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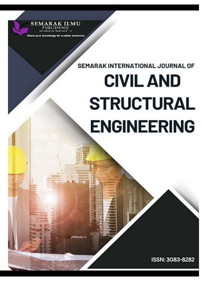

Understanding Road Infrastructure Failure in Kuala Lumpur: A Comprehensive Literature Review

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ABSTRACT

Road infrastructure failure poses significant challenges in Kuala Lumpur, Malaysia under conditions of rapid urbanization and high rainfall intensity. This review paper compiles and analyses real-world cases, causes and preventions strategies related to road infrastructure failure happened in Kuala Lumpur. Those road infrastructure failures include manholes, road pavement failure, soil slope failure, internally stabilized retaining wall failure and surface and subsurface drainage failure have impacted the urban transport efficiency and road quality. Real-world cases such as the 2024 sinkhole incident and the 2012 landslide incident indicates the potentially severe consequences of the road infrastructure failure on public safety and highlights the urgent need for better urban planning. This study was conducted through literature review on some government guideline, research papers, journals and online newspapers which are related with the road infrastructure failure to identify the causes and prevention strategies. Findings from past research indicates that factors such as heavy rainfall, poor installation, improper reinforcement replacement and inadequate materials are the causes of the road infrastructure failures. Prevention strategies suggested in the paper include proper drainage planning, consistent maintenance and improve design of road infrastructure may prevent the failure. This review aims to guide future road infrastructure development in Kuala Lumpur by summarizing the existing knowledge on the causes and prevention mitigation. By understanding those road infrastructure failures, engineers and planners may prepare for more sustainable and reliable design. Additionally, this paper also provides a foundation for future research focused on the road infrastructure failure.

1. Introduction

Road infrastructure serves as a vital component to facilitate the vehicles, freights and people within a country. It serves as a backbone for economic development, trade, cultural exchange, logistic and social interaction. A well designed and maintained road network may improve the connectivity

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between areas in a country. However, in recent years, road infrastructure failure has become an increasingly frequent issue, especially in urban areas in Malaysia. Road infrastructure failures such as deterioration of road pavement, slope failure, retaining wall failure and sinkholes have been reported frequently in Kuala Lumpur, Malaysia. It is believed that the road infrastructure failures may bring some safety concerns and economic disruption to a country. The road infrastructure failure may also disrupt the emergency response and transportation service in a country.

According to Chan [10], Kuala Lumpur City Hall (DBKL) have received 700 pothole complaints in 41 days. This indicates that the deterioration of road pavement in Kuala Lumpur is in a high frequency. In addition, 31 locations, including Cameron Highlands and roads along the Tapah, Cameron Highlands were identified as high-risk landslide areas as reported by The Straits Time [39]. A total of 602 fatalities have previously occurred in these areas due to slope failures. This may highlight the urgent need to understand the mechanisms and root causes of road infrastructure failure.

1.1 Types of Roads in Kuala Lumpur

The road network in Kuala Lumpur is structured into four main categories based on their function: expressways, arterial roads, collector roads and local streets.

Expressways are designed with full access control and grade-separate intersections to ensure uninterrupted traffic flow. Expressways in Kuala Lumpur have a minimum two lanes in different directions to accommodate the high traffic demand in urban areas and support long distance and high-speed travel according to Arshad [4].

Arterial roads provide partial access control and serve as primary routes for medium capacity within the city according to Garber and Hoel [15]. Arterial roads are designed to allows movement of large volumes of traffic for intermediate to high velocity.

Collector roads serve as intermediate links between arterial road and local streets according to Garber and Hoel [15]. They carry traffic from local roads and distribute to arterial network.

Local streets form the foundational road network within neighbourhoods that connect with collector roads according to Garber *et al.,* [15]. Local streets designed for short distance travel and low traffic volume.

1.2 Research Gaps, Contribution and Objective

Although numerous studies have investigated road infrastructure failures, several research gaps were identified. For example, a study conducted by Dastpak *et al.,* [12] focused on general geotechnical factors but did not focus on residual clay formation to Kuala Lumpur, which may exhibit different geotechnical behaviour compared to the soils analysed. In another study, Rotimi and Abdulazeez [36] analysed road failures in Nigerian Roads, where the infrastructure contexts different with Malaysia. Findings from these studies not fully applicable with local conditions in Kuala Lumpur. The significant of this review lies in its potential to enhance sustainability and reliability of road transportation systems in Kuala Lumpur. By identifying the root causes of road infrastructure failures, the review aims to support the development of effective mitigation to reduce the risk of structural deterioration. A clearer understanding of this failure mechanisms may guide the planning and design of safer and more durable road network that can withstand long-term operational stress. The objective of this review is to explore the types and causes of road infrastructure failure in Kuala Lumpur, Malaysia and to study proposed prevention strategies. By analysing existing research and real-world cases studies, this paper aims to contribute to academic research and provide practical insights to engineers and planners that involved in development and maintenance of road infrastructure.

