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Analysis of the Risk of Work Accidents in High-Story Building Construction Projects using the FMEA (Failure Modes and Effects Analysis) Method

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ABSTRACT

A construction project is a complex and exciting process, starting from planning and design, through to implementation and finishing. The process of building a construction project always has risks at every stage of its implementation. To prevent and minimize risks that could cause work accidents and losses on the project, it is necessary to carry out a work accident risk analysis on the project. This research carried out a work accident risk analysis on the Joint Lecture Building and FISIP Laboratory Phase 2 UPN "Veteran" East Java Construction Project using the FMEA method. The aim is to identify the risks of work accidents that could occur in building construction projects and to determine the severity level, incidence rate, detection level, and risk priority number (RPN) in these projects. The results of the research show that the risk of work accidents with the highest Risk Priority Number (RPN) value occurs in foundation structure work with the risk of workers being injured by these materials with RPN value of 174,857.14. Work on strengthening foundation structures with the highest RPN values requires the greatest attention and risk control measures.

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INTRODUCTION

Construction development activities in Indonesia are currently increasing and developing rapidly to create adequate infrastructure facilities. The increase in construction development in various sectors certainly has an impact on contractors. This impact can be positive or negative, depending on various factors such as economic conditions, market competition, and the contractor's management capabilities. To face competition and take advantage of emerging opportunities, contractors must have good contractor management as a strategy to maintain their business.

One contractor management that needs to be considered is K3 management. This is because project construction carries a risk of work accidents during the construction process. If a work accident occurs, it will hurt the continuity of the project. The negative impact of work accidents on projects can cause workers to be injured and suffer material and immaterial losses. To prevent work accidents and facilitate the continuity of development, a project must implement a K3 program. The implementation of the Occupational Health and Safety (K3) program in the field must always be monitored and all workers are required to carry out and comply with the K3 program properly.

Potential sources of danger must be identified to avoid work accidents that cause losses. Although work accidents cannot be eliminated, work accidents can be prevented and minimized so as not to cause major losses (Savitri et al., 2021). One of the risk management carried out on a project is to analyze the risk of work accidents on the project to find out what work has a high level of risk so that it can minimize the occurrence of work accidents on the work and overcome the negative impacts that could occur.

In this research, we will analyze the risk of work accidents that occurred in the Joint Lecture Building and FISIP Laboratory Phase 2 UPN "Veteran" East Java construction project. The Joint Lecture Building and FISIP Laboratory Phase 2 UPN "Veteran" East Java Construction Project has an area of 24,000m2 and consists of 12 floors which was carried out by PT. PP (Persero) Tbk. as implementing contractor, PT. Pola Data Consultant (PT. PDC) as a planner, and PT. Saranabudi Prakarsaripta as construction management consultant.

The UPN "Veteran" East Java Joint Lecture Building and Laboratory Phase 2 Construction Project aims to improve the quality of education by creating a conducive and inspiring learning environment for students as well as increasing student access to various educational support facilities, such as laboratories, libraries, and research centers.

The Joint Lecture Building and FISIP Laboratory Building Project Phase 2 of UPN "Veteran" East Java is a tall building project in the High rise building category because there are 12 floors in the construction. Buildings in the High-rise building category have a high risk of work accidents. Therefore, the implementation of the Occupational Health and Safety (K3) program must be considered and implemented appropriately. The occurrence of work accidents is not intentional, workers who work in unhealthy conditions and an unsafe environment can cause work accidents (Afnella & Utami, 2021).

Analysis of work accident risk in this research uses the Failure Mode and Effect Analysis (FMEA) method. FMEA is an analytical method used to identify, evaluate, and sort potential failures and dangers that can occur in a product or process (Mu'adzah & Firmansyah, 2020). Work accident risk analysis is carried out by calculating the RPN (Risk Priority Number) value for the work accident risk variables that have been identified.

LITERATURE REVIEW

Construction project

A construction project is a series of planned activities to construct a building within a certain period to achieve the desired results (Darsini et al., 2022). A construction project aims to provide the infrastructure needed by the community. Construction projects play an important role in driving the country's economy and development by creating jobs, attracting investment, and improving the quality of life through adequate infrastructure.

