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ORIGINAL ARTICLE

Landslide Emergency Response Preparedness in Mining Areas: Early Warning System Implementation

Ardhila Chadarisman[1], Tedi Cahya Nusantara Herdianto[2]
[1,2]PT. Pamapersada Nusantara, Laydown Bintang KPC Mine Project, Indonesia
Kutai Timur, Kalimatan Timur, Indonesia

ABSTRACT

Introduction: Coal mining operations present serious risks due to landslip risks, necessitating the use of efficient early warning systems and emergency preparation. This paper examines the use of an early warning system called LASER (Land Sliding Alert) in comparison to direct direction from the supervisor using conventional radio at the KPC Sangatta mining operation of PT. Pamapersada Nusantara. The study aims to evaluate how the system affects workers' response to approaching landslides as well as their degree of preparedness. **Method:** The researchers collected 12 data over 3 months from the emergency drill and continue with observations, interviews and document review. Substantive data including risk management screening, landsliding warning accuracy and response were assessed so response time from worker can be gathered. **Result:** The results displayed a better performance in the LASER early warning system than conventional land sliding alert, achieving 100% reactivity and increased pace of evacuation. The system uses Internet of Things (IoT) to ensure immediate notification for all buildings at the same time using sirens and radio equipment that leads to faster reaction. The LASER system is 96% effective at warning employees in the statistical research. **Conclusion:** The research demonstrates that the LASER-based early warning system is extremely efficient in monitoring dangerous slope conditions in mining areas. It effectively addresses the issue of response time and ensures that personnel are well-prepared to respond promptly and effectively. The study emphasises the significance of employing sophisticated monitoring systems and resilient emergency protocols to mitigate the hazards associated with landslides. The application of the landsliding alert can be implemented in other mining areas, especially in open pit mining activities and make contributions ultimately result in a workforce that is safer and mining operations that are more sustainable.

Keywords: early warning system, emergency, internet of things, landsliding alert, mining

Corresponding Author:
Ardhila Chadarisman
Email: Ardhila.chadarisman@gmail.com
Telephone: +6281258670158

INTRODUCTION

Coal mining areas suffer from frequent landslides. Factors such as topography, rainfall and mining activity also tend to make soil conditions unstable which can increase the risk of landslides. Mining slopes stability so basically depend on local geological conditions, slope geometry, groundwater condition in the area and external loads such a blasts vibration or mechanical loadings as summarized by (Fang *et al.*, 2023).

In this contribution, the research seeks to explore what an early warning system would be able to do about landslides in open-pit mining operations by using radar-based technology.

Accordingly, mining firms have to give importance on the preparedness and immediacy of their employees when this kind of circumstances are met. For better preparedness and response it is recommended to utilize dedicated early warning systems for detecting and alarming possible landslides. This system of early landslide warning is capable in informing the field labors and other persons who are important as soon as signalization of impending danger due to landslides occurs thus contributing towards lowering probability for landside disasters while mitigating secondary damages. (Menon and Kolathayar, 2022).

Open-pit mining operations are more susceptible to landslides due to factors such as erosion, precipitation, and explosives. These actions will

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cause a progressive deterioration in the strength of materials, which will exacerbate slope instability Devanand *et al.* (2023) argued that a monitoring and early warning system is essential for the management of slope collapses in this context. Zhao, Lyu and Kang (2022) maintained that the identical solutions constitute one of the issues

In the same vein, scientists have been employing machine learning techniques to develop systems for predicting landslips. In order to predict the likelihood of landslides, these systems employ a diverse array of data, such as soil moisture, rainfall trends, and other variables (Stanley *et al.*, 2021). Implementation of a slope monitoring system that is predicated on a global positioning system is an effective method for detecting failure events and monitoring ground movements (Devanand *et al.*, 2023).

The successful application of these early warning technologies in landslides shows that it is possible to help ensure the safety and emergency preparedness can make use of our time, producing timely warnings (Wang *et al.*, 2022).

Radar and robotic total station technologies are promising solutions for the specialised components needed in early warning systems of open-pit mines. A radar-based system provides continuous, real-time monitoring that can assist in the early detection of potential locations where a slope failure is likely to occur. Robotic total stations offer precise surface displacement measurements that, when combined with other monitoring data, enable a more comprehensive assessment of slope stability (Glueer *et al.*, 2021).

