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Hazard and Risk Identification in Earthworks for Road Tunnel Construction: A Case Study of the First Road Tunnel in Kalimantan Island, Indonesia

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ABSTRACT

Tunnel construction involves a high level of danger and risk compared to other types of geotechnical construction accidents. This research aims to identify hazards and risks associated with earthworks in tunnel projects in Kalimantan Island, Indonesia. The methodology includes a literature review and expert judgment, utilizing Level 4 of Work Breakdown Structure (WBS) to identify potential hazards and risks. The findings of this research highlight that involving experienced experts in hazard and risk identification through the WBS can uncover risks that might not be evident in the early stages of planning. The results showed that workers faced 33 potential hazards, the environment or public encountered 19, equipment presented 14, and materials posed 6. The identified hazards for workers include the risk of being buried in excavation landslides and exposure to hazardous gases, while the environment and public face risks such as air pollution and landslides. Equipment-related risks involve machine failure, material risks stem from unsafe storage. Based on the research findings, this research provides valuable input, demonstrating that the application of Work Breakdown Structure (WBS) and the involvement of appropriate experts can significantly improve the comprehensiveness and effectiveness of hazard and risk identification. This approach supports the development of safety plan documents to mitigate hazards and risks in tunnel projects located in geotechnically challenging areas such as Kalimantan.

1. INTRODUCTION

Tunnel construction is a high-risk construction activity compared to other types of geotechnical construction accidents [1]. Various types of accidents can occur at tunnel construction sites, such as rushing water, mudflows, and tunnel surface collapses. These incidents can disrupt construction progress, result in significant economic losses, and cause fatalities [2].

Statistical analysis of 48 major tunnel construction accidents (MTCAs) reveals that collapses are the most frequent type of accident, accounting for 65% of MTCAs. Nearly 40% of these MTCAs are primarily caused by human factors, such as mismanagement and irregularities. In addition, more than 60% of accidents are directly linked to insufficient prospecting, inadequate monitoring, and improper rescue efforts [3]. An illustration of a tunnel collapse is provided in Figure 1 [4].

Data from the Ministry of Manpower [5-7] show an average increase of 35.49% in work accidents in Indonesia during the period from 2022 to 2024. In particular, work accidents on Kalimantan Island increased by an average of 34.92% over the same period [5-7]. These statistics highlight the urgent need for more serious attention to construction safety in the Kalimantan region, which faces unique and complex geotechnical challenges.

Figure 1. Tunnel collapse [4]

In Indonesia, work accidents in the construction sector present challenges across various aspects of the work environment [8]. The high incidence of such accidents can be attributed to the inadequate implementation of construction safety regulations in project settings [9], namely:

1) Government Regulation (PP) Number 50 of 2012 concerning the Implementation of Occupational Safety and Health Management Systems [10].
2) Regulation of the Minister of Public Works and Housing of the Republic of Indonesia Number 10 of 2021 concerning Guidelines for Construction Safety Management Systems [11].

In the construction sector, despite efforts to improve the preparation of Health and Safety (H&S) Plans, significant shortcomings remain in regulatory compliance and the need for more comprehensive prevention planning [12]. Moreover, while advancements have been made in tunnel safety and risk assessment methods, there are still gaps that require a more integrated analytical approach [13]. Traditional risk assessment methods used today are often insufficiently accurate, requiring a multidisciplinary approach to hazard identification [14].

In tunnel construction, there are several stages of work with earthworks being the most critical due to the high risks associated with excavation and soil-bearing capacity [15, 16]. This is particularly true in Kalimantan where the unique soil characteristics provide additional challenges and risks for tunnel construction projects. The region is characterized by mineral soils with low fertility and primarily lacking nutrients such as calcium, magnesium, and potassium. In contrast, the lowland areas are dominated by peat and alluvial soils [17].

Challenges arising from soil characteristics can result in hazards and risks in construction safety. In Kalimantan, challenges due to podzolic/ultisol and peat soil characteristics include:

1) Poor water absorption [18], which can make the soil susceptible to erosion and the collapse of overlying structures [19].
2) Peat soil characteristics, which are less favorable for construction due to low soil bearing capacity, high moisture content, and large compressibility [20].

The literature review conducted on previous research highlights the critical role of risk identification in safety plans in tunnels due to the unique and complex levels of risk involved. Research related to risks [12-14, 20-24] such as uncertain geotechnical conditions, restricted working environments, and the potential for serious accidents during construction, have also been conducted.

Based on these results, the researchers identified gaps in previous studies, specifically:

1) There has been no empirical testing related to the application of risk on real projects.
2) There is limited research on the available data to understand the relationship between hazard and risk factors [21].

