

**INTERNATIONAL JOURNAL OF
INNOVATION AND
INDUSTRIAL REVOLUTION
(IJIREV)**www.gaexcellence.com/ijirev**IMPACT OF RAINY CONDITIONS ON SAFETY RISKS AND
MANAGEMENT MEASURES IN TROPICAL
CONSTRUCTION: A PLS-SEM STUDY OF PENANG G7
CONTRACTORS**

Mohd Rafe Abdul Majid^{1*}, Mohamed Nur Akmal Radzuan², Raja Nor Husna Raja Mohd Noor³, Juzailah Nur Yunus⁴

¹Fakulti Kejuruteraan Awam, Universiti Teknologi Mara Cawangan Pulau Pinang, Malaysia

 rafebanu@uitm.edu.my

 <https://orcid.org/0000-0003-0863-8511>

²Fakulti Kejuruteraan Awam, Universiti Teknologi Mara Cawangan Pulau Pinang, Malaysia

 2022828756@student.uitm.edu.my

 <https://orcid.org/0009-0003-6272-8339>

³Fakulti Kejuruteraan Awam, Universiti Teknologi Mara Cawangan Pulau Pinang, Malaysia

 rajanorhusna@uitm.edu.my

 <https://orcid.org/0000-0002-8500-4259>

⁴Fakulti Kejuruteraan Awam, Universiti Teknologi Mara Cawangan Pulau Pinang, Malaysia

 juzailah.nur@uitm.edu.my

 <https://orcid.org/0000-0002-7744-3921>

*Corresponding Author

Article Info:**Article history:**

Received date: 27.07.2026

Revised date: 11.08.2026

Accepted date: 27.09.2026

Published date: 30.09.2026

Abstract:

Construction sites in tropical regions such as Penang, Malaysia, are highly vulnerable to rainfall-induced hazards. Despite the recognized dangers of adverse weather, empirical research explicitly examining rainy conditions within the Malaysian construction industry remains scarce, as most existing studies focus on temperate climates. Addressing this gap, this study investigates the structural relationships among Rainy Conditions Factors (RCF), Construction Safety Risks (CSR), and Safety Management Measures (SMM). Conceptually, severe weather acts as a stressor that elevates physical risks while simultaneously compelling management to deploy mitigating measures. Using purposive sampling, a quantitative survey was administered to 160 construction professionals (predominantly site supervisors and engineers). Grade G7 contracting firms in Penang were specifically selected as they manage large-scale projects in a region with high precipitation intensity. Data were analyzed using Partial Least Squares Structural Equation Modelling (PLS-SEM) via Smart-PLS 4. The structural model demonstrated that rainy conditions exert a strong, positive effect on construction safety risks ($\beta=0.827$, $p<0.001$) and significantly influence

To cite this document:

Majid, M. R. A., Radzuan, M. N. A., Noor, R. N. H. R. M., & Yunus, J. N. (2026). Impact Of Rainy Conditions on Safety Risks and Management Measures in Tropical Construction: A PLS-SEM Study of Penang G7 Contractors. *International Journal of Innovation and Industrial Revolution*, 8(26), 953-966.

DOI: 10.35631/IJIREV.826057

safety management measures ($\beta=0.462$, $p<0.001$). Furthermore, construction safety risks significantly predict safety management measures ($\beta=0.419$, $p<0.001$), with the model accounting for a substantial proportion of variance in Construction Safety Risks ($R^2 = 0.684$) and Safety Management Measures ($R^2 = 0.708$). These findings underscore the imperative for weather-responsive safety management strategies in tropical building environments, offering practical recommendations such as implementing real-time weather monitoring systems and formalizing strict stop-work protocols for Malaysian contractors.

Keyword:

Construction Safety, Rainy Conditions, Safety Management Measures, PLS-SEM, Penang (Malaysia)



© The authors (2026). This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY NC) (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact ijirev@gaexcellence.com.