These state-of-the-art technologies will enable mining companies to identify and resolve slope instabilities, thereby guaranteeing the safety of their employees and the uninterrupted operation of their operations (Bar and McQuillan, 2021). The implementation of advanced monitoring technologies and efficient emergency response systems will significantly reduce the probability of landslip-related incidents in the mining industry. This will at last save workers' lives, protect priceless resources, and ensure the long-term survival of the sector (Wang *et al.*, 2022).

Alam and Syarif (2020) The study supports the idea that there is a connection between knowledge and follow-up actions in preparing for landslide disasters. The study will investigate the interplay between knowledge and behaviour in environments prone to triggering landslides. This study seeks to examine the implementation of landslide early warning systems to enhance the preparedness and response of employees to potential landslides in coal mining areas, specifically in the operations of PT. Pamapersada Nusantara KPC in Sangatta District.

The purpose of this research is to explore the utilization of landslide early warning systems to improve employee preparedness and response to potential landslides in coal mining areas, particularly in the operations of PT. Pamapersada Nusantara KPC Sangatta District.

This paper will discuss how landslide early warning systems can be effectively implemented in coal mining areas, what factors influence their success, and the benefits that can be obtained from using these systems. In this study, we will use interview methods, observation, and literature studies to collect data and analysis. Thus, it is hoped that the research in this paper can provide a clear and comprehensive picture of the use of landslide early warning systems to improve employee preparedness and response in coal mining areas.

METHODS

This research was conducted on the operational sites of PT. Pamapersada Nusantara KPC Sangata District, encompassing Pit Mustahil, Pit Pelikan South Extension, Pit Pelikan, Pit Kanguru, and Pit Pedayak. The study was carried out over a three-month period from February to April 2024, employing both primary and secondary data collection methodologies. Primary data was acquired through the assessment of slope stability monitoring system planning accuracy, response to landslide hazard warnings of 12 emergency drill carried out, and management of landslide risks. Literary searches of past studies using artificial intelligence help to support studies on early warning systems.

In the subsequent study, the authors utilized variables related to the application of conventional early warning systems and early warning systems based on the Internet of Things (IoT), and their correlation with the evacuation process of employees and mining equipment from affected locations to emergency assembly points.

The collected data will be processed and subjected to mathematical, empirical, and statistical analyses, with the results presented in the form of calculations, tables, graphs, and field documentation. Following the analysis, conclusions will be drawn and recommendations formulated based on the research findings.

RESULT

Types of Slope Stability Monitoring Equipment

Total Station

The total station is a frequently employed instrument in various surveying fields, including coal mine surveys. It is a combination of an electronic theodolite and an electronic caliper. This device is equipped with precise distance and angle sensors and can be connected to computers or surveying software for further data processing.In coal mine surveying, the total station serves multiple purposes: Topographic measurement: to measure and map soil contours, coal surfaces, and other topographic features in the mining area; Coal volume measurement: to quantify coal volumes at various locations within the mine; Mine boundary mapping: to delineate the extent of mining operations; Surface change monitoring: by utilizing the total station periodically, changes in coal mine surfaces can be monitored in conjunction with mining activities.

Robotic Total Station (RTS)

The Robotic Total Station (RTS) is applied to measure slope stability and, thus its design allows for the use of robotic technology as well as rapid data processing capacities such that authentic monitoring data are realized. These

