used, the data analysis in this study includes the processes of risk identification, risk analysis and evaluation using the FMEA approach and qualitative FTA, as well as the formulation of preventive risk mitigation strategies.

1. *Risk Identification*
   In the risk identification process, a comprehensive review of the situ normalization project is required so that construction safety risks can be identified based on potential events to determine critical values or activities, which may include processes, systems, or work operations. Subsequently, a list of potential risks is compiled and classified into several categories of project activities, including preparatory work, earth excavation and backfilling, retaining wall construction, and works around the situ area. The next step involves the distribution of a questionnaire based on the identified risks, with assessment focused on three factors: occurrence (the frequency of error occurrence), severity (the seriousness of the impact caused by the error), and detection (the ability of control mechanisms to detect potential causes).

2. *Risk Priority Number (RPN)*
   A quantitative approach is applied to assess risk by integrating three key dimensions: the severity of impact, the probability of occurrence, and the ability to detect potential failures. The resulting Risk Priority Number (RPN) reflects the relative significance of each risk within a given context. RPN values serve as the basis for risk prioritization, where higher RPNs signal more critical risks—typically due to severe consequences, high likelihood of occurrence, or low detectability.
   In essence, the Risk Priority Number is a mathematical indicator that captures how serious a potential failure is, how likely it is to occur, and how difficult it is to detect. The RPN is calculated by multiplying the scores assigned to occurrence (O), severity (S), and detection (D), as evaluated by experts. This relationship is expressed by the formula:

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

With description:

S : *Severity*
O : *Occurrence*
D : *Detection*

3. *Critical Risk Value*
   In FMEA-based risk analysis, a critical risk value is established to distinguish between high-priority risks and those of lower urgency. This value is determined by calculating the average Risk Priority Number (RPN) across all identified risks. The average serves as a threshold or benchmark to identify which risks require immediate attention and which can be monitored under standard procedures.
   Risks with an RPN greater than or equal to the critical value are categorized as high-priority and must be addressed through preventive or corrective actions. These may include redesign, safety reinforcement, or

procedural changes. Conversely, risks with an RPN below the critical value are considered acceptable or manageable under existing safety controls.
This classification aids in the efficient allocation of resources by directing mitigation efforts toward the most impactful and probable hazards. The determination of the critical value enhances decision-making and ensures a more objective, data-driven prioritization process in safety risk management.

4. *Root Cause Identification in Fault Tree Analysis (FTA)*
Fault Tree Analysis (FTA) is a qualitative analytical method used to systematically trace the pathways that lead to a specific failure or accident. In this study, FTA is employed to identify the root causes of high-priority construction safety risks that were previously determined using the Risk Priority Number (RPN) from the FMEA method. Root cause identification is conducted by developing a fault tree that begins with the Top Event and then breaks down into intermediate events and basic events, until the most fundamental causes are revealed. Key principles in determining root causes in FTA include:
The root cause data were obtained from expert interviews, risk questionnaires, and a review of relevant construction safety literature. Each Top Event is logically decomposed into a sequence of causal events that reflect deductive reasoning. The outcome of this analysis provides a solid foundation for developing targeted and effective risk prevention strategies for construction projects.

5. *Developing a Risk Mitigation Strategy*
The formulation of risk mitigation strategies in this study is based on the risks with the highest Risk Priority Number (RPN) and overall risk score. These critical risks are selected as priorities for further analysis. To determine the appropriate mitigation efforts, a brainstorming process was conducted involving safety experts and practitioners to explore feasible and effective solutions. The brainstorming results were then evaluated and aligned with the root causes identified through Fault Tree Analysis (FTA), ensuring that the proposed strategies are not only preventive in nature but also targeted at the fundamental sources of failure.

IV. FINDING AND DISCUSSION

PROJECT OVERVIEW

The Situ Rempoa Normalization Project is planned to take place in Situ Rempoa, located in Ciputat Timur District, South Tangerang City, Banten Province. The situ serves as one of the key natural retention areas in the region, helping to mitigate urban flooding and store rainwater. It is surrounded by densely populated residential neighborhoods, educational facilities, and public infrastructure, making the site highly sensitive to both environmental and construction safety impacts. The project site is characterized by low-lying terrain, soft and water-saturated soil, and limited access for heavy equipment—factors that increase the complexity and risk level of construction activities. Given these site conditions, combined with the presence of an active community nearby, a proactive safety risk assessment is essential to prevent work-related accidents and minimize disturbances during the implementation phase.

