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Original Article

Hirarc-Based Occupational Safety Risk Analysis in Sprinkler System Installation

Analisis Risiko Keselamatan Kerja Berbasis HIRARC pada Pekerjaan Instalasi Sistem Sprinkler

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A B S T R A C T

Introduction: *Sprinkler system installation involves manual handling, electrical exposure, hot work, work at height, and interaction with moving equipment, which may result in preventable occupational injuries.* ***Objective:*** *This study aimed to assess occupational safety risks and formulate risk-control measures for sprinkler system installation work at the PT Adiwarna Anugerah Abadi project.* ***Method:*** *A descriptive qualitative study was conducted using the Hazard Identification, Risk Assessment, and Risk Control (HIRARC) approach. Data were collected through workplace observation, questionnaires, and interviews involving 25 supervisors and workers selected by total sampling in December 2025. Risk levels were determined using probability and severity scores and were categorized according to the project risk matrix.* ***Results:*** *The initial assessment identified 26 risks, consisting of 5 low risks, 17 moderate risks, and 4 high risks. High risks included fire during grinding, falls from height, falling objects striking workers, and contact with moving equipment. After implementing engineering, administrative, and personal protective equipment controls, residual risks decreased to 23 low risks and 3 moderate risks.* ***Conclusion:*** *HIRARC provided a structured basis for prioritizing controls in sprinkler installation work. Continuous supervision, compliance with personal protective equipment, permit-to-work implementation, and periodic residual risk review are required to maintain an acceptable level of occupational safety.*

Keywords: *HIRARC, Occupational Safety, Risk Assessment, Sprinkler System, Risk Control*

Introduction

Occupational safety remains a major public health concern because workplace hazards can cause injury, disability, death, productivity loss, and long-term social consequences for workers and their families. The International Labour Organization reported that nearly three million workers die every year due to work-related accidents and diseases.[1] In Asia and the Pacific, occupational safety and health challenges remain substantial, with an estimated 2.9 million work-related deaths and at least 402 million non-fatal occupational injuries reported globally in occupational safety estimates.[2] In Indonesia, the burden is also increasing; the Ministry of Manpower recorded 462,241 occupational accident cases during January-December 2024.[3] These data indicate that risk prevention is not only a technical requirement but also a public health priority.

Construction and mechanical installation activities are among work settings with complex and dynamic hazards. Sprinkler system installation includes material lifting, valve isolation, pipe fabrication, grinding, dismantling of old pipes, work at height, and coordination with active workplace equipment. These tasks may generate ergonomic, mechanical, electrical, fire, and fall hazards. If hazards are not identified systematically, workers may experience musculoskeletal injury, hand entrapment, electric shock, burns, lacerations, falling-object injury, or fatal falls.

The Hazard Identification, Risk Assessment, and Risk Control (HIRARC) method is widely used to identify hazards, assess their likelihood and severity, and determine appropriate control measures. HIRARC provides a structured and objective approach to assess hazards and associated risks, and to determine controls that reduce risks to an acceptable level.4 The hierarchy of controls emphasizes elimination, substitution, engineering controls, administrative controls, and personal protective equipment, arranged from the most to the least effective safeguards.5 Therefore, HIRARC can support decision-making in prioritizing controls, particularly in high-risk installation work.

Previous studies have applied HIRARC in construction, shipyard, manufacturing, and industrial work processes, demonstrating its usefulness in mapping risk levels and recommending controls.6-9 However, risk assessment for sprinkler system installation remains less frequently discussed, despite its combination of fire-safety installation tasks, hot work, working at height, and manual material handling. This study aimed to analyze occupational safety risks using HIRARC and to formulate risk controls for sprinkler system installation work in the PT Adiwarna Anugerah Abadi project.

Method

This study used a descriptive qualitative design with a HIRARC approach. The study was conducted in December 2025 at the sprinkler system installation project of PT Adiwarna Anugerah Abadi. The study population consisted of supervisors and workers involved in the sprinkler installation process. Because the number of eligible participants was limited, total sampling was used, resulting in 25 participants.