Construction projects can be classified based on various factors, such as the type of infrastructure being built, the scale of the project, and the method of project implementation. By understanding the types and classifications of projects, stakeholders can make the right decisions and ensure the project runs smoothly and by the stated objectives.

Occupational Health and Safety

The Occupational Health and Safety (K3) is an effort to prevent accidents and illnesses that can harm workers in the workplace by creating a healthy and safe work environment (Ardiningrum et al., 2023).

The Occupational Health and Safety (K3) system is an important factor in the smooth implementation of project work. The definition of an Occupational Health and Safety (K3) system is a K3 control procedure or policy that is implemented to prevent work accidents and create an efficient and productive work location (Tambunan et al., 2021).

Implementation of a good Occupational Health and Safety (K3) management system plays an important role in the success of a project. This is because good K3 management can prevent work accidents at project locations which can cause both material and immaterial losses.

Work accident

A work accident is an event whose presence and losses cannot be predicted (Sari et al., 2024). Losses caused by work accidents on a project not only endanger worker safety but can also have fatal consequences for the project, such as causing delays and even stopping the entire project.

Risk

Risk is the possibility of an event that may occur in the future and cause negative impacts such as loss and damage (Gulo, 2020). The process of building a construction project is always accompanied by inevitable risks at every stage of the work.

Building construction work is one of the jobs that has a high risk at the implementation stage, this is caused by several factors such as the location of the work, the time of work, weather conditions, and the skills of the workforce used (Rama & Bhaskara, 2022).

Risk management

Risk management is a risk control effort to prevent or minimize the impacts that occur due to work accidents (Halwa Annisa Khoiri & Hanafi Setyawan, 2023). Risk management contributes to increasing efficiency and productivity because it can create a comfortable work environment and workers who feel protected from potential dangers that cause work accidents.

FMEA

The definition of Failure Mode and Effect Analysis (FMEA) method is a method used to identify, analyze, and prevent failure by researching potential failure modes, assessing the risks, and determining appropriate preventive actions (Ihsan & Nurcahyo, 2022). The FMEA method helps in finding solutions to prevent failure and improve quality by formulating appropriate corrective steps (Zuniawan, 2020).

This method uses an assessment based on the level of severity, level of occurrence, and level of detection which then calculates the RPN (Risk Priority Number) value to determine the risk of work accidents that have the highest RPN value.

The benefits of the Failure Mode and Effect Analysis (FMEA) method are being able to identify and prevent potential failures, improve the quality of a process, analyze the impact of failure, assess the level of risk of failure of a process, and develop control efforts to overcome the failure of a process.

The steps in the Failure Mode and Effect Analysis method are as follows:

1. Identify potential failures
2. Analyze the impact of failure
3. Conduct a risk assessment
4. Determine risk control measures

METHODOLOGY

Research Concept

This research is a type of research that is quantitative descriptive. The object of this research is the Joint Lecture Building and FISIP Laboratory Construction Project Phase 2 of UPN "Veteran" East Java. This research aims to identify the risk of work accidents occurring and calculate the level of risk using the FMEA method. The risk of work accidents identified in this research is the risk of work accidents in structural work.

Method of Collecting Data

This research data was collected through previous research literacy results and the results of questionnaires filled out by expert respondents. The questionnaire data is risk identification data and assessment of the level of work accident risk. The contents of the accident risk identification questionnaire are the result of previous research literacy which is then processed into work accident risk variables. In the work accident risk identification questionnaire, respondents will validate the work accident risk variables in the questionnaire.

Meanwhile, the contents of the work accident risk assessment questionnaire are work accident risk variables that have been validated by expert respondents in the first questionnaire and 3 assessment parameters, namely severity, occurrence, and detection level. Expert respondents will assess the risk variables for work accidents that occur using a scale level of severity, level of occurrence, and level of detection.

There were 7 respondents in this study consisting of 2 people as HSE (Health Safety Environment), 2 people as field implementers, and 3 people as field supervisors.