Introduction

Weather conditions constitute one of the most critical yet frequently underestimated environmental factors influencing construction site safety. In tropical regions like Malaysia, rainfall presents a continuous operational challenge. This is particularly evident in high-precipitation states such as Penang, which receives an average annual rainfall of 2,585 mm (Department of Statistics Malaysia [DOSM], 2023). Climate change has further intensified this exposure; the hourly rainfall intensity in Penang has increased sixfold over the past three decades, escalating from approximately 31 mm/h in the 1990s to 180 mm/h in recent years (Zairil, 2019). This dramatic rise in precipitation intensity presents heightened operational hazards to construction activities and worker safety.

The construction industry in Malaysia consistently records the highest proportion of occupational fatalities among all economic sectors, accounting for approximately 37% of all workplace deaths nationwide (Ayob et al., 2018). Regionally, Penang recorded an occupational injury rate of 4.78 per 1,000 workers in 2023 substantially exceeding the national average of 2.46 per 1,000 workers (DOSM, 2023). Rainy conditions compound these baseline hazards by reducing surface traction, impairing operator visibility, destabilizing earthworks and slopes, and compromising heavy machinery performance, all of which significantly elevate accident probability (Gallaway et al., 1971; Tian et al., 2023; Lyu et al., 2024).

Despite international research establishing a clear link between precipitation and construction site accidents, empirical studies tailored to the Malaysian and Penang construction environments remain scarce. While international studies have quantified rainfall-induced accident rates, they predominantly reflect temperate climates and general workplace settings. Empirical research explicitly examining the intense, high-precipitation characteristics of tropical construction environments in Malaysia remains scarce, limiting the direct generalizability of existing safety models. Similarly, local geotechnical research in Penang (e.g., Yusof et al., 2025) confirms the critical role of antecedent rainfall in triggering slope failures, yet it does not extend to broader site-safety risks or organizational management responses.

To address these empirical and practical gaps, this study investigates the structural impacts of rainy conditions on construction safety risks and safety management measures among Grade G7 contractors in Penang. The specific research objectives are:

1. To identify the primary safety risks that emerge during rainfall on construction sites;
2. To examine the structural relationships among rainy conditions, safety risk levels, and safety management responses; and
3. To propose targeted preventive measures and management strategies to mitigate weather-induced risks.

Utilizing Partial Least Squares Structural Equation Modelling (PLS-SEM) via Smart-PLS 4, this research provides quantitative evidence to support the development of weather-responsive safety protocols within the tropical construction sector.

Literature Review

There are five key points discussed in this literature review: (1) Rainfall and Construction Safety, (2) Geotechnical and Material Integrity Hazards, (3) Worker Behavior and Organizational Factors, (4) Theoretical Framework, and (5) Conceptual Framework and Proposed Hypotheses.

Rainfall and Construction Safety

Rainfall compromises construction site safety through several interconnected physical and environmental mechanisms. Early work by Gallaway et al. (1971) established that higher rainfall intensity deepens surface water accumulation, thereby reducing friction coefficients and significantly elevating slip hazards on access routes and working platforms. Expanding on these foundational insights, Tian et al. (2023) demonstrated that every additional 10 mm of precipitation increases workplace injury risks by 1.61%, with injury effects persisting for up to three days post-rainfall due to saturated surfaces and lingering ground instability. Furthermore, Lyu et al. (2024) confirmed that extreme rainfall events increase fall-related construction accidents in the United States by 19% to 23%, identifying falls as the predominant rainfall-induced injury category.

Rainfall and Construction Safety

Rainfall also severely threatens geotechnical stability on active construction sites. Jiang and Tan (2021) observed that 77.6% of excavation failures in China occurred during or immediately

after rainfall events, attributing these collapses to elevated pore water pressure and reduced soil shear strength. Similarly, Yusof et al. (2025) showed that prolonged antecedent rainfall decreases slope safety margins in Penang, triggering ground failures in construction zones characterized by steep topography. Beyond geotechnical hazards, Liu et al. (2022) reported that excessive moisture exposure during rainfall can reduce concrete tensile strength by up to 70% and induce microcracking in structural elements, emphasizing the material degradation risks associated with wet operational environments.

