

RISK MANAGEMENT OF EXCAVATION WORKS BENEATH SLOPES

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ABSTRACT

Excavation work beneath slopes is one of the construction activities that carries a high level of risk due to the potential for slope instability and occupational accidents. This study aims to analyze the risks associated with excavation work beneath slopes using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method. The research adopts a descriptive qualitative approach utilizing secondary data, including scientific literature, technical standards, and occupational health and safety (OHS) regulations. The analysis is conducted through stages of hazard identification, risk assessment based on likelihood and severity, and the determination of appropriate risk control measures. The results indicate that most identified hazards fall into the high-risk category, particularly those related to slope failure, excavation wall collapse, saturated soil conditions, high rainfall intensity, and inadequate supervision and work procedures. Geotechnical factors, such as soil conditions and slope geometry, are identified as the primary causes of instability, further exacerbated by operational and managerial factors in the field. Effective risk control measures include the implementation of slope reinforcement, proper drainage systems, the use of personal protective equipment (PPE), the establishment of standard operating procedures (SOPs), and enhanced supervision. This study demonstrates that the application of the HIRARC method needs to be integrated with geotechnical analysis to achieve more comprehensive risk management. The findings are expected to serve as a reference for construction practitioners and stakeholders in improving occupational safety in excavation work beneath slopes.

Keywords: excavation; HIRARC; risk; slope; safety

1. INTRODUCTION

Excavation work is one of the fundamental stages in the implementation of construction projects, including the development of buildings, roads, drainage systems, and other infrastructure. Although this activity is generally considered routine, in practice, excavation work carries a high level of risk, particularly when conducted under complex geotechnical conditions such as beneath slopes. This condition becomes more critical due to the interaction between the natural characteristics of the slope and the construction activities being carried out, which may lead to soil instability and increase the likelihood of occupational accidents.

From a geotechnical perspective, slope stability is determined by the balance between driving forces and resisting forces acting on the soil mass. Driving forces generally originate from the self-weight of the soil, additional loads, and the influence of water, while resisting forces are governed by soil shear strength parameters such as cohesion and the internal friction angle. When excavation work is carried out at the toe of a slope, the lateral support that previously functioned as a natural restraint is reduced. This condition leads to stress redistribution within the soil, which may decrease the factor of safety of the slope and increase the potential for failure. In certain situations, slope failure may occur suddenly without clear warning signs, thereby posing significant risks to workers in the excavation area. Therefore, monitoring geotechnical behavior is essential to ensure safety and enable more timely decision-making in risk management (Toyeb et al., 2025).

The risks associated with excavation work beneath slopes are influenced not only by geotechnical factors but also by environmental and operational conditions in the field. The presence of groundwater, high rainfall intensity, and inadequate drainage systems can increase pore water pressure and reduce soil strength. In addition, the use of heavy equipment, vibrations generated by construction activities, and errors in work methods can accelerate the occurrence of slope instability. The combination of these factors creates a highly vulnerable working environment, increasing the likelihood of accidents such as landslides, excavation wall collapse, and workers being buried.

Various cases of occupational accidents caused by landslides in excavation work indicate that the risks associated with these activities are often not managed optimally. In many instances, failures are not solely attributable to technical factors but are also influenced by the weak implementation of occupational health and safety (OHS) systems, inadequate hazard identification, and insufficient supervision in the field. Additionally, workplace accidents are often caused by non-compliance with safety procedures and the presence of unsafe working conditions (Yusril, 2025). This indicates that a purely technical approach is not sufficient to ensure occupational safety; rather, it must be supported by a comprehensive and structured risk management system.

In the context of construction risk management, the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach has been widely used as a systematic method to identify potential hazards, assess risk levels, and determine appropriate control measures (DNV GL, 2007). The HIRARC method is an effective approach for identifying and managing hazards in the workplace (Sahidila Putra & Agung Budi Broto, 2025). This method provides a clear framework for risk management, thereby helping to minimize the likelihood of occupational accidents. However, in practice, the implementation of HIRARC in excavation work, particularly beneath slopes, often remains administrative in nature and does not fully integrate geotechnical technical aspects in a comprehensive manner.

These limitations indicate the existence of a gap between risk analysis based on occupational health and safety (OHS) management and geotechnical technical analysis. On the one hand, geotechnical analysis is capable of explaining slope failure mechanisms in detail; however, it is often not translated into operational measures that can be easily implemented in the field.

On the other hand, the HIRARC approach tends to focus on general hazard identification without adequately considering the complexity of soil behavior and slope dynamics. As a result, critical risks, such as the potential for landslides due to changes in soil conditions, are not always accurately identified during the risk assessment process.

