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Identifying The Activity – Based Hazards Involved in The Terralink Construction Method

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ABSTRACT

A major geologic hazard that occurs frequently throughout the world is landslides. Slope failures and landslides are common in Malaysia, despite the country's lack of precipitation (less than 25% of the area is made up of hills and mountains). Each year, landslides will result in thousands of fatalities and injuries and billions of ringgits in property damage. In Malaysia, the terralink construction method was the new method used for the slope repair project at Simpang Pulai-Blue Valley Road. However, there is no existing risk management plan for the terralink construction method. Hence, there is a need to identify the activity-based hazards involved in this method. The study utilised a qualitative approach and was conducted via the interview method. The interview was conducted at three agencies, each represented by JKR, a consulting firm and the main contractor. It was found that six categories of hazards occur when using the terralink construction method, such as safety, natural disaster, schedule, scope, environment, and technical. Activity-based hazards were found in the above categories. This study intends to contribute to producing information and data regarding the Risk Management Plan to all stakeholders as future references.

INTRODUCTION

In Malaysia, despite there weren't many powerful or significant earthquakes in Malaysia, there were still numerous large-scale landslides, which were mostly caused by gravity combined with intense and protracted rains. 12 people were killed in Malaysia's first known landslide, which happened on December 7, 1919 (National Slope Master Plan 2009-2023). Approximately 440 landslides were documented between 1973 and 2007. Since 1973, landslides in Malaysia have claimed just around 600 lives (National Slope

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Master Plan 2009-2023). In addition, there are thousands more ‘unreported’ minor slope failures and landslides. Slope failures and landslides have occurred frequently in Malaysia from 1973 to 2007. The economic impact of the landslides was estimated to be around U.S. $1 billion (Abdul Rahman & Mapjabil, 2017).

The implementation of a new method, which is Terralink method, has been proposed for use in Malaysia for slope repair beginning in 2021. It will fall under the mechanical procedure. Connecting a new structure to an existing structure is an innovative alternative. Terralink can be used to connect an additional structure to the face of an existing concrete retaining wall, a soil-nail wall, or a natural feature like sloping terrain that only provides a small area for the required backfill and soil reinforcements (Soletanche Freyssinet Group, 2015).

Garis Panduan Pengurusan Risiko Projek JKR Version 2.0 (2023) provides the guideline for a risk management plan that provides a systematic and proactive approach for analysing and estimating identified project risks throughout the project life cycle. The risk management process also allows the project team to document a list of risks and treatment methods to extract lessons learned, provide examples, and add value to project implementation. Risk management plans have been done for all conventional methods for slope repair constructed in Malaysia. Nevertheless, there has yet to be a risk management plan for the Terralink construction method due to the new implementation of this method in Malaysia. Therefore, the main objective of this study is to identify the activity-based hazards involved in the Terralink construction method. The risk management plan for slope repair using the Terralink construction method must be developed, which aligns with Arahan KPKR 29/2023, which states it is compulsory to develop risk management on every tender project.

LITERATURE REVIEW

Landslide Failure in Malaysia

Malaysia has a tropical climate with substantial rainfall practically year-round, especially from October to February. Particularly in these few months, Malaysia has seen several natural disasters, including floods, mudslides and landslides brought on by excessive rainfall. The area frequently experiences landslides, especially during this monsoon season when rainfall can reach 700mm per month. Cameron Highlands and roads along the Tapah-Cameron Highlands and Simpang Pulai-Cameron Highlands route have been identified as landslide hot spots among 31 locations. Table 1 summarises several landslide tragedies in Malaysia from 1961 to 2022.

Table 1. Landslides Tragedy in Malaysia

Date	Location
1 May 1961	A landslide occurred in Ringlet, Cameron Highlands, Pahang.
21 October 1993	A new cove was created in the coastline as a result of the man-made Pantai Remis landslide.
11December 1993	In Taman Hillview, Ulu Klang, Selangor, a block of the Highland Towers collapsed, killing 48 people.
30 June 1995	22 people were killed in the landslide at Genting Highlands slip road near Karak Highway.
6 January 1996	A landslide close to Gua Tempurung, Perak, on the North-South Expressway (NSE). One fatality.
29 August 1996	Forty-four (44) individuals were murdered in a mudflow near the Pos Dipang Orang Asli village in Kampar, Perak.

