Journal of Science and Technology in Civil Engineering, HUCE, 2024, 18 (3): 60–75

AN ESTIMATION OF THE TOWER CRANE SAFETY RISK FACTORS IN THE VIETNAMESE CONSTRUCTION INDUSTRY

Ngo Thanh Long[a,*], Nguyen Hoang Giang[a]

[a]*Faculty of Mechanical Engineering, Hanoi University of Civil Engineering, 55 Giai Phong road, Hai Ba Trung district, Hanoi, Vietnam*

Article history:
Received 06/5/2024, Revised 12/6/2024, Accepted 07/8/2024

Abstract

The construction industry is among the riskiest sectors worldwide due to its involvement in complex and hazardous activities, primarily because of the use of tower cranes. Tower cranes are considered the most hazardous construction machinery, contributing to a high rate of serious accidents, including fatalities and disabling injuries, not only in Vietnam but also globally. In this paper, we identify and evaluate 42 tower crane safety risk factors specific to the Vietnamese construction industry based on their probability of occurrence, severity of impact, and associated risk levels. The paper reveals that the most probable risk factor is "Unfavorable winds (including intensity, direction, etc.)" with a mean value of 3.641. The factor with the highest severity is "Wire rope is broken" with a mean value of 4.179. Furthermore, the study shows that twenty-five out of forty-two (59.52%) factors present a moderate risk level, with a Relative Significant Index Score (RSIS) ranging from 8.019 to 13.047. Among these, the factor "Bad maintenance management of the tower crane and auxiliary aids" poses the highest risk level, with an RSIS value of 13.047. This paper aims to enhance the understanding of tower crane safety among subcontractors, government safety regulators, main contractors, maintenance personnel, and workers in the Vietnamese construction industry. Additionally, the methodology presented in this paper can be adapted for assessing safety risk factors in other industries within Vietnam.

Keywords: tower crane; safety risk; construction safety; construction sector.

https://doi.org/10.31814/stce.huce2024-18(3)-05

1. Introduction

The construction sector significantly influences the economies of nations. For instance, in the European Union, the construction industry contributes approximately 5.7% to its gross domestic product (GDP) [1]. Despite its economic importance, the construction industry is among the riskiest sectors, accounting for the highest number of tragic accidents [1–12]. According to the International Labour Organization (ILO), the number of casualties from occupational accidents in the construction sector surpasses 1.3 million annually, which is three times higher than any other industry [1]. In the United States, the construction sector represents roughly 20% of all workplace fatalities [13]. In the United Kingdom (UK) alone, between 2022 and 2023, there were approximately 53,000 non-fatal work-related injuries and 45 fatal injuries reported [14]. Similarly, in China, between 2010 and 2019, there were 6,005 fatal accidents resulting in 7,275 fatalities [15]. Korea reported 137,323 injuries and 2,846 fatalities within the construction industry from 2011 to 2016 [16], while Turkey documented 393,160 occupational accidents from 2012 to 2020 [17]. Notably, construction-related accidents accounted for 13.33% of the total number of accidents and 14.77% of fatalities from January to June 2023 [18].

Tower cranes are integral to construction projects, especially for building factories, skyscrapers, high-rise buildings, and commercial centers. They serve as the primary means of vertical and

*Corresponding author. *E-mail address:* longnt@huce.edu.vn (Long, N. T.)

horizontal material transportation on construction sites and play a crucial role in construction operations. However, tower cranes are also among the most hazardous pieces of equipment on construction sites, with a disproportionately high rate of critical accidents resulting in severe injuries and fatalities [12, 19–25]. For example, in China, between 2016 and 2018, there were over 100 tower crane accidents leading to more than 180 fatalities [26]. Australia reported 47 deaths related to tower crane accidents from 2003 to 2015 [27]. In Korea, tower crane accidents accounted for 18.4% of all fatal accidents on construction sites between 2001 and 2011 [28]. In the United States, there were 137 crane-related fatalities from 1992 to 2001, with tower cranes contributing to approximately 5% of the total fatalities in crane-related incidents [29, 30]. Similarly, tower cranes accounted for about 17% of all construction-related fatalities in England [31]. In the UK, between 2000 and 2009, there were five tower crane-related accidents reported [32], while Hong Kong documented nine tower crane-related accidents between 1998 and 2007 [33]. Vietnam has also experienced several tower crane-related accidents, including incidents in Bac Giang in 2023, Phu Yen in 2021, Hanoi and Nghe An in 2016, and multiple incidents resulting in fatalities and injuries in 2020 and 2021. Consequently, tower crane safety remains a prominent issue in the construction industry, attracting considerable research attention [21, 34–41], although there is a limited focus specifically on tower cranes [42, 43].