These gaps suggest the need for further research to formulate more effective hazard and risk identification strategies based on the above factors.

Considering the identified problems and research gaps, the researchers determined that this research focuses exclusively on earthworks in tunnel construction. The case study is centered on the Gunung Manggah Tunnel, Samarinda, the first road tunnel on the island of Kalimantan [25]. The research aims to identify hazards and risks based on the collected data and to validate the hypothesis that selecting the right experts, supported by the application of Work Breakdown Structure (WBS) as a tool, has positive impacts on the hazard and risk identification process. This approach ensures a systematic identification process, resulting in more comprehensive coverage.

2. METHODOLOGY

This research will commence with problem identification, followed by a literature review to determine the need for primary and secondary data collection following the Construction Safety Plan (RKK) outlined in PUPR Ministerial Regulation No. 10 of 2021. Hazard and risk identification will then be carried out. The results of both identifications will be integrated to prepare an expert validation questionnaire, which will subsequently be validated by experts. If the results receive approval from the experts, then this research will produce its final output. However, if there is disagreement or feedback, the researchers will repeat the identification process. The flowchart of this research is illustrated in Figure 2.

Figure 2. Research methodology flowchart

According to PUPR Ministerial Regulation No. 10 of 2021, the Construction Safety Plan (RKK) is a systematic effort aimed at ensuring safety in construction projects through the identification, assessment, and implementation of controls for hazards and risks. Thus, each job must be clearly described, potential hazards and risks identified, and assessments conducted based on their frequency and severity. Controls are applied through various measures such as elimination, substitution, engineering controls, administrative actions, and the use of Personal Protective Equipment (PPE). In addition, regular evaluation and monitoring are carried out to ensure the effectiveness of the RKK, thereby promoting safety and sustainability at each construction phase.

Based on the Ministerial Regulation, data collection related to the Work Breakdown Structure (WBS) for earthworks was conducted. The WBS was obtained through secondary data collection from the Gunung Manggah tunnel project. Subsequently, a systematic identification of hazards and risks affecting earthworks in tunnels was carried out, supported by additional literature studies, project documents, and historical analysis [26].

In the construction safety planning process, hazard and risk identification is a critical stage that must be conducted comprehensively. Careful identification focuses on four key aspects: workers, equipment, materials, and the environment/public [11]. By addressing these aspects, researchers aim to formulate more effective prevention and mitigation strategies.

The next stage involves the preparation of questionnaire questions for expert validation interviews. The Risk Register table compiled in the previous stage was transformed into a validation questionnaire for review by experts [2, 9, 22-24, 27]. The number of experts required at this stage of the questionnaire is 5 experts. The experts are tasked with validating and providing feedback on the identified hazards and risks initially compiled through a literature review. The validation process includes recording expert responses to determine whether they "Agree" or "Disagree" with variable X which represents a tunnel project work risk variable, specifically related to earthworks.

The experts involved must meet the following criteria:

1) Have at least 10 years of experience in construction safety; or
2) Have been involved in tunnel construction projects;
3) Have a minimum of a bachelor's degree.

By validating the identified hazards and risks, the preparation of hazard and risk variables is accurately arranged according to the format outlined in the Minister of Public Works and Housing Regulation No. 10 of 2021 [11]. The outcome of this research is a comprehensive list of hazards and risks associated with earthworks in the Gunung Manggah road tunnel case study. This serves the ultimate goal of formulating more effective prevention and mitigation strategies. This research begins with problem identification, followed by a literature review to determine data collection needs in alignment with the Construction Safety Plan (R.K.K.) as outlined in the regulation.

3. RESULT AND DISCUSSION

3.1 Identification of hazards and risks in tunnel construction earthworks

According to the Minister of Public Works and Housing Regulation No. 10 of 2021, the Work Breakdown Structure (WBS) is utilized at Level 4, namely the work package to identify potential hazards and risks in tunnel construction projects [11]. The Work Breakdown Structure (WBS) is a project management tool designed to break down work into more detailed levels for effective management. It consists of five hierarchical levels: (1) main project, (2) project phase, (3) work type, (4) work package, and (5) work activity [28]. Using a combination of literature review [26] and expert judgment [2, 9, 22-24, 27], work items at WBS Level 4 were identified and utilized as research variables, with the following details.

