Development of Risk-Based Work Breakdown Structure Standards for Design-Build Methods on High-Rise Building Structural Works to Improve Construction Safety Performance

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Development of Risk-Based Work Breakdown Structure (WBS) Standards for Design-Build Methods on High-Rise Building Structural Works to Improve Construction Safety Performance

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Abstract

The complex activities in the construction of high-rise buildings show many potential subjects of hazard which comprises a major safety concern for workers, equipment, material, the public, and the environment. In correspondence to that, determining a standardized Work Breakdown Structure (WBS) is required to manage the project construction. Previously, a standardized WBS has been performed without the identification and analysis of a risk factor at a design stage. The integrative approach to determine standardized WBS which involves the risk factors plays a primary role to prevent accidents because the risk is assessed early in the design stage and can be elaborate in the implementation steps. Based on that, this study is purposed to improve the construction safety performance by defining the risk factors in the standardized WBS on the design-build of the high-rise building. In this study, a descriptive qualitative methodology is carried out by giving questionnaires form to respondents and interviewing experts for validation. As many as 6 levels of WBS are generated and 419 risks are found to have an impact on the safety performance. Approximately 6% of the risk is categorized as high-level risk and the response has been determined. Thus, the development of risk factors in the standardized WBS for design and construction work with additional activities will minimize accidents and improve construction safety performance. Indeed, the risk of work accidents can be eliminated (zero accidents) in the project implementation.

Keywords

Work Breakdown Structure (WBS), Construction safety performance, Structural works, and Project risks.

1. Introduction

High-rise buildings' residential investment is growing rapidly due to the increasing need for housing and the limited availability of land (Adriansyah *et al.*, 2019). The construction of high-rise buildings is the right solution to solve the problem of increasingly limited land availability, especially in big cities (Rahmawati, 2018). A high-rise building's foundation related to a height must be able to support a heavy load. Furthermore, the structure is expected to withstand a wind force and possible earthquake. Hence, the complexity of the construction of high-rise buildings has many potential subjects of hazard which comprises a major safety concern for workers. According to a study, most elevation-related works also have the biggest risks which result in serious accidents leaving the victims permanently disabled or dead (King and Hudson,1985).

In Indonesia, work accidents in the sector industry increase significantly over years. The number of accidents reached 221,740 cases in 2020, then rose to 234,370 and 265,334 cases in 2021 and 2022 respectively (BPJS Ketenagakerjaan, 2022). Meanwhile, construction in industrial sectors gives the largest contribution of 32% of the total cases in which the 92% occurs from high-rise building projects.

Work Breakdown Structure (WBS) is a visual project tool for managing construction projects (Putro, 2022). Previously, research on WBS development is focused on conventional construction methods (design-bid-build), and there has been no research on WBS development for design-build methods of high-rise buildings. The development of risk-based WBS for design-bid-build methods of high-rise building structural work can reduce and mitigate project risks (Elsye and Latief, 2017). WBS development is the first step in planning after defining project requirements, and there is a breakdown of activities that are the most important thing in project planning (Rianty & Latief, 2018).

Although the use of WBS is very important in construction projects, there are still some problems related to WBS implementation, where all implementing parties involved have not accurately understood the scope and objectives of the project (Putro, 2020). The difference in perspectives on the WBS is due to the absence of standardization, guidelines, and calculation methods, which provide quick and easy guidance in project planning (Peli, 2017). Furthermore, a comprehensive WBS is determined without risk factors at the design stage. Moreover, the structural work in WBS and the construction stage are not standardized systematically on the design-build of a high-rise building. Therefore, this research was conducted to provide solutions and fill the gaps that exist in the development of WBS for design-build methods in high-rise building projects. To date, design-build methods are now applied to the construction of high-rise buildings. For an instant, this method will be utilized to build the government office in the new capital of Indonesia in 2022-2027.

