Identifying Safety Risk Sources in Bridges Construction: A Literature Review

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Abstract

The construction sector, particularly bridge construction, plays a vital role in the development of national infrastructure but also involves significant safety risks that may lead to various losses. To address these risks, effective risk management is required to identify potential hazards and prevent workplace accidents. This study aims to identify the sources of safety risks in bridge construction projects through a systematic literature review. A total of 100 relevant studies were collected and analyzed using the PRISMA approach, while VOS viewer was employed to map and visualize the relationships between risk factors. The findings indicate that six main sources of risk can occur in bridge construction projects, with human-related risks being the most frequent, followed by environmental and managerial factors. These results highlight the importance of systematically identifying safety risk sources to strengthen preventive measures and reduce the likelihood of accidents in construction projects. This study relies exclusively on secondary data derived from published literature, which may restrict its ability to comprehensively represent context-specific, dynamic, or emerging safety risks encountered in actual bridge construction practices. Future research should incorporate empirical investigations, such as field observations, surveys, or in-depth case studies, to validate the identified risk sources and to develop more robust, context-sensitive risk management frameworks for bridge construction projects.

Keywords: Bridge Construction, Construction Safety, Safety Risk Sources, Workplace Safety.

I. Introduction

The construction sector is crucial in large-scale national projects [1]. However, safety risks in the construction sector are more prevalent compared to other sectors [2]. Considering the high potential for risk and the serious consequences of work accidents, it is essential to manage these risks during the construction process [3]. Work accidents in construction projects, particularly in Indonesia, remain a major problem that cannot be overlooked. These accidents must be identified, assessed, and monitored to improve construction safety [4]. One of the major construction projects is bridge construction, which plays an essential role in the development of transportation infrastructure throughout the country, including railway systems, highways, and urban transportation networks [5]. In recent years, the number of bridge construction projects has increased in line with the need for regional economic integration [6]. However, bridge construction faces complex social and environmental conditions [7]. Therefore, significant investments and complex technologies are required in the bridge construction process [8].

The large number of bridge construction projects increases the risk of work accidents during the construction phase [9]. In developing countries, work accidents on bridge construction projects are more likely to occur during construction than during operation [5]. Between 2017 and 2020, several work accidents occurred in bridge and road construction projects in Indonesia, resulting in significant losses for these projects [9]. Meanwhile, in China, work accidents occurred during the construction of railway bridges [10]. Workplace accidents on construction projects can hinder progress, reduce worker morale, and decrease productivity. Accidents also lead to losses involving workers, equipment, materials, projects, and the environment [11]. Moreover, work accidents can result in occupational illnesses and, in severe cases, fatalities [12]. For example, accidents during railway bridge construction in China caused multiple fatalities [10]. If efforts to address work accidents are ineffective, they may lead to unnecessary waste of human resources and materials [13].

Managing a bridge construction project is a significant challenge due to the complexity of the structure. Unforeseen accidents cannot be fully avoided, even when workers act with great caution [13]. For instance, the construction of the Hangzhou Bay Bridge and the Hong Kong–Zhuhai–Macau Bridge illustrates how large-scale sea-crossing projects face complex construction processes and harsh environmental conditions, which further increase risks [6]. These risks may arise from various sources, including human factors, equipment, management, and the environment [4]. Given the severity of these risks, comprehensive control measures are required [4]. One effective approach is implementing a construction safety management system to ensure compliance with safety, health, and sustainability standards [12]. Therefore, identifying safety risks in bridge construction projects is a crucial step to prevent accidents caused by natural hazards or human activities during the construction process [5]. Although many studies highlight the importance of construction safety, research specifically focusing on the systematic identification of safety risk sources in bridge construction projects remains limited. This gap underscores the need for further investigation to provide a structured understanding of risk sources and strengthen preventive measures.