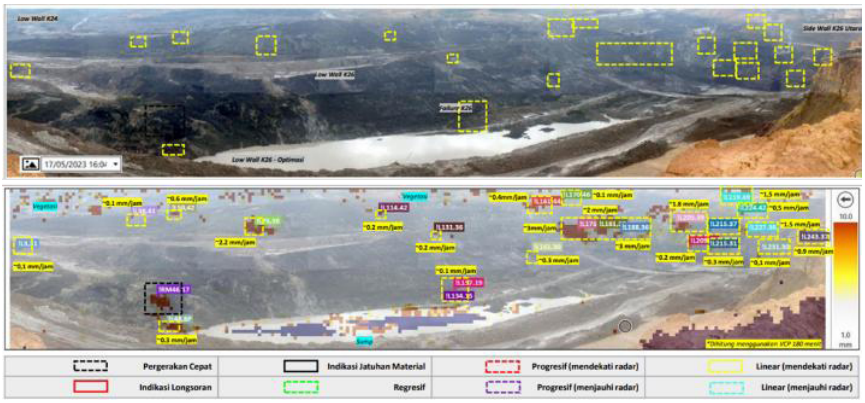

Figure 1. Example of Data Resulting from SSR Processing

Table 1. High Risk Area

OBJECT	PDY	KGR	PLK	PSE
Slope Stability Factors (SF)	medium	medium	medium	medium
Dumping into water or Bench Height	high	low	high	low
Weak Layer on the slope	high	high	high	high
Water infiltration / seepage	high	high	high	high
Fault / fracture / crack	high	low	low	low
Fold (syncline)	high	high	high	high
Creek, ponding area or water flow at the toe of the slope	low	low	low	low
Creek, ponding area or water flow at the top of the slope	high	high	high	high
Joint	high	high	high	high
Significant and frequent ground/material movement	high	high	high	high
Availability of appropriate monitoring tools for the movement	medium	medium	medium	medium
Work near rivers	low	low	low	low
Drilling & blasting activities near slopes	low	low	low	low
Barrier	high	high	high	high
Undercut bedding plan	high	high	high	low
Water flow / River / water ditch to disposal area	low	low	low	low
Water level reduction if exceeding safe limits	low	low	low	low
Placement of equipment / units such as Tower Lamps, Observation Posts, Evacuation aids, facility	low	low	low	low

are the systems that enable real-time monitoring (RTS) of slope deformations present in mining sites or large-scale building endeavors which, due to their geotechnical characteristics, may evolve into landslides and collapses. It operates by mapping the area to be monitored and collecting data on topographical changes and slope deformations.Slope stability monitoring using RTS can be conducted in real-time due to its integrated robotic system. The data generated from RTS monitoring consists of displacement data for an observation point, represented by a prism.

Slope Stability Radar

Slope Stability Radar (SSR) is a monitoring device used to observe ground movements on mine slopes with high accuracy. This instrument operates using radar technology that scans the mine slope surface and generates 3D images to continuously monitor surface changes.The working principle of SSR involves transmitting electromagnetic signals to the mine slope surface. These signals are reflected back to the SSR receiving antenna and then processed by software to produce 3D images that illustrate changes in the mine slope surface over time. The data generated from SSR monitoring includes movement velocity and deformation trends (Figure 1).

The data generated by SSR enables continuous monitoring of mine slope stability and identification of anomalous movements. This capability facilitates the implementation of preventive measures or early mitigation strategies prior to the occurrence of damage or potential disasters on mine slopes. The real-time nature of SSR data allows for proactive risk management and enhances overall safety in mining operations.

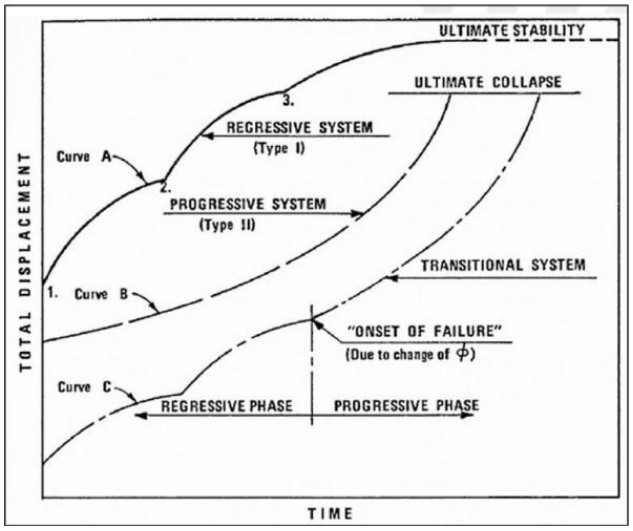

Figure 2. . Grafik Typical Displacement vs Time Graph (Broadbent and Zavodni, 1982)

Mapping High Risk Areas

Mapping of high risk areas in the PT mining area. Pamapersada Nusantara is carried out using a matrix mechanism, which consists of monitoring objects and determining the risk level per each area (Table 1). From these parameters, mapping is carried out based on a matrix mechanism combined with risk levels. Until you find a high risk area that requires real-time monitoring.