- Land Clearing and Stripping (X.1)
- Selected Tree Cutting with diameter > 30-50 cm (X.2)
- Road Body Preparation (X.3)
- Ordinary Land Excavation (X.4)
- Rock Excavation Outside the Tunnel (X.5)
- Rock Excavation in Tunnels (X.6)
- Geotextile Filter for Drainage (X.7)

Based on the compiled work stages, the following hazards were identified:

1) Land Clearing and Stripping
    - Workers 8 potential hazards;
    - Equipment 1 potential hazard;
    - Material 1 potential hazard;
    - Environment or Public 3 potential hazards.
2) Selected Tree Cutting >30-50 cm diameter
    - Workers 4 potential hazards;
    - Equipment 1 potential hazard;
    - Material 1 potential hazard;
    - Environment or Public 3 potential hazards.
3) Road Body Preparation
    - Workers 2 potential hazards;
    - Equipment 2 potential hazards;
    - Material 1 potential hazard;
    - Environment or Public 3 potential hazards.
4) Ordinary Land Excavation
    - Workers 4 potential hazards;
    - Equipment 1 potential hazard;
    - Material 0 potential hazard;
    - Environment or Public 2 potential hazards.
5) Rock Excavation Outside the Tunnel
    - Workers 3 potential hazards;
    - Equipment 3 potential hazards;
    - Material 1 potential hazard;
    - Environment or Public 4 potential hazards.
6) Rock Excavation in the Tunnel
    - Workers 7 potential hazards;
    - Equipment 4 potential hazards;
    - Material 2 potential hazards;
    - Environment or Public 3 potential hazards.
7) Geotextile Filter for Drainage
    - Workers 3 potential hazards;
    - Equipment 2 potential hazards;
    - Material 1 potential hazard;
    - Environment or Public 0 potential hazards.

3.2 Expert judgment of hazards and risks in tunnel construction

The identification of hazards was further developed through a literature analysis, which was incorporated into a questionnaire aimed at obtaining expert feedback. Experts were asked to indicate their agreement or disagreement regarding the hazards and risks presented as potential issues in earthworks for tunnel construction projects. Details of the experts involved in this study can be seen in Table 1.

Based on the validation data provided by the expert respondents, there were several expert recommendations in Table 2. The expert validation results summary is provided in Table 3.

Table 1. Expert profile

Categories	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Name	MS	DL	LN	RR	D.H.
Gender	Male	Male	Male	Male	Male
Occupational Position	Senior Quality Control Manager	Senior Site Manager	Chairman of the Indonesian Construction Safety Expert Association	H.S.E. Manager	Project Manager
Work Experience	32 years	30 years	31 years	11 years	11 years
Last Education	Master Degree	Bachelor Degree	Bachelor Degree	Bachelor Degree	Master Degree

Table 2. Experts' recommendations

Work Package	Types of Hazards and Risks	Hazard	Risk	Description
Land Clearing and Stripping (X.1)	Worker	Disturbed, bitten, or stung by wild animals	Injuries from wild animal bites/stings.	In new work zones, particularly in regions such as Kalimantan, wildlife habitats are often present before land clearing. This poses a significant risk to workers, who may become distracted or injured from wild animal bites and stings.
	Materials	Unsafe storage of materials during mobilization.	Material damage and loss resulting in obstruction of work.	During the clearing and stripping phase, mobilized materials are often hit by passing heavy equipment, causing significant material damage and disrupting the workflow. Therefore, it is essential to store materials in a safer location to mitigate this risk.
Rock Excavation Outside the Tunnel (X.5)	Worker	Falling on loose stones or soil	A serious injury occurred due to falling rocks or soil during excavation works.	During the rock excavation outside the tunnel, loose rock or soil can potentially cause serious injury to workers. Vibration from heavy equipment or unstable geological conditions can trigger the movement of these materials.
	Equipment	Heavy equipment hit by rock/soil avalanche	Damage to heavy equipment due to falling rocks or soil.	There is a high potential for heavy equipment to be struck by rock or soil avalanches during excavation outside the tunnel. This can damage the machinery, resulting in work delays and substantial repair costs.
Rock Excavation Inside the Tunnel (X.6)	Worker	Trapped by an avalanche	Fatal injuries and even fatalities due to being buried or trapped by an avalanche.	In tunnel excavations, soil structure collapse can potentially trap workers, and cause fatal injuries and even deaths.
	Worker	Struck by support steel.	Serious or fatal injury due to being crushed by unstable support steel.	Improperly installed work platforms, particularly if struck by heavy equipment, pose a significant danger to workers who risk falling or being crushed by the platform, and potentially causing equipment damage.
	Equipment	Collapsed work platform	Platform damage and fatal injuries due to falling on the work platform.	Heavy equipment can potentially damage improperly installed work platforms, posing a significant danger to workers who risk falling or being crushed by the platform, and potentially causing equipment damage.
	Environment/Public	Significant water source in the tunnel.	Sudden flooding of a significant water source in the tunnel (obstruction of work).	There is a risk of significant water sources in the tunnel that could cause sudden flooding. In addition to hindering work, this flooding also poses a threat to workers' safety.

