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Development of work safety procedures for PCI Girder installation using interactive analysis models

Chairul Ahmad[1,*], Fitri Nugraheni[1], Faisol[1]
[1]Faculty of Civil Engineering and Planning, Universitas Islam Indonesia, Yogyakarta, Indonesia

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Corresponding Author:

Chairul Ahmad
19914008@alumni.uii.ac.id

Abstract

As part of the government's infrastructure acceleration initiative, toll road construction has become a key focus to enhance regional development and connectivity. However, such projects, particularly those involving the installation of precast concrete girders, carry significant risks of workplace accidents. Between 2017 and 2021, six accidents related to girder erection occurred during toll road construction projects. This study aims to develop work safety procedures for the installation of Type I precast concrete girders in the Bakauheni–Sidomulyo toll road project. The proposed safety procedures, presented as a flow chart, are based on national and international safety standards, providing a clear and sequential overview of the process to ensure better understanding and risk mitigation. The study uses the Interactive Analysis Model for data analysis, encompassing Data Collection, Data Reduction, Data Presentation, and Conclusion Drawing, where data collection and analysis are conducted in an iterative and simultaneous manner. The results, validated by site engineers and safety officers both within and outside the project, identified 62 potential risks stemming from unsafe conditions and provided 85 safety recommendations. These findings offer practical guidance for contractors to minimize the risk of accidents during the PCI girder erection process.

Introduction

Infrastructure development is a critical component of government efforts to accelerate regional connectivity and economic growth, with toll road construction playing a significant role in this process (Syafrial & Ardiansyah, 2020). Toll roads offer travelers a faster and more efficient alternative to non-toll routes, providing better service and reducing travel time. However, construction projects, especially large-scale ones like toll roads, are inherently risky due to the unpredictability of potential profits, losses, and unforeseen circumstances. This makes effective risk management essential in reducing both the likelihood and impact of potential risks (Zuna et al., 2015).

One major concern in construction projects is the occurrence of work accidents, which can result from two key factors: unsafe actions and unsafe conditions (Tanojo, 2019; Larasatie et al., 2022). Unsafe actions often stem from human factors, such as failing to follow safety protocols, which endanger not only the individual but also others, equipment, and the surrounding environment. On the other hand, unsafe conditions arise from deviations from established safety standards that are meant to prevent accidents. Both factors are significant contributors to accidents in construction projects.

In Indonesia, work-related accidents remain a persistent issue, with 123,000 cases reported in 2017 and 157,313 cases in 2018

(Ayu et al., 2019). A key reason for these incidents is the failure to adhere to Standard Operating Procedures (SOPs) and inadequate use of Personal Protective Equipment (PPE), highlighting the need for stricter enforcement of safety protocols. To address these issues, specific regulations, such as the Minister of Manpower and Transmigration Regulation No. Per-05/Men/1996, OHSAS 18001:2007, and ISO 45001:2018, have been introduced to ensure workplace safety in construction (Ahmad, 2019). These regulations emphasize the importance of SOPs, which provide clear instructions for safe work practices and help minimize errors that may lead to accidents (Putri et al., 2017).

Despite the implementation of safety regulations, accidents continue to occur in toll road construction projects. This study aims to explore the causes of such incidents and offer recommendations for improving work safety during the installation of PCI girders in toll road projects (DPR RI, 2020). By examining past accidents and current safety practices, this research seeks to contribute to the development of more effective safety measures in the construction industry.

1. Cibitung – Cilincing toll road project
   A work accident occurred at the Cibitung-Cilincing Toll Road construction project on Sunday, August 16, 2020. During the casting process, a section of the toll road structure collapsed, injuring eight workers.
2. Pasuruan – Probolinggo toll road project
   On October 29, 2017, a work accident occurred at the Pasuruan-Probolinggo toll road project, resulting in one fatality and two injuries. All the victims were workers on duty at the time. The incident was caused by a girder collapse due to an installation error.
3. Pemalang – Batang toll road project
   On December 30, 2018, a girder (construction support beam) at the Pemalang-Batang toll road project collapsed during installation. The collapse occurred due to a failure in properly positioning the girder. Fortunately, there were no casualties, as the workers were able to evacuate just before the girder fell.