Li, Chan, & Skitmore [30] presented an innovative approach to training for the dismantling of tower cranes, which outperformed traditional methods. Shin [28] conducted an analysis of 38 tower crane-related accidents in Korea from 2001 to 2011, identifying 31 safety risk factors during installation and dismantling. Among these, five major factors were identified, with human error being the primary cause of accidents. Salihu, Aliyu, & Abubakar [44] identified 21 safety risk factors associated with the installation and dismantling of tower cranes in Nigeria. Their research assessed the likelihood of occurrence, severity of impact, and overall risk level for each identified factor. Similarly, Ngo [42] pinpointed 21 safety risk factors related to the installation and dismantling of tower cranes in Vietnam, evaluating their likelihood of occurrence, severity of influence, and risk degree. Long & Giang [43] identified 21 safety risk factors associated with the operation of tower cranes in Vietnam including evaluating their likelihood of occurrence, severity of influence, and risk degree. Shapira & Lyachin [45] examined the degree of influence of 21 safety factors during the operation of tower cranes in Israel. Building on this research, Shapira & Simcha [39] employed an Analytic Hierarchy Process (AHP) model to determine the weight of these safety risk factors during tower crane operations in Israel. Tam & Fung [46] identified four significant safety factors in tower crane operations in Hong Kong, emphasizing that human-related factors contribute significantly to tower crane safety risks. They also proposed 11 recommendations for mitigating tower crane safety risks on construction sites. Shapira, Simcha, & Goldenberg [24] introduced a model that integrates four modules to quantify safety risk factors. This model calculates an overall index representing the safety level during tower crane operations on any investigated construction site. Zhou et al. [47] proposed a model that integrates both qualitative and quantitative analysis methods to rank the 25 critical safety factors affecting tower cranes in China using the AcciMap technique. They categorized the 25 factors into nine groups, including quality and reliability of tower cranes, safety management and maintenance, safety programs, workers' safety practices, working environment, on-site working conditions for tower cranes, supervisors' safety practices, auxiliary safety equipment, and government safety supervision. Furthermore, Zhang et al. [26] identified 34 causal factors based on 141 tower crane accident reports in China from 2013 to 2018. Similarly, Ngo & Nguyen [43] identified 21 safety risk factors associated with tower crane operations in Vietnam, evaluating their likelihood of occurrence, degree of influence, and risk levels.

Globally, numerous researchers have addressed tower crane-related safety risk factors. However, most of these studies have focused on specific aspects of tower crane safety, such as installation/dismantling or operation. Consequently, there is a need to comprehensively identify and evaluate safety risks associated with tower cranes across all phases of their use, particularly on construction sites in Vietnam. This paper aims to achieve several key objectives. Firstly, it reviews existing literature on tower crane-related safety risk factors. Secondly, it identifies safety risk factors specific to the Vietnamese construction industry. Lastly, the paper evaluates these risk factors based on their probability of occurrence, severity of impact, and overall risk levels.