2. Methodology

The review paper was conducted through a systematic literature search and analysis to examine the causes and prevention strategies of road infrastructure failures. The study focuses on the road infrastructure failures that have occurred in Kuala Lumpur, Malaysia, due to its high urban density and rapid urbanization.

Academic sources were collected from well-established databases, including Google Scholar, ScienceDirect, Springer Link and university publications. The literature research was limited to publications from 2010 to 2025 to ensure the inclusion of recent and relevant findings. A total of approximately 35 journal articles and research papers were reviewed.

In addition to academic sources, news reports and engineering guidelines were also studied to identify real world incidents and case studies related to road infrastructure failure in Kuala Lumpur.

3. Results

3.1 Ground Subsidence Failure: Sinkholes

Ground subsidence sinkholes occurred when there is a sudden sinking of ground surface. Sinkholes is focused in this review paper as sinkhole is the most prevalent type of ground subsidence failure in Kuala Lumpur, Malaysia. Sinkholes can disrupt the natural underground drainage patterns and increase risk of flooding as water flow around the affected areas will become unpredicted according to Rose and Marco [35]. As illustrated in Figure 1 and Figure 2, there are two types of sinkholes: cover subsidence sinkhole and cover collapse sinkhole. Cover collapse sinkhole are more dangerous than cover subsidence sinkhole because cover subsidence sinkhole forms suddenly without warning. Cover collapse sinkhole has higher potential on swallowing vehicles and passersby. In contrast, cover subsidence sinkhole forms gradually and provides visible warning signs. The formation of sinkholes may be influenced by underlying geological condition and human activities.

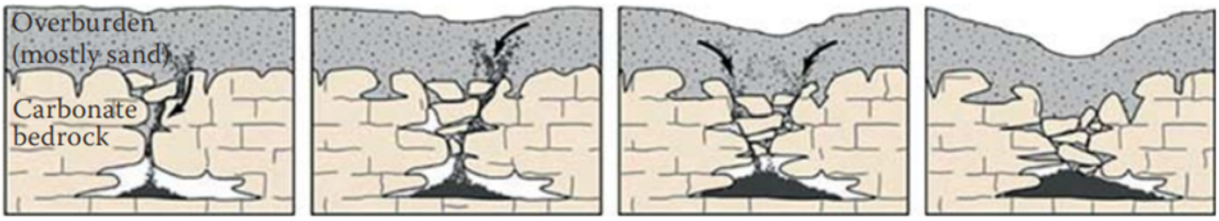

Fig. 1. Cover subsidence sinkhole [28]

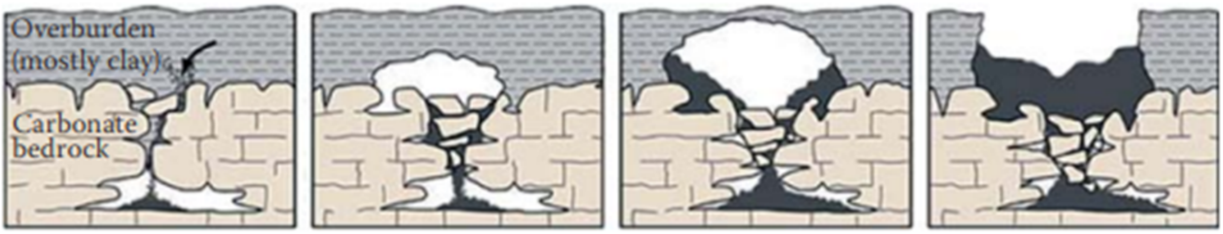

Fig. 2. Cover collapse sinkhole [28]

Table 1 presents a summary of sinkholes incident.