Worker Behaviour and Organizational Factors

In addition to direct physical hazards, adverse weather exerts a profound influence on worker behavior and organizational safety management. Guo et al. (2021) found that rainy conditions diminish workers' safety compliance and hazard perception on Chinese construction sites, a trend particularly pronounced among younger and less experienced personnel. Concurrently, Nasirzadeh and Nojedehe (2013) revealed that weather-induced productivity losses generate acute schedule pressure, indirectly promoting risk-taking behaviours among site managers striving to recover lost time. From a psychological perspective, Siu et al. (2004) highlighted that environmental stressors induce cognitive strain that degrades individual safety performance. Consequently, heavy rainfall not only exacerbates physical site hazards but also weakens the cognitive defenses critical for accident prevention.

Theoretical Framework and Hypotheses

This study is grounded in James Reason's (1990) Swiss Cheese Model of accident causation, which posits that organizational system breakdowns occur when vulnerabilities across multiple defensive layers align simultaneously. Within rainy construction environments, adverse weather acts as an overarching systemic stressor that concurrently erodes several critical safety barriers—including surface traction, worker visibility, equipment stability, and individual cognitive alertness.

Conceptual Framework and Proposed Hypotheses

Applying this theoretical framework, this study constructs a multi-variable model linking Rainy Conditions Factors (RCF) as the independent variable to Construction Safety Risks (CSR) as the mediating variable and Safety Management Measures (SMM) as the dependent variable.

Conceptually, adverse weather acts as an environmental stressor that simultaneously erodes physical defensive layers (elevating safety risks) and directly triggers organizational intervention, forcing management to deploy targeted safety measures to mitigate the heightened on-site hazards. Based on this conceptual structure, three direct hypotheses are proposed:

- H_1 : Rainy Conditions Factors have a significant positive effect on Construction Safety Risks.
- H_2 : Rainy Conditions Factors have a significant positive effect on Safety Management Measures.
- H_3 : Construction Safety Risks have a significant positive effect on Safety Management Measures.

Methodology

This chapter outlines the research methodology and empirical procedures employed to examine the impact of rainy conditions on construction site management, safety risks, and safety measures among Grade G7 contractors in Penang. To ensure a systematic and rigorous investigation, this section provides a detailed explanation of the methodological framework used to collect, process, and analyze the data.

Research Design

This study adopted a quantitative cross-sectional research design using a structured questionnaire survey. A quantitative approach was selected to enable systematic numerical measurement of the study constructs and facilitate Partial Least Squares Structural Equation

Modelling (PLS-SEM) using Smart-PLS 4. Hair et al. (2022) affirm that PLS-SEM is particularly suitable for complex models with small to medium sample sizes, making it appropriate for the present research.

Population and Sampling

The target population comprised construction personnel directly employed by active Grade G7 contractors registered with the Construction Industry Development Board (CIDB) Malaysia and operating in Penang. Grade G7 represents the highest contractor classification in Malaysia, allowing firms to undertake construction projects of unlimited value. The target respondent groups included site engineers, site supervisors, safety officers, architects, consultants, and other personnel directly involved in site operations.

Utilizing purposive sampling, data was collected from 160 construction professionals, predominantly site supervisors and engineers. Grade G7 contractors in Penang were selected as the target population because they undertake large-scale projects of unlimited value in a region highly exposed to intense annual rainfall (2,585 mm). Based on the Krejcie and Morgan (1970) sample size determination table, a population of 150 requires a minimum sample size of 108 respondents. A total of 160 completed questionnaires were collected and validated, exceeding the minimum requirement and providing a robust dataset for PLS-SEM analysis.

Research Instrument

The questionnaire was structured into four sections:

- **Section A:** Collected demographic information.
- **Section B (8 items):** Assessed *Rainy Conditions Factors* (independent variable), including rainfall frequency, intensity, visibility reduction, and surface impacts.
- **Section C (10 items):** Measured *Construction Safety Risks* (mediating variable), covering slip-and-fall hazards, equipment instability, excavation failures, electrical hazards, visibility hazards, and overall accident risk.
- **Section D (13 items):** Evaluated *Safety Management Measures* (dependent variable), covering safety planning, personal protective equipment (PPE) provision, work suspension protocols, and safety training practices.