2. Methodology

The research methodology contains the following steps: Forty-two (42) tower crane-related safety risk factors, previously designated in a study [34] and showed in Table 1, were selected. To investigate tower crane-related safety risks in the Vietnamese construction industry, a questionnaire survey with 42 crane safety risk factors was conducted. There are four sections in the questionnaire: (1) general information including job description, educational qualification, and years of experience; (2) 5 point Likert scale of likelihood of occurrence and 5 point Likert scale of degree of influence; (3) tower crane safety risk factors with likelihood of occurrence and degree of influence, and (4) other opinions. The research uses MS excel to count the collected data and discovery the likelihood of occurrence, degree of influence, and safety risk level of factors. The safety risk level of factors was shown by relative significant index score (RSIS). The RSIS is equal to the combined risk score (ΣRS) divided by the population (N). The combined risk score (ΣRS) is equal to likelihood risk score ($\Sigma\alpha$) multiplied by the degree of influence risk score ($\Sigma\beta$). These RSIS values were then evaluated and compared against a table of standard risk values developed by the Construction Plant Hire Association (CPA) [48]. It suggests that RSIS with value from 1 to 6 is low and acceptable, does not require any control actions. RSIS with value from 7 to 8 is moderate and is acceptable but it needs a sufficient level of control with operations. RSIS with value from 15 to16 is high and acceptable only if no other method is viable and with high level controls in place. RSIS with value from 20 to 25 is very high and is an unacceptable risk, plan out or add further controls.

Table 1. List of tower crane safety risk factors

No	Factors
1	Insufficient employees to ensure the work correctly and safely
2	Erection and dismantling employees quit the work due to heavy work
3	Constraint time by project-related people (including employer, main contractor, or investor)
4	Workers try to accomplish the work early but not pay attention to the work safety
5	Workers do not usually follow necessary safety regulations and procedures
6	Workers with insufficient competence
7	Construction sites with insufficient instruction and supervision
8	Contractors without sufficient perception for tower crane safety during erection and dismantling
9	Unfavorable condition of construction sites (including working area, groundwork conditions, weather, etc.)
10	Components of tower crane with reduced quality

No	Factors
11	Erection and dismantling workers with unsuitable character (including careless, impulse, etc.)
12	Objects exceed the lifting capacity of tower crane
13	Operators with insufficient experiences
14	Erection and dismantling workers are not followed process of erection and dismantling in manuals for the tower cranes
15	Breakdown of a tower crane
16	Erection and dismantling cage with buckling
17	Wire rope is broken
18	Insufficient working platforms for erection and dismantling
19	Components of tower cranes with incompatibility
20	Dropping tools
21	Connection details of tower crane (including pins, bolts, and nuts, etc.) with attrition and break
22	Tower crane's work region with difficulty, specially in urban areas such as building next to site, equipment, various temporary facilities at the construction site
23	The tower crane's work region with overhead power lines
24	The tower crane operator can not see the lifts
25	Multi tower cranes in a working region on construction site
26	The unfavourable height and distance of the tower crane cabin
27	Inconvenience status of the tower crane cabin
28	Tower crane-related worker with excessive overtime, specially by night
29	Tower crane-related workers use different languages on the construction site
30	Retrofit auxiliary aids for operator to increase the safety
31	Dangerous load (including weight, dimensions, packaging, configuration, etc.) and unsuitable rigging way
32	Unfavorable winds (including intensity, direction, etc.)
33	Bad weather (including hard temperatures, rain and other bad weather phenomena)
34	Tower crane-related workers with bad visibility
35	Insufficient experience and skills of a tower crane operator
36	Bad attitude of tower crane operator such as impulsive, defiant, sluggish, etc.
37	Tower crane operator is not a staff of the construction company
38	Bad attitude of manager such as insufficient accountability, alertness, and sensibility
39	Signalperson and rigging worker with insufficient experience
40	Insufficient safety management at the construction site level
41	Insufficient safety management at the company level
42	Bad maintenance management of the tower crane and auxiliary aids

3. Results and Discussion

3.1. Respondents profile

A number of 120 questionnaires were sent to practitioners who are handling crane-related works, including managers, tower crane operators, installation and dismantling workers, and tower crane-related workers. Seventy-eight valid answers were received, resulting in an impressive 65.0% response rate including managers (26.9%), tower crane operators (24.4%), installation and dismantling workers (30.8%), and tower crane-related workers (17.9%) as in Table 2. About 10.3%, 24.4%, 29.4%, 20.5% and 15.3% of the respondents have between 0 and 5 years of experience, between 6 and 10 years of

experience, between 11 and 15 years of experience, between 16 and 20 years of experience, and more than 20 years of experience respectively. In terms of educational qualification, high school holders are the least represented at 10.3%, secondary graduation holds the highest representation, standing at 62.8.7%.