Determination of Threshold Values

Establishing an early warning system using Total Station, RTS, or SSR requires a threshold value in determining slope stability conditions. This is done to eliminate human error in interpreting slope movement patterns. Determining the threshold value is used to determine the status of the slope, whether the condition of the slope is still safe or will move. Determining the trend of movement rate threshold values to determine slope status classification is based on the graph from Broadbent and Zavodni (1982) in Figure 2.

Early Warning System Design

Conventional Early Warning System

It is an early warning system with a mechanism where the movement of the mine walls is captured by sensors and then PIC Geotechnics informs manually via conventional radio to notify employees in the affected area of evacuation.

Land Sliding Alert (LASER)

Land sliding alert is an early warning system combined with the Internet of Things, so that it can directly provide alerts via sirens and radio rigs simultaneously to alert employees working in areas affected by landslides.

Overview of LASER early warning systems

Landslide early warning system in PT. Pamapersada Nusantara is carried out using several hardware devices that are programmed to provide warnings regarding landslide-prone preparedness (Figure 3).

Slope Stability Radar (SSR) is used to obtain real time mine slope movement data, slope monitoring is carried out by SSR, and RTS is adjusted to TARP (Trigger Action Response Plan).

Monitoring data on the speed of movement of landslides in the High Wall block, Low Wall pit area from the SSR tool. Linear and progressive landslide movement data (Evacuation) GroundProbe Team/ Engineer. Geotek Select the location area and press the "ON/OFF" button in the 1PAMA web or android application.

Microcontroller Technology turns on the siren sound and rotary lamp on the tower/mega tower at the Pit location, during the Evacuation Process and can be turned OFF according to the situation and conditions in the pit area. Simultaneously, the micro controller technology automatically moves the RIG Radio channel and emits an urgent traffic sound 3x, evacuates the landslide area and alarms (for 20 seconds).

Testing of Landslide Preparedness Systems and Attitudes

A cross-tabulation was carried out between the type of early warning and the achievement value (table 3). Based on the data obtained from the emergency drill, the early warning system that is more widely used is the conventional warning system, while the LASER early warning system has a percentage of 50% of conventional. Of the 4 incidents that exist, 100% of alerts with LASER get achievements above 100%.

Based on the analysis of the achievement of evacuation time compared to the target, the use of the LASER method early warning system shows very good results, where 100% of tests in emergency drills reach the target time, when compared with conventional there are 50% of tests with conventional systems that do not reach the target. evacuation time in landslide-prone areas.