Errors implementations of the design are the primary cause of the accident. All things that exist in the design phase are very influential on the occurrence of construction accidents during implementation (Suraji, 2003). Therefore, it is essential to create an integrative risk-based WBS starting from design and construction work. Preliminary identification and analysis of the potential risk in the WBS can reduce the probability of accidents (Elsye and Latief, 2017). If project activities are well planned and work packages are organized at the appropriate levels and tiers of risk-based standardized WBS, construction accidents may potentially be decreased. Thus, the potential risk in the WBS is essential to be projected early at the design stage, then the construction is carried out in an integrated manner and elaborated according to the design. As a consequence, accidents can be minimalized. This is because the potential risks of each step have been identified in the WBS standards, then the risk mitigation can be mapped from the existing risk sources for the project implementation (Nugroho and Latief, 2020).

In correspondence to that, developing the risk factors in WBS standards starting from design work and construction work on high-rise building structure work is performed in this study. This study aims to formulate the WBS standards including the identification of the risk factors that affect construction safety performance. Moreover, the development of the risk-based WBS standard is also formulated with the additional activities of risk response actions. Then, this research is expected to improve the construction safety performance of a design-build method of high-rise building projects. In addition, this research will have advantages as recommendations and references in making comprehensive standardized WBS on high-rise building construction for consultants, executing contractors, and practitioner users.

2. Literature Review

2.1 Standardized WBS

In Project Management Body of Knowledge (PMBOK) Sixth Edition (Project Management Institute, 2017), it is stated that the Work Breakdown Structure (WBS) is a deliverable-oriented hierarchical decomposition of work to be carried out by the project team to achieve project goals and produce the required deliverables. Deliverables are unique products, results, or capabilities for performing services that must be produced to complete a process, phase, or project. The WBS standard-making approach methods that will be studied include:

1. Guidelines approach, using a guideline from an organization or institution in WBS preparation.
2. The analogy approach is to review the WBS on ~~a~~ similar project as a reference for the next project (*Department of Defense Handbook Work Breakdown Structure*, 1998).
3. A top-down method is an approach that assumes the project structure which begins by identifying the project's major deliverables, requirements, and objectives.
4. The bottom-up method starts with detailing the lowest level of work elements.

5. The mind-mapping approach is to write down each output on a separate note with the project team to find all the tasks that will be required to be completed.

2.2. Design-Build Methods

Design-build methods are procurement method that assigns a single point of responsibility to the supplier. In this case, the contractor is required to be responsible for meeting all the needs of the owner in terms of design, material requirements, and methods of carrying out the work. In designing and building contracts, the owner can contract directly with the contractor without going through an intermediary (Putro and Latief, 2020).

According to a study, design-and-build projects have better performance than design-bid-build projects in terms of time, cost, and quality (Konchar and Sanvindo, 1998). Then, the advantages of design contracts in this method will offer a single point of responsibility, inherent building ability, and clear allocation of risk to providers (Gambo and Gomez, 2016).

2.3. Risk Management

The definition of risk management is an effort to implement regulatory policies and practical efforts of management systematically in analyzing the use and control of risks to protect workers, the community, and the environment (Hermawan, 2010). Based on OHSAS 18001:2015, organizations must implement project management by establishing procedures on hazard identification, risk assessment, and risk control named HIRARC. Based on the Project Management Institute (2017), the stages of risk management consist of planning the risk management, identifying risks, controlling risk, then conducting qualitative and quantitative risk analyses. In addition to that, responses to those analyses must be planned and implemented.

The implementation of risk identification, risk assessment, and risk control activities are carried out based on aspects that influenced safety, including several risks that afflict workers, equipment, materials, communities, and the environment. In determining the risk score in qualitative risk analysis, the value of the risk frequency level is multiplied by the value of the risk impact level according to Project Management Institute (2017). The values of the risk frequency level and the risk impact level are set using a Likert scale of 1 to 5 which is described as very low, low, medium, high, and very high. Based on the probability and impact matrix from the Project Management Institute (2017), the risk rating is grouped into three ranges of values, namely low risk with a value of 0.01-0.05 then medium risk with a value of 0.06-0.17. High-risk values are set in the range of 0.18-0.72.