Primary data were collected using direct workplace observation, structured risk-assessment forms, questionnaires, and interviews with supervisors and workers. Observation focused on work activities, tools and equipment, material handling, work-at-height practices, hot-work activities, electrical exposure, housekeeping, permit-to-work implementation, and use of personal protective equipment. Secondary data consisted of project work procedures, job hazard analysis documents, and safety control documentation when available.

The HIRARC process was conducted in three stages. First, hazards were identified for each main

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activity of sprinkler installation. Second, each identified hazard was assessed based on probability and severity, producing an initial risk level. Third, risk controls were formulated using the hierarchy of controls, including engineering controls, administrative controls, and personal protective equipment. After the proposed controls were mapped, residual risk was reassessed to determine whether the remaining risk was at an acceptable level. Results are presented descriptively in tables and narrative interpretation.

Results

Five main work activities were assessed: preparation of tools and materials, gate valve isolation and lockout-tagout implementation, pipe fabrication using grooving and threading machines, dismantling of old pipes using grinders and manual handling, and dismantling of old pipes at height. The hazard identification process showed that workers were exposed to ergonomic, electrical, mechanical, fire, fall, falling-object, and moving-equipment hazards.

The initial HIRARC assessment identified 26 risk events. The distribution consisted of 5 low-risk events, 17 moderate-risk events, and 4 high-risk events. The high-risk events were fire due to grinding, worker falls from height, falling objects striking workers, and contact with conveyor or moving equipment. These findings indicate that priority control should focus on hot work, working at height, exclusion-zone management, equipment isolation, and supervision during critical tasks.

After control measures were formulated and implemented, residual risk decreased to 23 low-risk events and 3 moderate-risk events. No residual risk remained in the high-risk category. The remaining moderate risks were mainly related to work at height, falling objects, and interaction with moving equipment. These activities require continuous monitoring because failure of supervision, anchorage, barricading, or lockout-tagout can rapidly increase the risk level.

Table 1. Hazard Identification in Sprinkler System Installation Work

Work activity	Main hazards	Potential consequences
Tools and material preparation	Manual handling, electricity, wet or cluttered work area	Muscle injury, sprain, finger entrapment, struck-by object, electric shock, slip/trip/fall
Gate valve isolation and lockout-tagout	Stored pressure, unapproved work, manual valve operation	Isolation failure, unauthorized work exposure, hand sprain
Pipe fabrication using grooving/threading machines	Pinch point, sharp edges, rotating equipment	Finger entrapment, laceration, hand injury
Old-pipe dismantling using grinder and manual handling	Manual handling, sparks, rotating grinding wheel, combustible material	Muscle injury, burns, laceration, fire
Old-pipe dismantling at height	Height, falling objects, conveyor or moving equipment	Fall from height, struck-by object, contact with moving equipment

Table 1 shows that the work process contains several high-consequence hazards. The most critical tasks were dismantling old pipes using grinders and dismantling pipes at height because both activities may involve fire, falling objects, falls from height, and contact with moving equipment.

Table 2. Initial Risk Distribution Based on HIRARC Assessment

Risk level	Number of initial risks	Percentage	Main examples
Low	5	19.2%	Stored pressure after isolation, permit documentation gaps, low-severity housekeeping issues

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Risk level	Number of initial risks	Percentage	Main examples
Moderate	17	65.4%	Manual handling, electric shock potential, slips/trips, hand injury from grooving/threading and grinding
High	4	15.4%	Fire during grinding, fall from height, falling objects striking workers, contact with moving equipment
Total	26	100%	-

Table 3. Priority Risk Controls and Residual Risk Levels

Priority hazard/risk	Initial risk level	Recommended control measures	Residual risk level
Fire during grinding/hot work	High	Remove combustible materials; apply hot-work permit; provide APAR, hydrant or fire standby; install barricade; conduct fire watch; use face shield and safety gloves.	Low
Worker falling from height	High	Use inspected scaffolding; inspect full-body harness; apply three-point contact; ensure working-at-height competency; connect hook to approved anchorage; conduct pre-work safety assessment.	Moderate
Falling objects striking workers	High	Secure materials and tools; apply exclusion zone; install barricade and warning signs; use safety helmet; assign spotter; coordinate lifting and lowering activities.	Moderate
Contact with conveyor or moving equipment	High	Coordinate with area owner; apply lockout-tagout when required; isolate moving equipment; install physical barrier; ensure permit-to-work and supervision.	Moderate
Manual handling injury	Moderate	Use crane, forklift, chain block, or tag line; limit manual load; coordinate team lifting; conduct manual-handling briefing; use safety gloves.	Low
Electrical exposure	Moderate	Inspect electrical tools and cables; use suitable connectors and grounding; keep cables away from wet areas; stop work during unsafe conditions; supervise tool use.	Low

