



OHS Risk Analysis of Steel Facade Work on The Building X Construction Project using JSA and HIRARC

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Abstract

The high risk of accidents in construction projects highlights the importance of hazard identification and risk control, particularly in steel facade works involving work at height and heavy equipment. This study aims to identify potential hazards, assess risk levels, and formulate risk control recommendations for steel facade works at the Building X Construction Project. The Job Safety Analysis (JSA) and Hazard Identification, Risk Assessment, and Risk Control (HIRARC) methods were used as analytical approaches to evaluate risks based on actual site conditions. Data were collected through field observations, interviews, and questionnaires involving 10 respondents familiar with the project activities. The analysis identified six work stages with 32 potential hazards. Extreme risks were mainly associated with work at height and heavy equipment operations, including falls from structures, contact with steel materials, and electric shock. Recommended controls include engineering and administrative measures, supported by the use of appropriate personal protective equipment (PPE). The findings indicate that JSA and HIRARC can provide a systematic assessment of work-related risks and serve as a basis for developing OSH control recommendations for steel facade works.

Keywords: OSH, JSA, HIRARC, Steel Facade, Building Construction

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INTRODUCTION

In Indonesia, the construction sector continues to face significant challenges in implementing Occupational Safety and Health (OSH) practices. The high incidence of occupational accidents indicates that risk management in construction environments still needs to be strengthened [1]. In 2018, the construction sector was reported as one of the sectors with a high incidence of occupational accidents [2]. These accidents may be associated with unsafe acts and unsafe conditions in the workplace [3]. This situation highlights the importance of systematic hazard identification and risk assessment so that potential accidents can be

recognized and controlled before work activities are carried out.

One approach that can be used to analyze occupational risks is Job Safety Analysis (JSA). This method breaks down a job into several work steps to identify potential hazards associated with each activity and determine appropriate control measures [4]. Meanwhile, Hazard Identification, Risk Assessment, and Risk Control (HIRARC) provides a broader framework involving hazard identification, risk assessment based on likelihood and consequences, and the determination of appropriate risk control measures [5]. The use of these two approaches can provide a more

structured understanding of the characteristics of occupational risks, particularly in construction activities involving various types and levels of hazards.

The application of JSA and HIRARC in previous studies has covered various work environments and types of activities,

particularly those involving occupational hazards in manufacturing and construction. A summary of relevant previous studies, including their research objects, methods, identified hazards, and main findings, is presented in Table 1. The comparison also highlights the research gaps that provide the basis for the present study.

Table 1. Previous studies on JSA and HIRARC

Author	Research Object	Method	Number of Hazard	Main Finding	Research Gap
[5]	Manufacturing industry	JSA and HIRARC	56	Identified potential hazards with moderate to high risk levels and proposed appropriate risk control measures	Conducted in a manufacturing environment rather than a construction project and did not focus on steel façade work.
[6]	Hospital construction project	JSA and HIRARC	93	Various potential hazards were identified, with control measures including PPE and worker training	Focused on general hospital construction activities and did not specifically examine steel facade work.
[7]	Phase II Christian Center Construction Project, Manado	JSA and HIRARC	Risk levels: 12% high, 50% moderate, and 38% low	Various physical, mechanical, electrical, and chemical hazards were identified in fabrication, ring beam, roof frame, and roof covering works. The curved roof-frame work had the highest risk level, with 12% high risk	Although JSA and HIRARC were combined, the study focused mainly on fabrication and structural/roof activities rather than steel facade installation.
[8]	Padang Pariaman Hajj Dormitory Building Construction Project	HIRARC	17 risks: 7 extreme and 10 high	Extreme risks included falling materials, struck-by hazards, injuries, and fires; high risks involved excavation falls, equipment collisions, and respiratory hazards. Controls followed the hierarchy of controls and PPE.	Used HIRARC without a detailed JSA-based analysis of individual work steps; covered general construction activities and did not specifically address steel facade work.
[9]	Construction project of PT Brantas	HIRARC	26	Risks included 6 high, 6 medium, and 14 low, with high risks involving falls, slipping, fire, and scaffolding.	Used HIRARC without detailed JSA-based job-step analysis and did not focus on steel facade work.