Table 1
Summary of sinkhole incident

Features	Details
Real-world case	Sinkhole in Jalan Masjlid India, Kuala Lumpur
Causes	1. Pipeline Failures 2. Mining Activities
Prevention strategies	1. Geographic Information System (GIS) 2. Analytical Hierarchy Process (AHP)

On 23rd August 2024, a sinkhole formed along Jalan Masjid India in Kuala Lumpur. An eight metres deep sinkhole appeared suddenly on the roadside and a 48-year-old Indian woman accidentally fell into it while walking, as reported by Camoens [9]. Although the failure did not occur directly on the roadway, it still underscores the potential risk of sinkhole formation within traffic zone.

One of the major causes of sinkhole formation is pipeline failure. Pipeline failures caused by multiple causes such as poor workmanship, external and internal pressures, sediment buildup and erosion. When a leak occurs, it progressively erodes the surrounding soil, forming a mobilized zone. A shear surface will be formed and grow until sinkholes formed according to Dave and Juneja [13]. The point is supported by a study conducted by Dastpak *et al.,* [12]. They emphasized factors such as size and position of defect are those critical factors of erosion of soil due to the malfunctioning underground pipes.

Another significant cause is underground mining activity, which can lead to formation of underground voids and ground subsidence. Mining induced fractures can develop double funnel shaped fracture zone in the rock layers. These fractures may propagate upward, casusing cracks and collapse of surrounding rocks. Once the fracture zone reaches the ground surface, sinkholes will appear according to Dave and Juneja [13].

Several studies have proposed some techniques to assess sinkhole hazards. Kouri *et al.,* [21] applied Geographic Information System (GIS) technique to develop a sinkholes hazard map for Kinta Valley, illustrating the effectiveness of technology in identifying sinkhole formation. In Klang Valley region, Dewan Bandaraya Kuala Lumpur (DBKL) and Majlis Perbandaran Ampang Jaya (MPAJ) have applied the Analytical Hierarchy Process (AHP) to evaluate the sinkhole related factors and generate sinkhole hazard zones, which can help in urban planning and infrastructure resilience according to Rosdi *et al.,* [34]. Future study are encouraged to focus on remote sensing technologies and predictive models that can help in early detection of sinkhole formation.

3.2. Flexible Road Pavement Failure

The most common type of road infrastructure failures in Kuala Lumpur, Malaysia is deterioration of road pavement, including cracks, rutting and potholes. According to Mkwata *et al.,* [26], uneven pavement surface negatively impact driving conditions. The condition of road pavement can be assessed using International Roughness Index (IRI). The International Roughness Index (IRI) always derived from the vertical variations recorded along the longitudinal road profiles according to Madeh Piryonesi and El-Diraby [23] and widely used to assess the ride quality and serviceability of road pavements. In Malaysia, International Roughness Index (IRI) has been adopted by Public Works Department (JKR) and widely used in Pavement Management System for road pavement performance assessment. Table 2 presents a summary of road pavement failure.

Table 2
Summary of road pavement failure

Features	Details
Real-world case	Road from Kuala Lumpur to Mid Valley
Causes	1. Excessive traffic loading 2. Poor construction practices
Prevention strategies	1. Prevent moisture infiltration 2. Timely repair and maintenance

According to Perimbanayagam [32], a 75-year-old man was killed after crashing into a pothole while riding from Kuala Lumpur to Mid Valley. The man was reportedly thrown approximately 30 meters away after losing control of his motorcycle. This incident highlights that the urgent need to address road pavement deterioration in urban settings.

One of the significant causes contributing in road pavement failure is excessive stress exerted by increasing traffic volume. In Kuala Lumpur, rapid urbanization has led to the growth of various industries such as manufacturing and construction. This has led to the increased use of heavy transportation including lorries and vans according to Bukhari and Aman [8]. According to Saharuddin *et al.,* [37], Malaysia position as a leading global palm oil producer, leading to a high volume of freight transport. These vehicles often apply extra loadings that surpas the initial design capacity of the road according to Prajapati *et al.,* [31], which may lead to acceleration of road pavement damage.

Additionally, poor construction practices are a contributing factor that cause road pavement failure. In some cases, contractors may bypass established procedures, guidelines, design specifications, or they may use low quality materials for the road construction to reduce their construction cost according to Bukhari and Aman [8]. This may reduce the structural strength and durability of the road pavements. Inadequate pavement thickness and improper material selection may lead to structural weakness and reduce load-bearing capacity of the road pavement. This may bring negative impact to the roadway's performance. For instance, Rotimi and Abdulazeez [36] conducted a study on the Nigerian Roads and identified that poor design practices and inadequate quanlity control are major contributors leading to early pavement failure. Future studies could explore predictive modelling of long-term impacts of overloaded traffic and rainfall infiltration on pavement deterioration under tropical climate condition such as Kuala Lumpur.