II. METHOD

A. Research Design

This study uses a literature review method by relating the findings of previous studies [14]. A literature review is needed due to the abundance of information, differing viewpoints, and the lack of consensus on certain issues [15]. The literature review is used not to replicate what has been previously studied but to critique prior research to facilitate further studies [16]. A systematic literature review method is characterized by detailing how previous studies are connected and analyzed [17].

B. Research Stages

The research process follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA is used to improve the systematic review and meta-analysis process. The research stages according to PRISMA include identification, screening, eligibility, and inclusion. Figure 1 shows the review stages for scanning and sorting relevant references.

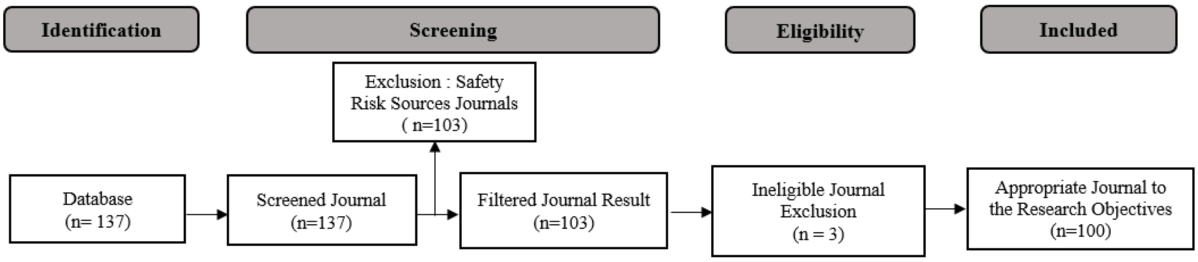


Figure 1 PRISMA Flow Diagram of the Research

Furthermore, this study aims to identify safety risk sources in bridge construction projects through a literature review method. This research involves identifying, screening, and evaluating articles that meet the criteria. A total of 137 articles were initially collected from databases such as Scopus, ScienceDirect, ResearchGate, and Taylor&Francis using keywords including bridge construction, safety risk, and risk management. During the screening process, duplicate and irrelevant studies were excluded, leaving 34 articles for further eligibility assessment. The inclusion criteria required that studies be peer-reviewed, published between 2015-2025, written in English, and focused specifically on safety risk sources in bridge construction projects. Exclusion criteria consisted of non–peer-reviewed papers, studies without full text, and articles addressing general construction safety without bridge-specific context. After applying these criteria, 100 articles were selected for analysis. Data extraction was carried out systematically by recording each study's author, year, context, methodology, and identified risk sources. To ensure reliability, two researchers independently performed the extraction, and any discrepancies were resolved through discussion until consensus was reached.

C. Research Variables

The research variables in this study are categorized based on potential sources of safety risks in construction. These risk sources were gathered from various scientific articles reviewed earlier. The variables identified in previous research are linked to relevant references as shown in Table 1.

Table 1. Research Variables

No	Variable Code	Variable	Reference
1	X1	Man	[7], [9], [10], [18], [19]
2	X2	Method	[7], [10], [18], [19], [20]
3	X3	Machine	[7], [9], [10], [18], [19]
4	X4	Material	[7], [9], [10], [18], [19]
5	X5	Environment	[7], [10], [19], [20], [21]
6	X6	Management	[7], [10], [18], [19], [20]

The variables in Table 1 represent sources of safety risks in construction. These sources include human, method, machine, material, environment, and management. These variables will be further studied through a literature review from various articles and prior research that discuss safety risks in bridge construction projects.

D. Data Collection Techniques

The data collection technique in this literature review involves gathering various research articles available in scientific journals [22]. This research involves about 100 scientific articles published in scientific journals from 2015 to 2025. The articles reviewed in this study are international articles indexed in Scopus, from Q1 to Q4 journals, as well as non-Q journals. The articles were accessed through several platforms that provide access to various research articles, such as ResearchGate. Journal searches were performed by inputting several keywords such as safety risk, bridge construction, bridge project, and construction risk. Data obtained in the following table will be processed using a checklist method to determine how often each reference mentions the related risk sources.