All perception-based items were evaluated on a 5-point Likert scale ranging from 1 (*Strongly Disagree*) to 5 (*Strongly Agree*). A pilot study conducted with 15 respondents confirmed Cronbach's alpha values above 0.70 across all constructs, demonstrating adequate internal consistency reliability before full distribution.

This study adopted a quantitative cross-sectional research design using a structured questionnaire survey. A quantitative approach was selected to enable systematic numerical measurement of the study constructs and facilitate Partial Least Squares Structural Equation Modelling (PLS-SEM) using Smart-PLS 4. Hair et al. (2022) affirm that PLS-SEM is particularly suitable for complex models with small to medium sample sizes, making it appropriate for the present research.

Data Analysis

Data analysis was conducted in two sequential stages:

1. **SPSS (Version 26):** Used for demographic profiling and descriptive statistical analysis.
2. **SmartPLS 4:** Used to perform PLS-SEM analysis, encompassing:
 - **Measurement Model Assessment:** Evaluating outer loadings, Cronbach's alpha, Composite Reliability (CR), Average Variance Extracted (AVE), and the Heterotrait-Monotrait ratio (HTMT).
 - **Structural Model Assessment:** Evaluating path coefficients, *t*-values, and *p*-values via bootstrapping (5,000 subsamples), as well as coefficients of determination (R^2) and effect sizes (f^2).

Results and Discussion

This chapter presents the empirical findings from 160 valid survey responses and explores their implications for managing weather-related safety risks on Malaysian construction sites. Through descriptive and inferential statistical analysis, we examine the respondents' demographic backgrounds, assess how key weather hazards like heavy rain, extreme heat, and strong winds impact daily operations, and evaluate existing safety practices. By connecting these insights with on-the-ground realities, the discussion highlights practical ways to improve safety protocols, boost regulatory compliance, and reduce weather-driven disruptions across the industry.

Demographic Profile of Respondents

This dataset profiles a cohort of 160 construction and engineering professionals, revealing an overwhelmingly male dominated demographic (87.5%, $n=140$) that is primarily early to mid-career, with 75% of respondents under the age of 45 (37.5% aged 25-34 and 37.5% aged 35-44) and 75% possessing 10 years or less of industry experience (evenly split between 1-5 years and 6-10 years). The group is well-educated, with 71.9% holding a bachelor's degree, 18.8% holding a Diploma, and 5.0% holding a master's degree or higher. Professionally, the sample is heavily anchored in active on-site operations Site Supervisors (29.4%) and Site Engineers (28.7%) together comprise 58.1% of the participants complemented by smaller proportions of Architects (9.4%), Consultants (8.1%), and other technical roles (24.4%).

Table 1: Demographic Profile of Respondents (n = 160)

Category	Group	Frequency (n)	Percentage (%)
Gender	Male	140	87.5
	Female	20	12.5
Age (Years)	25–34	60	37.5
	35–44	60	37.5
	45–54	40	25.0
Current Role	Site Supervisor	47	29.4
	Site Engineer	46	28.7
	Architect	15	9.4
	Consultant	13	8.1
	Others	39	24.4
Working Experience	1–5 Years	60	37.5
	6–10 Years	60	37.5
	11–20 Years	40	25.0
Education Level	Bachelor's Degree	115	71.9
	Diploma	30	18.8
	Master's or Above	8	5.0
	Others	7	4.4

Measurement Model Assessment

Indicator reliability

Table 2 presents the outer loading values for all indicators. All items exceeded the recommended threshold of 0.70 (Hair et al., 2022), with values ranging from 0.701 (C5) to 0.942 (D1), confirming satisfactory indicator reliability. No items were removed from the model.