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November 1998	Massive rockslide at Bukit Saujana, Paya Terubung, Penang.
January 1999	Shallow rotational slide. Heavy rain triggered landslides – buried several house/huts in squatters' settlement, Sandakan, Sabah. 13 deaths.
15 May 1999	A massive landslide near Bukit Antarabangsa, Ulu Klang, Selangor. Most of the Bukit Antarabangsa civilians were trapped under the rubble. Only two victims survived - an Indonesian maid and a child.
January 2000	Debris flowed from an upstream landslide and erosion washed away worker squatters in the vegetable farm, Cameron Highlands, Pahang. 6 deaths.
January 2001	Debris flow in Johor's Gunung Pulai. Debris flowing from many small landslides upstream of Sungai Pulai was caused by heavy rain. – washed away settlements along the riverbank. 5 deaths.
20 November 2002	A landslide in the early hours of the morning in Taman Hillview, Ulu Klang, Selangor, caused the house of Affin Bank Chairman General (RtD) Tan Sri Ismail Omar to collapse, killing a member of the family.
November 2003	The New Klang Valley Expressway (NKVE) was closed for more than six months due to a rock fall or rock debris at the Bukit Lanjan interchange.
November 2004	Taman Harmonis, Gombak, Selangor has a debris flow. Following a week of nonstop rain, the back portion of the neighbouring downslope bungalow was toppled by debris soil from the uphill bungalow project sliding or flowing. 1 death
December 2004	Rockfall – buried back portion of the illegal factory at the foot of limestone hill in Bercham, Ipoh, Perak. 2 deaths.
31 May 2006	The landslides at Kampung Pasir, Ulu Klang, Selangor, claimed the lives of four people. Buried 3 blocks of longhouses.
March 2007	Landslide at Precint 9, Putrajaya. Some 23 cars were buried under the debris.
26 December 2007	Two villagers were buried alive in a major landslide, which destroyed nine wooden houses in Lorong 1, Kampung Baru Cina, Kapit Sarawak.
2 February 2009	One contract worker was killed in a landslide at the construction site for a 43-storey condominium in Bukit Ceylon, Kuala Lumpur.
21 May 2011	Heavy rains caused a landslide at the Children's Hidayah Madrasah Al-Taqwa orphanage in FELCRA Semungkis, Hulu Langat, Selangor, which killed 16 persons, mostly children and an orphanage caretaker.
29 Dec 2012	Due to soil movement, 88 occupants of bungalows, shophouses, and double-story terrace houses in Puncak Setiawangsa, Kuala Lumpur, were given the order to leave.
4 Jan 2013	Following a landslide that left multiple cars buried in mud, work on the Kingsley Hill housing project in Putra Heights has been suspended.
11 November 2015	A landslide occurred at km 52.4 of the Kuala Lumpur-Karak Expressway between Lentang and Bukit Tinggi, Pahang and Gombak-Bentong old roads. The Lentang-Bukit Tinggi stretch of the expressway was closed to traffic.
January 2016	The primary route that links Genting Highlands and other regions of Pahang state with the capital Kuala Lumpur has been completely blocked by a landslide, obstructing all lanes in both directions. All occupants of the four cars that were caught in the landslide escaped unharmed.
February 2016	194 minor landslides and embankment failures. Puncak Borneo area, comprising mainly Bidayuh settlements and Padawan Ring Road, was the most "critical".
December 2022	Landslides at Father's Organic Farm campsite, Jalan Batang Kali-Genting Highlands, resulted in 30 fatalities and 50 injuries.