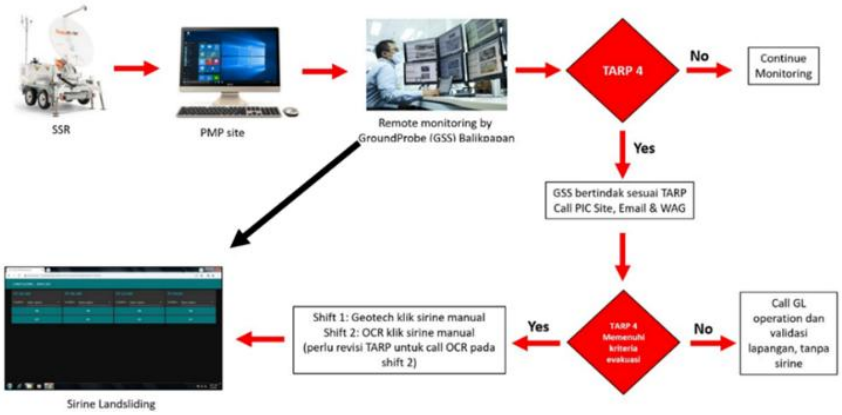

Figure 3. Landslide Early Warning (LASER) Scheme

Table 2. Testing of Landslide Preparedness Systems and Attitudes

Area	Tipe Alert	Early Warning	Duration (minute)	Achievement
Front Loading	Laser	12:00:00	00:05:00	450%
Front Loading	conventional	11:32:00	00:13:00	173%
Front Loading	conventional	11:15:00	00:12:00	200%
Front Loading	conventional	15:15:00	00:25:00	72%
Disposal	conventional	11:29:00	00:06:00	75%
Front Loading	Laser	09:30:00	00:10:00	240%
Disposal	conventional	22:30:00	00:12:00	38%
Front Loading	Laser	23:30:00	00:11:00	218%
Front Loading	Laser	11:50:00	00:13:00	185%
Front Loading	conventional	11:46:00	00:23:00	104%
Front Loading	conventional	11:45:00	00:30:00	90%
Front Loading	conventional	11:32:00	00:12:00	150%

The results of linear regression testing (Table 4) show that the conclusion from the statistical analysis data is that the use of an early warning system using a LASER system is better than a conventional system. From the data that can be tested using linear regression. From the results of the regression analysis, it was found that the p-value was less than 0.05 (Table 5), which convinced the author that the type of early warning had an effect on achievement. This concluded that it was true that the LASER early warning system was mathematically proven to be more effective in providing early warning to employees. who work in mining areas.

DISCUSSION

Infrastructure Readyness:

Trigger Action Response Plan

Readings on the slope stability radar are monitored in real time by groundprobe (radar team) and carried out assessments based on TARP criteria, as well as mine slope movement data monitored by RTS which will later be used as a reference to activate the Land Sliding Alert (LASER) early warning mechanism.

The implementation of TARP (Trigger Action Response Plan) criteria in the assessment of monitoring data facilitates the standardization of responses to various detected risk levels. This method makes more ordered and successful mitigating and preventive actions possible. In geotechnical risk management, the application of TARP criteria is essential in methodically evaluating and handling possible hazards.

By establishing predefined thresholds and By defining certain thresholds and developing matching action plans, TARP enhances the decision-making process in crucial events. This system ensures controls are proportional to the risk found, which makes for a more mature and detailed approach to managing risks. The monitoring systems even captured TARP and it dramatically increases the proactive approach in safety control. It provides a precise, levels-based approach to escalate responses in line with risk level — thus optimising resource utilisation and increasing overall operations performance.

Conducting a systematic status quo analysis also increases the capacity to forecast risk management measures and it supports an effective stakeholder communication in risk reduction processes (Lian *et al.*, 2024).

A mechanism that can be a very useful tool and an effective instrument especially in the case of long term risk management, are fixed monitoring systems with alarms for early warning, to identify where it is needed either geotechnical work to increase slope stability or focal interventions. For the ground engineering industry, this methodology assists in taking pre-emptive actions to minimize risks and facilitates making informed decisions. Employing modern monitoring technologies such as Robotic Total Station (RTS) and slope stability radar, can help in detecting changing of the slopes real-time thus becoming an early warning for possible landslides. These sophisticated systems can quickly detect minute shifts in slope behaviour, delivering precise measurements and unbroken data streams.The continuous gathering of data from these technologies significantly increases trend analysis of slope movements' capability.

Through this analytical method, geotechnical engineers and risk managers can find out the distinct trend lines in slope behaviour over a certain duration which presents considerable understanding of never stagnant nature with regards to slope stability.

Table 3. Cross Tabulation of Laser VS Conventional Early Warning Types

	Laser	Conventional
<100		4
>=100	4	4
Total	4	8

Table 4. Linear Regression

Regression Statistics	
Multiple R	0.716583242
R Square	0.513491543
Adjusted R Square	0.464840697
Standard Error	0.806748102
Observations	12

Table 5. Data Testing

	Coefficients	Standard Error	t Stat	P-value
Intercept	4.3375	0.855686	5.069035	0.000486
X Variable 1	-1.605	0.49403	-3.24879	0.008738

Moreover, these devices offer immediate information which aids to provide specific and also quick danger level analyses. With remedial action directly linked to real-time information on things like traffic, road surface or even bridge and tunnel stress, engineers can take decisive action based upon the data supplied (Zulkarnain *et al.*, 2024).