2.4 Construction Safety Performance

Suraji and Bambang Endoyo (2009) describe that safety in construction covers people safety (people working on construction projects), public safety, property safety, and safety of the environment as the result of the construction projects carried out. Safety performance is the result or success rate of safety achievements produced by a job function over a certain period. For this reason, periodic monitoring is needed so that it can be seen to what extent these safety regulations have been complied with and carried out following the real conditions in the field (Dorji *et al.*, 2006). There are two types of safety performance indicators, namely "leading" and "lagging" (output measurement safety indicators and post-accident measurement indicators). Leading indicators are preferred in both industry and academia (Jazayeri and Dadi, 2017).

After obtaining information from the literature review above, and also based on the research objectives, the hypothesis in this study can be conveyed as "with the development of risk-based WBS standards on high-rise building structural work at the design and construction stage for design-build methods, it will be able to improve construction safety performance".

3. Methodology

In this study, a qualitative descriptive approach was carried out into 3 main stages compiling the WBS of the structural work in the design and construction stage, identifying the risk factors for design-build methods on the structural work, and developing risk factors on standardized WBS of a high-rise building that affects construction safety performance. As an illustration, the research flowchart is presented in Figure 1.

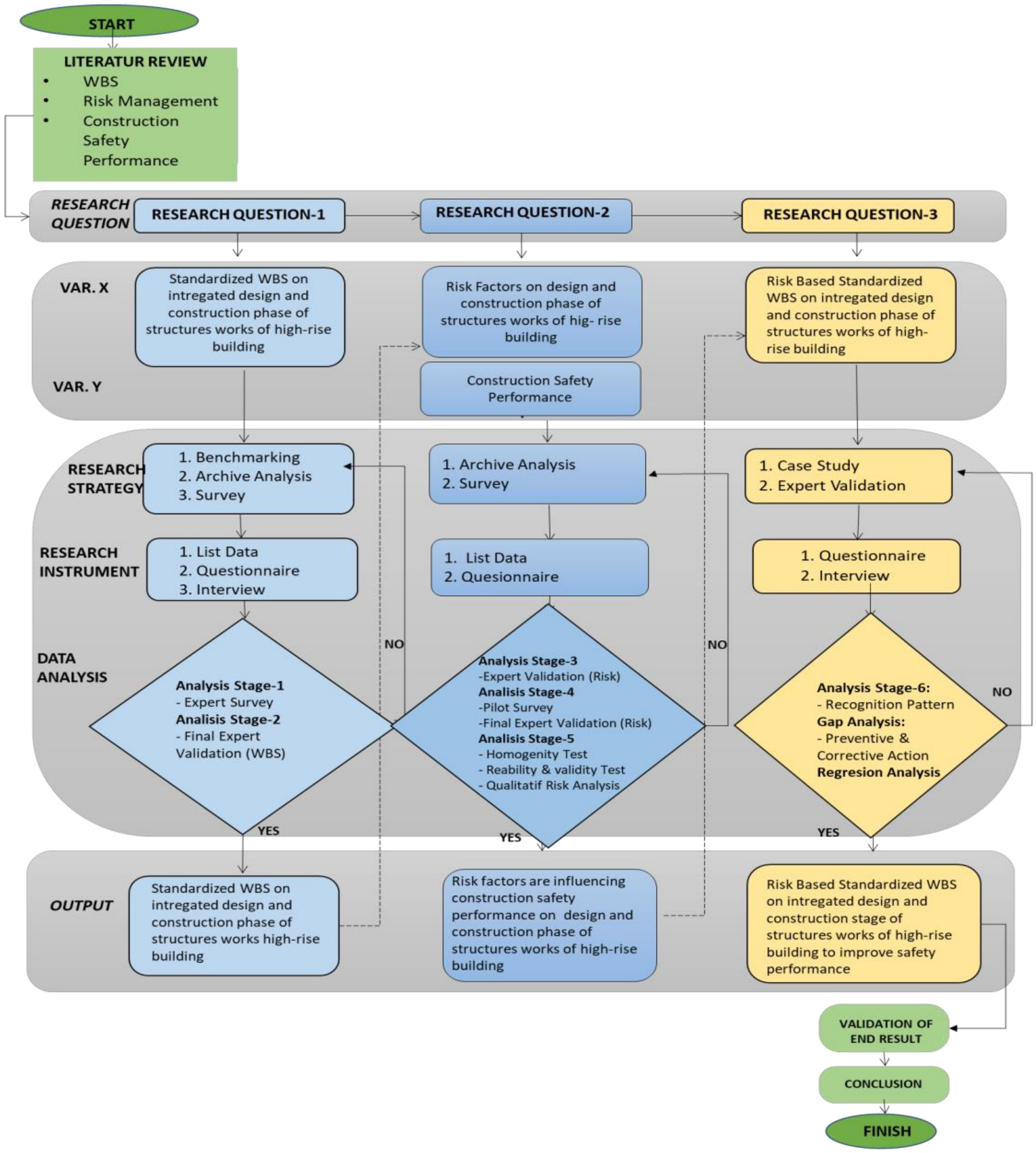

Figure 1. Research Flowchart Diagram

Research Question 1 (RQ-1) is defined to create WBS standards for the work design and construction phases on structural works of high-rise buildings by implementing the question of "how" the archival and survey analytic methodologies are applied. According to Hadi (2015), the survey is carried out to obtain data from speakers, experts, and other competent persons by using questionnaires form, interviews, and tests that have the aim of systematically observing and recording the phenomenon under investigation. From the literature, the RQ-1 will be determined to obtain information from the experts by giving questionnaires form and interviews for validation. Preliminary data collection was conducted to compile a questionnaire in the form of the project's Bill of Quantity data. The experts have criteria of at least 10 years of experience in high-rise building projects to compile WBS starting from levels 1 to 4 and then continuing for WBS levels 5 and 6.