E. Data Analysis Techniques

In this study, data were analyzed using descriptive analysis methods, where the characteristics of the collected data were described and illustrated to provide an understanding to the reader [23]. Descriptive analysis involves using naturalistic data, which means no intervention or manipulation of any variables [24]. The data in the descriptive analysis method are simplified and presented in the form of characterizations and identification based on research questions [25]. Descriptive research leads to hypotheses, not hypothesis testing, and the research questions typically begin with “what,” “when,” “where,” and “how” [23].

III. RESULTS AND DISCUSSION

A. Data Analysis Results

1. Search Categories

To visualize and analyze the research data more easily, VOSviewer was used in this study. VOSviewer is a tool for visualizing and analyzing bibliometric data. Bibliometric analysis can identify relevant literature in this research. Additionally, it can easily identify research trends through frequently appearing keywords in the literature.

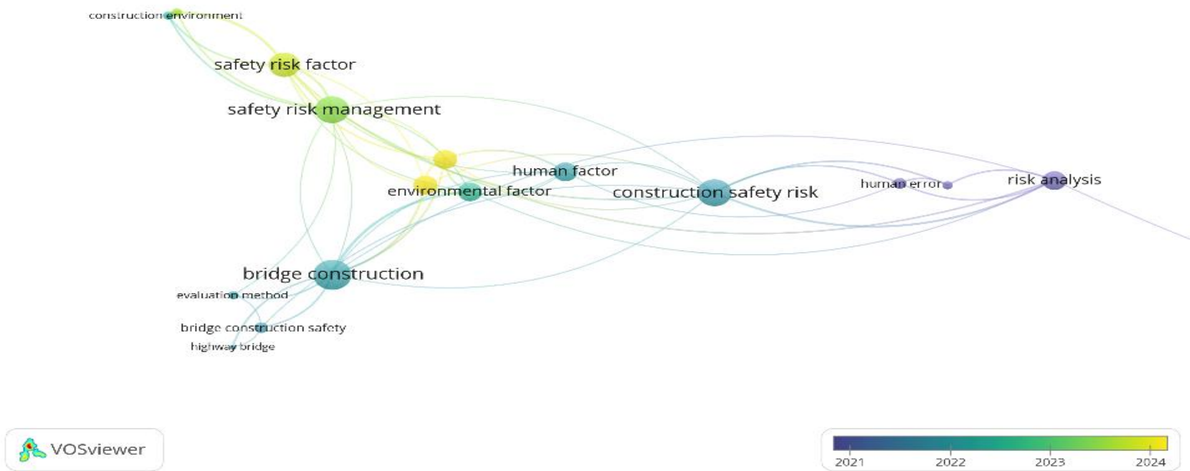


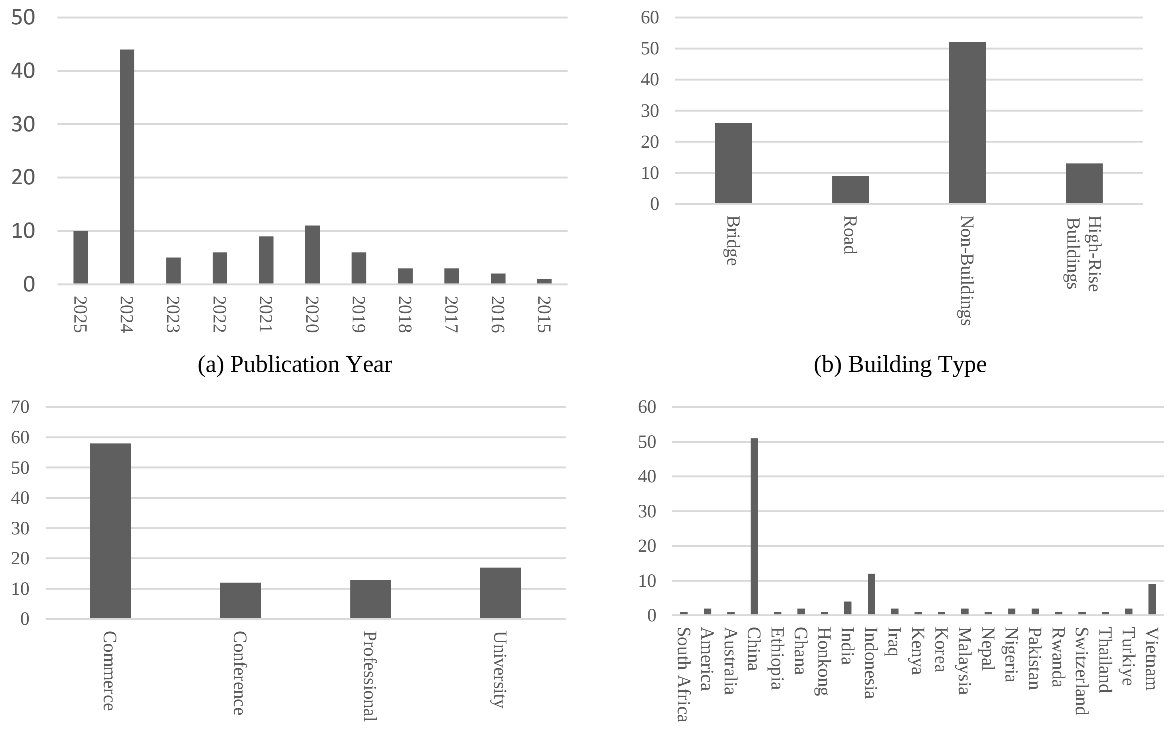
Figure 2 Research Mapping Based on Article Themes

The visual map generated using VOSviewer illustrates the relationships between various risk sources in bridge construction safety based on a literature review. From the analysis, several main groups in the research can be identified. The first group focuses on bridge construction, which includes specific aspects of bridge projects such as highway bridges and bridge construction safety. The next group, safety risk management, is linked to risk sources in the construction environment, such as safety risk sources and construction environment. Another group, construction safety risk, highlights sources influencing safety in construction projects, including human and environmental sources. Meanwhile, the risk analysis group focuses on risk analysis methods and causes of risks, such as human error and earthquakes.