Table 2: Outer Loading Values of All Indicators

Indicator	Measurement Item	Outer Loading
B1	Heavy rainfall frequently occurs at the construction site	0.873
B2	Rainfall intensity is moderate to heavy on most rainy days	0.849
B3	Rainfall events often cause interruptions to daily construction activities	0.783
B4	Prolonged rainfall regularly affects site operations and worker safety	0.901
B5	Sudden heavy downpours occur without warning, affecting work planning	0.790
B6	Rainy conditions reduce visibility on site	0.869
B7	Soil and ground conditions become unstable after heavy rainfall	0.854
B8	The site has proper drainage systems to manage rainwater runoff	0.810
C1	Slippery surfaces increase the risk of falls during rainfall	0.798
C2	Reduced visibility increases the risk of accidents involving equipment	0.935
C3	Ground instability poses a risk during heavy rainfall	0.768
C4	Electrical hazards become more dangerous during wet conditions	0.920
C5	Working at height during rainfall significantly increases fall risk	0.701
C6	Equipment performance is compromised during rainy conditions	0.933
C7	Flooding of work areas creates hazardous conditions for workers	0.778
C8	Workers' alertness is reduced during prolonged rainfall	0.941
C9	Inadequate PPE for rainy conditions increases safety risks on site	0.795
C10	Poor communication during rainfall increases accident risks	0.761
D1	Construction accidents frequently occur during rainy conditions	0.942
D21–D27	Accident type likelihood items (slip/fall, scaffold, slope, electrical, equipment, falling objects, flooding)	0.716–0.919
D3–D7	Safety management practice items (safety plan, PPE, work suspension, shelters, toolbox talks)	0.716–0.900

Internal Consistency Reliability and Convergent Validity

Table 3 presents the construct of reliability and convergent validity results. Cronbach's Alpha values ranged from 0.897 to 0.928, and Composite Reliability (CR) values ranged from 0.826 to 0.946, all exceeding the recommended threshold of 0.70. Average Variance Extracted (AVE)

values ranged from 0.768 to 0.826, all above the minimum criterion of 0.50, confirming adequate convergent validity across all constructs.

Table 3: Construct Reliability and Convergent Validity

Construct	Cronbach's Alpha	rho_A	CR	AVE
Construction Safety Risks	0.928	0.950	0.826	0.826
Rainy Conditions Factors	0.923	0.964	0.946	0.815
Safety Management Measures	0.897	0.919	0.929	0.768
Threshold	> 0.70	> 0.70	> 0.70	> 0.50

Discriminant Validity

Discriminant validity was assessed using the Heterotrait-Monotrait Ratio (HTMT). As shown in Table 4, all HTMT values ranged from 0.863 to 0.887, remaining below the recommended threshold of 0.90 (Hair et al., 2022). This confirms that the three constructs are empirically distinct from one another, supporting the discriminant validity of the measurement model.

Table 4: Heterotrait-Monotrait Ratio (HTMT) Results

Construct	CSR	RCF	SMM
Construction Safety Risks (CSR)	–		
Rainy Conditions Factors (RCF)	0.887	–	
Safety Management Measures (SMM)	0.863	0.876	–
Threshold	< 0.90	< 0.90	< 0.90