Meanwhile, Research Question 2 (RQ-2) is purposed to determine the risk factors that affect safety performance. The question of "what" will be used as a questionnaire instrument. The questionnaires of risk identification are taken from the study based on the literature. After that, the question points are confirmed by the five experts who are experienced in risk management of high-rise building projects. A pilot survey was conducted on ten respondents to determine the level of understanding of the respondents about the contents of the questionnaire, then followed by a risk value survey of thirty contractor respondents. Furthermore, a qualitative risk analysis is conducted to determine the dominant level of risk that affects construction safety performance.

In the 3rd Research Question (RQ-3), after obtaining a high score for a risk, a validation survey was conducted among experts about the description of the impact, causes, and risk response actions, both preventive and corrective, with questionnaires and interviews. After the expert validation data was collected, a recognition pattern analysis was conducted to determine the risk response with a high-risk value in WBS activities. The development of a risk-based, standardized WBS with additional activities based on predetermined risk response actions will be obtained.

4. Data Collection

Data collection was conducted for pilot surveys and risk-level surveys, with a recapitulation of respondent profiles, which is presented in Figure 2.

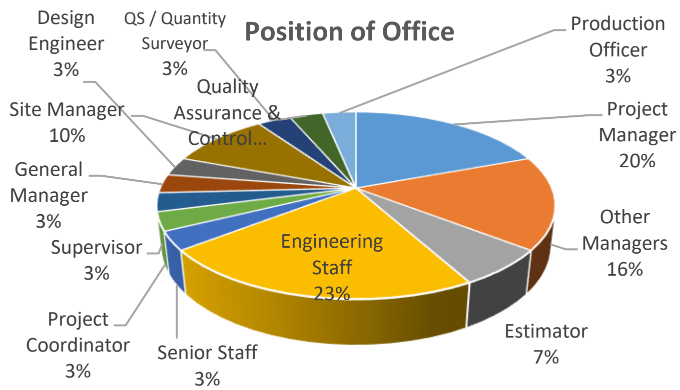

Figure 2. Respondent Profile Based on Position in The Company

The number of respondents which is classified based on their position is shown in Figure 2. As can be seen, most respondents are the engineering staff in the company (23%), then the respondents from the project manager are 20%. The project coordinator, supervisor, senior staff, design engineer, and general manager have the same percentage number of 3%. Meanwhile, the percentage of respondents at other managers' level are 16%. This condition shows that all levels of positions in construction companies have taken part in the survey.