Table 3. Hazard and risk identification register

Work Package	Variable	Types of Hazards and Risks	Hazard	Ref.	Risk	Ref.	Regulations or Requirements
Land Clearing and Stripping (X.1)	X.1.1	Worker	Splashed or splashed with chemicals such as herbicides	[29]	Skin and eye irritation.	[30]	[10, 31-35]
	X.1.2	Worker	Slipped due to steep ground conditions	[36]	Injury caused by slipping.	[37]	
	X.1.3	Worker	Worker's foot hit by a hoe	[38]	Minor injury caused by being hit by a hoe.	[39]	
	X.1.4	Worker	Worker's hand hit by sickle	[40]	Minor injury from being hit by a sickle.	[41]	
	X.1.5	Worker	Exposed to chainsaw	[40]	Severe injury from being hit by a chainsaw.	[41]	
	X.1.6	Worker	Hit by heavy equipment (excavator, bulldozer)	[42]	Severe injuries due to being hit by heavy equipment.	[43]	

Work Package	Variable	Types of Hazards and Risks	Hazard	Ref.	Risk	Ref.	Regulations or Requirements
	X.1.7	Worker	Disturbed, bitten, or stung by wild animals	Expert Judgement	Injuries from wild animal bites/stings.	Expert Judgement	
	X.1.8	Equipment	Heavy equipment (excavator, bulldozer) overturned	[38]	Significant damage to heavy equipment due to rollovers, which temporarily halts operations.	[43]	[10, 44-46]
	X.1.9	Materials	Unsafe storage of materials during mobilization.	Expert Judgement	Material damage and loss that results in obstruction of work.	Expert Judgement	[31, 34, 44]
	X.1.10	Environment/Public	Damage to vegetation	[47]	Environmental degradation due to vegetation destruction (ecosystem damage).	[48]	[10, 34, 44, 49, 50]
	X.1.11	Environment/Public	Noise pollution	[51]	Disruption around the project due to noise	[52]	
	X.1.12	Environment/Public	Air pollution	[53]	Disruption around the project due to air pollution and respiratory problems.	[54]	
Selected Tree Cutting diameter >30–50cm (X.2)	X.2.1	Worker	Exposed to chainsaw	[40]	Serious injury from being hit by a chainsaw (severe wound/injury).	[41]	[10, 31-35]
	X.2.2	Worker	Falling tree trunk	[38]	Severe injury due to being hit by a tree trunk.	[38]	
	X.2.3	Worker	Falling from a height	[37]	Injury caused by falling from a tree	[55]	
	X.2.4	Worker	Hit/stabbed by a piece of wood	[36]	Minor injury due to being hit by a piece of wood.	[37]	
	X.2.5	Equipment	Chainsaw failure/damage	[56]	Damage to the chainsaw.	[40]	[10, 44]
	X.2.6	Environment/Public	Damage to vegetation	[47]	Environmental degradation due to vegetation destruction (ecosystem damage).	[48]	[10, 34, 44, 49, 50]
	X.2.7	Environment/Public	Noise pollution	[51]	Disruption around the project due to noise	[52]	
	X.2.8	Environment/Public	Air pollution	[53]	Disruption around the project due to air pollution and respiratory problems.	[54]	
Pavement Road Preparation (X.3)	X.3.1	Worker	Hit by heavy equipment (motor grader, excavator, dump truck)	[57]	Serious injury due to being hit by heavy equipment (serious accident).	[43]	[10, 31-35]
	X.3.2	Worker	Run over by heavy equipment (vibrator roller, motor grader)	[58]	Fatal injuries from being run over by heavy equipment, serious accidents, and even fatalities/deaths.	[43]	
	X.3.3	Equipment	Accidents between machines during equipment mobilization	[38]	Damage to heavy equipment and obstruction of work due to accidents between heavy equipment (traffic congestion).	[43]	[10, 44-46]
	X.3.4	Equipment	Rollover of heavy equipment (motor grader, excavator, dump truck)	[38]	Significant damage to heavy equipment due to rollovers, which temporarily halts operations.	[43]	
	X.3.5	Materials	Scattering of aggregates on the road	[59]	Loss of material damage and traffic disruption due to scattered aggregates	[55]	[31, 34, 44]
	X.3.6	Environment/Public	Heavy equipment crashes into nearby facilities (public)	[29]	Damage to public facilities around the project environment.	[43]	[10, 34, 44, 49, 50]