Emergency Escape Plan

Displacement plays a key role in enabling greater landslide awareness and preparedness as well as risk reduction of landslides through infrastructure upgrades. The development of an emergency escape plan (Figure 4), which also provides instructions for the staff to perform specific tasks in case a landslide is potentially triggered, helps bolster proper infrastructure that makes landslide disaster preparation ready as required. Put up signs highlighting landslide prone areas, establish emergency meeting points and offer evacuation routes. These precautions are necessary to inform the workers of their threats and increase focus on potential landslides in your place.

A study published earlier this month highlights the importance of emergency evacuation preparedness in enhancing community resilience to landslides. The result carried out by Basofi, Fariza and Kamal (2019) shows that the understanding in terms of which road are safer to be passed every location for evacuation when a landslide occurs after confirmed with an emergency plan showed significant improvement.

Any good emergency evacuation plan will include an evaluation of the potential for landslides in your area. This includes knowing how often landslides actually happen, where they occur, what sort of damages are possible and who might be vulnerable or at risk to those events.

Understanding the specific hazards unique to community provides a blueprint of how they can shape, address their individual needs and obstacles in an emergency evacuation strategy (Bachri *et al.*, 2021).

Emergency evacuation plans should specify what communication and coordination methods will be used between different groups of people within the company. A prompt and synchronized response in the event of a landslide disaster require efficient communication, coordination (Akbar *et al.*, 2024).

In addition to that, the Emergency Escape Plan should include mechanisms for identification and marking of safe evacuation routes as well as assembly points. Communicating this information to the community should involve a variety of methods, including public awareness campaigns as well as signage. You can make sure that only people who are registered receive notifications of the evacuation routes and respond to emergencies (Geng, Hou and Geng, 2021).

Well organized evacuation plans are able to provide a standard template which leads more harmonised means during the time of crisis. More ordered evacuation procedures and faster response times can follow from improved coordination (Basofi, Fariza and Kamal, 2019).

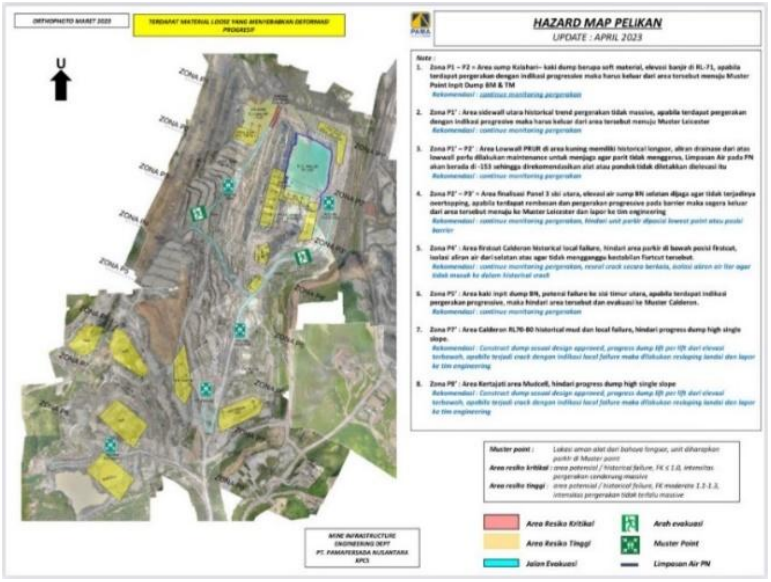

Figure 4. Landslide Emergency Escape Plan

Having an increased level of consciousness is essential for cultivating a culture that prioritises readiness and takes proactive measures to reduce risks. Furthermore, following a comprehensive emergency evacuation plan will help to significantly reduce panic and improve the success of the evacuation process. Emergency response plans offer a methodical approach to handle disasters, so reducing the anarchy sometimes seen in such conditions. Minimising possible casualties and damage in landslide events depends mostly on lowering panic and improving efficiency. The paper emphasises the need of cooperation among people living in a community and emergency responders.