5. Results and Discussion

5.1 Result of Research Question-1: WBS standards

From the archive analysis process for compiling the WBS questionnaire, expert validation, and improving construct content, the following results were obtained:

1. The work structure for designing and building high-rise buildings consists of nine (9) clusters of work, which include design and development work, preparatory work and site work, Construction Safety Management System (CSMS) application work, architectural, mechanical, electrical, structural work, outside and regional work, and other miscellaneous work.

2. WBS Level 1: Project Name
The entire project is described on the first or highest level WBS (Ibrahim Y.M., Kaka, Aouad, and Kagioglu, 2009). Therefore, in the implementation of this project, the name of the high-rise building design project is depicted in WBS level 1.
3. WBS Level 2: Job Clusters
The cluster of work is a smaller element of the project, the combination will form the construction of a building the project (Rianty *et al.*, 2018; Mintoharjo, 2022). For this study, the preparation of WBS standards for design-build methods of high-rise building structural work resulted in 9 (nine) clusters of work.
4. WBS Level 3: Type of Work
A smaller family of jobs is split into job types (Anggraini and Latief, 2021). The four work clusters in the scope of this study have produced 24 (twenty-four) types of work that are WBS level 3.
5. WBS Level 4: Work Package
The work package is the most basic variation of the type of work. Work packages can be given to individuals or work teams as their job desks in the construction of a construction project (Ibrahim *et al.*, 2009).
6. WBS Level 5: Activities
As the packages of work at the previous level have been classified, it can be transformed into project activities, The activities in this study aim to assist project managers in supervising work packages. At this level, the steps in completing a work package are detailed (Nugroho and Latief, 2021).
7. WBS Level 6: Resources
The lowest or last level on a WBS is the resource (Rianty et al., 2018). This level of resources will be divided into three categories: material resources, equipment resources, and labor resources. The following Figure 5 is a tree diagram of the WBS of high-rise buildings for the cluster of design and development work as illustrated in Figure 3.

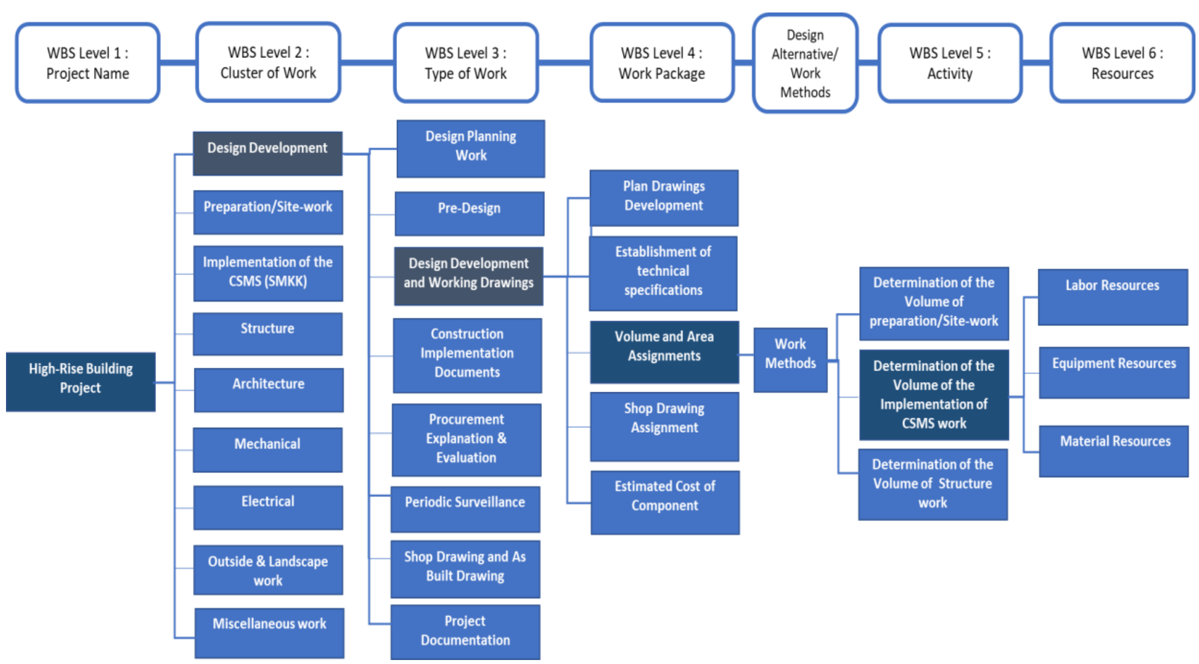

Figure 3. Tree Diagram of The WBS Standard of Design Development Work of High-Rise Building