As summarized in Table 1, previous studies have applied JSA, HIRARC, or a combination of both methods to assess occupational risks in construction and industrial environments [5], [6], [7], [8], [9]. However, most studies have focused on general building construction, structural work, fabrication, and roofing activities, while specific risk assessments of steel facade work remain limited. In addition, some studies have applied HIRARC without detailed analysis of individual work steps [8], [9]. Although JSA and HIRARC have been combined in previous research [7], the focus was on fabrication and structural/roof activities rather than steel facade installation. Therefore, this study aims to identify potential hazards, assess associated risk levels, and formulate appropriate control recommendations for steel facade work using JSA and HIRARC based on actual site conditions.

METHOD

This study employed a quantitative descriptive design with a case study approach to analyze occupational safety risks associated with steel facade work in the construction of Building X in Bandung City. The project characteristics and technical specifications of the steel facade work are presented in Table 2.

Table 2. Characteristics of the case study project

Project Characteristics	Description
Project type	Building construction project
Location	Bandung City, West Java
Work duration	300 working days
Steel type	Wide Flange (WF)
Steel Profile	WF 250 and WF 200
Connections	Bolted and welded connections Aluminium
Facade type	Composite Panel (ACP)

The study focused on steel facade activities involving WF 250 and WF 200 steel profiles with bolted and welded connections supporting an Aluminium Composite Panel (ACP) facade.

These activities were considered due to their potential exposure to work-at-height, equipment, mechanical, and ergonomic hazards.

JSA and HIRARC were used as analytical approaches for hazard identification and risk assessment. Data were collected through field observations, interviews, and questionnaires. Observations identified work stages and potential hazards, while interviews with site personnel, project supervisors, and workers provided information on safety procedures and experiences with potential hazards. Questionnaires were used to assess the level of occupational accident risk associated with the project activities.

Job Safety Analysis (JSA)

JSA was used to identify potential hazards based on the sequence of activities involved in steel facade work. Each work step was systematically analyzed to identify potential hazards and determine initial control measures [10]. The JSA process consisted of four main steps: (1) selecting the work activity to be analyzed, (2) breaking the activity into sequential work steps, (3) identifying potential hazards or accident risks at each step, and (4) determining appropriate control measures to prevent occupational accidents [11].

Hazard Identification, Risk Assessment, and Risk Control (HIRARC)

HIRARC is a systematic approach for identifying and evaluating potential workplace hazards and determining appropriate control measures to reduce or eliminate identified risks [12]. The HIRARC process consists of three main stages: hazard identification, risk assessment, and risk control.

Hazard Identification

Hazard identification is the initial stage of risk management and involves systematically identifying potential hazards associated with each work activity [13]. For high-risk activities, a more detailed identification process is required to ensure that potential hazards are comprehensively recognized. In this study, JSA was used to break down high-risk activities into specific work steps, allowing potential hazards to be identified and

appropriate control measures to be considered [5], [14].

Risk Assessment

Risk assessment is the process of evaluating identified hazards to determine their associated risk levels and acceptability. It considers two main factors: the likelihood of an accident occurring and the severity of its consequences. Table 3 and Table 4 present the Likelihood and Severity scales based on the Australian

Standard/New Zealand Standard of Risk Management AS/NZS 4360:2004. The Likelihood Index (LI) and Severity Index (SI) are calculated using Equation (1) [5].

$$SI/LI = \frac{\sum(a \cdot x_i)}{5 \sum x_i} \times 100\% \quad (1)$$

where:

a : rating constant (1–5),

x_i : number of respondents in each rating category.

Table 3. Likelihood scale based on AS/NZS 4360:2004

Level	Description	Explanation	LI (%)
1	Rare	May occur under certain circumstances	0 – 20
2	Unlikely	May occur, but is unlikely	21 – 40
3	Possible	May occur, but not frequently	41 – 60
4	Likely	Occurs several times within a certain period	61 – 80
5	Almost Certain	May occur at any time under normal conditions	81 – 100

Table 4. Severity scale based on AS/NZS 4360:2004

Level	Description	Explanation	LI (%)
1	Insignificant	No injury and minor financial loss	0 – 20
2	Minor	Minor injury and minor financial loss	21 – 40
3	Moderate	Moderate injury requiring medical treatment and considerable financial loss	41 – 60
4	Major	Severe injuries affecting more than one person, major financial loss, and production disruption	61 – 80
5	Catastrophic	More than one fatality, very large financial loss, major disruption to company operations, and widespread impacts	81 – 100

After determining the Likelihood and Severity scores for each risk, the overall risk level was classified as low, medium, high, or extreme using a Risk Assessment Matrix. The matrix combines the likelihood of occurrence and severity of consequences to determine risk levels and prioritize risks requiring attention. The Risk Assessment Matrix is presented in Table 5.