In term of prevention strategies, Imran *et al.,* [17] suggested that the importance of preventing moisture infiltration through the cracks and damaged pavement layers to extend the lifespan for the road infrastructure. Basheer and Ahmad [6] suggested that applying a thin overlay is an effective method to address pavement deterioration during initial stages. This may reduce the risk of moisture entering the subgrade. Furthermore, Imran *et al.,* [17] have proposed that the pothole repair methods should be tailored and designed according to specific environmental conditions. Basheer and Ahmad [6] also suggested that patching technique can be employed to restore damaged areas and prevent further deterioration.

3.3. Internally Stabilized Retaining Wall Failure

Reinforced soil walls are widely implemented in Kuala Lumpur, Malaysia due to their cost effectiveness and ease to construction. Reinforced soil wall fall under the category of internally stabilized wall. Table 3 summarizes the causes and prevention strategies of retaining wall failure.

Table 3
Summary of retaining wall failure

Features	Details
Real-world case	Retaining wall failure in Taman Bunga Raya
Causes	1. Improper reinforcement installation
	2. Inadequate backfilling
Prevention strategies	1. Using tiebacks and cantilever girders
	2. Addressing drainage issues

A retaining wall failure occurred in Taman Bunga Raya area along Jalan Genting Klang, Kuala Lumpur in August 2024 due to continuous rainfall. The collapse of a 3.5 metres heights of retaining wall led to the relocation of 52 residents from 17 terrace houses according to Malay Mail [25], highlighting the severe impact of such structure failures. This incident highlights the importance of preventive strategies to address rainfall-related factors that contributing to retaining wall failures.

Improper reinforcement installation is one of the key factors contributing to retaining wall failure. The performance of retaining wall highly influenced by size, depth and spacing of reinforcement according to Ali and Dhapekar [3]. Additionally, construction errors such as incorrect positioning of the reinforcement on the wrong side will significantly reduce the passive resistance require to withstand the lateral earth pressure according to Kong *et al.,* [20]. According to study conducted by Patil *et al.,* [30], rainfall infiltration will reduce the stability of retaining wall.

Backfilling quality may be very important in maintaning the stability of a retaining wall. Poorly compacted backfill can create voids that can reduce the structural support of retaining wall. The accumulation of moisture may increase hydrostatic pressure and lead to failure according to Ali and Dhapekar [3]. Karunakaran and Tan [18] conducted an experiment showing that elevated groundwater levels will reduce the safety factor and lead to deformation in the retaining wall structure. This may highlight the importance of well compacted and properly drained backfill materials.

Drainage deficiencies have been identified as a common reason of retaining wall failures due to the water accumulation behind the wall structure, as highlighted by Ali and Dhapekar [3]. Since full reconstruction of a retaining wall may be impractical, improving the drainage system may be a good idea to prevent retaining wall failure. Techniques such as constructing small concrete culvert and increasing numbers of weep holes can effectively reduce the excessive moisture from the back filling materials of the retaining wall.

Furthermore, Ali and Dhapekar [3] proposed that structural reinforcement such as tiebacks and cantilever girders can be used to support and enhance the stability of retaining wall. Tiebacks, which involving drilling holes behind the retaining wall and adding support cables may provide sufficient support to the retaining wall. However, the design must consider about the shear forces and bending moment of the retaining wall. They also proposed to construct a cantilever girder fixed at the foundation of the retaining wall to transfer lateral load to the ground to improve the stability of retaining wall.

For future improvement, research is suggested to focus more on the impact of heavy rainfall towards the retaining wall through software-based analysis.

3.4. Surface and Subsurface Drainage Failure

An effective drainage system is very important for ensuring the safety and durability of road infrastructure, as it regulates ground moisture and prevents water accumulation and flooding according to Bibi *et al.,* [7]. However, during periods of prolonged rainfall, the capacity of the existing drainage system may be exceeded and resulting in flooding according to Bibi *et al.,* [7]. Surface drainage such as open drains and culverts is used to collect and runoff rainwater. Subsurface drainage, such as perforated pipes and subsoil drainage are designed to maintain the soil stability beneath. Drainage system failure can contribute to roadway deterioration because the excessive water will weaken the road pavement over time according to Ahmed [1]. Table 4 presents a summary of surface and subsurface drainage failure.