Work Package	Variable	Types of Hazards and Risks	Hazard	Ref.	Risk	Ref.	Regulations or Requirements
	X.3.7	Environment/Public	Noise pollution	[51]	Disruption around the project due to noise	[52]	
	X.3.8	Environment/Public	Air pollution	[53]	Disruption around the project due to air pollution and respiratory problems.	[54]	
Ordinary Land Excavation (X.4)	X.4.1	Workers	Worker's foot hit by a hoe	[38]	Minor injury from being hit by a hoe	[39]	[10, 31-35]
	X.4.2	Workers	Hit by heavy equipment (excavator, dump truck)	[42]	Serious injury due to being hit by heavy equipment (serious injury).	[43]	
	X.4.3	Workers	Falling into the excavation site	[56]	Severe injury due to falling into excavation pits.	[60]	
	X.4.4	Workers	Buried in an excavation landslide	[42]	Fatal injuries due to landslides, even fatalities/deaths.	[60]	
	X.4.5	Equipment	Overturning of heavy equipment (excavator, dump truck) due to unstable soil	[38]	Significant damage to heavy equipment due to rollovers, which temporarily halts operations	[43]	[10, 44-46]
	X.4.6	Environment/Public	Damage to vegetation	[47]	Environmental degradation due to vegetation destruction (ecosystem damage).	[48]	[10, 34, 44, 49, 50]
	X.4.7	Environment/Public	Landslides	[61]	Damage to project facilities due to landslides.	[62]	
Rock Excavation Outside the Tunnel (X.5)	X.5.1	Workers	Falling from a height	[37]	Serious injury due to a fall from a height. (Serious injury).	[55]	[10, 31-35, 61, 62]
	X.5.2	Workers	Buried by landslide excavation (stone/soil)	[58]	Fatal injuries due to landslides, even fatalities/deaths.	[60]	
	X.5.3	Workers	Hit by heavy equipment (excavator, dump truck)	[42]	Severe injuries due to being hit by heavy equipment.	[43]	
	X.5.4	Workers	Falling loose stones or soil	Expert Judgement	Serious injuries as a result of falling rocks or soil during the excavation.	Expert Judgement	
	X.5.5	Equipment	Overturning of heavy equipment (excavators, dump trucks) due to unstable ground	[38]	Significant damage to heavy equipment due to rollovers, which temporarily stopped operations	[43]	[10, 44-46, 63, 64]
	X.5.6	Equipment	Heavy equipment slips into an excavation pit	[65]	Severe damage to heavy equipment slowed down work substantially due to slipping into excavation pits.	[62]	
	X.5.7	Equipment	Heavy equipment hit by rock/soil avalanche	Expert Judgement	Damage to heavy equipment due to falling rocks or soil.	Expert Judgement	
	X.5.8	Materials	Unsafe storage of materials	[55]	Material damage and significant losses due to unsafe storage of materials.	[66]	[31, 34, 44]
	X.5.9	Environment/Public	Damage to vegetation	[47]	Environmental degradation due to vegetation destruction (ecosystem damage).	[48]	[10, 34, 44, 49, 50]
	X.5.10	Environment/Public	Landslides	[61]	Damage to project facilities due to landslides.	[62]	