Table 2. Respondents profile

No	Item	Number	Percentage
	Job description		
1	Managers (Safety managers; Equipment managers and project managers)	21	26.9
2	Tower crane operators	19	24.4
3	Installation and dismantling workers	24	30.8
4	Tower crane-related workers	14	17.9
	Total	78	100
	Educational qualification		
1	High school	6	7.7
2	Secondary graduation	49	62.8
3	Bachelors	15	19.2
4	MSc	8	10.3
	Total	78	100
	Years of experience		
1	0-5	8	10.3
2	6-10	19	24.4
3	11-15	23	29.5
4	16-20	16	20.5
5	Over 20	12	15.3
	Total	78	100

3.2. Probability of occurrence for safety risk factor

Table 3 shows the probability of occurrence for each tower crane-related safety risk factor based on a five point Likert scale and scores from respondents. Mean values and standard deviation of the safety risk factor were calculated to help rank from high mean values to low mean values. Table 3 shows that all of 42 factors have a mean value of > 2.0, in which there are 16/42 (38.1%) factors with mean values > 3.0. This value indicates that probability of occurrence for safety risk factors is moderate. It means that these factors have the probability of appearing and may repeat sometimes. The most probable factor is "Unfavorable winds (including intensity, direction, etc.)." with a mean value of 3.641. This implies that winds for tower cranes in Vietnam is abnormal and need to pay more attention. The least probable factor is "Components of tower crane with incompatibility." with a mean value of 2.128. Table 3 also present the first two (2) factors that had mean values ≥ 3.5 including: "Unfavorable winds (including intensity, direction, etc.)" (mean value of 3.641) and "Constraint time by project-related people (including employer, main contractor, or investor)" (mean value of 3.603). It means that these factors have the high probability of appearing and may repeat. The factors from 17th

to 42nd positions had mean values of ≥ 2.0 indicating that they are remote to repeat but have a chance of occurring. The result shows that there are 42 tower-related safety risk factors on construction sites in Vietnam.

Table 3. Probability of occurrence for safety risk factor

No	Factors	Frequency									
		1	2	3	4	5	Σf	Σα	Mean	Std.Dev	Rank
1	Unfavorable winds (including intensity, direction, etc.)	2	5	31	21	19	78	284	3.641	1.006	1st
2	Constraint time by project-related people (including employer, main contractor, or investor)	3	9	23	24	19	78	281	3.603	1.097	2nd
3	Tower crane operator is not a staff of the construction company	5	10	27	15	21	78	271	3.474	1.203	3rd
4	Bad weather (including hard temperatures, rain and other bad weather phenomena)	6	12	23	22	15	78	262	3.359	1.184	4th
5	Insufficient safety management at the construction site level	4	14	28	21	11	78	255	3.269	1.077	5th
6	Tower crane-related workers with bad visibility	5	10	38	15	10	78	249	3.192	1.032	6th
7	Tower crane-related worker with excessive overtime, specially by night	4	15	37	7	15	78	248	3.179	1.113	7th
8	Insufficient experience and skills of a tower crane operator	9	17	21	15	16	78	246	3.154	1.316	8th
9	Bad maintenance management of the tower crane and auxiliary aids	6	19	27	10	16	78	245	3.142	1.224	9th
10	Workers try to accomplish the work early but not pay attention to the work safety	9	7	33	22	7	78	245	3.141	1.089	10th
11	Signalperson and rigging worker with insufficient experience	7	15	26	21	9	78	244	3.128	1.132	11th
12	Insufficient safety management at the company level	9	19	24	7	19	78	242	3.102	1.334	12th
13	Dropping tools	8	17	31	6	16	78	239	3.064	1.241	13th