In addition, research on risk management in excavation work is still dominated by partial approaches that separate technical aspects from occupational safety aspects. Geotechnical studies primarily emphasize slope stability analysis using analytical and numerical methods, while research in the field of OHS focuses more on safety procedures, worker training, and regulatory compliance. The integration of these two approaches remains relatively limited, even though in real field conditions, both aspects are closely interconnected and cannot be separated.

Based on these issues, there is a need for an approach that integrates HIRARC-based risk analysis with geotechnical understanding related to slope stability. Such an approach is expected to produce more accurate hazard identification, more realistic risk assessment, and more effective risk control strategies in reducing the potential for occupational accidents. Thus, risk management should not merely be administrative in nature but must also be grounded in the actual technical conditions encountered in the field.

In line with this, this study aims to analyze the risks associated with excavation work beneath slopes using the HIRARC method. Specifically, the study focuses on identifying potential hazards at each stage of the work, assessing risk levels based on likelihood and impact, and formulating appropriate risk control measures in accordance with geotechnical and operational conditions in the field. Furthermore, this study seeks to contribute to the development of a more integrated risk analysis approach that combines technical and occupational safety aspects.

Through this research, it is expected that a more comprehensive understanding of the risk characteristics associated with excavation work beneath slopes can be achieved, along with the development of mitigation strategies to improve occupational safety. The findings of this study are also expected to serve as a reference for construction practitioners, academics, and regulatory authorities in formulating policies and technical guidelines related to risk management in excavation work, particularly in slope conditions with high levels of risk.

2. METHODOLOGY

This study employs a descriptive qualitative approach to analyze the risks associated with excavation work beneath slopes using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method. This approach is chosen to comprehensively understand potential hazards and the characteristics of risks influenced by geotechnical and operational factors in the field. The data used in this study are secondary data obtained through a literature review, including scientific journals, geotechnical reference books, and standards and regulations

related to occupational health and safety (OHS). The selection of data is based on relevance and credibility criteria to ensure accurate analysis.

The primary instrument in this study is the HIRARC framework, which consists of three stages: hazard identification, risk assessment, and risk control. Risk assessment is conducted based on the levels of likelihood and severity to classify risks into low, medium, and high categories. Data analysis is carried out through several stages, including the identification of potential hazards in excavation work beneath slopes, risk assessment using a risk matrix, analysis of risk causative factors, and the determination of appropriate control measures. The results of the analysis are then formulated into a HIRARC-based risk management model integrated with geotechnical aspects.

3. RESULTS

Based on the results of hazard identification using the HIRARC method, several major potential risks were identified in excavation work beneath slopes, arising from geotechnical, environmental, and operational aspects. Risk assessment was conducted by considering the levels of likelihood (L) and severity (S), using a scale of 1–5. The risk value (R) was obtained by multiplying L and S, and was subsequently classified into low, medium, and high-risk categories.



Figure 1. Excavation Works Beneath Slopes

Based on Figure 1, heavy equipment is observed removing part of the soil on the slope to reduce the potential for landslides. The risk assessment of excavation work beneath the slope is presented in Table 1.

Table 1. HIRARC analysis for excavation works beneath slopes

Activity	Potential Hazard	Impact	L	S	R	Category
Excavation beneath slopes	Landslide	Buried, died	4	5	20	High
Vertical excavation	Wall collapse	Worker injury	4	4	16	High
Unsaturated condition	Decrease the soil strength	Local landslide	3	5	15	High
Heavy equipment operation	Ground vibration	Unstable slopes	3	4	12	Medium
High intensity rain	Elevated pore water pressure	Landslide	4	4	16	High
Limited work access	Slip and fall	Minor and major injuries	3	3	9	Medium
Lack of PPE	Direct hazard exposure	Worker injury	3	3	9	Medium
Absence of SOPs	Procedural error	Occupational accident	4	4	16	High
Poor drainage	Water ponding	Soil softening	3	4	12	Medium
Lack of supervision	Undetected risk	Fatal incident	4	5	20	High

4. DISCUSSION

The results of the risk analysis using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method indicate that excavation work beneath slopes is a highly hazardous activity. This is evidenced by the dominance of high-risk categories in several key activities, particularly those directly related to changes in slope stability, saturated soil conditions, rainfall, and weak supervision and work procedures. Excavation activities therefore have a high potential for occupational accidents based on the risk assessment. (Pagoray, 2022). This finding confirms that excavation work beneath slopes cannot be regarded merely as routine earthwork, but rather as an activity involving complex interactions among geotechnical, environmental, equipment-related, and occupational safety management factors.