Risk Identification Data Analysis

Risk identification data was obtained from the results of a questionnaire filled in by expert respondents. This data contains work accident risk variables which will then be validated by expert respondents. Work accident risk variables that are not selected by expert respondents will be eliminated and work accident risk variables selected by experts will be used in this research.

Risk Assessment Data Analysis

The risk assessment analysis in this research uses the Failure Mode and Effect Analysis (FMEA) method. Accident risk assessment using the FMEA method is carried out based on severity, occurrence, and detection.

The severity level assessment aims to determine how serious the risk of work accidents is. In this study, the severity rating scale uses a scale of 1-5. The severity scale can be seen in table 1.

Table 1. Severity Level Scale

Level/Impact	**Value**
Death, material losses are enormous.	5
Western injury, can result in disability or	4
loss of bodily functions, major material losses.	3
Moderate injury, loss of work days, requiring medical treatment, substantial material losses.	2
Minor injury, moderate material loss.	1

The Occurrence level assessment aims to find out how often the risk of accidents occurs. In this study, the occurance rating scale uses a scale of 1-5. The occurance level scale can be seen in table 2.

Table 2. Occurrence Level Scale

Probability of Event	Occurrence Rate	Value
Very high and unavoidable.	1 in 3	5
High and occurs frequently.	1 in 20	4
It is and sometimes happens.	1 in 400	3
Low and relatively rare.	1 in 15,000	2
Very low and almost unheard of.	1 in 1,500,000	1

The detection level assessment aims to determine the level of possibility that the risk of work accidents can be detected. In this study, the detection level assessment scale uses a scale of 1-5. The detection level scale can be seen in table 3.

Table 3. Detection Level Scale

Probability of Detection	Occurrence Rate	Value
The controller has a very small chance of detecting the form and cause of the failure.	Very low	5
The controller has a very low probability of detecting the form and cause of the failure.	Low	4
The controller has a moderate probability of detecting the form and cause of the failure.	Moderate	3
The controller has a high probability of detecting the form and cause of failure.	High	2
Control tools can detect the exact form and cause of failure.	Almost certain	1

In calculating the assessment results of the level of severity, level of occurrence, and level of detection it is necessary to calculate the index of the three assessment parameters. Calculations for severity level assessments use the Severity Index (SI) formula, calculations for incident level assessments use the Occurrence Index (OI) formula, and calculations for detection level assessments use the Detection Index (DI) formula. This formula can be seen as follows::

$$SI = \frac{\sum_{i=1}^{5} a_i . x_i}{5 \sum_{i=1}^{5} x_i} x100\%$$

$$OI = \frac{\sum_{i=1}^{5} a_i . x_i}{5 \sum_{i=1}^{5} x_i} x100\%$$

$$DI = \frac{\sum_{i=1}^{5} a_i . x_i}{5 \sum_{i=1}^{5} x_i} x100\%$$

Where:

SI = Severity Index

OI = Occurance Index
DI = Detection Index
a = assessment constant (1 to 5)
xi = respondent probability
i = 1,2,3,4,5

After calculating the index of severity, occurrence, and detection values, the results of the work accident risk assessment can be classified based on the following table:

Table 4. Severity Index Classification

Classification	Categori	Severity Index (SI)
Very Low/Very Small	(VL/VS)	0.00 ≤ SI ≤ 12.5
Low/Small	(L/S)	12.5 ≤ SI ≤ 37.5
Fair/Moderate	(F/M)	37.5 ≤ SI ≤ 62.5
High/Big	(H/B)	62.5 ≤ SI ≤ 87.5
Very High/Very Large	(VH/VL)	87.5 ≤ SI ≤ 100

Source: Choiruddin & Dani (2023)

Table 5. Occurance Index Classification

Classification	Categori	Occurance Index (OI)
Very Low/Very Small	(VL/VS)	0.00 ≤ OI ≤ 12.5
Low/Small	(L/S)	12.5 ≤ OI ≤ 37.5
Fair/Moderate	(F/M)	37.5 ≤ OI ≤ 62.5
High/Big	(H/B)	62.5 ≤ OI ≤ 87.5
Very High/Very Large	(VH/VL)	87.5 ≤ OI ≤ 100

Source: Choiruddin & Dani (2023)