Figure 1 - Project site plan for the Situ Rempoa normalization project

THE RESULT OF RISK IDENTIFICATION

The risk identification process in this study refers to incidents that have occurred in previous situ normalization projects managed by the Public Works and Spatial Planning Agency (Dinas PUPR) of Banten Province. These projects generally share similar challenges, including working in open and waterlogged areas, deep excavation works, and direct interaction with water bodies. From those field experiences, several recurring safety risks were identified, such as workers falling into excavations, slipping on muddy surfaces, being struck by heavy materials during transportation, and drowning due to the absence of protective barriers around the situ.

Based on those previous occurrences, this study compiled an initial list of 25 potential construction safety risks, which were then validated by safety experts, resulting in 22 main risks relevant to the conditions of the Situ Normalization Project. These risks were analyzed using the FMEA method through a structured questionnaire that assessed three key factors: probability of occurrence (O), severity of impact (S), and detectability (D). The questionnaire was completed by 39 safety practitioners with direct experience in similar water infrastructure projects under the supervision of the Banten Province Public Works Agency. This approach ensured that the risk identification was contextually grounded and reflected real-world safety concerns in comparable project environments.

Table 4 – Identification Risk

Variable	Failure Mode
X1	Worker slips in a slippery work area
X2	Worker falls in uneven terrain
X3	Worker bitten or attacked by animals in open areas
X4	Worker injured by manual tools
X5	Worker buried by landslide in the excavation area
X6	Worker falls into excavation pit
X7	Worker slips on muddy ground
X8	Worker falls at the edge of excavation
X9	Worker exposed to dust during excavation
X10	Worker slips on uneven compaction area
X11	Worker falls in compaction area
X12	Worker exposed to equipment vibration during operation
X13	Worker exposed to dust in compaction area
X14	Worker drowns during work in the situ area
X15	Worker struck or crushed by heavy equipment
X16	Worker struck by stones during installation
X17	Worker slips in a sloped work area
X18	Worker falls from the retaining wall slope
X19	Worker injured from manually lifting stones
X20	Worker slips on wet paths around the situ
X21	Worker falls at the edge of the situ
X22	Worker struck by materials during facility installation

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 slips in a slippery work area	14	14	4	3
X2	Worker falls in uneven terrain	17	10	7	3
X3	Worker bitten or attacked by animals in open areas	17	8	2	3
X4	Worker injured by manual tools	18	11	0	3
X5	Worker buried by landslide in the excavation area	4	16	14	4
X6	Worker falls into excavation pit	10	10	18	4
X7	Worker slips on muddy ground	13	13	9	4
X8	Worker falls at the edge of excavation	12	20	4	4
X9	Worker exposed to dust during excavation	12	1	0	2
X10	Worker slips on uneven compaction area	23	7	1	3
X11	Worker falls in compaction area	21	2	2	3
X12	Worker exposed to equipment vibration during operation	12	6	0	3
X13	Worker exposed to dust in compaction area	18	2	0	2

Variabel	Failure Mode	S	O	D	RPN
X14	Worker drowns during work in the situ area	4	16	14	4
X15	Worker struck or crushed by heavy equipment	18	16	0	3
X16	Worker struck by stones during installation	13	16	5	4
X17	Worker slips in a sloped work area	15	19	4	4
X18	Worker falls from the retaining wall slope	6	16	13	4
X19	Worker injured from manually lifting stones	18	11	0	3
X20	Worker slips on wet paths around the situ	15	13	7	4
X21	Worker falls at the edge of the situ	14	13	9	4
X22	Worker struck by materials during facility installation	17	7	2	3
	TOTAL				666

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 and classify the risk levels accordingly. This step aims to identify failure modes that are considered critical and require more serious risk response measures. The calculation of the critical RPN value is as follows:

$$\text{Critical RPN Value} = \frac{\text{Total RPN Value}}{\text{Number of Failure Modes}}$$

$$\text{Critical RPN Value} = \frac{666}{22} = 30$$

Failure modes that fall into the category of critical failures are those with RPN values exceeding the critical threshold, namely RPN > 30. The failure modes with RPN values greater than 30, classified as critical failures, are presented in the following table:

Table 6 - Critical RPN Value

Variabel	Failure Mode	RPN
X6	Worker falls into excavation pit	57
X7	Worker slips on muddy ground	44
X17	Worker slips in a sloped work area	43
X5	Worker buried by landslide in the excavation area	43
X18	Worker falls from the retaining wall slope	39
X20	Worker slips on wet paths around the situ	36
X2	Worker falls in uneven terrain	34
X14	Worker drowns during work in the situ area	33
X8	Worker falls at the edge of excavation	33
X16	Worker struck by stones during installation	33
X1	Worker slips in a slippery work area	32
X21	Worker falls at the edge of the situ	31