In general, the highest risks identified in the HIRARC table are associated with excavation activities at the toe of the slope and inadequate supervision, each yielding a risk value of 20. This indicates that both factors have a very high combination of likelihood and impact and therefore must be prioritized in risk control measures. In excavation at the toe of the slope, the primary hazard is slope failure, which may result in workers being buried, equipment damage, disruption of operations, and even fatalities. Technically, this condition can be explained by the fact that excavation at the toe of the slope removes the natural lateral support of the soil. When the soil mass at the lower part is cut or reduced, stress redistribution occurs, causing the slope to lose its stability. Under such conditions, the slope becomes more susceptible to soil movement, particularly when the soil shear strength parameters are relatively low or when the presence of water further weakens the soil structure.

From a geotechnical perspective, this finding is highly logical, as the toe of the slope functions as a natural support for the soil mass above it. When this part is excavated without adequate reinforcement design, the resisting forces decrease while the driving forces from the overlying soil mass remain active. As a result, the factor of safety of the slope is reduced. Therefore, control measures such as slope reinforcement, slope angle reduction, and stability monitoring, as presented in the table, are not merely administrative actions but essential technical interventions. This implies that in excavation work beneath slopes, occupational safety is highly dependent on the quality of technical decisions made prior to the commencement of work.

In addition to excavation at the toe of the slope, another high-risk hazard is the collapse of excavation walls during vertical excavation, with a risk value of 16. This finding indicates that the geometry of the excavation plays a crucial role in determining the level of risk. Excavation walls constructed too steeply without adequate support systems increase the likelihood of collapse, particularly in soils with low cohesion or those affected by vibrations and water infiltration. Although such collapses are typically localized, they remain hazardous because workers at the bottom of the excavation have limited space to escape. In this context, the use of sheet piles, bracing, or other retaining systems represents highly relevant control measures. In other words, the HIRARC analysis demonstrates that the physical configuration of the work has a direct influence on risk levels, and therefore, work methods must be designed based on soil characteristics and excavation depth.

High risks are also observed under saturated soil conditions, with a risk value of 15, and under high rainfall conditions, with a risk value of 16. These findings indicate that water is a dominant factor in increasing the risks associated with excavation work beneath slopes. In soil mechanics, an increase in moisture content and pore water pressure reduces the effective stress within the soil. This reduction directly decreases soil shear strength, making the soil more susceptible to movement or failure. In slope conditions, the impact of water becomes even more critical, as it not only weakens the soil but also adds additional weight to the soil mass. Consequently, the risk of slope failure typically increases significantly after heavy rainfall or in areas with inadequate drainage systems.

These results highlight that risk control in excavation work beneath slopes cannot be separated from effective water management. Control measures such as drainage systems, dewatering, and surface water channels must be treated as core components of mitigation strategies rather than merely supplementary technical measures. In construction practice, greater attention is often given to heavy equipment and excavation methods, while drainage issues are considered secondary. However, the findings of this analysis demonstrate that failure to control water can transform a previously stable slope into a highly hazardous condition. Therefore, field hydrological aspects must be regarded as a primary variable in planning occupational safety for excavation work beneath slopes.

Meanwhile, moderate risks were identified in activities such as heavy equipment operation (risk value of 12), limited access to the work area (risk value of 9), inadequate use of personal protective equipment (PPE) (risk value of 9), and poor drainage conditions (risk value of 12).

Although these risks are not classified as the highest, they still have a significant impact on occupational safety. Heavy equipment operations, for example, can generate vibrations that trigger slope instability. Vibrations from excavators, dump trucks, or compacting equipment may accelerate the failure of soil that is already in a critical condition. In addition, heavy equipment operating too close to the edge of a slope can introduce additional external loads, thereby increasing driving forces. This indicates that control measures such as maintaining a safe distance for heavy equipment and regulating loads are essential to prevent risks from escalating to higher categories.

Regarding limited access to the work area, the primary hazard involves workers slipping or falling. Although the impact is generally less severe than that of landslides, this condition remains significant as it can reduce productivity, cause injuries, and increase the likelihood of secondary accidents. For instance, a worker who falls within a confined excavation area may obstruct evacuation during emergency situations. A similar concern applies to the inadequate use of PPE, which, although categorized as a moderate risk, reflects a weak safety culture in the field. PPE may not prevent slope failure, but it can reduce the severity of injuries resulting from falling materials or minor accidents. Therefore, this analysis indicates that occupational safety in excavation areas is not only determined by major risks such as landslides but also by a series of operational risks that, if neglected, can exacerbate the consequences of accidents.