Crane accidents in construction projects are not unique to Indonesia. In Australia, at least 77 factors contribute to such incidents, including human error, unsafe crane operation practices, poor communication between contractors and service providers, inadequate planning, and insufficient maintenance (Lingard et al., 2021). The most common issues arise during casting and girder installation, where the highest risk factors include crane collapse while lifting girders, slings becoming disconnected, and spreader beam structural failure. Contributing factors to these risks include improper use of Personal Protective Equipment (PPE), worker health, wind speed at the site, and equipment settings (Nugraha, 2022). This was further emphasized in an interview with the Site Engineer Manager of the Bakauheni–Sidomulyo Toll Road project, who noted that girder installation is particularly high-risk due to its reliance on heavy equipment and working at height, necessitating stricter supervision to address unsafe conditions and actions.

Research methods

This study employs a qualitative descriptive method. In qualitative research, conceptualization, categorization, and descriptions are developed based on the "events" observed during field activities. For data analysis, the Interactive Analysis Model (Figure 1) was utilized, as data collection and analysis are inseparable in this approach. Both occur simultaneously in a cyclical and interactive process, rather than following a linear progression. The stages of interactive analysis are outlined and explained below (Saleh, 2021).

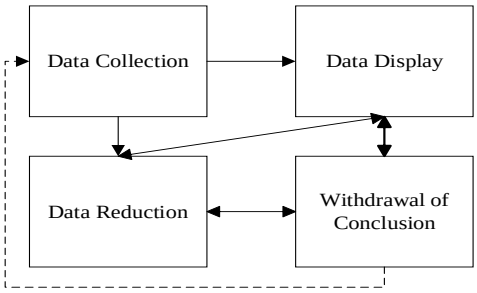

Figure 1. Interactive Analysis Model

Data Collection

The data and information for this study were collected through several methods:

1. Literature review from various sources related to the research, including PCI girder erection using the crane method, standard operating procedures, and occupational safety and health systems (SMK3).
2. Observation at the Bakauheni–Sidomulyo Toll Road construction project, conducted either directly or through media such as photos, videos, and online resources.
3. Interviews with Safety Officers and Site Engineer Managers, facilitated by online platforms like WhatsApp and Zoom.
4. Documentation of interview and observation results, including images, videos, and company documents.

Data Reduction

In this study, data reduction was performed to simplify and eliminate irrelevant information, ensuring that the remaining data aligns with the research objectives. The stages of data reduction are as follows:

1. Drafting a flowchart of the recommended work procedures based on the collected data.
2. Validating the draft flowchart of work procedure recommendations through source triangulation and Focus Group Discussions (FGD).

Data Display

Data presentation can be done in various forms, such as descriptive text, flowcharts/schematics, networks, and tables, to aid explanation. In this study, data is presented in two ways:

1. Flowchart of the recommended work procedures, created using the Microsoft Visio application.
2. Table outlining unsafe conditions, identifying potential injury risks to workers, and recommending measures to prevent accidents. The table was prepared with the help of Microsoft Excel.

The use of flowcharts and tables is intended to make the data easier for field workers to understand. Flowcharts visually represent procedures, while tables provide detailed explanations. This approach aligns with the research objective of presenting work procedure recommendations in the form of flowcharts.

Drawing conclusions

The conclusions are presented in a separate chapter titled "Conclusion and Suggestions." The stages of data analysis using the Interactive Analysis Model are illustrated in the figure below.

Data Type

This study utilizes both primary and secondary data. Primary data is collected directly from the research subject and includes information obtained through interviews, field surveys, documentation, and observations (Nurjanah, 2021). Secondary data supports the primary data and is sourced from company documents and literature (Riadi, 2016). In this study, secondary data includes work method statements from PT PP (Persero) related to the Bakauheni–Sidomulyo Toll Road development project, as well as government publications and online sources (PT PP – PT Arkonin, 2021).