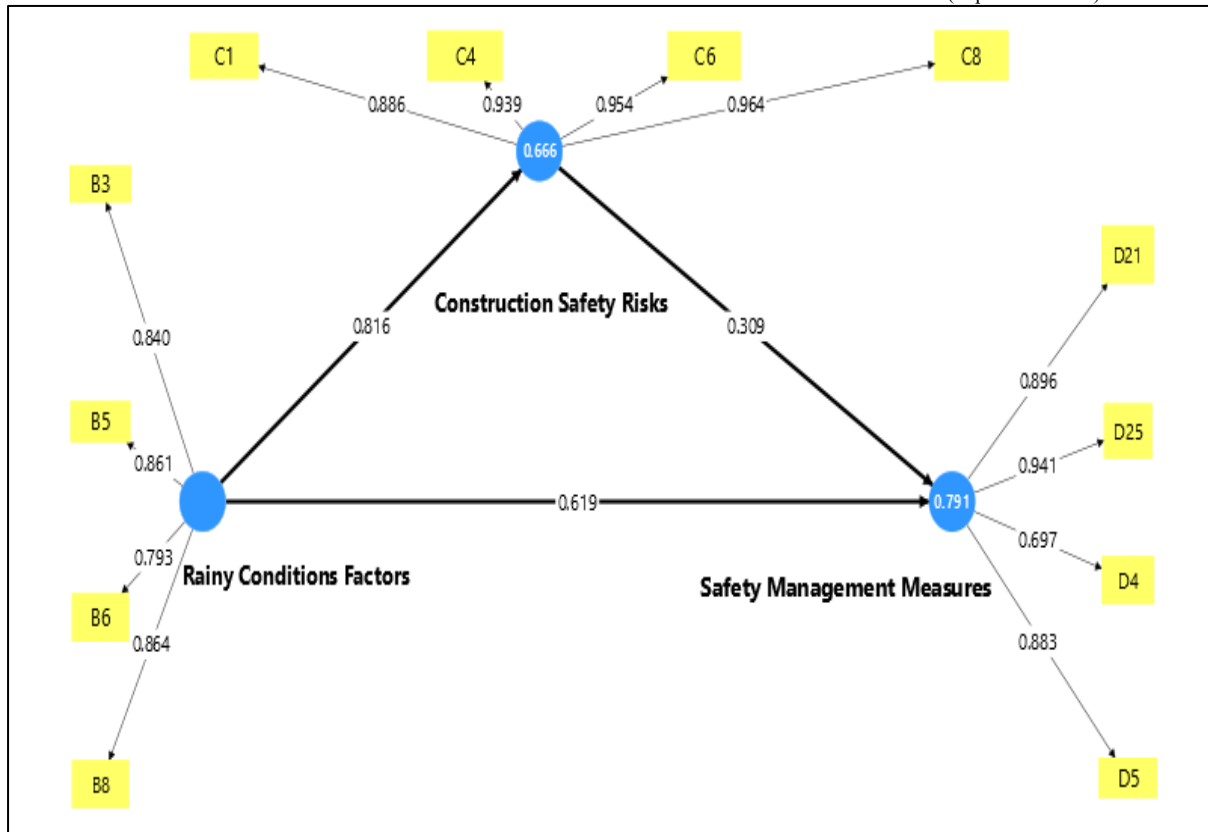


Figure 1: Structural Model Assessment

The structural model assessment (Figure 1) evaluates the path coefficients (β) and coefficients of determination (R^2) to establish the explanatory power and direct relationships between the latent constructs. The path analysis reveals that Rainy Conditions Factors exert a strong direct positive effect on both Construction Safety Risks ($\beta = 0.816$) and Safety Management Measures ($\beta = 0.619$). Furthermore, Construction Safety Risks positively influences Safety Management Measures ($\beta = 0.309$), reflecting a partial mediating role where heightened risk perception further drives safety implementation. Regarding the model's predictive capability, Rainy Conditions Factors account for 66.6% of the variance in Construction Safety Risks ($R^2 = 0.666$), while both antecedent constructs combined explain a substantial 79.1% of the variance in Safety Management Measures ($R^2 = 0.791$), confirming strong overall structural validity and predictive power.

Coefficient of Determination (R^2)

Table 5 presents the R^2 values for the endogenous constructs. The R^2 for Construction Safety Risks was 0.684, indicating that Rainy Conditions Factors explain 68.4% of the variance in construction safety risks. The R^2 for Safety Management Measures was 0.708, indicating that Rainy Conditions Factors and Construction Safety Risks jointly explain 70.8% of the variance in safety management measures. According to Hair et al. (2022), both values fall within the moderate to substantial range, indicating that the proposed model explains a considerable proportion of variance in the endogenous constructs.