From Figure 3, it is shown that there are eight types of work in the WBS Level 3. Furthermore, each type of work is decomposed, so a total of 34 (thirty-four) work packages are obtained in the WBS level 4. In the WBS 5, the decomposition of each work package is based on alternative designs and methods of work implementation to produce work activities. After that, each activity is conducted to determine the necessary resources. On the cluster of structural work, a tree diagram of the WBS standard is displayed in Figure 4.

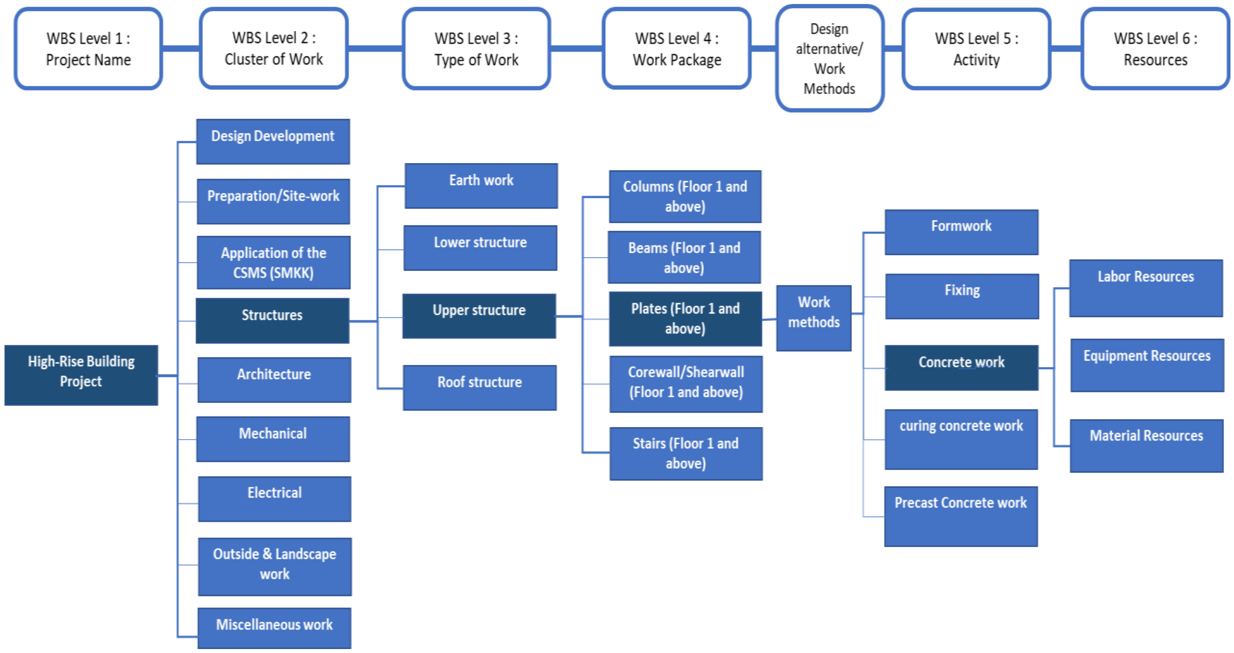

Figure 4. Tree Diagram of Standardized WBS of Structure Work High-Rise Building

Based on the diagram of Figure 4, the WBS Level 3 comprises four different types of work, then each type of work is decomposed, which results in 38 (thirty-eight) work packages in the WBS level 4. Based on the identification of alternative designs or work methods, each work package in this cluster of structures is split into activities as a level 5 WBS and contains as many as 237 activities. The results of the division of the activity determined the number of resources needed, with a total of 2,374 resources.

5.2 Result of Research Question-2: A risk factor

From the determination of risk variables data, there are 419 risk variables approved by experts that will affect construction safety performance. The following list of risk variables is shown in Table 1.