Source: Abdul Rahman & Mapjabil (2017) & Raja Rahim (2023)

Causes of Slope Failure

Slope instability may be caused by vegetation, meteorological, morphological, topography, climate and geology, or a combination of these factors (Psarropoulos et al., 2024; Basile et al., 2003). Slope failures are caused by the soil mass moving downward above the slip surface. According to Hossain et al. (2017), any changes in soil condition might lead to instability in the soil mass, which results in slope failure. These changes disturb the balance between driving and resisting forces. Malaysia experiences up to 4500 mm of yearly precipitation. This, along with consistently high temperatures throughout the year, results in strong chemical weathering and the development of dense residual soil profiles, some of which may be found down to a depth of 100 meters (Abdul Rahman & Mapjabil, 2017). Together with other contributing elements, this combination of climate and geology makes landslides one of Malaysia's most deadly natural catastrophes (Jamaludin et al., 2008). In addition, landslides may be caused by design errors, such as inadequate site-specific ground investigation, a poor investigation into prior failures, and the misuse of recommended procedures (Abdul Rahman & Mapjabil Rahman, 2017).

Slope Repair Method

Numerous repair methods have been identified for stabilising embankment slope failures. Basically, it will be divided into five methods: Mechanical Method, Earthwork Method, Biotechnical Method, Chemical Method and Water Method (Refer to Figure 1). First, to achieve the intended result, mechanical slope restoration techniques stabilise slopes by either changing the physical makeup of the soil or adding a barrier to the soil. Various methods exist for repairing slopes mechanically. These methods encompass a range of techniques, including but not limited to the installation of retaining walls, the use of launched soil nails, the application of recycled plastic pins, the utilisation of geosynthetics, and the deployment of gabion (Chairullah et al., 2024; Khan et al. 2021). Second, Earthwork slope repair methods stabilise slopes through the physical manipulation of the affected area. In general, these methods are the most popular ways for repairing shallow embankment failures (Zhang, 2014; Collin et al., 2008) and among the most economical solutions available (Hossain et al., 2017). Using standard tools like rollers, compactors, and backhoes, agency maintenance workers typically perform earthwork slope repair techniques.

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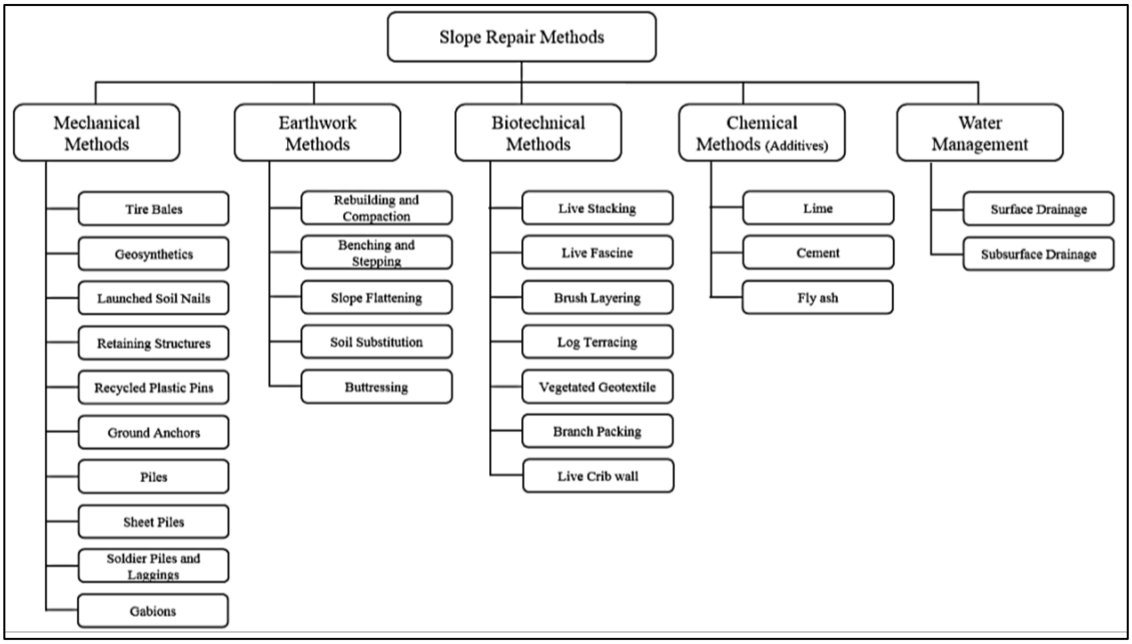

Fig. 1. Classification of Slope Repair Methods.