No	Factors	Frequency									
		1	2	3	4	5	Σf	Σα	Mean	Std.Dev	Rank
14	Unfavorable condition of construction sites (including working area, groundwork conditions, weather, etc)	9	10	31	25	3	78	237	3.039	1.037	14th
15	Dangerous load (including weight, dimensions, packaging, configuration, etc.) and unsuitable rigging way	13	20	12	18	15	78	236	3.025	1.395	15th
16	Tower crane's work region with difficulty, specially in urban areas such as building next to site, equipment, various temporary facilities at the construction site	9	12	38	7	12	78	235	3.012	1.139	16th
17	Components of tower cranes with reduced quality	8	18	26	20	6	78	232	2.974	1.104	17th
18	Connection details of tower crane (including pins, bolts, and nuts, etc.) with attrition and break	8	26	20	9	15	78	231	2.961	1.283	18th
19	Bad attitude of tower crane operator such as impulsive, defiant, sluggish, etc.	11	19	26	7	15	78	230	2.948	1.298	19th
20	Retrofit auxiliary aids for operator to increase the safety	14	14	26	12	12	78	228	2.923	1.297	20th
21	Bad attitude of manager such as insufficient accountability, alertness, and sensibility	9	18	25	23	3	78	227	2.910	1.071	21st
22	The unfavorable height and distance of the tower crane cabin	11	21	22	15	9	78	224	2.871	1.220	22nd
23	Erection and dismantling workers with unsuitable character (including careless, impulse, etc.)	13	18	27	14	6	78	217	2.862	1.161	23rd
24	Breakdown of a tower crane	8	20	31	14	5	78	222	2.846	1.045	24th

No	Factors	Frequency									
		1	2	3	4	5	Σf	Σα	Mean	Std.Dev	Rank
25	Erection and dismantling employees quit the work due to heavy work	11	20	21	24	2	78	220	2.820	1.101	25th
26	Tower crane-related workers use different languages on the construction site	20	19	11	13	15	78	218	2.794	1.480	26th
27	Erection and dismantling workers are not followed process of erection and dismantling in manuals for the tower cranes	19	17	18	11	13	78	216	2.769	1.404	27th
28	Workers do not usually follow necessary safety regulations and procedures	16	15	23	23	1	78	212	2.718	1.138	28th
29	Inconvenience status of the tower crane cabin	13	15	38	5	7	78	212	2.717	1.103	29th
30	The tower crane operator can not see the lifts	13	18	34	7	6	78	209	2.679	1.098	30th
31	Insufficient employees to ensure the work correctly and safely	20	10	29	16	3	78	206	2.641	1.184	31st
32	Construction sites with insufficient instruction and supervision	17	20	16	25	0	78	205	2.628	1.152	32nd
33	Erection and dismantling cage with buckling	9	31	21	15	2	78	204	2.615	1.009	33rd
34	Workers with insufficient competence	13	26	24	12	3	78	200	2.564	1.064	34th
35	Multi tower cranes in a working region on construction site	14	27	22	10	5	78	199	2.551	1.124	35th
36	Contractors without sufficient perception for tower crane safety during erection and dismantling	19	18	22	18	1	78	198	2.538	1.136	36th
37	Objects exceed the lifting capacity of tower crane	22	17	22	15	2	78	192	2.461	1.169	37th
38	The tower crane's work region with overhead power lines	18	21	30	4	5	78	191	2.440	1.100	38th

No	Factors	Frequency									
		1	2	3	4	5	Σf	Σα	Mean	Std.Dev	Rank
39	Operators with insufficient experiences	24	17	20	15	2	78	188	2.410	1.189	39th
40	Wire rope is broken	20	20	30	5	3	78	185	2.371	1.058	40th
41	Insufficient working platforms for erection and dismantling	13	35	22	6	2	78	183	2.346	0.937	41st
42	Components of tower crane with incompatibility	26	23	24	3	2	78	166	2.128	1.011	42nd

1 = Improbable; 2 = Remote; 3 = Possible; 4 = Probable; and 5 = Almost certain.

3.3. Severity of influence for factors

The degree of influence of each tower crane-related safety risk factor was calculated by using a 5 point Likert scale. The variant severity of influence of the factors were regrouped if they occurred, and then, the mean value of the factors was calculated and ranked as in Table 4. Table 4 indicates that all of 42 factors had a severity of influence from minor injury to fatality. There were 16/42 (38.09%) factors which had severity of influence with a mean value > 3.0. This means that these factors had a severity of influence from major injury to fatality if they occur. The factor of "Wire rope is broken" had the highest severity of influence with a mean value of 4.179 which indicates that there may have fatality if it appears. However, the factor has the quite low probability of occurrence (40th) as shown in Table 3. There were 26/42 (61.91%) factors with mean values from 1.948 to 2.961. In which, the factor of "Retrofit auxiliary aids for operator to increase the safety" had the lowest severity of influence with a mean value of 1.948 which implies that it can only lead to minor injury if it arises. However, the factor has the medium probability of occurrence (20th) as shown in Table 3.