From the research trends, the colors in the visualization represent the development of studies from 2021 (blue) to 2024 (yellow). Keywords such as management and environmental have gained more attention in recent research, indicating a growing focus on managerial and environmental aspects in mitigating construction safety risks. Based on this mapping, it can be concluded that safety in bridge construction is influenced by various sources, including environment, human, management, and technical approaches in project implementation.

2. Reference Categories

To analyze the various literature used, this study categorizes the references into several groups. This categorization process is conducted to identify the publication trends in this research. The categories used to identify these trends include year, type of building, journal source, and country.



(a) Publication Year (b) Building Type

(c) Journal Source (d) Country

Figure 3 Journal Distribution

Based on the graphical analysis, most of the references in this study are from 2024, showing a dominance of recent studies, while articles published before 2020 have a lower frequency. In terms of building types, the non-building category has the highest number of publications, followed by bridges and high-rise buildings, suggesting that many studies are not limited to a specific building type. Regarding publication sources, commercial journals dominate with 58 sources, followed by university, professional, and conference journals, reflecting a trend toward commercial publication. Meanwhile, in terms of publication country, China has the highest number of publications, followed by Indonesia and Vietnam, reflecting a significant focus on bridge construction safety, especially in countries with rapid infrastructure development such as China.

3. Meta-Analysis

The data collected from 100 scientific articles will be presented in the following table. This table shows the results of identifying safety risk sources in bridge construction projects, where the risk sources are categorized into six groups: human (X1), method (X2), machine (X3), material (X4), environment (X5), and management (X6). The findings of risk sources from each article will be marked (✓) in the relevant risk sources column.