Table 4
Summary of surface and subsurface drainage failure

Features	Details
Real-world case	Flooding incident in Klang Valley
Causes	1. Poor design and installation 2. Clogging issue
Prevention strategies	1. Improving pipeline system design 2. Effective management and policy

As reported by Augustin [5], a flooding incident happened in Klang Valley in October 2024 due to drainage system failure. The drainage channels were blocked by debris, but the timely response from relevant authorities was lacked. The incidents significantly disrupted the transport networks in Klang Valley, including both railways and roadways.

Poor design and installation are one the causes of the drainage system failure according to Ghane [16]. Design deficiencies such as incorrect pipe gradients and failure to consider soil permeability can severe reduce the flow efficiency. For example, inadequate design parameters may result in system overwhelming during the period of heavy rainfall, while installing drains in low-permeability soil will reduce the efficiency of water flow. Additionally, construction related errors such as inappropriate techniques and equipment may reduce the system's effectiveness according to Ghane [16]. Hydrological modelling under climate change scenarios can be carried out in the future studies to evaluate whether current drainage can accommodate future surface runoff.

Drainage failure also commonly caused by clogging, as it obstructs water flows and leads to backflow. Ghane [16] has categorized several types of clogging mechanisms, which are summarized in Table 5.

Table 5
Types of Clogging in Drainage Systems [16]

Types of clogging	Explanation
Root clogging	Poor installation of pipe allows root growth at the centre of exit of drainpipe
Sediment clogging	Fine sand and silt enter the pipe and sediment in the drainpipe.
Iron Ochre clogging	Soluble iron enters the drainpipe and the bacterial oxide the soluble iron into insoluble iron
Calcium carbonate clogging	Occur in soil with high pH and dissolved calcium ions concentration in high temperatures. Formation of insoluble calcium carbonate will lead to drainage block.

Those clogging types identified in Table 5 emphasize the critical role of effective design, material selection and routine maintenance in drainage system. Dorairaj and Osman [14] demonstrated that the insufficient drainage during periods heavy rain will weaken the stability of retaining wall. Their findings highlight that drainage system not only used to prevent flooding, it also used to prevent retaining wall failure. Future studies can explore the usage of Internet of Things (IoT) and Artficial Intelligent (AI) technology on detecting clogging of drainage system in the real time.

To address such risks, Wang *et al.,* [40] proposed some prevention strategies to mitigate drainage failures in China. One of the key recommendations involves the improvement of pipeline design. Multiple factors such as topography, rainfall intensity, urban planning and future urban development should be considered when designing the drainage system to improve the overall funtionality of drainage system. In addition, the selection of pipeline materials should be highly durable and reliable.

Besides, effective management and regulatory policies are very important in maintaining the performance of drainage system accordig to Wang *et al.,* [40]. They have suggested that the implementation of real time water level regulation system to help to maintain the water quality. Moreover, Wang *et al.,* [40] recommended that local authorities should develop effective monitoring guidelines to enforce strict performance standards to ensure the consistent drainage function.

3.5 Soil Slope Failure

The majority of slopes in Malaysia are soil slope. However, rock slopes are gaining more attention as future developments continue to expand to mountainuos areas according to Rahim *et al.,* [33]. The failure of soil slopes can result in economic losses, environmental damage, soil erosion, transportation disruption and agriculture losses, as highlighted by Alamanis *et al.,* [2] and Nhu *et al.,* [29]. Table 6 presents a summary of soil slope failure.

Table 6
Summary of soil slope failure

Features	Details
Real-world cases	Landslide in Puncak Setiawangsa, Taman Setiawangsa
Causes	1. Heavy Rainfall
	2. Improper Slope Design
Prevention strategies	1. Surface protection covers on soil slope
	2. Use of vegetation for stabilization

The majority of slopes in Malaysia are soil slope. However, rock slopes are gaining more attention as future developments continue to expand to mountainuos areas according to Rahim *et al.,* [33]. The failure of soil slopes can result in economic losses, environmental damage, soil erosion, transportation disruption and agriculture losses, as highlighted by Alamanis *et al.,* [2] and Nhu *et al.,* [29]. Table 6 presents a summary of soil slope failure.

Liu *et al.,* [22] conducted controlled artificial rainfall experiments to analyze the effect of rainfall on soil slope instability.