Table 4. Severity of influence of factors

No	Factors	Frequency								
		1	2	3	4	5	Σf	Σβ	Mean	Rank
1	Wire rope is broken	1	4	10	28	35	78	326	4.179	1st
2	Bad maintenance management of the tower crane and auxiliary aids	2	6	30	29	34	78	324	4.153	2nd
3	The tower crane's work region with overhead power lines	4	11	12	26	25	78	291	3.730	3rd
4	The tower crane operator can not see the lifts	7	8	14	28	21	78	282	3.615	4th
5	Objects exceed the lifting capacity of tower crane	10	8	14	18	28	78	280	3.589	5th
6	Workers do not usually follow necessary safety regulations and procedures	9	7	18	27	17	78	270	3.461	6th
7	Erection and dismantling workers are not followed process of erection and dismantling in manuals for the tower cranes	7	14	16	22	19	78	266	3.410	7th

No	Factors	Frequency								
		1	2	3	4	5	Σf	Σβ	Mean	Rank
8	Workers with insufficient competence	8	4	30	23	13	78	263	3.371	8th
9	Contractors without sufficient perception for tower crane safety during erection and dismantling	12	9	15	23	19	78	262	3.359	9th
10	Operators with insufficient experiences	13	6	19	21	19	78	261	3.346	10th
11	Breakdown of a tower crane	7	14	28	13	16	78	251	3.218	11th
12	Components of tower crane with reduced quality	8	13	19	33	5	78	249	3.192	12th
13	Insufficient employees to ensure the work correctly and safely	8	15	19	27	9	78	248	3.179	13th
14	Dropping tools	9	11	26	25	7	78	244	3.128	14th
15	Construction sites with insufficient instruction and supervision	16	8	20	24	10	78	238	3.051	15th
16	Unfavorable condition of construction sites (including working area, groundwork conditions, weather, etc.)	13	14	22	17	12	78	235	3.012	16th
17	Insufficient experience and skills of a tower crane operator	17	12	18	19	12	78	231	2.961	17th
18	Tower crane's work region with difficulty, specially in urban areas such as building next to site, equipment, various temporary facilities at the construction site	19	16	14	10	19	78	228	2.923	18th
19	Constraint time by project-related people (including employer, main contractor, or investor)	15	11	26	18	8	78	227	2.910	19th
20	Workers try to accomplish the work early but not pay attention to the work safety	21	8	22	20	7	78	218	2.794	20th
21	Insufficient safety management at the construction site level	17	16	24	9	12	78	217	2.782	21st
22	Insufficient working platforms for erection and dismantling	19	18	15	14	12	78	216	2.769	22nd
23	Erection and dismantling cage with buckling	18	19	19	8	14	78	215	2.756	23rd
24	Unfavorable winds (including intensity, direction, etc.)	7	37	12	14	8	78	213	2.730	24th
25	The unfavourable height and distance of the tower crane cabin	24	12	19	8	15	78	212	2.717	25th
26	Erection and dismantling workers with unsuitable character (including careless, impulse, etc.)	16	21	17	18	6	78	211	2.705	26th