Table 5. Risk assessment matrix

Risk Frequency	Risk Impact				
	1	2	3	4	5
5	H	H	E	E	E
4	M	H	E	E	E
3	L	M	H	E	E
2	L	L	M	H	E
1	L	L	M	H	H

Risk levels in the matrix are classified by color to facilitate interpretation and decision making. Red (E) indicates extreme risk requiring immediate action. Orange (H) represents high risk requiring prompt attention from senior management. Yellow (M) indicates medium risk, for which management responsibilities should be clearly defined. Green (L) represents low risk that can be managed through routine work procedures in accordance with existing operating standards.

Risk Control

Risk control is an essential stage of occupational safety management aimed at reducing or eliminating identified hazards. Control measures are selected based on the hierarchy of controls, which ranks interventions from the most to the least effective [8]. As shown in Figure 1, the hierarchy consists of five levels: elimination,

substitution, engineering controls, administrative controls, and personal protective equipment (PPE).



Figure 1. Hierarchy of control

Elimination involves removing the hazard entirely, while substitution replaces a hazardous material, process, equipment, or activity with a safer alternative. Engineering controls reduce exposure by modifying the workplace, equipment, or work process, such as installing guards or physical barriers. Administrative controls involve safe work procedures, training, supervision, work rotation, and housekeeping. PPE provides the

final layer of protection when higher-level controls are insufficient or cannot be fully implemented [8], [14]. The selection of control measures should consider site conditions, organizational factors, available resources, operational requirements, and human factors [14]. In this study, the hierarchy of controls was used as a basis for formulating risk control recommendations according to the risk levels and hazards identified in steel facade work.

RESULTS AND DISCUSSION

Hazard Identification

Based on direct field observations, six work stages were identified in the steel facade work at the Building X construction project: site measurement, steel cutting, steel welding, steel lifting, installation of steel facade elements onto the structure, and finishing. Each stage involved different technical characteristics and potential hazards, requiring hazard identification and control measures tailored to the actual site conditions. The JSA-based hazard identification results are presented in Table 6.

Table 6. Hazard identification for steel facade work

Work Stage	Hazard Identification	Potential Risk
Site measurement	Contact with temporary structural elements, tools, uninstalled steel materials, or scaffolding	Physical injuries (bruises or open wounds), head injuries, and loss of balance
	Fall from height	Serious injuries, fractures, head trauma, or fatality
	Slipping on wet or slippery surfaces	Sprains, strains, and minor to moderate injuries
	Measuring equipment becoming entangled with improperly arranged steel frame components	Loss of balance, minor injuries, and/or damage to measuring equipment
	Measuring equipment breaking or malfunctioning	Sudden injury, work disruption, and operational delays
Steel cutting	Hands or body parts trapped between the steel being cut and the cutting equipment or workbench	Hand/finger injuries, bruises, minor fractures, and soft-tissue injuries
	Contact with cutting tools such as grinders, machine saws, or chisels	Open wounds, bleeding, infection, or severe injury involving body parts
	Electric shock due to current leakage, damaged cables, or inadequate grounding	Burns, cardiac disturbances, nerve injuries, or fatality
	Dehydration or <i>heat stroke</i> during steel cutting in high-temperature outdoor conditions	Dizziness, extreme fatigue, loss of consciousness, and serious heat-related illness