Another important finding is the high level of risk associated with the absence of standard operating procedures (SOPs), with a risk value of 16, and inadequate supervision, with a risk value of 20. These factors indicate that the risks in excavation work beneath slopes are not only derived from natural or technical conditions but also from managerial and institutional aspects. The absence of SOPs results in work being carried out without clear procedural standards, causing decisions in the field to rely heavily on individual experience. It is also important to note that the level of education is a significant contributing factor to occupational accidents, particularly in the mining sector. (Harahap, 2023). This condition is hazardous because work beneath slopes requires strict control, including excavation sequencing, positioning of heavy equipment, inspection of slope conditions, and procedures for halting work during rainfall. Without standard operating procedures (SOPs), risks become difficult to manage consistently.

Inadequate supervision emerges as one of the most critical findings in this analysis. Weak supervision leads to hazards that could otherwise be detected early being overlooked. Minor cracks on slopes, water ponding, changes in excavation wall geometry, or heavy equipment operating too close to the slope are often not promptly addressed in the absence of intensive supervision. This indicates that supervision functions as the final control mechanism to ensure that all risk control measures are implemented as planned. From a HIRARC perspective, supervision is not merely an administrative component but a critical element that determines the overall effectiveness of the risk management system.

Overall, the results of the HIRARC table indicate that the risks associated with excavation work beneath slopes can be categorized into three main sources. First, geotechnical risks,

including slope failure, excavation wall collapse, saturated soil conditions, and the influence of rainfall. Second, operational risks, which include the use of heavy equipment, work access conditions, and site drainage. Third, managerial risks, which are related to standard operating procedures (SOPs), the use of personal protective equipment (PPE), and supervision. These three categories of risk are interrelated. Geotechnical risks can be exacerbated by operational errors, while managerial failures may result in technical risks not being properly identified or addressed. Therefore, risk control can be implemented through a combination of technical measures, administrative controls, and the use of personal protective equipment (PPE) (Revanza & Wibero, 2023). Therefore, the findings of this study emphasize that risk analysis in excavation work beneath slopes must be conducted in an integrated manner.

From a methodological perspective, HIRARC has proven to be effective in identifying hazards and prioritizing risks based on their scores. The HIRARC method also provides effective outcomes in reducing occupational accident rates and strengthening safety culture. (Luthfiansyah et al., 2025) and (Hermawan et al., 2025). HIRARC becomes more meaningful when supported by adequate geotechnical technical understanding. Without such integration, the hazard identification process tends to produce only a general list of risks without adequately explaining their underlying technical causes. Therefore, the main contribution of this analysis is to demonstrate that the application of HIRARC in excavation work beneath slopes needs to be integrated with the evaluation of slope conditions, drainage systems, and construction methods.

From a practical perspective, the findings of this study emphasize that risk control strategies should not rely on a single type of intervention. Technical controls, such as slope reinforcement, retaining systems, drainage, and dewatering, must be integrated with administrative controls, including standard operating procedures (SOPs), training, supervision, and OHS audits. This approach is essential because the risks associated with excavation work beneath slopes are multidimensional. If only one aspect is addressed—for example, slope reinforcement without proper supervision—the risk remains high. Conversely, effective supervision without adequate technical improvements is also insufficient to prevent slope failure.

Thus, this discussion indicates that excavation work beneath slopes is a high-risk activity that requires a comprehensive risk management approach. Strict supervision, continuous training, and improved risk management practices are essential to reduce the likelihood of occupational accidents. (Bayhaqi & Kristian Sumual, 2025). The dominance of high-risk categories in the HIRARC results indicates that primary priority should be given to slope stability, water control, the provision of standard operating procedures (SOPs), and field supervision. This finding also confirms that occupational safety in excavation work beneath slopes is not merely a matter of OHS compliance, but also a matter of the accuracy of technical planning and the overall quality of project management.

5. CONCLUSION

Excavation work beneath slopes is a high-risk activity influenced by geotechnical, environmental, operational, and managerial factors. The results of the analysis using the HIRARC method indicate that the dominant risks arise from potential slope failure, excavation wall collapse, saturated soil conditions, and weak supervision and work procedures. These factors contribute to the likelihood of serious to fatal occupational accidents. Therefore, risk management cannot rely solely on administrative approaches but must be integrated with geotechnical technical analysis to produce more accurate and contextual risk assessments.

To minimize risks, comprehensive technical planning is required, along with the implementation of control measures such as slope reinforcement and drainage systems, as well as the strengthening of occupational safety management through standard operating procedures (SOPs), training, and consistent supervision. In addition, further research based on field data is necessary to enhance the validity of the findings and to develop a more applicable risk management model.

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