Table 2. Meta-Analyse of Literature Articles

No	Author (s)	Year	Risk Sources					
			X1	X2	X3	X4	X5	X6
1	Hartono et al.	2025	✓		✓	✓		
2	Hartono et al.	2025	✓		✓	✓		
3	Bilim	2025	✓					
4	Aidoo et al.	2025	✓					✓
5	Adharia Ghaisani et al.	2025	✓				✓	
6	Giri	2025	✓	✓	✓	✓		✓
7	Umuhoza et al.	2025	✓					✓
8	Pavate	2025	✓	✓		✓		✓
9	Singh	2025					✓	✓
10	Liu et al.	2025	✓			✓		✓
11	Zafar	2024	✓	✓	✓			
12	Song et al.	2024					✓	✓
13	Bundeh et al.	2024	✓		✓	✓		✓
14	Dubey et al.	2024	✓					✓
15	Hu et al.	2024	✓	✓	✓	✓	✓	
16	Yue	2024	✓		✓	✓	✓	
17	Joshi et al.	2024	✓	✓				✓
18	Shan et al.	2024	✓	✓	✓	✓	✓	✓
19	Ran et al.	2024	✓			✓	✓	✓
20	Y. Wang et al.	2024	✓			✓	✓	✓
21	Y. Wu et al.	2024	✓		✓	✓	✓	
22	Long et al.	2024	✓		✓	✓	✓	✓
23	Datta et al.	2024	✓		✓			✓
24	Noshin et al.	2024		✓			✓	✓
25	Chen et al.	2024	✓	✓			✓	
26	Tang et al.	2024		✓	✓			✓
27	Ren et al.	2024	✓				✓	✓
28	Adebowale et al.	2024	✓		✓		✓	✓
29	Afuye et al.	2024		✓	✓		✓	✓
30	Ali et al.	2024	✓		✓	✓	✓	✓
31	Kong et al.	2024	✓	✓				✓
32	Ma & He	2024	✓		✓	✓		✓
33	Wu et.al	2024	✓		✓	✓	✓	✓
34	Long et al.	2024	✓		✓	✓	✓	✓
35	Akomah et al.	2024	✓					
36	Xu et al.	2024	✓		✓	✓	✓	✓
37	Piri et al.	2024	✓	✓	✓	✓	✓	
38	Shehu et al.	2024	✓					✓
39	Qaddoori et al.	2024	✓					✓
40	Aghimien,	2024	✓	✓		✓		
41	Lee et al.	2024			✓		✓	
42	Ogundare et al.	2024	✓		✓	✓	✓	✓
43	Kotey et al.	2024	✓		✓			✓
44	Zhao et al.	2024	✓		✓	✓	✓	✓
45	Feng et al.	2024	✓		✓			
46	Bundeh et al.	2024					✓	✓
47	Marliana et al.	2024	✓			✓		
48	Victory et al.	2024	✓					✓
49	Yure et al.	2024	✓		✓			✓
50	Mamman et al.	2024	✓			✓		
51	Makki Dishar et al.	2024	✓	✓			✓	
52	Yao et al.	2024	✓		✓		✓	✓
53	Han et al.	2024	✓		✓	✓	✓	✓
54	Sorbi et al.	2024	✓				✓	✓
55	Damanik et al.	2023	✓		✓	✓	✓	✓
56	Shan et al.	2023	✓			✓	✓	✓
57	Rashid et al.	2023	✓				✓	✓
58	Aurellina et al.	2023	✓			✓		
59	Ran et al.	2023	✓				✓	✓
60	Jeong et al.	2022	✓		✓	✓		
61	Suwaini et al.	2022			✓		✓	
62	Ji et al.	2022	✓		✓	✓	✓	✓
63	Li et al.	2022	✓	✓		✓	✓	
64	Wuni et al.	2022	✓				✓	✓
65	Zhu et al.	2022	✓		✓			
66	Nugroho et al.	2021	✓	✓	✓	✓	✓	
67	Ongkowijoyo et al.	2021	✓	✓				✓
68	Liang et al.	2021		✓	✓	✓	✓	✓
69	Latupeirissa et al.	2021	✓	✓		✓	✓	✓
70	Li et al.	2021	✓	✓	✓	✓	✓	
71	Yang et al.	2021		✓			✓	
72	Wu et al.	2021	✓	✓		✓	✓	✓
73	Ongkowijoyo et al.	2021	✓	✓				✓
74	Jeong et al.	2021				✓	✓	
75	Li et al.	2020	✓	✓	✓	✓	✓	✓
76	Ren et al.	2020	✓		✓	✓	✓	✓
77	Li et al.	2020	✓	✓	✓		✓	
78	Bai et al.	2020	✓		✓	✓		✓
79	Li et al.	2020	✓		✓	✓		✓
80	Srinivasan at al.	2020	✓		✓	✓		✓
81	Los Pinos et al.	2020	✓			✓	✓	
82	Supriyatna et al.	2020	✓				✓	
83	Nkurunziza	2020	✓		✓	✓	✓	
84	Jkhsi	2020	✓			✓	✓	
85	Yap et al.	2020	✓				✓	✓
86	Fisac et al.	2019				✓	✓	
87	Mairizal et al.	2019	✓		✓	✓		
88	Chen et al.	2019	✓	✓	✓	✓	✓	✓
89	Wan et al.	2019		✓		✓		
90	Yıldırım et al.	2019	✓				✓	
91	Innella et al.	2019				✓	✓	✓
92	Nguyen-Xuan et al.	2018			✓	✓		
93	Purohit et al.	2018	✓		✓		✓	
94	Razzaq et al.	2018					✓	✓
95	Tixier et al.	2017	✓		✓	✓		✓
96	Kang et al.	2017	✓		✓	✓		
97	Chan et al.	2017	✓					✓
98	Daniel E Maurino et al.	2016	✓	✓	✓		✓	✓
99	Larsen et al.	2016						✓
100	Zhou et al.	2015	✓		✓	✓	✓	✓