Work Stage	Hazard Identification	Potential Risk
Steel welding	Short circuit in the electrical connection of cutting equipment	Fire, equipment damage, and injuries caused by sparks or minor explosions
	Electric shock due to current leakage from the welding machine, damaged cables, or inadequate grounding	Burns, cardiac disturbances, nerve injuries, or fatality
	Exposure to welding sparks	Minor to severe burns, eye irritation, and injuries to the face or hands
	Dehydration or heat stroke caused by high heat generated during welding	Dizziness, extreme fatigue, loss of consciousness, and serious heat-related illness
	Exposure to welding fumes	Respiratory irritation, coughing, shortness of breath, and potential long-term respiratory effects
Steel lifting	Short circuit in the welding machine electrical system	Fire, equipment damage, and injuries caused by sparks or minor explosions
	Being struck by falling steel loads during lifting	Serious injuries, fractures, head trauma, or fatality
	Being caught between the moving steel and another surface	Hand/finger injuries, bruises, minor fractures, and soft-tissue injuries
	Being struck by shifting steel edges during lifting	Bruises, minor head injuries, and minor to moderate injuries
	Falling while assisting with steel positioning at height	Open wounds, head injuries, fractures, or fatal injuries depending on the fall height
	Lifting equipment (crane or forklift) overturning	Fatality to operators or nearby workers, equipment damage, and project losses
	Sling or rigging rope becoming entangled	Uncontrolled load movement, sudden impact, or unexpected release of the load
	Equipment falling from height	Head injuries, open wounds, or serious injuries to workers below or nearby
Steel installation	Rigging, sling, or crane components breaking	Free-falling loads, fatal or severe injuries, and major project damage
	Being struck by steel components during installation	Head or body injuries, fractures, severe trauma, or fatality
	Being caught between steel components during connection	Hand/finger injuries, bruises, minor fractures, and soft-tissue injuries
	Being struck by structural components, tools, or steel pieces	Physical injuries, head injuries, and loss of balance
	Falling from height during installation	Serious injuries, fractures, head trauma, or fatality
Finishing	Work tools becoming entangled during steel installation	Sudden injuries, falling tools striking workers below, hand injuries, or tripping
	Being caught between steel elements that have not been properly secured	Hand/finger injuries, bruises, minor fractures, and soft-tissue injuries
	Contact with sharp edges or surfaces of facade components	Physical injuries, bruises or open wounds, head injuries, and loss of balance

Work Stage	Hazard Identification	Potential Risk
	Falling from height during finishing work	Serious injuries, fractures, head trauma, or fatality
	Finishing tools becoming entangled with steel structures or scaffolding	Minor injuries from tripping or loss of balance, and falling tools endangering workers below

Risk Assessment

After identifying the risk variables associated with each work stage, the next step was to determine the corresponding risk levels by calculating the Likelihood Index (LI) and Severity Index (SI). Data were collected through questionnaires completed by 10 respondents who were competent and familiar with the activities carried out at the project site.

Risk assessment was conducted using the HIRARC approach, in which each respondent assessed the likelihood of occurrence and the potential severity of each identified risk. Table 7 presents the LI and SI values for each analyzed risk variable, along with the corresponding overall risk levels based on the risk assessment matrix.

Table 7. Risk levels of steel facade work

Work Stage	Hazard	Risk	LI (%)	L	SI (%)	S	Risk Level
Site Measurement	Contact with scaffolding	Bruises, minor head injuries	55	3	26	2	Medium
	Fall from height	Serious injuries, head trauma, fatality	28	2	83	5	Extreme
	Slipping	Sprains, minor strains	60	3	35	2	Medium
	Measuring equipment entangled	Loss of balance, minor injuries	63	3	30	2	Medium
	Equipment breakage	Sudden injury, work delays	45	2	40	3	Medium
Steel Cutting	Caught between	Hand/finger injuries, soft-tissue injuries	65	3	55	3	High
	Cuts/punctures	Open wounds, bleeding	70	3	80	4	Extreme
	Electric shock	Burns, cardiac disturbances, fatality	40	2	85	5	Extreme
	Dehydration/heat stroke	Fatigue, exhaustion, loss of consciousness	62	3	50	3	High
	Short circuit	Localized fire, equipment damage, injuries	42	2	75	4	High
Steel Welding	Electric shock	Burns, cardiac disturbances, fatality	38	2	82	5	Extreme
	Welding sparks	Minor to moderate burns	68	3	80	4	Extreme
	Dehydration/heat stroke	Fatigue, exhaustion, loss of consciousness	60	3	55	3	High
	Inhalation of welding fumes	Respiratory irritation	50	2	45	3	Medium
	Short circuit	Localized fire, equipment damage, injuries	46	2	70	4	High
Steel Lifting	Struck by falling material	Serious injuries, fatality	35	2	90	5	Extreme