Source: Processed results Alone, 2025

Based on the results of the FMEA identification, occupational safety risks can be classified into several categories according to the type of incident or accident commonly found in the construction sector. This classification aims to facilitate the risk analysis and mitigation process using the Failure Mode and Effect Analysis (FMEA) method. The five main categories of identified safety risks are as follows:

1. Falls

   This category includes incidents where workers lose balance and fall from heights or into excavated or water areas. Common causes include lack of guardrails, uneven surfaces, and absence of fall protection systems. Falls are one of the leading causes of fatalities in construction [13]. Related risk variables:

   X6: Worker falls into excavation pit
   X2: Worker falls on uneven ground
   X8: Worker falls at the edge of excavation
   X21: Worker falls at the edge of the situ
   X18: Worker falls from the retaining wall slope

2. Slips
   Slip accidents often result from slippery, muddy, or sloped surfaces, especially after rainfall or compaction activities. Contributing factors include poor drainage and unsafe work paths. Slips and trips account for a significant portion of construction site injuries. Relevant variables include:
   X7: Worker slips on muddy ground
   X17: Worker slips in sloped work area
   X20: Worker slips on wet paths around the situ
   X1: Worker slips in a slippery work area

3. Struck by Falling Objects
   This risk occurs when workers are hit by falling materials or tools, often due to poor material handling or lack of lifting equipment. ISO 45001:2018 emphasizes the need to manage risks from moving or falling objects. Related variable:
   X16: Worker struck by stone during installation

4. Caught-in or Between (Buried)
   This category involves workers being buried by soil collapse, particularly during excavation without slope protection. Trench collapses are known for their high fatality rate [14]. Related variable:
   X5: Worker buried by landslide in excavation

5. Drowning
   Drowning risks arise when workers fall into the situ or water channels without safety measures. The risk increases if workers lack swimming ability and personal flotation devices are unavailable. Work near water bodies requires specific controls and emergency protocols [14]. Related variable:
   X14: Worker drowns during situ area work

After the risk classification, root cause identification was conducted through qualitative Fault Tree Analysis (FTA), which involved structuring the top events, intermediate events, and basic events associated with each risk.

1. Falls

Table 7 - Root Cause FTA for Worker Falls

Intermediate Event	Basic Event	Root Cause
Loss of balance while working	Uneven or slippery working surface	Inadequate compaction or leveling before use
	Worker carrying heavy loads	- Inefficient material distribution - Unsafe transport path planning
Absence of fall protection system	No body harness available	- Incomplete PPE procurement - No minimum safety standard from management
	No anchor point installed	- Not included in the work method plan - No inspection of fall protection
	Lifeline not used	- Workers not trained - Poor enforcement by field supervisors
	Damaged PPE not replaced	- No regular PPE inspection - No spare PPE available
	Worker not wearing PPE	- No safety induction - PPE not ergonomic or uncomfortable
No physical barriers in risk areas	Guardrails not installed	- Guardrail materials not available at project start - Not included in procurement
	Warning signs not visible	- No additional lighting - Inadequate safety signage design

Source: Processed results Alone, 2025

Table 8 - Root Cause FTA for Worker

Intermediate Event	Basic Event	Root Cause
Slippery or muddy working surface	Muddy ground due to rain	- No temporary pavement installed - No emergency paths during rainfall
	Surface contaminated by mud/oil	- Lack of routine cleaning - No standard operating procedure (SOP) for site cleanliness
Inadequate drainage	No drainage channels provided	- Not included in detailed engineering design (DED) - Field drainage not considered during execution
No designated safe work path	No pedestrian-only lanes established	- Circulation layout did not account for construction safety - Not included in initial planning
Unrepaired sloped terrain	Slopes ungraded and not compacted	- No slope assessment conducted - Rushed work without compaction equipment
Inappropriate footwear	Non-standard or non-slip-resistant shoes	- No work shoe standards set - Workers self-funded PPE- No contractor-issued PPE

Source: Processed results Alone, 2025

Table 9 - Root Cause FTA for Worker Struck by Objects

Intermediate Event	*Basic Event*	*Root Cause*
Materials not safely stacked	Materials stacked too high without locks	- No material stacking SOP - No limit on stacking height
	Stone positions misaligned	- Rushed work execution - No inspection during material arrangement
No lifting equipment available	No equipment in the installation area	- Not included in the project budget (BoQ) - No lifting equipment logistics plan
	Materials too heavy to lift manually	No material weight classification in the work plan
Improper installation procedures	No written SOP for stone installation	Safety not integrated into work methods
	Installation performed in a hurry	Time pressure without schedule adjustment
Supervision negligence	No field supervisor during installation	- Limited personnel - No dedicated supervision schedule
	Final position of stones not checked	- End-of-task checking SOP not implemented - No daily reporting system
Work environment does not support stability	Sloped ground causes stone movement	No technical site assessment conducted prior to work commencement