Table 6. Detection Index Classification

Classification	Categori	Detection Index (DI)
Very Low/Very Small	(VL/VS)	0.00 ≤ DI ≤ 12.5
Low/Small	(L/S)	12.5 ≤ DI ≤ 37.5
Fair/Moderate	(F/M)	37.5 ≤ DI ≤ 62.5
High/Big	(H/B)	62.5 ≤ DI ≤ 87.5
Very High/Very Large	(VH/VL)	87.5 ≤ DI ≤ 100

Source: Choiruddin & Dani (2023)

The next step after classifying the index of severity, occurrence, and detection is to calculate the RPN (Risk Priority Number) value. The RPN value is calculated using the following formula:

RPN = Severity (S) x Occurance (O) x Detection (D)

The accident risk variable that gets the highest RPN value will be the accident risk variable that must be prioritized in its control to prevent and minimize work accidents that occur.

RESEARCH RESULT

Risk Identification

Risk identification was carried out by distributing a questionnaire containing 31 work accident risk variables that occurred in structural work from the results of previous research literature which were then validated by expert respondents. The results of the questionnaire show that there are 13 work accident risk variables that occur in structural work in the Joint Lecture Building and FISIP Laboratory Phase 2 UPN "Veteran" East Java construction project. The results of the recapitulation of work accident risk variables can be seen in table 7.

Table 7. Risk Identification Recapitulation Results

Job Description	Code	Risk of Work Accidents
A. Earthworks		
Excavation and Landfill Works	V1	Excavated land landslides
B. Foundation Work		
Drilling	V2	Fall down
Reinforcing	V3	Got electric shock
	V4	Fallen
	V5	Injured by material
Formwork Work	V6	Workers injured due to materials
Foundry Works	V7	Dropped during casting
C. Upper Structure Work (Floor Plates, Columns and Beams)		
Casting Works	V8	Workers working on bar cutter/bar bender machines
	V9	Got electric shock
	V10	Fallen
	V11	Injured by material
Formwork Work	V12	Workers injured due to materials
D. Roof Structure Work		
Installation of Steel Roof Frames	V13	Injured by materials or tools

Risk Analysis

Risk analysis in this study uses the FMEA method by assessing the risk of work accidents based on 3 assessment parameters, namely the level of severity, the occurrence rate, and detection level. The assessment of these three parameters is obtained from the results of the work accident risk assessment questionnaire. After obtaining assessment data for the three parameters from expert respondents, the next step is to calculate the index of the three parameters using the Severity Index (SI), Occurrence Index (OI), and Detection Index (DI) calculation formula to be able to categorize the risk of the accident.

Example of calculating the level of severity using the Severity Index (SI) on the risk of work accidents with the variable code V1 which gets a value of 1 from 0 respondents, 2 from 1 respondent, a value of 3 from 2 respondents, a value of 4 from 3 respondents, and a value of 5 from 1 respondent are as follows:

$$SI = \frac{\sum_{i=1}^{5} a_i . x_i}{5\sum_{i=1}^{5} x_i} x100\%$$

$$SI = \frac{\{(1x0)+(2x1)+(3x2)+(4x3)+(5x1)\}}{5x7} x100\%$$

$$SI = \frac{25}{35} x100\%$$

$$SI = 71.4\%$$

The calculation results above show that the Severity Index (SI) value of the severity level with the variable code V1 has a value of 71.4%. The severity of work accident risk in variable V1 with a value of 71.4 is included in the high work accident risk category because it is on a scale between 62.5 ≤ SI ≤ 87.5.

A recapitulation of the calculation results for the severity severity level assessment using the Severity Index (SI) can be seen in table 8.