Table 2 details the comprehensive meta-analysis of the 100 literature articles selected for this study. The matrix categorizes each source by author and publication year, covering a timeline from 2015 to 2025 to ensure the recency of the data. The columns X1 through X6 represent the specific risk sources identified in each study, where a checkmark indicates that the respective variable was analyzed or discussed by the author. This tabulation serves as the primary dataset for calculating the frequency and dominance of risk factors presented in the subsequent analysis. Furthermore, table 3 summarizes the frequency of risk source findings based on a review of 100 articles. The data classifies risks into six variables Man, Method, Machine, Material, Environment, and Management and ranks them by their occurrence percentage to identify the most dominant factors.

Table 3. Frequency of Risk Source Findings

Variable Code	Source	Number of Articles	Frequency	Percentage	Rank
X1	Man	100	83	83,0%	1
X2	Method	100	28	28,0%	6
X3	Machine	100	51	51,0%	5
X4	Material	100	54	54,0%	4
X5	Environment	100	59	59,0%	3
X6	Management	100	61	61,0%	2

According to the results, the variable 'Man' (X1) ranks highest with a frequency of 83.0%, indicating it is the most common risk source found in the literature. This is followed by 'Management' (X6) and 'Environment' (X5) in second and third place, respectively. Conversely, 'Method' (X2) is the lowest-ranked variable, appearing in only 28.0% of the reviewed articles.

Figure 4. ***Word Cloud of Construction Safety Risk Sources***

The word cloud above displays various keywords that frequently appeared in the literature review related to the Identification of Safety Risk Sources in Bridge Construction Projects. Words such as human, management, environment, and material indicate that the primary sources of safety risks encompass these aspects. The following are explanations of each safety risk source along with the percentage of frequency of occurrence, which will be discussed in the discussion section.