No	Factors	Frequency								
		1	2	3	4	5	Σf	Σβ	Mean	Rank
27	Signalperson and rigging worker with insufficient experience	13	20	31	8	6	78	208	2.666	27th
28	Insufficient safety management at the company level	15	18	32	5	8	78	207	2.653	28th
29	Multi tower cranes in a working region on construction site	18	24	15	10	11	78	206	2.641	29th
30	Tower crane-related workers with bad visibility	14	26	25	7	6	78	199	2.551	30th
31	Bad attitude of tower crane operator such as impulsive, defiant, sluggish, etc.	26	14	22	6	10	78	194	2.487	31st
32	Connection details of tower crane (including pins, bolts, and nuts, etc.) with attrition and break	27	14	22	7	8	78	189	2.423	32nd
33	Tower crane-related worker with excessive overtime, specially by night	28	18	17	2	13	78	188	2.410	33th
34	Inconvenience status of the tower crane cabin	33	13	15	3	14	78	186	2.384	34th
35	Erection and dismantling employees quit the work due to heavy work	29	14	21	9	5	78	181	2.320	35th
36	Bad weather (including hard temperatures, rain and other bad weather phenomena)	14	43	8	9	4	78	180	2.307	36th
37	Dangerous load (including weight, dimensions, packaging, configuration, etc.) and unsuitable rigging way	24	28	10	12	4	78	178	2.282	37th
38	Components of tower cranes with incompatibility	32	16	18	6	6	78	172	2.205	38th
39	Tower crane operator is not a staff of the construction company	26	26	15	7	4	78	171	2.192	39th
40	Bad attitude of manager such as insufficient accountability, alertness, and sensibility	31	23	16	5	3	78	160	2.051	40th
41	Tower crane-related workers use different languages on the construction site	34	22	14	4	4	78	156	2.000	41st
42	Retrofit auxiliary aids for operator to increase the safety	31	30	10	4	3	78	152	1.948	42nd

1 = Negligible; 2 = Minor Injury; 3 = Major Injury; 4 = Fatality; and 5 = Multiple Fatality.

3.4. Safety risk level of factors

Table 5 shows that there were 25/42 (59.52%) tower crane-related safety risk factors with RSIS value of > 8.0. This means that these factors have a moderate risk level and need a sufficient degree

of controls. There were 17/42 (40.48%) tower crane-related safety risk factors with RSIS values from 4.693 to 7.805. They are small safety risk factors without requiring any control actions. The factor of "Bad maintenance management of the tower crane and auxiliary aids" obtained the highest RSIS of 13.047 while "Components of tower cranes with incompatibility" had the lowest RSIS of 4.693. Table 5 represents that tower crane-related safety risk in Vietnam is a moderate level and need to pay attention to maintenance management of the tower crane and auxiliary aids and time for performing the project.

Table 5. Safety risk level of factors

No	Factors	$\Sigma\alpha$	$\Sigma\beta$	ΣRS	N	RSIS	Rank	Risk level
1	Bad maintenance management of the tower crane and auxiliary aids	245	324	79380	6084	13.047	1st	Moderate
2	Constraint time by project-related people (including employer, main contractor, or investor)	281	227	63787	6084	10.484	2nd	Moderate
3	Unfavorable winds (including intensity, direction, etc.)	284	213	60492	6084	9.943	3rd	Moderate
4	Wire rope is broken	185	326	60310	6084	9.913	4th	Moderate
5	The tower crane operator can not see the lifts	209	282	58938	6084	9.687	5th	Moderate
6	Dropping tools	239	244	58316	6084	9.585	6th	Moderate
7	Components of tower crane with reduced quality	232	248	57536	6084	9.457	7th	Moderate
8	Erection and dismantling workers are not followed process of erection and dismantling in manuals for the tower cranes	216	266	57456	6084	9.444	8th	Moderate
9	Workers do not usually follow necessary safety regulations and procedures	212	270	57240	6084	9.408	9th	Moderate
10	Insufficient experience and skills of a tower crane operator	246	231	56826	6084	9.340	10th	Moderate
11	Breakdown of a tower crane	222	251	55722	6084	9.159	11th	Moderate
12	Unfavorable condition of construction sites (including working area, groundwork conditions, weather, etc.)	237	235	55695	6084	9.154	12th	Moderate
13	The tower crane's work region with overhead power lines	191	291	55581	6084	9.135	13th	Moderate
14	Insufficient safety management at the construction site level	255	217	55335	6084	9.095	14th	Moderate
15	Objects exceed the lifting capacity of tower crane	192	280	53760	6084	8.836	15th	Moderate