Table 8. Recapitulation of Severity Assessment

Job description	Code	Risk of Work Accidents	Severity Scale					SI (%)	Categori
			1	2	3	4	5		
A. Earthworks									
Excavation and Landfill Works	V1	Excavated land landslides		1	2	3	1	71.4	H
B. Excavated land landslides									
Drilling	V2	Fall down		2	1	3	1	68.6	H
Reinforcing	V3	Got electric shock			3		4	82.9	H
	V4	Fallen	1	1	1		4	74.3	H
	V5	Injured by material		1	5	1		60	M
Formwork Work	V6	Workers injured due to materials		1	5	1		60	M
Foundry Works	V7	Dropped during casting		1	3	1	2	71.4	H
C. Upper Structure Work (Floor Plates, Columns and Beams)									
Casting Works	V8	Workers working on		1	2	4		68.6	H

Job description	Code	Risk of Work Accidents	Severity Scale					SI (%)	Categori
			1	2	3	4	5		
		bar cutter/ bar bender machines							
	V9	Got electric shock		1	2	1	3	77.1	H
	V10	Fallen	2		1	1	3	68.6	H
	V11	Injured by material		2	5			54.3	M
Formwork Work	V12	Workers injured due to materials			6	1		62.9	H
D. Roof Structure Work									
Roof Structure Work	V13	Injured by materials or tools		3	2	2		57.1	M

A recapitulation of the calculation results for the occurance level assessment using using the Occurance Index (OI) can be seen in table 9.

Table 9. Recapitulation of Occurance Assessment

Job description	Code	Risk of Work Accidents	Occurance Scale					OI (%)	Categori
			1	2	3	4	5		
A. Earthworks									
Excavation and Landfill Works	V1	Excavated land landslides	4	2	1			31.4	L
B. Foundation Work									
Drilling	V2	Fall down	5	2				25.7	L
Reinforcing	V3	Got electric shock	1	5	1			40	M
	V4	Fallen	1	5	1			40	M
	V5	Injured by material		4	3			48.6	M
Formwork Work	V6	Workers injured due to materials		6	1			42.9	M
Foundry Works	V7	Dropped during casting		6	1			42.9	M
C. Upper Structure Work (Floor Plates, Columns and Beams)									
Casting Works	V8	Workers working on bar cutter/ bar bender machines	3	1	3			40	M

Job description	Code	Risk of Work Accidents	Occurance Scale					OI (%)	Categori
			1	2	3	4	5		
	V9	Got electric shock		5	2			45.7	M
	V10	Fallen	2	4	1			37.1	L
	V11	Injured by material	1	4	2			42.9	M
Formwork Work	V12	Workers injured due to materials	1	3	3			45.7	M
D. Roof Structure Work									
Installation of Steel Roof Frames	V13	Injured by materials or tools	4	2		1		34.3	L

A recapitulation of the calculation results for the detection level assessment using the Detection Index (DI) can be seen in table 10.

Tabel 10. Recapitulation of Detection Assessment

Job description	Code	Risk of Work Accidents	Detection Scale (Detection)					DI (%)	Categori
			1	2	3	4	5		
A. Earthworks									
Excavation and Landfill Works	V1	Excavated land landslides		2	4	1		57.1	L
B. Foundation Work									
Drilling	V2	Fall down	2	1	4			45.7	L
Reinforcing	V3	Got electric shock	4		2	1		40	L
	V4	Fallen		2	4	1		57.1	L
	V5	Injured by material		1	5	1		60	L
Formwork Work	V6	Workers injured due to materials		2	5			54.3	L
Foundry Works	V7	Dropped during casting		2	5			54.3	L
C. Upper Structure Work (Floor Plates, Columns and Beams)									
Casting Works	V8	Workers working on bar cutter/ bar bender machines	1		5	1		57.1	L

Job description	Code	Risk of Work Accidents	Detection Scale (Detection)					DI (%)	Categori
			1	2	3	4	5		
	V9	Got electric shock	3	2	1	1		40	L
	V10	Fallen	1	2	3	1		51.4	L
	V11	Injured by material		1	5	1		60	L
Formwork Work	V12	Workers injured due to materials		2	4	1		57.1	L
D. Roof Structure Work									
Installation of Steel Roof Frames	V13	Injured by materials or tools		3	3	1		54.3	L

After calculating the level of severity, level of occurrence, and level of detection calculated, then calculate the RPN (Risk Priority Number). An example of RPN calculation for a variable with code V1 is as follows:

$RPN = S \times O \times D$

$RPN = 71.4 \times 31.4 \times 57.1$

$RPN = 128{,}279.88$

The calculation above, shows that the risk of work accidents in the variable with code V1 gets an RPN value of 128,279.88. The results of calculating the RPN values for all variables can be seen in Table 11.