Work Stage	Hazard	Risk	LI (%)	L	SI (%)	S	Risk Level
	Caught between	Hand/finger injuries, soft-tissue injuries	66	3	55	3	High
	Struck by material	Bruises, minor head injuries	62	3	30	2	Medium
	Fall from height	Serious injuries, fatality	40	2	90	5	Extreme
	Lifting equipment overturning	Fatal accident, equipment damage	25	1	90	5	High
	Sling or rigging rope entanglement	Sudden impact, unstable load/equipment	50	2	55	3	Medium
	Falling equipment	Head injuries, open wounds	45	2	80	4	High
	Equipment/component failure	Free-falling load, fatality	30	2	90	5	Extreme
Steel Installation	Struck by steel components	Head injuries, severe trauma, fatality	32	2	88	5	Extreme
	Caught between during connection	Hand/finger injuries, soft-tissue injuries	70	3	55	3	High
	Struck by steel edges	Bruises, minor head injuries	60	3	30	2	Medium
	Fall from structure	Serious injuries, fatality	34	2	90	5	Extreme
	Equipment entanglement	Hand injuries, falling tools, tripping	65	3	70	3	Extreme
Finishing	Caught between	Hand/finger injuries, soft-tissue injuries	60	3	55	3	High
	Struck by tools or structures	Bruises, minor head injuries	55	3	30	2	Medium
	Fall during finishing work	Serious injuries, fatality	32	2	90	5	Extreme
	Tool entanglement during finishing	Hand injuries, falling tools, tripping	65	3	55	3	High

Based on Table 7, extreme risks were mainly associated with work at height, material lifting, equipment use, and high-energy hazards. Falls from height had high SI values (83%–90%) despite relatively lower LI values (28%–40%), indicating potentially severe consequences, including serious injuries and fatality. Similar extreme risks were identified for falling steel materials, electric shock, and lifting equipment or component failure.

High risks were mainly related to direct contact with materials and equipment, including caught-between hazards, dehydration or heat stroke, short circuits, and falling equipment. Medium risks included contact with structures or materials, slipping, tool entanglement, and welding-fume exposure. Although their consequences were relatively lower, these

hazards still require appropriate controls through safe work procedures, housekeeping, supervision, and suitable PPE.

The assessment shows that LI and SI jointly determine risk levels: some hazards have high severity despite lower likelihood, while repetitive and dynamic activities such as cutting and welding tend to have higher likelihood. Therefore, both likelihood and severity should be considered when prioritizing controls, particularly for extreme and high risks, in accordance with the hierarchy of controls.

Risk Control

After hazards have been identified and their risk levels determined through the calculation of the LI and SI values, the next step in the

HIRARC approach is to formulate appropriate risk control strategies. The primary objective of this stage is to reduce or eliminate potential hazards through structured and systematic interventions. Risk control is implemented

based on the principle of the hierarchy of controls. Table 8 presents the risk control strategies based on the hierarchy of controls (HIRARC) for steel facade work.

Table 8. Risk control strategies based on the hierarchy of controls

Work Stage	Hazard	Risk Level	Risk Control Strategy
Site Measurement	Contact with scaffolding	Medium	Administrative control: Warning signs PPE: Safety helmet and protective vest
	Fall from height	Extreme	Engineering control: Fall-arrest system with secure anchorage Administrative control: Restricted access to elevated work areas and work-at-height SOP PPE: Full-body harness
	Slipping	Medium	Engineering control: Anti-slip surfaces Administrative control: Routine work-area inspections PPE: Safety footwear
	Measuring equipment entangled	Medium	Engineering control: Proper organization of work pathways Administrative control: Supervision of tool positioning
	Equipment breakage	Medium	Administrative control: Routine equipment inspection PPE: Work gloves
Steel Cutting	Caught between	High	Engineering control: Machine guards Administrative control: Safe work training
	Cuts/punctures	Extreme	Substitution: Automated cutting equipment with built-in safety features Administrative control: Steel-cutting SOP PPE: Work gloves
	Electric shock	Extreme	Engineering control: Proper grounding and cable insulation Administrative control: Equipment inspection PPE: Insulating gloves
	Dehydration/heat stroke	High	Administrative control: Scheduled rest breaks and adequate hydration PPE: Breathable, sweat-absorbent work clothing
	Short circuit	High	Engineering control: Overcurrent protection system Administrative control: Periodic electrical inspections
Steel Welding	Electric shock	Extreme	Engineering control: Proper grounding of the welding machine Administrative control: Welding safety training PPE: Insulating gloves
	Welding sparks	Extreme	Engineering control: Welding screen/shield Administrative control: Restricted area for