Work Package	Variable	Types of Hazards and Risks	Hazard	Ref.	Risk	Ref.	Regulations or Requirements
	X.5.11	Environment/Public	Noise pollution	[51]	Disruption around the project due to noise	[52]	
	X.5.12	Environment/Public	Air pollution	[53]	Disruption around the project due to air pollution and respiratory problems.	[54]	
Rock Excavation Inside the Tunnel (X.6)	X.6.1	Workers	Falling from a height	[37]	Fatal injuries from falling from heights, even fatalities/deaths.	[55]	[10, 31-35]
	X.6.2	Workers	Exposed to rockfall	[67]	Fatal injuries due to rockfall and even fatality.	[41]	
	X.6.3	Workers	Buried by landslide excavation (stone/soil)	[60]	Fatal injuries due to landslides, even fatalities/deaths.	[42]	
	X.6.4	Workers	Exposure to harmful dust and gases	[62]	Respiratory distress caused by exposure to dust and harmful gases (carbon monoxide (C.O.), L.E.L., hydrogen sulfide (H_2S)).	[68]	
	X.6.5	Workers	Lack of oxygen	[69]	Respiratory distress due to lack of oxygen.	[68]	
	X.6.6	Workers	Hit by heavy equipment (excavator, dump truck, mixer)	[42]	Severe injuries due to being hit by heavy equipment.	[70]	
	X.6.7	Workers	Exposed to machinery (welding, grouting, cutting)	[40, 71]	Severe injuries from being hit by welding, grouting, or cutting machines.	[40]	
	X.6.8	Workers	Trapped by an avalanche	Expert Judgement	Fatal injuries and even fatalities due to being buried and trapped by an avalanche.	Expert Judgement	
	X.6.9	Workers	Struck by support steel	Expert Judgement	Serious or fatal injuries due to being crushed by unstable support steel.	Expert Judgement	
	X.6.10	Equipment	Failure/damage of heavy equipment (excavator, drill)	[72]	Damage to heavy equipment and obstruction of work (congestion).	[73]	[10, 44-46, 63, 64]
	X.6.11	Equipment	Machine failure (welding, grouting, cutting machine)	[74, 75]	Machine/equipment breakdowns and work delays due to machine failure.	[41]	
	X.6.12	Equipment	Heavy equipment hit by rock/soil avalanche	[62, 76]	Severe damage to heavy equipment due to falling rocks/soil.	[76]	
	X.6.13	Equipment	Heavy equipment overturned due to unstable ground	[38]	Significant damage to heavy equipment due to rollovers, which temporarily halts operations.	[43]	
	X.6.14	Equipment	A collapsed work platform	Expert Judgement	Platform damage and fatal injuries due to work platform collapses.	Expert Judgement	
	X.6.15	Materials	Unsafe storage of materials (iron/steel)	[66]	Material damage and significant losses due to unsafe storage of materials.	[55]	[31, 34, 44]
	X.6.16	Materials	Flammable or explosive materials (gas)	[14, 75]	Material damage due to fire or explosion on combustible materials.	[14]	
	X.6.17	Environment/Public	Landslides	[61]	Damage to project facilities due to landslides.	[62]	[10, 34, 44, 49, 50]
	X.6.18	Environment/Public	Noise pollution	[51]	Disruption around the project due to noise.	[52]	

Work Package	Variable	Types of Hazards and Risks	Hazard	Ref.	Risk	Ref.	Regulations or Requirements
	X.6.19	Environment/Public	Air pollution	[53]	Disruption around the project due to air pollution and respiratory problems.	[54]	
	X.6.20	Environment/Public	Significant water source in the tunnel	Expert Judgement	Sudden flooding of a significant water source in the tunnel (obstruction of work).	Expert Judgement	
Geotextile Filter for Drainage (X.7)	X.7.1	Workers	Slipping/Falling from a height	[29]	Serious injury due to a fall from a height.	[55]	
	X.7.2	Workers	Exposed to geotextile sewing tools	[40]	Minor injury from being hit by geotextile sewing tools. (minor injury).	[36]	[10, 31-35]
	X.7.3	Workers	Struck by geotextile material	[36]	Serious injury due to being crushed by geotextile material.	[77]	
	X.7.4	Equipment	Sewing machine failure/breakdown (geotextile)	[78]	Geotextile sewing machine malfunction, electrocution from the machine.	[38]	[10, 44, 63, 64]
	X.7.5	Materials	Unsafe storage of materials (geotextiles)	[77]	Material damage and significant losses due to unsafe storage of materials.	[78]	[31, 34, 44]

3.3 Results of hazard and risk identification analysis in earthworks for tunnel construction

Based on the expert recommendations in Table 2, these recommendations are aligned with the findings of previous studies discussing similar hazards and risks in tunnel construction. A total of 72 hazards and risks associated with earthworks in road tunnel construction projects were identified, comprising 64 variables from the literature review and 8 variables derived from expert input (see Figure 3).