Research Limitations

The limitations of this study include the potential subjectivity of the researcher and the interpretation of interview responses, which may introduce bias. To mitigate this bias, source triangulation has been employed, as detailed in this study, to enhance the reliability and validity of the findings.

Research Variables and Indicators

The variables in this study are Work Procedures (SOP) and Occupational Safety, with the indicators being hazard identification and hazard control.

Results and Discussion

Draft flow chart of work procedure recommendations

The draft flowchart is developed based on the data analysis results and is correlated with the relevant regulations outlined in the introduction and company documents, including the Work Method Statement for the Bakauheni–Sidomulyo Toll Road construction. The draft flowchart of the work procedure recommendations is shown in Figure 2 below.

Results of validation of source triangulation method and FGD (Focus Group Discussion)

Source triangulation is employed to ensure the validity and cross-check the data by comparing information from multiple sources, both from the collected data and the draft work procedures. This approach helps ensure that the developed work procedures align with the research objectives (Alfansyur, 2020). In this study, source triangulation was conducted through Focus Group Discussions with four experts: two Site Engineer Managers and two Safety Officers, each with experience in PCI girder erection using the crane method. The results of this source triangulation validation are presented in Table 1 below.

Risk Identification Recapitulation and Safe Condition Recommendations Based on Regulations

Based on the safety officer's advice, a separate table has been created to identify risks and provide recommendations for safe conditions according to the regulations used in this study. This table aims to highlight the potential risks associated with PCI girder erection and offer recommendations for mitigating these risks. The Recapitulation Table of Risk Identification and Safety Recommendations, based on the applicable regulations, is presented in Table 2 below.

Flow chart of work procedure recommendations based on validation results

Following the validation results, several improvements have been recommended for the flow chart of work procedure recommendations. These include replacing "Activities" with "Accident Risk Identification," substituting "Tools Used" with "Person in Charge of Activities," and adding "Accident Prevention Recommendations," among other changes. The revised flow chart, incorporating these improvements based on source triangulation validation, is presented in Figure 3 below.

The results of the analysis are in the form of risks that can arise

Based on interviews and literature studies, 19 unsafe conditions have been identified, leading to 62 potential risks. Among these, the conditions that pose the highest risk, each with five associated risks, are:

1. Bracing Welding
2. Use of Non-Standard Generators
3. Non-Standard Use of Mobile Crawler Cranes
4. Procurement of Heavy Equipment and Non-Standard Vehicles

The bar diagram illustrating these risks is presented in Figure 4 below.