Table 4. Residual Risk Profile After Control Measures

Residual risk category	Number of residual risks	Interpretation and follow-up
Low	23	Risk is acceptable with routine monitoring, housekeeping, worker briefing, and periodic inspection.
Moderate	3	Risk requires continuous supervision, repeated inspection, and verification of controls before and during work.
High	0	No high residual risk remained after controls were formulated and implemented.

Discussion

The findings demonstrate that sprinkler system installation is a multidisciplinary work process with interrelated hazards. Manual handling during material preparation may cause muscle injury, sprain, finger entrapment, or struck-by injuries. Electrical exposure during tool use creates the risk of electric shock. Wet and cluttered work areas increase the likelihood of slips, trips, and falls. These risks are generally controllable through housekeeping, material organization, cable management, use of mechanical lifting aids, and worker coordination. Such measures are consistent with the HIRARC principle that risk controls should be selected after identifying the source of hazards and estimating the level of risk.[4]

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The high-risk finding related to grinding is important because hot work can create ignition sources in areas where combustible materials, dust, flammable substances, or inadequate fire protection are present. Control should not rely only on personal protective equipment. A safer strategy includes hot-work permit, removal of combustible materials, provision of active fire extinguishers, barricading, standby fire watch, and verification of emergency-response equipment. The hierarchy of controls supports this approach by placing engineering and administrative controls above personal protective equipment.[5]

Work at height remained an important residual-risk source after controls. Even when scaffolding, full body harnesses, three-point contact, anchorage, and working-at-height training are available, the residual severity of a fall can remain high. This means that supervision and compliance monitoring are essential. Similar HIRARC studies in construction and industrial settings also emphasize that high-risk tasks require continuous inspection, competent workers, and strict adherence to standard operating procedures.[7,8]

The residual moderate risks related to falling objects and contact with moving equipment show the importance of exclusion zones, barricades, tool tethering, material securing, and equipment isolation. Inadequate lockout-tagout or weak coordination with the area owner may expose workers to stored energy and moving-equipment hazards. Therefore, job hazard analysis, authorization to work, permit-to-work, and toolbox meetings should be consistently applied before work begins. These administrative controls should be supported by visible signs, area supervision, and documentation of control implementation. From a public health perspective, the use of HIRARC in this project contributes to prevention-oriented occupational health practice. The method helps organizations move from reactive accident response to proactive hazard control. The results can guide project management in prioritizing resources for high-risk tasks, strengthening safety communication, and improving worker safety behavior. The finding that no high residual risk remained after controls suggests that HIRARC can be an effective practical tool when implemented through continuous supervision and management commitment.

This study has several limitations. The assessment was conducted in one project and involved 25 participants, so the results may not represent all sprinkler installation projects. The risk scoring was based on observation, questionnaire responses, interviews, and the project risk matrix, which may involve subjective judgment. Future studies should combine HIRARC with quantitative incident data, behavioral safety observation, or repeated assessments across different project stages to strengthen validity and generalizability.

Conclusion

This study found that sprinkler system installation at the PT Adiwarna Anugerah Abadi project involved multiple occupational safety hazards, particularly manual handling, electrical exposure, hot work, work at height, falling objects, and moving equipment. The initial HIRARC assessment identified 26 risk events, including 4 high risks, 17 moderate risks, and 5 low risks. After implementing risk controls based on the hierarchy of controls, the residual risk profile decreased to 23 low risks and 3 moderate risks, with no high residual risk remaining. HIRARC is therefore useful for prioritizing risk control in sprinkler installation work. However, sustained safety performance requires strong supervision, consistent permit-to-work implementation, strict use of personal protective equipment, worker competency assurance, and periodic review of residual risks.

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Conflict of Interest

The authors declare no conflict of interest related to this study.

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