Employee Competency

Employee Training

Employee training is an important point in increasing the knowledge aspect of preparedness. Of the 2978 people who work in areas at high risk of landslides, 100% of employees have received geotechnical awareness training which is the basis for employees' understanding of the characteristics of landslides, steps to prevent landslides including aspects of preparedness for potential landslides.

Landslide disaster preparedness training for employees has a significant relationship with their level of preparedness in the evacuation process. Emergency response training can increase employee alertness in the event of a disaster(Solikhah, Krisdianto and Kusumawardani, 2020). This training helps employees better understand evacuation procedures, recognize signs of danger, and act quickly when an emergency situation occurs.

Furthermore, research conducted by Zulkarnain *et al.* (2024.) revealed that activities to increase community capacity, including employees, in disaster preparedness can improve their cognitive and psychological aspects. This means that through training, employees not only gain knowledge of evacuation procedures, but also develop the mental readiness necessary to deal with emergency situations.

Emergency Drill

Emergency drill or emergency training is one way to increase preparedness in dealing with emergency situations, including landslides in mining areas.

Evacuation training, including emergency drills, has a positive impact on employee evacuation behavior. This research revealed that participants who received video-based training more often chose to follow safety recommendations when faced with emergency situations (Liu *et al.*, 2021).

Emphasizes the importance of emergency drills in preparing building occupants for actual evacuation situations. Although there are differences between drills and actual evacuations, drills remain a key component in improving employee preparedness (Liu *et al.*, 2021).

Meanwhile, research conducted by Zhuge, 2024 identified factors that influence the effectiveness of emergency drills. This study found that availability of equipment and facilities, quality of training, involvement of leaders, frequency of training, skills in designing emergency drill plans, adequacy of funding, and coordination between departments were the main predictors in evaluating the effectiveness of emergency drills. These findings emphasize the importance of various aspects in implementing emergency drills to increase employee readiness in the evacuation process (Zhuge *et al.*, 2024).

Carrying out regular emergency drills can help increase awareness and skills in dealing with landslides, so as to minimize damage and danger at the time of the actual incident. Several steps that can be taken in landslide emergency drills in mining areas include, Planning, namely selecting scenarios and locations, determining roles. and team responsibilities, as well as determining goals and evaluating training results.

Preparations to ensure that all personnel involved in emergency drills have sufficient knowledge and skills, as well as the necessary tools and equipment. The simulation or scenario carried out must be as accurate as possible to the conditions that may occur in the mining area. And evaluation is carried out after the simulation is completed to evaluate the suitability of the scenario and the effectiveness of the actions taken by personnel. Evaluations can also help identify weaknesses and make improvements for future emergency drills.

Carrying out regular emergency drills can help increase preparedness in dealing with landslides in mining areas. This helps to guarantee personnel safety and reduce possible losses during a real incident.

Consequently, one can say that improving employee readiness for evacuation situations depends

much on emergency drills.These drills enhance the comprehension and skills of staff members while also assisting companies in identifying and rectifying deficiencies in their evacuation plans.Drills are a great way to promote a culture of safety awareness and preparedness in the workplace, so improving the general resilience and effectiveness of the emergency response capacity of a company.

Landslide Emergency Response Behaviour

This research shows a significant relationship between employee knowledge and behavior in the evacuation process. revealed that employees' knowledge of evacuation routes has a positive influence on their behavior when an emergency situation occurs. This research found that employees with higher levels of knowledge tended to have better responses and follow evacuation procedures more effectively.

Simulations of emergency drills and training help greatly increase staff knowledge of ideas related to landslip disasters. This corresponds with studies showing that different cognitive domain levels among people affect the knowledge level of respondents, so producing different understanding of disaster concepts. Through structured training, employees can acquire a more comprehensive and cohesive understanding of the characteristics, origins, and consequences of landslide occurrences (Prasetyaningsih, Mappewali and Naniwarsih, 2023).

Companies conduct disaster preparedness education and simulations to enhance employees' knowledge and understanding. The acquisition of knowledge through both formal and non-formal education, such as training and emergency drills, helps to improve employees' understanding of disaster preparedness (Matunhay, 2022).

Emergency drills let staff members apply their learned skills in modelled disaster situations. This is crucial because knowledge that does not emphasize experience is typically prone to being forgotten. By conducting regular simulations, employees can develop practical skills necessary for emergency situations.