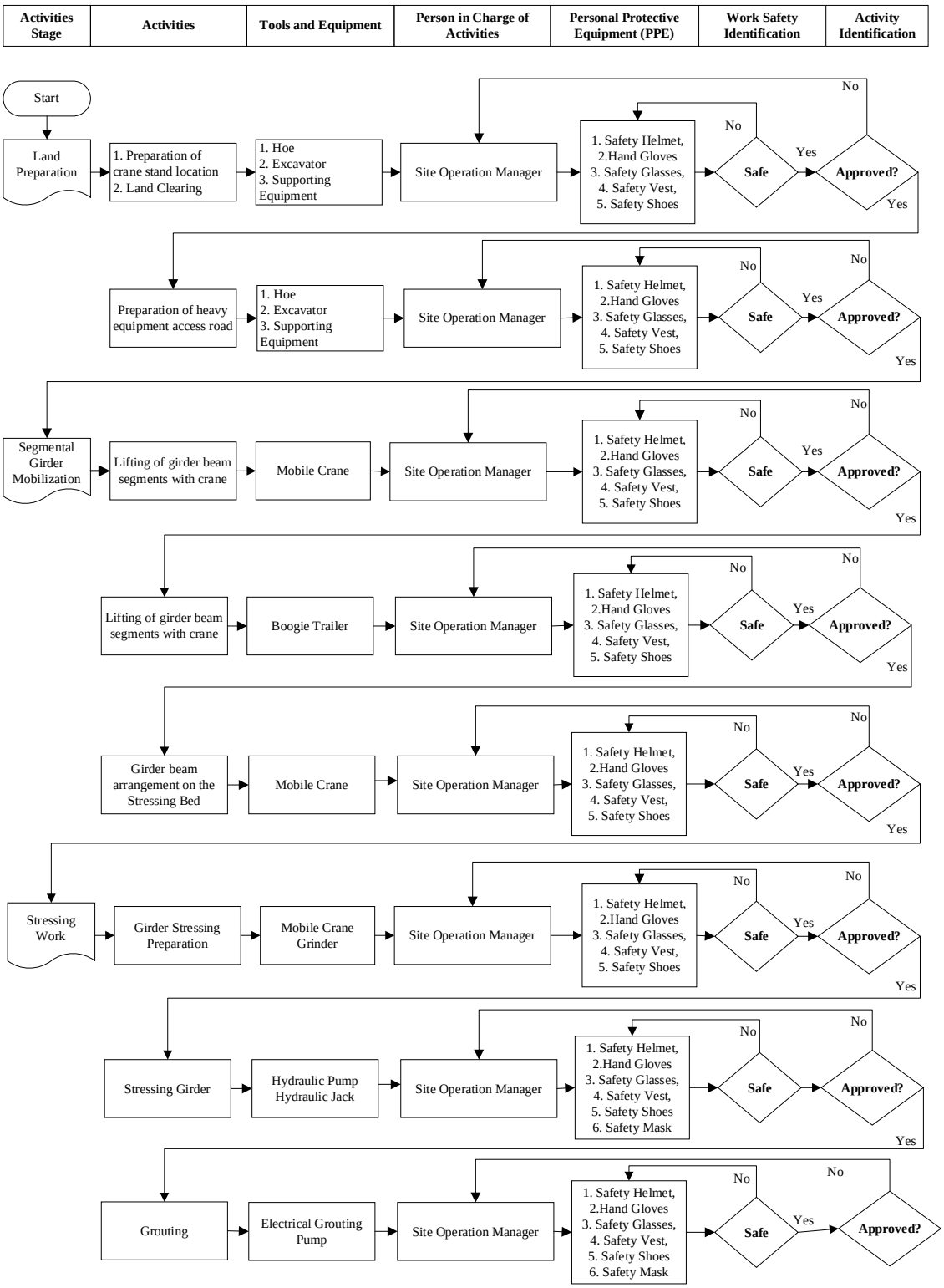

Figure 2. Draft flow chart recommendations for work procedures

Table 1. Results of validation of source triangulation method and *focus group discussion*

Assessed Aspects	Conformity		SUGGESTION	
	Yes	Not	SITE ENGINEER MANAGER	SAFETY OFFICER
1. Preparatory Work			1. Replace "Activity" with "Accident Risk Identification" in the work procedure. 2. Substitute "Tools Used" with "Person in Charge of the Activity" in the work procedure. 3. Include "Accident Prevention Recommendations" under the work procedures section. 4. Add restrictions between unsafe conditions in the work procedure, such as using dashed red lines to demarcate boundaries between different tasks. 5. Add the project name to the work procedure.	1. Create a recapitulation table that includes unsafe conditions, risk identification, and prevention efforts. 2. In the land clearance recapitulation table, identify the risk of being struck by operating heavy equipment or dump trucks. 3. In the recapitulation table for landslides or subsidences at heavy equipment access points, add measures for improving the stability of the bottom soil to address landslide risks. 4. In the recapitulation table for working in low visibility conditions, include control measures such as requiring workers to wear high-visibility vests. 5. In the recapitulation table for weather changes, identify risks such as impediments to the movement of heavy equipment and dump trucks that may reduce productivity. Add control measures including providing sufficient drinking water and nutritious food for all workers, and ensuring the proper and complete use of PPE.
A. Methods used	✓			
B. Control actions	✓			
C. Unsafe Conditions	✓			
D. Risk of Accidents	✓			