Source: Shahandashti et al. (2018)

Third, to prevent erosion and surficial collapse, biotechnical slope stabilisation techniques combine structural elements and living plants on slopes, embankments, and stream banks. Fourth, additives are used in slope repair to improve the strength and durability of the soil, change the gradation of the soil, or serve as a binder to cement the soil (Shahandashti et al., 2018) Lastly, Water-based methods are often integrated with other slope repair techniques to enhance the longevity of repairs and mitigate recurrent failures caused by drainage issues. Efficient water drainage diminishes driving forces and augments soil shear strength (Lohnes et al., 2001). Furthermore, after implementation, appropriate monitoring and maintenance are necessary for the long-term and effective operation of water management techniques (Collin et al., 2012).

Basically, in Malaysia, there are 3 methods used for slope repair method which are the Mechanical Method, Earthwork Method and Water Management (Refer Figure 2). The terralink method is a new method that has been implemented in Malaysia.

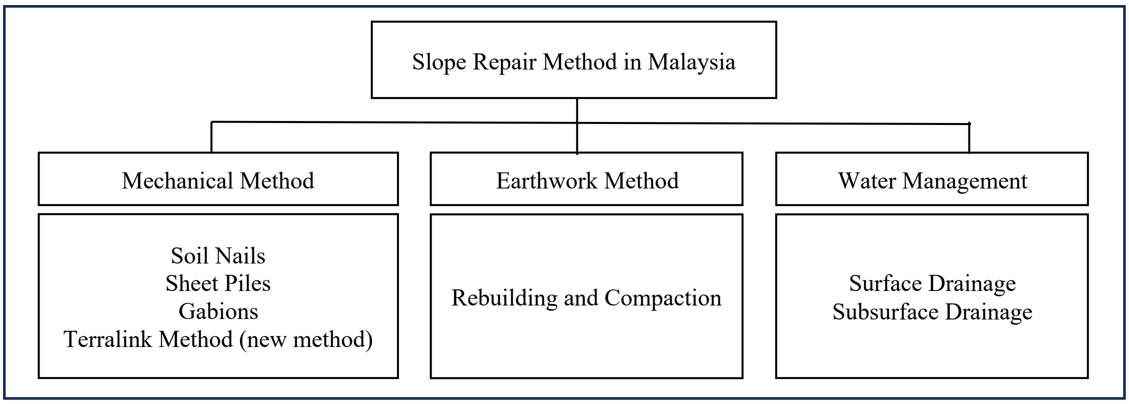

Fig. 2. Classification of slope repair method in Malaysia

Source: Shahandashti et al. (2018)

Terralink Construction Method

Starting in 2021, a new method has been proposed to implement in Malaysia for slope repair, the terralink method, which will be under the mechanical method. It is an innovative solution to link a new structure to an old one. Terralink can be used to connect an additional structure to the face of an existing concrete retaining wall, a soil-nail wall, or a natural feature like sloping terrain that only provides a small area for the required backfill and soil reinforcements (Soletanche Freyssinet, 2015). It is mainly used for earth shoring and road widening. Terralink anchored retaining walls are an excellent cost-effective way for building conventional earth-retained structures or a shoring system near an existing slope or structure reducing the high costs involved in typical design conceptions for the significant earthwork. Terralink structures can be developed up to 10 meters to 15 meters of slope.

Terralink is an innovative solution created by Reinforced Earth. The difficulties of constructing new earth-retained structures in front of preexisting ones where there is little space for expansion are resolved by this technique. The objective of this method is to connect the new Terralink structure to an existing structure. One or both two linking techniques are used in the design of these structures. Friction links are the first. The alternating soil reinforcement layers are solely attached to the back face of the new structure and the face of the current structure, with each layer being connected to one or the opposite surface. The second method is Direct Link, in which each component of soil reinforcement that joins the two extremities is structurally connected. The main benefits of using the Terralink construction method are 1) using less materials, taking up less space, and producing less CO2 than traditional construction methods; 2) the Terralink technique reduces its environmental impact; 3) Terralink structures are quick to install; and 4) the design can be modified to fit a variety of existing structures, including soil nail walls, existing Reinforced Earth® walls, and natural features like bedrock or sloped terrain. Materials can be delivered to the site just in time for construction.