Table 1. List of Risk Variables for Design and Construction Work of High-Rise Building

Num.	**Risks Description**				
	Description of work		**Identification of Hazard and the risk**		
	Activity (WBS Level 5)		**Type of Hazard**	**Description of the Hazard**	**Description of the risk**
	Design Development Work				
1	Administrative and technical preparation Work	X'1	Workers	Workers are exhausted from too much overtime	Workers become ill
		X'2	Engineering Assets/material	Deficiencies in determining the scope of work when designing	Design defects, errors in the planning results document

		X'3	Equipment	The designer team's computer/laptop is not working	Equipment malfunctions
		X'4	Environment	The occurrence of natural disasters	There was an accident, the designer's office building and surrounding environmental facilities collapsed
	Preparation of a preliminary report	X'6	Workers	Employees are exhausted from overtime work	Employees become ill
		X'7	Equipment	Faulty work tools cannot function normally	Equipment malfunctions interfere with planning
		X'8	Engineering Assets/material	Report document damaged due to wet exposure to water	Damage to reports, loss of assets of planning documents resulting in difficulties in the implementation of work
		X'9	Environment	Piling up of unused and uncleaned paper waste and ink waste	Environmental pollution, waste pollution
		X'10	….		
Structure Work					
2	Roof Covering Installation	X'411	Worker	Workers falling from a height	Muscle injuries, bone injuries, and brain injuries may cause death
		X'412	Worker	Workers exposed to dust / exposed to smoke	Workers infected with ARI disease, and skin dermatitis
		X'413	Worker	Workers Struck by lightning	Burns may cause death
		X'414	Material	Materials that fall from a height	Material loss, material damage
		X'415	Environment	Residual materials that adversely affect the environment	Environmental pollution
		X'416	Public	The surrounding community was hit by falling material	Muscle injuries, bone injuries, and brain injuries may cause death
3	Helipad casting work	X'417	Worker	Workers falling from a height	Muscle injuries, bone injuries, and brain injuries may cause death
		X'418	Worker	Workers Struck by lightning	Burns may cause death
		X'419	Public	The surrounding community was hit by falling material	Muscle injuries, bone injuries, and brain injuries may cause death

The table of risk variables shows a list of hazard identifications and risk descriptions that have been validated by risk analyst experts, and then a survey is conducted on the respondents to find out the value of the level of each risk variable. After surveying 31 respondents related to the value of the risk level, data on the frequency of occurrence and impact values for each risk variable were obtained. Furthermore, a qualitative analysis of risks is conducted to generate a level of risk. The outcomes of the qualitative risk analysis are displayed in Table 2.

Table 2. Results of Qualitative Risk Analysis

Risk Variables	Description of the Hazards	Average Frequency Value	Average Impact Value	Risk Value	Risk Level
X'1	Workers are exhausted from too much overtime	0,675	0,169	0,114	Medium
X'2	Deficiencies in determining the scope of work when designing	0,65	0,413	0,268	High
X'3	The designer team's computer/laptop is not working	0,325	0,175	0,057	Low
X'4	The occurrence of natural disasters	0,275	0,450	0,124	Medium
X'5	Employees exposed to sharp equipment	0,425	0,100	0,043	Low
X'6	Employees are exhausted from overtime work	0,6	0,169	0,101	Medium
X'7	Faulty work tools cannot function normally	0,475	0,231	0,110	Medium
X'8	Report document damaged due to wet exposure to water	0,25	0,263	0,066	Medium
X'9	Piling up of unused and uncleaned paper waste and ink waste	0,425	0,125	0,053	Low
X'10	Expert planners have an accident during the survey	0,175	0,406	0,071	Medium
X'11	…	…	…	…	…
X'411	Workers falling from a height	0,411	0,567	0,233	High
X'412	Workers exposed to dust / exposed to smoke	0,356	0,128	0,045	Low
X'413	Workers Struck by lightning	0,200	0,467	0,093	Medium
X'414	Materials that fall from a height	0,356	0,333	0,119	Medium
X'415	Residual materials that adversely affect the environment	0,267	0,244	0,065	Medium
X'416	The surrounding community was hit by falling material	0,322	0,567	0,182	High
X'417	Workers falling from a height	0,311	0,589	0,183	High
X'418	Workers Struck by lightning	0,200	0,467	0,093	Medium
X'419	The surrounding community was hit by falling material	0,222	0,489	0,109	Medium