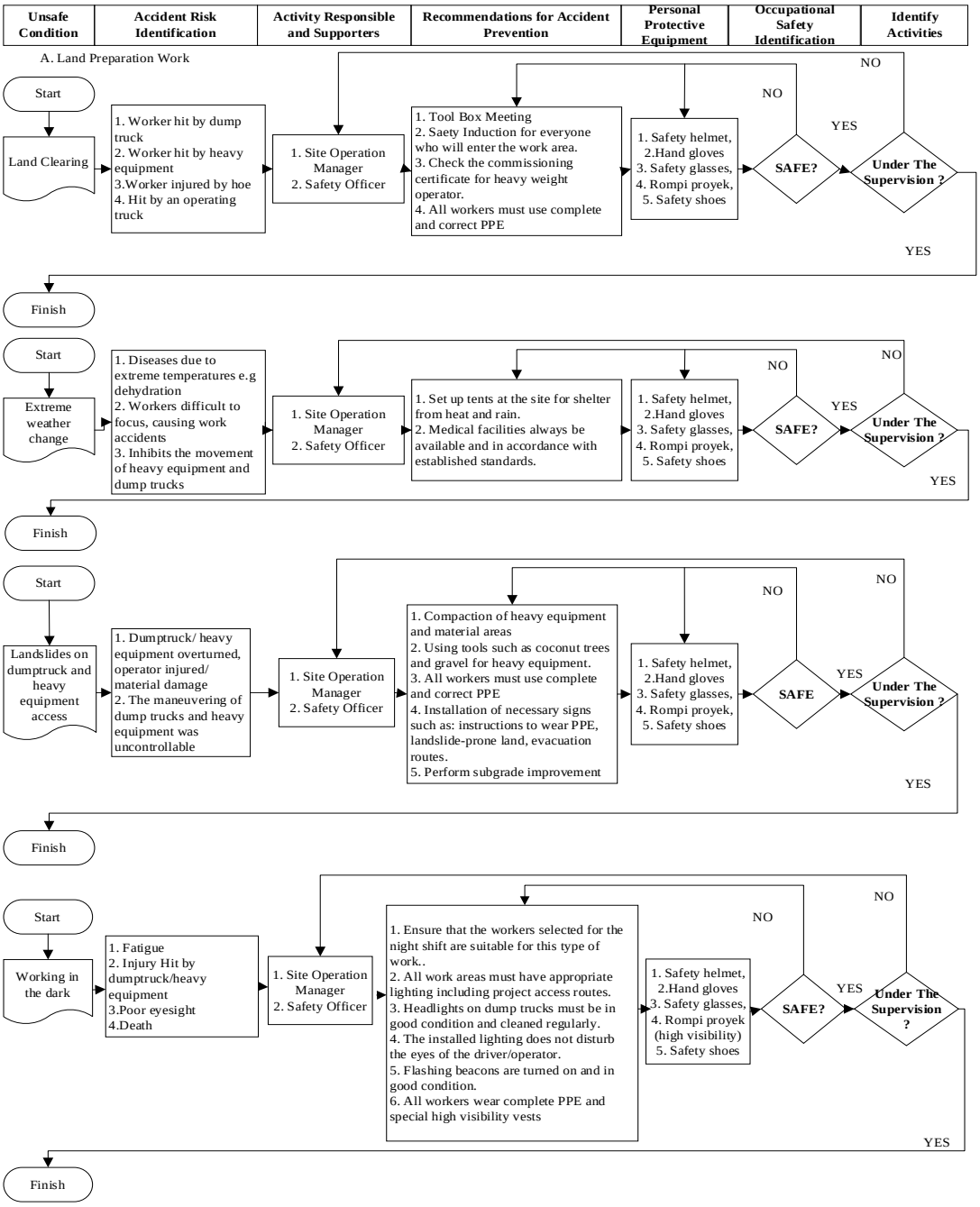

Figure 3. Flow chart of work procedure recommendations based on validation results

Table 2 Recapitulation of risk identification and recommendations for safe conditions based on regulations

Unsafe Conditions		Risks that can arise		Recommendations for Safe Conditions Based on Regulations
Land Clearing	1	Workers Hit by Dump Truck	1	Tool *Box Meeting*
	2	Workers hit by heavy equipment	2	A brief induction is carried out to everyone who will enter the work area.
	3	Injured worker hit by hoe	3	Check the SILO (Operator Permit) for heavy equipment and the SIO (Operator License) for heavy equipment operators.