The routine implementation of emergency drills enables organizations to identify weaknesses in their evacuation and preparedness procedures. This provides opportunities for refinement and improvement of procedures, which in turn enhances the effectiveness of employee responses to landslide disasters (Graff, 2019).

In addition to enhancing knowledge, training and simulations can also influence employees' attitudes towards disaster preparedness. Research indicates a strong correlation between knowledge and disaster preparedness behavior, where increased knowledge corresponds to higher levels of preparedness behavior.

Based on research conducted by employees at PT. Pamapersada Nusantara already has adequate knowledge in emergency aspects, especially in the aspect of landslides in mining areas. From the results of the quality of answers related to slope stability knowledge, it was found that 100% of employees were able to answer questions correctly, the percentage of this knowledge influenced the actions taken when they received an early warning from the system running at PT. Pamapersada Nusantara.

Employee behavior regarding mine slope landslide preparedness attitudes at PT. Pamapersada Nusantara can be categorized as good. This form of good behavior is reflected in the supervisor's compliance when receiving evacuation information from the early warning system. The information received by the supervisor is immediately passed on to employees working in the affected area/operator. Evacuation instructions were carried out without any questions or objections from employees in the affected area.

Another clear form of behavior is that the supervisor immediately isolates the affected area and coordinates according to the emergency chain of command. The supervisor isolates the area so that no one enters the affected area. Heavy equipment operators also gather at the emergency assembly point according to the supervisor's instructions.

The relationship between knowledge, early warning and landslide preparedness attitudes in mining areas. Based on the results of studies on the implementation of early warning in the PT area. Pamapersada Nusantara, shows that knowledge related to emergencies has a significant influence on preparedness attitudes. This preparedness attitude is demonstrated in the periodic emergency drill process which is carried out to obtain a good response time and the isolation actions carried out by operational supervisors in securing facilities, infrastructure, installations and equipment in the affected mining area.

In order to maintain reliable laser system performance, it is necessary to carry out maintenance on equipment that functions as sensors and emergency message sending devices on radio

channels in the affected area. The main device that provides triggers for the Land sliding alert system is the Slope stability radar, in the process maintenance of the slope stability radar is carried out daily and periodically. Where daily checking of engine oil and fuel levels in the SSR is required. Periodical service is also carried out every 3 month to ensure this sensor device can operate optimally, so for long-term application, this lans sliding alert is very feasible and reliable.

CONCLUSION

Research conducted on emergency drill evacuation data utilizing two types of alerts, laser and conventional, yielded significant findings regarding landslide preparedness in mining operations. The study concluded that the LASER-type Early Warning System (EWS) is highly suitable for monitoring landslide-prone slopes with critical criteria, demonstrating superior performance in alert speed and achieving a 100% response rate among employees in affected areas. Moreover, the successful accomplishment of evacuation targets in high-risk areas indicates a positive correlation between employees' preparedness knowledge and their behaviour concerning landslide preparedness. This development is ascribed to a basic change in PT. Pamapersada Nusantara employees' safety attitude. Comparative study of conventional and LASER early warning systems showed that the LASER approach greatly exceeded its conventional counterpart, displaying a 50% higher achievement rate in evacuation speed in areas of critical landslide risk. These results highlight how well LASER-based EWS improves general landslide response and preparedness in mining area.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding the research, authorship, and/or publication of this article. This study was conducted independently without any external influence or intervention that could affect the objectivity of the research findings. All data and information utilized in this research were obtained through legitimate and ethical methods, and no party had privileged access to the research data. The authors also affirm that there are no personal or professional relationships that could influence the interpretation or presentation of the research results. Hereby, the authors guarantee that the research was conducted with full integrity and is free from any bias that may arise due to conflicts of interest.

AUTHORS' CONTRIBUTION

ACH contributed to the emergency concept analysis, data collection and statistical analysis, initial draft writing, and research conceptualization. TCN conducted geotechnical aspect analysis, methodology and manuscript refinement. Both authors contributed to the interpretation of results, manuscript revision, and final manuscript refinement. All authors have read and agreed to the published version of the manuscript.

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