Work Stage	Hazard	Risk Level	Risk Control Strategy
			welding and hot-work activities PPE: Flame-resistant jacket
	Dehydration/heat stroke	High	Administrative control: Scheduled rest breaks and adequate hydration PPE: Breathable, sweat-absorbent work clothing
	Inhalation of welding fumes	Medium	Engineering control: Mechanical ventilation PPE: Welding respirator
	Short circuit	High	Engineering control: Overcurrent protection system Administrative control: Routine electrical inspections
Steel Lifting	Struck by falling material	Extreme	Engineering control: Certified lifting slings Administrative control: Designated signalman and lifting SOP
	Caught between	High	Administrative control: Safe work training PPE: Work gloves
	Struck by material	Medium	Administrative control: Controlled and restricted work area PPE: Safety helmet
	Fall from height	Extreme	Engineering control: Secure anchorage and fall-arrest system PPE: Full-body harness
	Lifting equipment overturning	High	Engineering control: Stable working surface Administrative control: Use of certified operators
	Sling or rigging rope entanglement	Medium	Engineering control: Proper positioning of lifting equipment and load Administrative control: Rigging inspection and safe lifting training
	Falling equipment	High	Engineering control: Regular inspection and maintenance of lifting equipment; use of certified lifting gear (slings, shackles, and hooks) Administrative control: Lifting procedures; appointment of certified signalman and lifting supervisor
	Equipment/component failure	Extreme	Engineering control: Scheduled preventive maintenance and use of lifting equipment within rated load capacity Administrative control: Safe heavy-equipment work SOP, equipment inspection checklist, and competency training for crane operators and rigging crews
Steel Installation	Struck by steel components	Extreme	Engineering control: Temporary support system Administrative control: Lifting and installation coordination SOP
	Caught between during connection	High	Administrative control: Technical work procedures PPE: Work gloves

Work Stage	Hazard	Risk Level	Risk Control Strategy
Finishing	Struck by steel edges	Medium	Administrative control: Marking of sharp edges PPE: Safety helmet and elbow protection
	Fall from structure	Extreme	Engineering control: Standard-compliant scaffolding and secure anchorage PPE: Full-body harness
	Equipment entanglement	Extreme	Engineering control: Clear and unobstructed work pathways Administrative control: Tool organization SOP
	Caught between	High	Administrative control: SOP for work in confined areas PPE: Work gloves and safety footwear
	Struck by tools or structures	Medium	Administrative control: Proper tool organization PPE: Safety helmet
	Fall during finishing work	Extreme	Engineering control: Permanent guardrails and lifeline system PPE: Full-body harness
	Tool entanglement during finishing	High	Engineering control: Proper cable management Administrative control: Supervision of finishing tools

As presented in Table 8, the proposed risk controls mainly consist of engineering controls, administrative controls, and PPE. Although elimination and substitution are the most effective levels in the hierarchy of controls, their application to steel facade work is limited due to the inherent risks associated with working at height, handling heavy steel materials, and using electrical and heat-generating equipment for cutting and welding.

Elimination is not feasible because removing hazards such as falls from height would require eliminating essential facade installation activities. Similarly, substitution is difficult because the work methods, technical specifications, and material types were established during the planning stage, limiting major changes during construction. Therefore, engineering, administrative, and PPE controls are considered the most applicable measures for managing identified hazards while maintaining construction activities. These controls provide a basis for safer and more structured work practices and may support work continuity, quality, and overall project performance [15].

The integration of JSA and HIRARC enables systematic hazard identification and risk

assessment and supports the formulation of control recommendations based on the hierarchy of controls. The findings can serve as a technical and operational reference for project personnel, OSH managers, and contractors. The identification of extreme risks, particularly falls from height and being struck by heavy steel materials, highlights the need for layered protection through engineering and administrative controls in addition to PPE.

CONCLUSION

The OHS risk analysis of steel facade work in Building X was conducted by integrating JSA and HIRARC. Based on field observations and questionnaire data from 10 respondents, 32 potential hazards were identified across six work stages, with risk levels ranging from medium to extreme. Extreme risks were mainly associated with falls from height, being struck by steel components or falling materials, electric shock, and equipment failure. Risk control recommendations were developed based on the hierarchy of controls, particularly engineering controls, administrative controls, and PPE. The integration of JSA and HIRARC provided a systematic basis for identifying hazards, assessing risk levels, and formulating control

recommendations. However, the effectiveness of these controls in reducing residual risk was not directly evaluated in this study.

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