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Fig. 3. Terralink Construction Method

Source: GPC Integrated Sdn. Bhd. (2022)

The construction sequence for the terralink structure is:

(i) Establishing the base of the structure. If the base of the structure is found to be weak, an extra layer of soil nailing shall be done, ensuring minimum embedment of the structure.

(ii) The base of the TerraLink® structure shall be compacted before laying the PCC levelling pad and an embedment depth of 2m shall be provided at the toe of the structure. The minimum distance between the Toe of the structure and the soil nailing profile shall be kept at 3-4 m.

(iii) Survey layout shall be done to ensure proper alignment of the structure.

(iv) GI welded Mesh fixing, and alignment Mesh fixing & alignment shall be started 7 days after laying the PCC pad. Fabricated steel templates @ 1m c/c shall be used at the base layer of GI steel mesh at each tier for proper alignment.

(v) Horizontal and vertical bracings with ledger pipes shall be provided at higher levels as the structure develops.

(vi) The angle of inclination of the facia shall be checked with an inclinometer at each layer.

Categories of Risk

Risk can be categorised into project type, management, personnel, government regulations, current weather, culture, and hazardous site conditions (Ghazali et al., 2024). The identification of risks is the initial step in the risk management process. The fundamental process involves a comprehensive review of the entire project to identify critical events that could impede the project from achieving its objectives. Table 2 shows the category of risk including related explanations. Based on the Garis Panduan Pengurusan Risiko Projek JKR Version 2.0 (2023), risk can be categorised into several categories.

Table 2. Types of Risk Category

Item	Category of Impact	Description
1	Political	Political Risks arise from changes in policy, political climate, or intervention by influential parties. (e.g., altering original decisions, cancelling existing decisions)
2	Scope	Scope Risks related to the status or changes/amendments to the project scope. (e.g., undefined scope, unclear brief)
3	Schedule	Schedule Risks related to the duration of project activities in each phase or the overall project life cycle. (e.g., delays in approving drawings, delays in issuing acceptance letters)
4	Financial	Financial Risks related to the financing and funding of part or the entire project. (e.g., insufficient allocation, delayed funding)
5	Human Resources	Human Resources Risks arising from human resources related to competence, performance, quantity, and attitude. (e.g., lack of personnel, less competent designers, less competent contractors)
6	Quality	Quality Risks related to the quality of project materials, construction, processes, and packaging. (e.g., packaging not meeting specifications, use of unauthorised construction materials)

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7	Communication	Communication Risks related to communication among project stakeholders. (e.g., unsatisfactory collaboration, lack of coordination among designers)
8	Other Resources	Other Resources Risks arising from sources other than human resources and finances, such as materials, machinery, technology, etc. (e.g., lack of suitable equipment, construction machinery damage, uncertainty in site boundary determination, no site access, site requiring treatment)
9	Contracts and Legal	Contracts and Legal Risks related to the tender process, contract documents, contract administration process, as well as regulations and laws. (e.g., lack of understanding of contract documents, delays in calling tenders, legal violations)
10	Technical	Technical Risks arise from technical aspects requiring specialised knowledge in related fields such as engineering specifications, construction techniques, design, and maintenance. (e.g., design not meeting engineering specifications, insufficient technical project information)
11	Environmental	Environmental Risks related to factors affecting the environment for example slope failure
12	Supply	Supply Risks related to the supply of materials, utilities, and services during project implementation. (e.g., insufficient material supply, delayed electrical supply connection)
13	Agency Relations	Agency Relations Risks related to work transactions between agencies that affect project implementation. (e.g., changing requirements from the local authority, delays in approvals from the land office)
14	Organisational	Organisational Risks related to the internal structure or operations of the organisation during project implementation. (e.g., project team formation delayed, change in standard operating procedures)
15	Health & Safety	Health & Safety Risks related to the health and safety of workers or those in the vicinity during project implementation. (e.g., lack of awareness of safety on the construction site, spread of a dengue outbreak)
16	Culture & Social	Social Risk During the Construction Period Focus on the Project Team and Workers. (e.g Diversity Among Foreign Worker)
17	Integrity	Integrity Risks stemming from human misconduct due to dishonesty, lack of integrity, unreliability, and susceptibility to influence.
18	Natural Disasters	Natural Disasters Risks related to adverse events resulting from natural phenomena. (e.g., floods, storms, droughts, earthquakes, and attacks by destructive creatures)