Source: Processed results Alone, 2025

Table 10 - Root Cause FTA for Worker Burried

Intermediate Event	*Basic Event*	*Root Cause*
No slope protection	Excavation carried out manually without shoring	- No technical excavation safety design - No depth control procedures
Unstable soil conditions	Water-saturated soil after rain	- No daily weather monitoring - No soil inspection after rainfall
	No soil bearing capacity test conducted	No geotechnical investigation prior to excavation
Workers inside excavation without	Supervisor not present at work site	- No supervision task distribution - No mandatory direct supervision system

supervision	Workers entered excavation without permit	No work permit system for restricted areas
Work continued during adverse weather	Work continued during rain	- Rigid work schedule - Project timeline does not account for weather risks
	No soil evaluation after rainfall	No visual inspection or penetration testing after rain

Source: Processed results Alone, 2025

Table 11 - Root Cause FTA for Worker Drowning

Intermediate Event	*Basic Event*	*Root Cause*
Worker falls into water body	No guardrails installed along the edge of the situ	- Not prioritized in early safety planning - Not allocated in initial budget
	Slippery or sloped working surface at the water edge	No pavement or vegetation control implemented along the banks
No water safety equipment available	Life jackets not provided	- Not included in the construction safety procurement list - Not budgeted from project start
	No emergency rescue ropes	- No dedicated water rescue procedures - No risk identification performed
Worker cannot swim	No swimming ability assessment conducted	- No pre-assignment safety assessment - Not part of worker qualification criteria

Source: Processed results Alone, 2025

THE RESULTS OF DEVELOPING A RISK MITIGATION STRATEGY

Based on the results of the risk analysis using the FMEA and FTA methods, mitigation strategies were formulated to reduce the potential for occupational accidents in the Situ Rempoa normalization project. The main objective of these preventive efforts is to address the root causes of high-priority risks identified through the RPN scores. The mitigation measures are designed systematically, covering both technical aspects such as the provision of personal protective equipment and safety systems and managerial aspects, including the development of SOPs, safety training, and enhanced field supervision. By implementing these strategies, construction safety risks are expected to be significantly minimized throughout the project execution.

SUMMARY OF PRIORITY RISKS AND PREVENTIVE MEASURES

A set of preventive measures has been developed to address the main categories of construction safety risks identified in the project. These efforts include technical improvements such as installing physical barriers, providing appropriate personal protective equipment, and enhancing site conditions. Additionally, managerial actions such as supervision, safety training, and the implementation of clear procedures are emphasized to ensure a safe working environment. These measures aim to reduce the occurrence and severity of accidents, supporting a safer and more controlled construction process.

Table 12 - 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

CONCLUSION

This study aims to identify, analyze, and formulate mitigation strategies for construction safety risks in the Situ Rempoa normalization project. Based on the identification and analysis using the Failure Mode and Effect Analysis (FMEA) method, 22 major risks were identified that pose significant hazards to occupational safety. These risks were classified into five main categories: falling, slipping, struck by, buried, and drowning. Furthermore, 12 risks were categorized as critical failure modes based on their Risk Priority Number (RPN) values exceeding the critical threshold (RPN > 30), and were subsequently analyzed in greater depth using the Fault Tree Analysis (FTA) approach to determine their root causes.

The mitigation strategies were formulated based on the root causes identified through FTA, focusing on preventive measures that include both technical aspects (such as the provision of personal protective equipment, fall protection systems, and proper work surface treatment) and managerial aspects (such as safety training, on-site supervision, and the development of standard operating procedures). The results of this study are expected to serve as an initial reference for project implementation, enabling better preparedness in addressing potential occupational accidents and supporting the development of a stronger safety culture in the construction sector.

LIMITATION & FURTHER RESEARCH

This study has limitations in terms of scope, as it was applied to a single project that has not yet commenced (pre-construction phase), with a focus on potential risks based on common incidents from similar projects previously handled by the Public Works and Spatial Planning Agency (Dinas PUPR) of Banten Province. In addition, the Fault Tree Analysis (FTA) used in this research was qualitative in nature and did not include probabilistic simulations. To enhance the effectiveness of occupational safety risk control in construction projects, future research is recommended to develop a more optimal and integrated safety risk management model, particularly for water infrastructure projects such as situ (lake) normalization or reservoir construction.

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