Table 11. Risk Priority Number (RPN) Value

Job description	Kode	Risk of Work Accidents	S	O	D	RPN
A. Earthworks						
Excavation and Landfill Works	V1	Excavated land landslides	71.4	31.4	57.1	128,279.88
B. Foundation Work						
Drilling	V2	Fall down	68.6	25.7	45.7	80,606.41
Reinforcing	V3	Got electric shock	82.9	40	40	132,571.43
	V4	Fallen	74.3	40	57.1	169,795.92

Job description	Kode	Risk of Work Accidents	S	O	D	RPN
	V5	Injured by material	60	48.6	60	174,857.14
Formwork Work	V6	Workers injured due to materials	60	42.9	54.3	139,591.84
Foundry Works	V7	Dropped during casting	71.4	42.9	54.3	166,180.76
C. Upper Structure Work (Floor Plates, Columns and Beams)						
Casting Works	V8	Workers working on bar cutter/bar bender machines	68.6	40	57.1	156,734.69
	V9	Got electric shock	77.1	45.7	40	141,061.22
	V10	Fallen	68.56	37.1	51.43	130,985.42
	V11	Injured by material	54.3	42.9	60	139,591.84
Formwork Work	V12	Workers injured due to materials	62.9	45.7	57.1	164,198.25
D. Roof Structure Work						
Installation of Steel Roof Frames	V13	Injured by materials or tools	57.1	34.3	54.3	106,355.69

From table, it is revealed that variable V5 with the risk of injury due to materials in foundation work which has an RPN value of 174,857.14 is the highest work accident risk variable.

DISCUSSION

Risk Identification

From the results of the risk identification data processing that has been carried out, it can be seen that in the Phase 2 FISIP Joint Lecture Building and Laboratory Construction Project, UPN "Veteran" East Java was identified as having 13 work accident risk variables from the 31 variables that had been identified in previous research.

Risk Analysis

The severity level assessment shows that the majority of work accident risks identified are high work accident risks, with 9 variables in the high category and 4 variables in the moderate category. The occurrence level assessment shows that the majority of work accident risks identified are moderate work accident risks, with 9 variables in the sufficient category and 4 variables in the low category. The detection level assessment showed that the 13 work accident variables that occurred were in the adequate category of work accident risk. The risk priority number assessment of the 13 work accident risk variables that happen, it shows that variable V5 has the highest RPN value with a value of 174,857.14. Variable V5 which has the highest RPN value is a variable that needs more attention when implementing risk control.

CONCLUSIONS AND RECOMMENDATIONS

Analysis of the risk of work accidents in the Joint Lecture Building and FISIP Laboratory Phase 2 UPN "Veteran" East Java project using the FMEA method identified 13 variables out of 31 variables that had the potential to cause a risk of work accidents. The accident risk variables that have been identified are the risk of land excavation accidents, landslides during excavation and embankment work, falls during foundation drilling work, electric shocks during foundation pouring work, falls during foundation work, injuries due to material during foundation work, workers are injured due to materials in foundation formwork work, falls during foundation casting, workers hit by bar cutter/bar bender machines in upper structure work, electric shocks in top structure work, falls in top structure work, injured by materials in top structure work, workers are injured by materials in upper structure formwork work, and injured by materials or tools in steel roof frame installation work.

Assessment of the severity of work accident risks shows that 9 variables are classified as "high" and 4 variables are classified as "moderate". The incidence rate assessment shows that 9 variables are classified as "moderate" and 4 variables are classified as "low". The detection rate assessment showed that all variables were classified as "moderate".

In the Risk Priority Number (RPN) assessment, it was found that the risk of work accidents with the highest RPN value was in foundation work with a job description, namely reinforcement which had a risk of work accidents being injured due to materials with an RPN value of 174,857.14.

ADVANCED RESEARCH

There is a need for further research related to analysis of work accident risk control based on index detection in construction safety management. The recommended method for further research is to use the Failure Mode Effects and Criticality Analysis (FMECA) method.

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