Source: Authors (2024)

METHOD

Qualitative approaches were held via the interview method. The interview was conducted with 10 participants from three agencies represented by the Public Works Department, a consulting firm and the main contractor involved in the Slope Repair Project at Simpang Pulai-Blue Valley Road. The scope of works involved for the project is 1) Repairing a 400-meter road length, 2) Restructuring of slope 35m from road level and 3) Using the permalink method for slope repair. These stakeholders are the key players on this project that have been involved in the terralink construction method. They were involved with the first adoption of the TerraLink construction method. Through the different areas, team members gained unique insights into potential risks. The interview method will promote open communication about risks and concerns. In addition, an informal discussion can reveal risks that might not be documented or immediately apparent.

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RESULTS AND DISCUSSION

Table 3 shows the demographics of the participants involved in this research. The participants are spread across various roles and stakeholders within the construction and engineering sector, specifically in the government sector, contractors, consultants, and safety and environment officers. The years of experience range from 3 to 12 years. Participants from government and contractor roles tend to have more years of experience (between 9 to 12 years), while consultants and officers generally have less experience (between 3 to 6 years).

Table 3. Demographics of the Participants

Participant	Stakeholder	Position	Years of Experience
Participant 1 (P1)	Jabatan Kerja Raya	Engineer	12
Participant 2 (P2)	Jabatan Kerja Raya	Engineer	9
Participant 3 (P3)	Jabatan Kerja Raya	Engineer	10
Participant 4 (P4)	Contractor	Project Manager	9
Participant 5 (P5)	Contractor	Engineer	10
Participant 6 (P6)	Consultant	Engineer	6
Participant 7 (P7)	Consultant	Engineer	5
Participant 8 (P8)	Consultant	Engineer	5
Participant 9 (P9)	Officer	Safety Officer	6
Participant 10 (P10)	Officer	Environmental Officer	3

Source: Authors (2024)

It indicates that government and contractor engineers often accumulate more experience, likely due to longer tenures and possibly more structured career paths in these sectors. In contrast, consultants and officers, often in supportive roles, may have a higher turnover or start later in their respective fields. The consultants and government represent the largest groups (30% each) of participants in this research, emphasising their significant role in this project. While safety officer, environment officer and contractors are evenly split at 20%, reflecting balanced yet smaller representation in these sectors.

Table 4. Results of the Participants

Item	Activity Based - Hazard	Risk Category	Participant
1	Topple of the vehicle during backfilling, levelling, and compaction works	Safety	P1
2	High risk of slope collapses due to underground water	Normal Disaster	P2
3	High risk of scaffolding process due to unstable soil and strong wind	Schedule	P3
4	Trip and fall of the machinery and worker because of working height	Scope & Technical	P4
5	High risk of another landslide failure during construction	Scope & Environment	P5
6	Dusty environment while constructing soil nailing	Scope & Environment	P6
7	Exposed to accidents during working due to confines spaced	Scope, Technical & Safety	P7

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8	Changes of structure design from Contiguous Bored Pile to Micropile because of current site condition	Scope, Technical, Contract	P8
9	Construction of temporary facilities for example site office without electricity supply from TNB.	Technical	P9
10	Soft and unstable ground soil during establishing temporary access which can lead to topple of machineries.	Scope & Environment	P10

Source: Authors (2024)

Based on Table 3, the responses have identified hazards and determined risk categories for the implementation of the terralink construction method. Participant 1 (P1) stated that vehicle toppling is a significant hazard during backfilling, levelling, and compaction activities, particularly when these tasks are performed on uneven or sloped terrain that contributes to a safety risk category. Then, for the normal disaster risk category, Participant 2 (P2) found that there is a high risk of slope collapse due to underground water, which can weaken the soil structure and reduce the stability of the slope. Water infiltration into the slope material increases pore water pressure, leading to a loss of cohesion and making the slope more susceptible to failure. Moreover, high risk is associated with the scaffolding process when conducted on unstable soil and in strong wind conditions. Unstable soil can cause scaffolding foundations to shift or sink, compromising the entire structure's stability, which can affect the construction schedule, such as delay that leads to an extension of time to complete the project by Participant 3 (P3).