B. Discussion

This literature review provides a comprehensive identification of the current research on safety risk sources in bridge construction projects. The results show that the most frequently mentioned source of risk comes from human sources, followed by management, environment, material, machine, and method sources. In this section, we will discuss in detail the safety risk sources in bridge construction. Indeed, human factors represent the most dominant source of safety risks, accounting for 83% of identified issues, with 83 out of 100 reviewed studies emphasizing their critical contribution to accident causation [46, 47]. These risks frequently arise from limited skills, fatigue, negligence, and inadequate compliance, all of which are closely shaped by worker experience, training quality, and psychological resilience, while repetitive or strenuous tasks further elevate the likelihood of human error [9, 18, 45]. Falls remain the most severe accident type, followed by slips and entrapments, indicating that physical work environments exacerbate human vulnerability [1, 4, 36].

Moreover, human factors rarely operate independently, as they often interact with environmental conditions and managerial deficiencies, reinforcing the need for rigorous supervision and sustained safety interventions [28, 32, 34, 51]. In comparison, method risks factor contributes a lower proportion (28%) yet remain significant due to their strong association with poor planning, inappropriate method selection, and insufficient worker training, all of which can compromise structural integrity and overall site safety [4, 9, 20]. Failures in concrete pouring, steel assembly, or scaffolding installation highlight persistent procedural gaps and demonstrate why continuous education and strict adherence to technical standards are essential to prevent severe accidents stemming from method errors [4, 21, 49].

Machines and equipment contribute 51% of safety risks, with crane, excavator, and truck overturning identified as the most critical hazards that threaten both operators and project continuity [4, 29]. These risks are intensified by the absence of routine inspections, insufficient maintenance, and non-compliance with safety protocols, all of which heighten the likelihood of mechanical failures [1, 26, 41]. Failures in hydraulics, scaffolding, or electrical systems can lead to catastrophic accidents, emphasizing the need for stronger preventive measures in equipment management [19, 31, 42]. Material factors comprising 54%, originate from poor material quality, incompatibility with site conditions, and unsafe storage or handling practices that undermine structural stability [3, 32, 33]. Structural failures such as girder falls or reinforcement collapses frequently result from substandard materials or improper installation, illustrating the severity of material-related hazards [1, 4]. To mitigate these risks, strict material inspection, proper storage protocols, and the adoption of advanced monitoring technologies like BIM and sensors are essential for enhancing both safety and structural reliability [13, 39].

Environmental factors contribute 59% of risks, driven mainly by extreme weather, pollution, and hazardous site conditions that can compromise both worker safety and structural performance [5, 50]. Heavy rain, strong winds, and extreme temperatures pose direct threats, while dust and noise exposure reduce concentration and impair long-term health, further increasing accident likelihood [40, 43]. Projects located in disaster-prone or high-altitude regions also encounter additional hazards such as landslides, unstable slopes, and high wind pressures, which require heightened vigilance [37, 38]. Management factors, accounting for 61%, arise from ineffective planning, weak supervision, poor communication, and budget limitations that weaken the implementation of safety standards [4, 30, 51]. Insufficient investment in safety often leads to low-quality PPE, inadequate training, and unsafe site facilities, conditions that elevate accident rates and increase legal liabilities for project stakeholders [12, 27, 48]. These risks are further amplified by management failures that interact with human and equipment-related factors, underscoring the need for stronger safety governance supported by systems such as a Bridge Management System (BMS), routine monitoring, and committed leadership [35, 44, 51].

IV. Conclusion

This study concludes that safety risks in bridge construction arise from six main sources: human, management, environment, material, machine, and method. The human factor contributes the most (83%), followed by management (61%), environment (59%), material (54%), machine (51%), and method (28%). These findings underline the need for stronger safety policies and management practices, particularly in workforce training, supervision, and resource allocation. However, the study is limited by the diversity of countries, project types, and timeframes in the reviewed literature, making broad generalizations difficult. Future research should apply structured risk assessment methods such as HIRADC or FMEA and consider project-specific factors like type, location, and period. For policymakers and construction managers, the results provide evidence to prioritize human- and management-related risks when designing safety programs, allocating budgets, and formulating regulations, thereby reducing accidents and improving project outcomes.

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