Unsafe Conditions		Risks that can arise		Recommendations for Safe Conditions Based on Regulations
	4	Hit by a truck in operation	4	All workers are required to use complete and correct PPE.
Weather Changes	1	Diseases caused by extreme temperatures e.g. dehydration, heat stress	1	Set up tents at the work site/field for shelter from hot and rainy weather.
	2	Workers have difficulty concentrating, causing work accidents	2	Medical facilities must always be available and according to the set standards.
	3	Hindering the movement of heavy equipment and dump trucks		
Landslides/sinks on dump *truck* and heavy equipment access	1	*Dump truck* / heavy equipment overturned, operator suffered injury / material damage	1	Compaction of machine and material areas
	2	The maneuver *of dump trucks* and heavy equipment is uncontrollable.	2	Using the help of tools such as coconut trees and sirtu for the foundation of heavy equipment.
			3	Installation of signs that are injured such as: instructions for using PPE, landslide-prone land, evacuation routes.
			4	Performing basic soil repairs
			5	All workers must use the correct PPE (Personal Protective Equipment)
Working in dark or night conditions	1	Fatigue	1	Make sure that the workers selected for the night shift are suitable for this type of work.
	2	Accident Hit by dumptruck/heavy equipment	2	The entire work area must have appropriate lighting including the project access route.
	3	Poor eyesight	3	The headlights on the *dump truck* must be in good condition and cleaned regularly.
	4	Death	4	The installed illumination does not interfere with the driver/operator's eyes.
			5	Flashing beacons are turned on and in good condition.
			6	All workers use full PPE and special *high visibility vests*
There are no warning signs on the work area	1	Workers were hit by a dump truck/heavy equipment that was in operation	1	Provide safety signs in accordance with standards (size, material, design) and function well
	2	Workers / dump trucks mired in landslide-prone areas	2	Safety signs installed in dangerous locations
Unsafe lifting area (loose, muddy)	1	Heavy equipment, *boogie-truck* sinked/rolled over	1	Compaction on access lifting area
	2	The operator suffered injuries.	2	Conducting a work site inspection before carrying out lifting activities
	3	Girder material damage	3	All workers must use the correct PPE (Personal Protective Equipment)
			4	Installation of signs that are injured such as: instructions for using PPE, landslide-prone land, evacuation routes.
Landslides on heavy equipment and *boogie-truck access*	1	*Boogie-truck*/heavy equipment overturned,	1	Compaction on access lifting area
	2	The operator has suffered injury / material damage	2	Conducting a work site inspection before carrying out lifting activities
	3	Loss of production and finance due to damage to tools or materials.	3	All workers must use the correct PPE (Personal Protective Equipment)
			4	Installation of signs that are injured such as: instructions for using PPE, landslide-prone land, evacuation routes.
Procurement of heavy equipment and non-standard vehicles	1	Physical injury due to failure during surgery	1	Request for certificates of conformity and calibration at the procurement stage
	2	Accidents with other vehicles	2	Inspect all machines and vehicles before they are brought into the project
	3	Workers hit by heavy equipment	3	Keeping the machine always using original parts
	4	Machine rollover	4	All heavy equipment must be serviced regularly
	5	Production and financial losses due to engine repairs	5	All workers must use the correct PPE (Personal Protective Equipment).
Use of non-certified or damaged lifting accessories	1	Workers injured/killed due to heavy materials being lifted and falling	1	Lifting equipment and accessories must comply with the requirements set out in QSHE-TQM-AE-P-019 Procedures for the selection and mobilization of lifting equipment