The hazards that P4 find is trip and fall incidents involving both machinery and workers, which are heightened when working at elevated heights. Uneven surfaces, loose materials, and inadequate footing can lead to machinery becoming unstable or workers losing their balance, resulting in potentially severe accidents contributing to scope and technical risk. In the scope and environment risk category there, several hazards can be found by Participant 5 (P5), Participant 6 (P6) and Participant 10 (P10), such as another landslide occurring during construction, particularly in areas with soft and unstable ground. This unstable soil can create hazardous conditions when establishing temporary access, increasing the likelihood of machinery toppling. Additionally, the dusty environment generated during soil nailing activities further complicates the situation by impairing visibility and exacerbating respiratory risks for workers.

Another hazard that can be found during the implementation of the terralink construction method is exposure to accidents during work due to confines spaced and changes in structure design, for example, Contiguous Bored Pile to Micropile because of current site condition that leads to affecting scope, technical, contract and safety Participant 7 (P7). Lastly, for P9, temporary facilities, for example, site offices without electricity supply from TNB, will contribute to the technical category.

The findings show that the risk category that is mostly mentioned is the scope of work during construction. It is essential for the stakeholders and project team to be more concerned about scope because it may expose them to multiple hazards that can affect the project's results. For example, the project team must have clear and proper planning based on the current site condition before executing the work. Then, in the technical risk category, all of the project team, including workers, must understand the characteristics and needs of every process to minimise the hazard.

The third risk category is environment, it is related to factors affecting the environment for example, slope failure by a current site condition that may lead to a major effect on the project and supported by Hossain et al. (2017) stated instability in soil mass which causes slope failure, can be a result of any changes in soil condition. It can be avoided by being a prepared project team and fully monitoring every data that has been collected, such as soil movement and rainfall data. Next, in the safety risk category, where all the construction players must follow the rules and guidance of the Safety Officer in a construction area. The schedule in risk is related to the duration of project activities in each phase or the overall project life cycle. In this method, schedule, it is significant for every construction to be executed at the right time and the right place because of the site conditions.

Lastly is a natural hazard; in this study, it is found out that while implementing the Terralink construction method, there is a potential for another landslide to occur. In that case, the least that can done is to be well prepared for any contingencies by natural phenomena. In my study, the findings align with existing research on the causes of landslides, highlighting the significant roles of physical, geological, and human factors. According to forensic statistical data on large-scale landslide events from 2004 to 2007, Nanak & Harahap (2011) found that approximately 57% of landslides were attributed to human influences, 29% were linked to physical factors, and 14% were due to various geological elements.

CONCLUSION

Identifying hazards involved in the terralink construction method at the slope construction site is crucial for ensuring safety, efficiency, and successful project completion. The construction site can mitigate potential hazards and enhance overall project outcomes by implementing a comprehensive risk study and for future references to all stakeholders to determine risk in implementing the terralink construction method. This study is also needed because of Malaysia's frequent landslides, especially in areas with heavy rainfall and unstable soils. The study will address specific hazards aligned with local guidelines, especially in compliance with Arahan KPKR 29/2023, which mandates risk management integration in tendered projects.

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CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

AUTHORS' CONTRIBUTIONS

Muhamad Afiq Al-Amin Mohd Kabri is the main author, who carried out this research and wrote the article. Izatul Farrita Mohd Kamar is the corresponding author who helps to review the article, supervises the research progress and helps the main author to complete and submit this article. Husrul Nizam Hussin conceptualised the central research idea and provided some literature from the previous research. Wahyudi Putra Utama helps to give opinions regarding slope repair methods and specifically terralink construction methods.

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