According to Table 2, the results of qualitative risk analysis give the percentage of high-risk value is 6%, medium-risk value is 81%, and low-risk value is 13%. High-level risks exist in the cluster of design development work, Construction Safety Management System (CSMS) implementation work, and structural work. Twenty-eight risk variables have a high-risk value, such as the risk of design errors that result in design defects, workers falling from a height, formwork collapse during concrete casting, tower crane overload, and falling material on residents. After knowing the value and level of risk on all risk variables, a response risk is developed to control the risk for a high-risk level. The determination of actions on how to respond to the risks both preventive and corrective action was determined initially from a literature study and then validated by experts who produced a list of causes and impacts of risks and risk response actions specific to risks with high-risk levels. The following tabulations of causes, impacts, and risk response actions are shown in Table 3.

Table 3. Tabulation of causes, impacts, and risk response actions

Variable	Aspect	Potential Risks	Cause (P)	Action Type	Preventive Action (TP)	Impact (D)	Corrective Action (TK)
X'1	Worker	Workers are exhausted from too much overtime	Workers are not in good health or stamina	Elimination	Workers are not allowed to work overtime	Workers become ill	Rescuing and dealing with victims, as well as recovery activities
				Substitution	Workers must be in good health when working overtime (conducting physical checks on the health of workers)		
				Administration	Develop Standard Operating Procedure (SOP) for overtime work for employees		Changing operators/manpower
X'29	Material /Engineering assets	Workers are incorrect in carrying out the calculation of the analysis of the structure	Errors in planning design methods of structure analysis	Administration	Evaluate/review the calculation method of structural analysis and recheck the results of structural calculations before finalization	Design defects, and technical specification errors, thus the building becomes unsafe	Conducting a safety plan/safety procedure for the working method of structural calculation design to be carried out
							Revise the structural calculation analysis by determining the structure calculation method according to the applicable code/ rules standards

5.3 Result of Research Question-3: Risk-Based Standardized WBS

Conforming to the experts, all risk response recommendations can be incorporated into several alternative actions for the development of WBS standards, which are expanded to include management items, other WBS, relevant WBS, job requirements, and modifications to the WBS coefficient. It creates risk-based WBS standards by adding these alternate actions as new activities to the WBS high-rise building designing and construction work standard. The analysis develops risk responses that can be distinguished into five dissimilar categories:

1. Items needed to complete a project or a risk response connected to project management from the beginning to the end should be included in the managerial item.
2. Inclusion to another WBS: Items added to a different Level 3 sub-work package from the associated WBS that is at risk, or to the WBS for preliminary, structural, or earthwork work (Level 2).

3. Adding items to relevant WBS elements that are at risk. This is connected to organizational policy regarding how much they choose to control the items.
4. Adding items to the activity requirement: These might be included in the work instructions, the specifications, or the contracts.
5. Influencing the WBS coefficient: Risk response can also affect the resource structure-related coefficients.

6. Conclusion

Based on the results, it can be concluded that WBS standards on design-build methods of the structural work in high-rise buildings consist of six levels (Level 1: The name of the project. Level 2: Occupational Clusters. Level 3: Type of Work. Level 4: Work Package. Level 5: Activity. Level 6: Resources). There are 419 risks are found to have an impact on the construction safety performance of which 28 risk (6%) is categorized as high-level risk. The response actions to prevent an accident from these risks have been determined. The dominant risk at the design stage is errors that cause design defects. Whilst the dominant risk at the construction stage is workers falling from a height. The development of risk-based WBS standards has been performed by adding the risk response activities into five categories of development that can be resolved. The results of these risk-based WBS standards can be a guideline and input in preparing construction safety plan documents. Indeed, this study shows that establishing risk-based WBS standards for high-rise buildings during the design and construction phases leads to an improvement in construction safety performance. The hazards and risks to people, equipment, materials, the public, and the environment can be minimalized and mitigated.

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