No	Factors	$\Sigma\alpha$	$\Sigma\beta$	ΣRS	N	RSIS	Rank	Risk level
16	Tower crane's work region with difficulty, specially in urban areas such as building next to site, equipment, various temporary facilities at the construction site	235	228	53580	6084	8.807	16th	Moderate
17	Workers try to accomplish the work early but not pay attention to the work safety	245	218	53410	6084	8.778	17th	Moderate
18	Workers with insufficient competence	200	263	52600	6084	8.645	18th	Moderate
19	Contractors without sufficient perception for tower crane safety during erection and dismantling	198	262	51876	6084	8.526	19th	Moderate
20	Insufficient employees to ensure the work correctly and safely	206	248	51088	6084	8.397	20th	Moderate
21	Signalperson and rigging worker with insufficient experience	244	208	50752	6084	8.341	21st	Moderate
22	Insufficient safety management at the company level	242	207	50094	6084	8.233	22nd	Moderate
23	Tower crane-related workers with bad visibility	249	199	49551	6084	8.144	23rd	Moderate
24	Operators with insufficient experiences	188	261	49068	6084	8.065	24th	Moderate
25	Construction sites with insufficient instruction and supervision	205	238	48790	6084	8.019	25th	Moderate
26	The unfavourable height and distance of the tower crane cabin	224	212	47488	6084	7.805	26th	Low
27	Bad weather (including hard temperatures, rain and other bad weather phenomena)	262	180	47160	6084	7.751	27th	Low
28	Tower crane-related worker with excessive overtime, specially by night	248	188	46624	6084	7.663	28th	Low
29	Tower crane operator is not a staff of the construction company	271	171	46341	6084	7.616	29th	Low
30	Erection and dismantling workers with unsuitable character (including careless, impulse, etc.)	216	211	45576	6084	7.491	30th	Low
31	Bad attitude of tower crane operator such as impulsive, defiant, sluggish, etc.	230	194	44620	6084	7.333	31st	Low
32	Erection and dismantling cage with buckling	204	215	43860	6084	7.209	32nd	Low

No	Factors	$\Sigma\alpha$	$\Sigma\beta$	ΣRS	N	RSIS	Rank	Risk level
33	Connection details of tower crane (including pins, bolts, and nuts, etc.) with attrition and break	231	189	43659	6084	7.176	33rd	Low
34	Dangerous load (including weight, dimensions, packaging, configuration, etc.) and unsuitable rigging way	236	178	42008	6084	6.904	34th	Low
35	Multi tower cranes in a working region on construction site	199	206	40994	6084	6.738	35th	Low
36	Erection and dismantling employees quit the work due to heavy work	220	181	39820	6084	6.545	36th	Low
37	Insufficient working platforms for erection and dismantling	183	216	39528	6084	6.497	37th	Low
38	Inconvenience status of the tower crane cabin	212	186	39432	6084	6.481	38th	Low
39	Bad attitude of manager such as insufficient accountability, alertness, and sensibility	227	160	36320	6084	5.969	39th	Low
40	Retrofit auxiliary aids for operator to increase the safety	228	152	34656	6084	5.696	40th	Low
41	Tower crane-related workers use different languages on the construction site	218	156	34008	6084	5.589	41st	Low
42	Components of tower cranes with incompatibility	166	172	28552	6084	4.693	42nd	Low

4. Conclusions

The factors affecting tower crane safety in the Vietnamese construction industry were assessed. The results indicate that all 42 factors identified in previous studies have a potential to occur on construction sites in Vietnam. Among these, "Unfavorable winds (including intensity, direction, etc.)" emerged as the most probable factor, with a mean value of 3.641, while "Wire rope is broken" was identified as having the greatest degree of influence, with a mean value of 4.179. Of the 42 factors evaluated, 25 were categorized as having a moderate risk level. This suggests that these factors warrant a moderate level of attention and require adequate control measures. "Bad maintenance management of the tower crane and auxiliary aids" recorded the highest Relative Significant Index Score (RSIS) of 13.047, highlighting the need for improved maintenance management practices for tower cranes and their auxiliary aids. It is worth noting that this research primarily utilized investigative methods to evaluate tower crane safety in the Vietnamese construction industry. Exploring alternative research methods could be a valuable direction for future studies.

Acknowledgements

This research has been financially supported by Hanoi University of Civil Engineering, Vietnam (HUCE), through grant number 22-2023/KHXD.

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