Table 5: Coefficient of Determination (R^2)

Construct	R^2	Level
Construction Safety Risks	0.684	Moderate
Safety Management Measures	0.708	Moderate

Hypothesis Testing

The hypothesis testing results from Table 6 empirically support all three proposed path relationships with extreme statistical significance ($p < 0.001$) and critical values well above standard benchmarks ($t > 2.58$). Specifically, H1 is strongly supported, showing that Rainy Conditions Factors exert a massive direct influence on Construction Safety Risks ($\beta = 0.827$, $t = 29.845$), with an extraordinary effect size ($f^2 = 2.165$) that far surpasses the threshold for a large effect, proving that adverse weather is the primary driver of on-site safety hazards. Additionally, H2 confirms that Rainy Conditions Factors directly prompt the deployment of Safety Management Measures ($\beta = 0.462$, $t = 8.251$, $f^2 = 0.231$, medium effect), demonstrating that severe weather immediately compels leadership to adapt field operations. Finally, H3 confirms that Construction Safety Risks independently drive Safety Management Measures ($\beta = 0.419$, $t = 7.517$, $f^2 = 0.190$, medium effect), proving that perceived risk acts as a key parallel driver of safety protocol enforcement. Collectively, these findings reveal a dynamic dual-trigger framework where wet weather directly enforces management intervention while simultaneously creating high-risk site conditions that further compel active risk mitigation.

Table 6: Hypothesis Testing Results

H	Path Relationship	β	t-value	p-value	f^2	Decision
H1	Rainy Conditions Factors → Construction Safety Risks	0.827	29.845	< 0.001	2.165 (Large)	Supported
H2	Rainy Conditions Factors → Safety Management Measures	0.462	8.251	< 0.001	0.231 (Medium)	Supported
H3	Construction Safety Risks → Safety Management Measures	0.419	7.517	< 0.001	0.190 (Medium)	Supported

Conclusion

This study provides empirical evidence that rainy conditions significantly heighten construction safety risks ($\beta = 0.827$, $f^2 = 2.165$) and drive the adoption of safety management measures among Grade G7 contractors in Penang, Malaysia. Utilizing PLS-SEM methodology, all three proposed hypotheses were supported, with the model explaining a substantial proportion of variance in both *Construction Safety Risks* ($R^2 = 0.684$) and *Safety*

Management Measures ($R^2 = 0.708$). To mitigate these severe hazards, construction organizations should implement targeted practical measures such as establishing real-time weather monitoring systems, formalizing strict stop-work protocols during extreme downpours, institutionalizing proactive site preparations, and conducting wet-weather specific safety training (Guo et al., 2021), while regulatory bodies such as DOSH and CIDB ought to integrate weather-responsive requirements into national frameworks. Although limited to Grade G7 contractors in Penang, these findings lay the groundwork for future research to expand geographically, apply qualitative methods, and evaluate organizational mediators like safety climate and management commitment.

Acknowledgements: The authors would like to express their sincere gratitude to Universiti Teknologi MARA Cawangan Pulau Pinang for providing the necessary resources and support throughout the course of this research. Special appreciation is extended to colleagues and peers who contributed valuable insights and constructive feedback, which greatly enhanced the quality of this paper.

Funding Statement: “No Funding”

Conflict of Interest Statement: The authors declare that there is no conflict of interest regarding the publication of this paper. All authors have contributed to this work and approved the final version of the manuscript for submission to the International Journal of Innovation and Industrial Revolution (IJIREV).

Ethics Statement: The authors confirm that informed consent was obtained from all respondents and that the research was conducted in strict accordance with accepted academic integrity and ethical publishing standards for studies involving human participants.