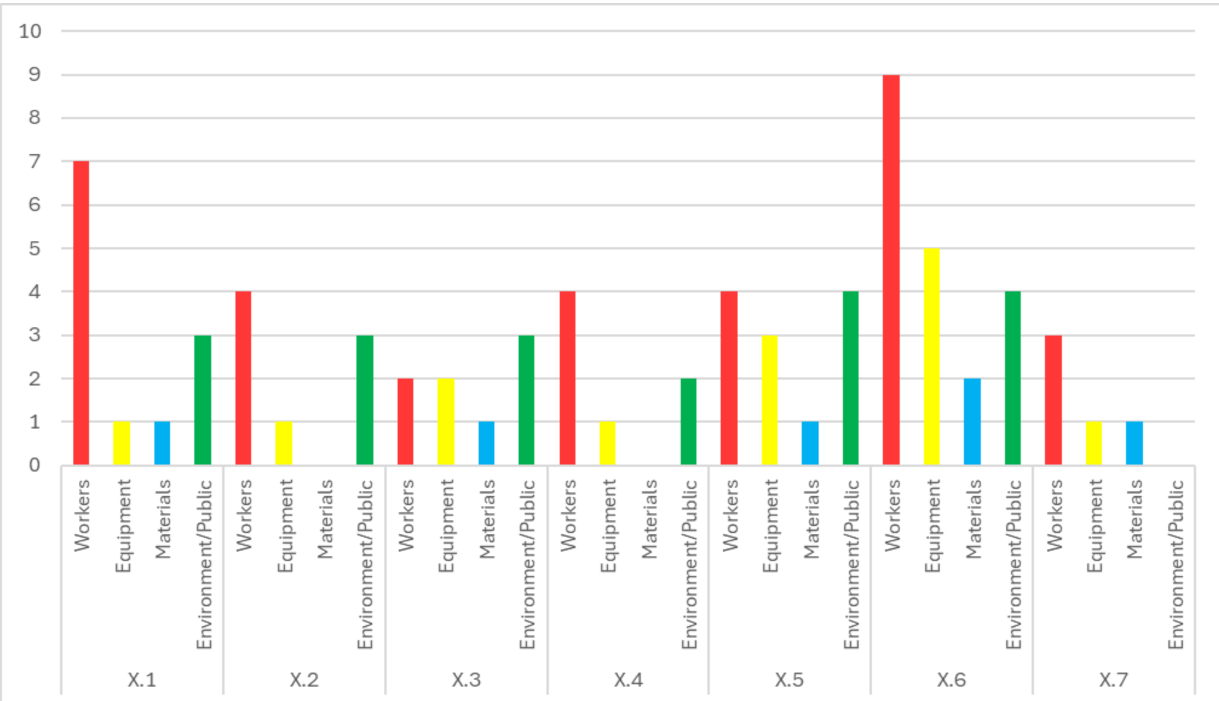

Figure 3. Hazard and risk categorization analysis

Through the expert validation conducted, researchers received several notes from experts for each stage of work at Level 4 earthworks, namely:

- Land Clearing and Stripping (X.1) has 11 rules or requirements that must be followed.
- Cutting of Selected Trees with diameter >30-50cm (X.2) has 9 rules or requirements that must be followed.
- Road Body Preparation (X.3) has 11 regulations or requirements that must be complied with.
- Ordinary Land Excavation (X.4) has 11 regulations or requirements that must be complied with.
- Rock Excavation Outside Tunnels (X.5) has 13 regulations or requirements that must be complied with.
- Rock Excavation in Tunnels (X.6) has 13 regulations or requirements that must be complied with.

- Geotextile Filter for Drainage (X.7) has 9 rules or requirements that must be followed.

Four hazard identifications were found: workers, equipment, materials, and the environment or public. In this study, the dominant risks were identified among workers with 33 potential hazards and risks, followed by the environment/public with 19 potential hazards and risks, equipment with 14 potential hazards and risks, and materials with 6 potential hazards and risks. The details of the hazard and risk identification obtained are as follows:

3.3.1 Workers

Workers are exposed to significant risks, including wild animal bites or stings that can cause injury [29], as well as the danger of being struck by loose rock or soil during excavation, potentially causing serious injury or even death [3, 79]. Previous research has also highlighted the hazards posed by unstable steel supports [22, 23] and soil avalanches in tunnels, which can trap workers and cause fatal injuries [3, 22, 62].

The land clearing and stripping work (X.1) identified 7 hazards and risks related to workers, while selected tree cutting for trees with diameters >30-50 (X.2) identified 4 hazards. The preparation of road body (X.3) revealed 2 hazards, ordinary soil excavation (X.4) had 4 hazards, rock excavation outside the tunnel (X.5) identified 4 hazards, rock excavation inside the tunnel (X.6) highlighted 9 hazards, and the use of geotextile filters for drainage (X.7) indicated 3 hazards. This results in a total of 33 hazards identified for workers.

3.3.2 Equipment

In addition to risks to workers, expert recommendations point to equipment vulnerabilities, such as machine damage caused by rock or soil avalanches [79, 80], and the collapse of work platforms [29].

The land clearing and stripping work (X.1) showed 1 hazard and risk related to equipment, while selected tree cutting for trees with diameters > 30-50cm (X.2) revealed 1 hazard. Road body preparation (X.3) indicated 2 hazards, ordinary soil excavation (X.4) had 1 hazard, rock excavation outside the tunnel (X.5) identified 3 hazards, rock excavation inside the tunnel (X.6) highlighted 5 hazards, and the use of geotextile filters for drainage (X.7) presented 1 hazard. This results in a total of 14 hazards identified for equipment.

3.3.3 Materials

The expert recommendations indicate a vulnerability risk associated with the unsafe storage of materials during the mobilization process, which could lead to material losses and work delays [2, 58]. This hazard has been addressed in previous research.