The experiment results proved that rainfall intensity and distribution patterns significantly impact the slope stability. Heavy and prolonged rainfall may increase the soil water content, raise pore water pressure and elevate total stress within the soil. This finding is supported by the study conducted by Chen *et al.,* [11], which conclude that long duration of surface water inflow may significantly reduce the Factor of Safety and increasing the risk of slope failure.

In addition, insufficient slope design also another critical element affecting slope instability. Mahmood and Ayup [24] conducted a global stability assessment using the Ordinary Method of Slice at multiple locations. Their analysis found that several slopes had Factor of Safety below the acceptable threshold, proving that design deficiencies will lead to slope failure.

To prevent such failures, Slope Engineering Branch (KKR) of Public Works Department (JKR) [38] has proposed several prevention strategies in Cerun 1 Guidelines. Figure 3 illustrates the prevention strategies stated in Cerun 1 Guidelines. These include protecting slopes with impermeable surface covers to minimize the infiltration of moisture. Regular inspections should be conducted to detect the cracks at the joints between old and new layers. Additionally, the use of vegetation as soft engineering approach helps to stabilize slopes through root reinforcement. However, the unhealthy trees may pose risks of structure collapse. Inspection can be done regularly to detect the signs of root damage or declining slope health as stated in Cerun 1 [38].

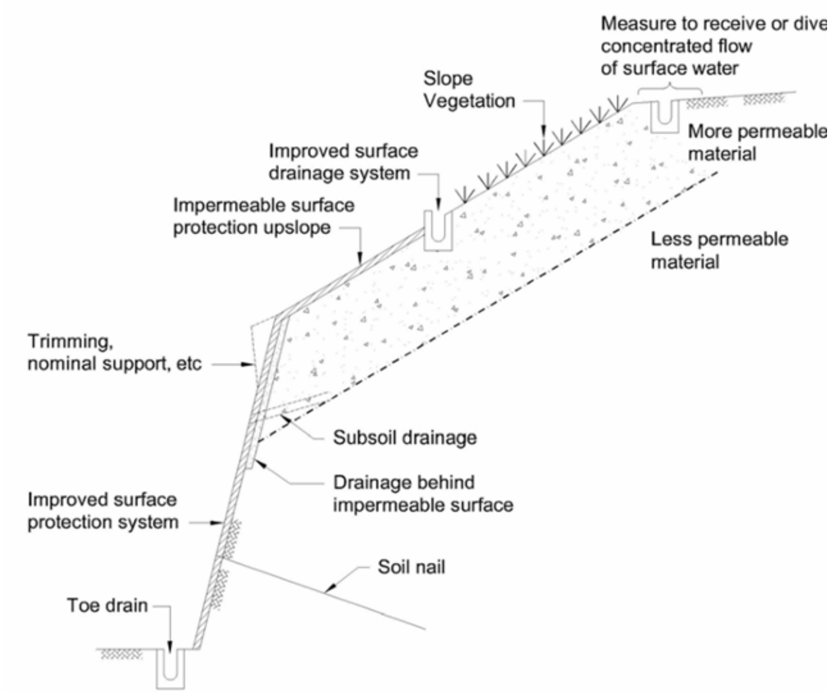

Fig. 3. Prevention strategies in Cerun 1

Using Plaxis modellig, Kokutse et al., [19] discovered that the presence of plant roots may contribute to additional soil cohesion, which may improve the slope stability. Future studies is suggested to explore the integration for remote sensing such as satellite imagery to monitor and detect the slope movements in high-risk areas. Additionally, the application of vegetation can be integrated with bioengineering techniques to enhance slope stabilization.

4. Conclusions

In conclusion, this review has identified that road infrastructure failures in Kuala Lumpur are caused by environmental and human-related factors, such as heavy rainfall, poor construction practices and improper material selections. These findings directly address the research objectives by identifying the types and causes of road infrastructure failure. The findings also contribute to future urban planning improvement. Additionally, the review also highlighted the prevention strategies of road infrastructure. The strategies are essential to enhance the long-term performance of road network.

Real world incidents have highlighted the urgent need to investigate and develop effective prevention strategies of the road infrastructures failure as the failures can cause significant negative impacts. Urban planning and policy enforcement should be incorporate long-term maintenance plans and adhere to high-quality design standards.

For the future studies, it is encouraged to explore broader range of causes and mitigation methods. Simulations from previous studies can be further analysed. Moreover, there is a need for the more field-based and long-term research focused on geotechnical and environmental condition such as pollution and rainfall intensity specific to Kuala Lumpur, Malaysia.

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