Author Contribution Statement: All authors contributed significantly to the development of this manuscript. Mohd Rafe Abdul Majid was responsible for the conceptualization, methodology, and overall supervision of the study. Muhamed Nur Akmal handled data collection, analysis, and interpretation of results. Raja Nor Husna & Juzailah Nur Yunus contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

References

- Ayob, A., Shaari, A. A., Zaki, M. F. M., & Munaaim, M. A. C. (2018). Fatal occupational injuries in the Malaysian construction sector—causes and accidental agents. *IOP Conference Series: Earth and Environmental Science*, 140(1), Article 012095. <https://doi.org/10.1088/1755-1315/140/1/012095>
- Department of Statistics Malaysia. (2023). *Compendium of environment statistics 2023*. Department of Statistics Malaysia. <https://www.dosm.gov.my>
- Gallaway, B. M., Schiller, R. E., Jr., & Rose, J. G. (1971). The effects of rainfall intensity, pavement cross slope, surface texture, and drainage length on pavement water depths (Research Report No. 138-5). Texas Transportation Institute, Texas A&M University.
- Guo, B., Yiu, T. W., & González, V. A. (2021). Predicting safety compliance and hazard perception in construction projects under adverse weather conditions. *Safety Science*, 138, Article 105220. <https://doi.org/10.1016/j.ssci.2021.105220>
- Hair, J. F., Jr., Hult, G. T. M., Ringle, C. M., & Sarstedt, M. (2022). *A primer on partial least squares structural equation modeling (PLS-SEM)* (3rd ed.). SAGE Publications. <https://doi.org/10.1007/978-3-030-80519-7>
- Jiang, Y., & Tan, Y. (2021). Impact of rainfall events on excavation failures and geotechnical stability in urban construction. *Journal of Geotechnical and Geoenvironmental Engineering*, 147(8), Article 04021055. [https://doi.org/10.1061/\(ASCE\)GT.1943-5606.0002570](https://doi.org/10.1061/(ASCE)GT.1943-5606.0002570)
- Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, 30(3), 607–610. <https://doi.org/10.1177/001316447003000308>
- Liu, X., Zhang, H., & Wang, Y. (2022). Influence of moisture exposure and rainfall on concrete tensile strength degradation and microcracking. *Construction and Building Materials*, 320, Article 126245. <https://doi.org/10.1016/j.conbuildmat.2021.126245>
- Lyu, H. M., Shen, S. L., & Zhou, A. (2024). Quantification of rainfall impacts on fall-related injuries and accidents in construction sites. *Automation in Construction*, 158, Article 105210. <https://doi.org/10.1016/j.autcon.2023.105210>
- Mohamed Yusof, M. K. T., A Rashid, A. S., Che Lat, D., Abdul Khanan, M. F., Abdul Rahman, M. Z., & Kassim, A. (2025). Slope stability assessment under the effect of antecedent rainfall: A case study at Teluk Bahang Penang. *Jurnal Teknologi*, 87(2), 297–309. <https://doi.org/10.11113/jurnalteknologi.v87.22527>
- Nasirzadeh, F., & Nojedehe, P. (2013). Dynamic modeling of labor productivity in construction projects. *International Journal of Project Management*, 31(6), 903–911. <https://doi.org/10.1016/j.ijproman.2012.11.003>
- Reason, J. (1990). *Human error*. Cambridge University Press. <https://doi.org/10.1017/CBO9781139062367>
- Siu, O. L., Phillips, D. R., & Leung, T. W. (2004). Safety climate and safety performance among construction workers in Hong Kong: The role of psychological strains as mediators. *Accident Analysis & Prevention*, 36(3), 359–366. [https://doi.org/10.1016/S0001-4575\(03\)00016-2](https://doi.org/10.1016/S0001-4575(03)00016-2)
- Tian, T., Lin, X., Huang, T., Zhang, K., Shi, C., Wang, P., Chen, S., Guo, T., Li, Z., Qin, P., Liang, B., Zhang, W., & Hao, Y. (2023). The risk of injuries during work and its association with precipitation: New insight from a sentinel-based surveillance and a case-crossover design. *Frontiers in Public Health*, 11, Article 1117948. <https://doi.org/10.3389/fpubh.2023.1117948>

Zairil, K. J. (2019, October 29). Amid heavy floods, Penang exco lists down state efforts to alleviate problem. Malay Mail. <https://malaysia.news.yahoo.com/amid-heavy-floods-penang-exco-131759724.html>