The land clearing and stripping (X.1) showed 1 hazard and risk related to materials, while selected tree cutting for trees with diameters > 30-50 cm (X.2) revealed no hazard. The preparation of the road body (X.3) indicated 1 hazard, excavation of ordinary soil (X.4) presented no hazard, rock excavation outside the tunnel (X.5) had 1 hazard, rock excavation inside the tunnel (X.6) revealed 2 hazards, and the use of geotextile filters for drainage (X.7) had 1 hazard. This results in a total of 6 hazards identified for workers.

3.3.4 Environment or public

The working environment in the tunnel poses risks such as sudden flooding from large water sources [2, 3, 22], which can result in work stoppages. This finding is consistent with previous research.

Land clearing and stripping work (X.1) showed 3 hazards and risks related to the environment or the public, while selected tree cutting for trees with diameters > 30-50 cm (X.2) revealed 3 hazards. Road body preparation (X.3) highlighted 3 hazards, ordinary soil excavation (X.4) had 2 hazards, rock excavation outside the tunnel (X.5) presented 4 hazards, rock excavation inside the tunnel (X.6) had 4 hazards, and the use of geotextile filters for drainage (X.7) presented no hazards. This results in a total of 22 hazards identified for the environment or public.

4. DISCUSSION ON HYPOTHESIS PROVING

By critically analyzing previous studies [14, 15, 40, 56, 59, 69, 77, 78], it was found that they did not specifically apply Work Breakdown Structure (WBS) in their analysis, resulting in poorly organized hazard and risk identification. The absence of WBS can lead to miscoordination and miscommunication, which can lead to changes in the scope of work and increased accident risks, ultimately causing material losses and loss of life.

With this evidence, the researcher pursued different research focusing on the application of WBS in hazard and risk identification. WBS serves as a systematic tool to that enables the management team to implement more effective and planned preventive measures.

Furthermore, previous studies [9, 29, 36, 57, 58] showed differences in the aspects reviewed during hazard and risk identification. This research examines four main aspects of construction safety: workers, materials, equipment, and environment/public, which are classified based on Ministerial Regulation No. 10 of 2021. Through this approach, the risk classification process becomes more focused on various aspects of construction, improving the effectiveness of safety management and reducing the incidence of accidents on construction sites. In contrast, previous studies did not specifically analyze these aspects.

This research has identified various hazards and risks associated with earthworks in tunnel construction projects. Hazards to workers include the potential of being buried in excavation landslides, falling from heights, being struck by heavy equipment, and exposure to hazardous gases, all of which pose risks of injury, serious injury, and fatalities. In addition, environment/public hazards include damage to vegetation, noise and air pollution, landslides, and the potential for large water sources within the tunnel, all of which pose a risk of injury and environmental damage. Equipment hazards include the risks of heavy equipment rollovers, impacts from rock or soil avalanches, and equipment failures that could hinder work. Meanwhile, material-related hazards include the potential risks of unsafe storage practices, which can cause material damage.

The findings indicate that the selection of appropriate experts and the application of Work Breakdown Structure (WBS) as a tool positively impacts the hazard and risk identification process. This systematic approach results in more comprehensive coverage. By involving experienced experts to identify hazards and risks through WBS, risks and hazards that may not be apparent at the beginning of planning or literature studies can be uncovered, as evidenced by the additional hazards and risks identified during expert validation.

This statement is aligned with PUPR Ministerial Regulation No. 10 of 2021, which emphasizes the use of WBS Level 4, specifically work packages, to identify hazards and risks.

5. CONCLUSIONS

This study shows that the application of Work Breakdown Structure (WBS) and the selection of appropriate experts can significantly improve the comprehensiveness and effectiveness of the hazard and risk identification process in construction safety planning. This finding confirms the importance of an organized structure and the right expertise in strengthening safety practices, ultimately reducing risks and increasing the success of construction projects, particularly in the context of tunnel construction within geotechnically challenging regions such as Kalimantan.

With the results of this study, the researcher can further analyze the main objective: that the application of WBS and the selection of suitable experts will improve the comprehensiveness of identifying hazards and risks in construction safety planning, thereby supporting construction control to ensure safety during tunnel construction. Overall, the findings and implications of this study provide a strong foundation for improving safety and risk management practices through WBS and expert judgment.

The results of this research can benefit various stakeholders in the construction industry, particularly construction service providers in Kalimantan. This research provides a list of hazards and risks affecting tunnel construction, which will be instrumental in planning safety measures for construction projects, thereby improving overall construction safety. This is important for mitigating hazards and risks in tunnel projects situated in geotechnically challenging areas such as Kalimantan. However, this study has limitations as it focuses solely on earthwork risks in tunnel construction. Future research could expand the scope to include all construction risks associated with tunnel projects.

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