Unsafe Conditions		Risks that can arise		Recommendations for Safe Conditions Based on Regulations
	2	Operator injured/killed due to *overturning* of the machine	2	All lifting equipment parts and accessories must be certified first from a third party before use and 12 months thereafter
			3	Physical inspection of all lifting equipment before use
			4	Any damaged lifting equipment haurs are replaced immediately.
			5	All workers must use the correct PPE (Personal Protective Equipment)
Irregular traffic management	1	Workers/access users were hit by boogie-trucks or heavy equipment.	1	Installation of traffic signs and providing flagmen
	2	Traffic accidents between access users.	2	Coordination with parties related to traffic management such as the police if needed.
Non-standard use *of Mobile crawler cranes*	1	Overturned due to overload	1	The capacity and type of *crane* are determined in advance by *the site management* and the crane transport coordinator.
	2	Load fall due to lifting gear failure	2	Crane operators and *riggers* do not use mobile phones when *crane* operation starts
	3	Trapped injury / hit injury	3	Operators check security systems daily
	4	Financial losses	4	*The crane* should not hang the load when *the crane* is unattended
	5	Unsuitable or unstable base surface	5	*The crane* should not be moved when left unattended
			6	Only trained *slingers/signalers* to provide signals to the operator and swing the load
			7	Checklist the tool before use
			8	*The crane* should stop operating at the wind speed specified by the manufacturer.
			9	*The crane* should be equipped with an anemometer at the highest point so that the wind speed can be determined
			10	The *crane operator* must be at least 18 years old and have a third-party certificate
			11	*Crane* mats/other auxiliary materials are used on unstable surfaces
			12	All workers must use the correct PPE (Personal Protective Equipment).
Use of non-standard grinding	1	Broken discs or damaged discs due to non-standard causes injury	1	The machine must be properly maintained and if there is any damage, it is immediately marked and repaired without waiting
	2	Hand or foot injury due to unsafe use by an inexperienced or incompetent person	2	Checking the grinding edge before use
	3	Eye injury to the operator or others near the projectile	3	The use of PPE is mandatory for all workers and visitors (guests) who are around the location.
PC Strand Residual Cutting	1	Fire due to unsafe work site from flammable materials	1	The machine must be properly maintained and if there is any damage, it is immediately marked and repaired without waiting
	2	Limb cut off cutter grinder	2	Checking the grinding edge before use
	3	Burns caused by sparks from PC Strand cutting	3	The use of PPE is mandatory for all workers and visitors (guests) who are around the location.
			4	Given warning signs/*police lines* around the location
			5	Especially for operators, they are required to use special glasses that have met the standards.
Use of non-standard generators	1	Burns to the worker's body parts during refueling.	1	Avoid using when wet
	2	Generator exploded	2	Make sure that each appliance connected to the generator is specifically designed for outdoor use
	3	Carbon monoxide poisoning	3	Turn off the engine when refueling and use the funnel
	4	Dropped/slipped due to fuel spill while refilling.	4	Fire extinguishers to be close to the plant
	5	Electrocution when surfaces are wet.	5	Perform maintenance and report any damage.
			6	All workers are required to use complete and correct PPE coupled with carbon masks

Unsafe Conditions		Risks that can arise		Recommendations for Safe Conditions Based on Regulations
Epoxy glue smearing	1	Eye irritation	1	Check to see if the exposed person is using eyeglasses. Remove if any. Immediately wash your eyes with running water for at least 15 minutes with the eyelids open.
	2	Skin allergies	2	Remove exposed clothing. Wash the skin with soap and rinse with water until clean. Do not rinse with solvents or thinners used in epoxy glue products
	3	Damage to the body's organs if exposed repeatedly.	3	All workers must use the correct PPE (Personal Protective Equipment).
Use of non-certified or damaged lifting accessories	1	Workers injured/killed due to heavy materials being lifted and falling	1	Lifting equipment and accessories must comply with the requirements set out in QSHE-TQM-AE-P-019 Procedures for the selection and mobilization of lifting equipment
	2	Operator injured/killed due to mobile crane overturning	2	All lifting equipment parts and accessories must be certified first from a third party before use and 12 months thereafter
	3	Lost time and costs due to stalled work	3	Physical inspection of all lifting equipment before use
			4	Any damaged lifting equipment haurs are replaced immediately.
			5	All workers must use the correct PPE (Personal Protective Equipment)
Bracing Welding	1	Fire due to unsafe work site from flammable materials	1	Make a work permit and carry out a pre-start briefing before starting work.
	2	Electrocution caused by welding tool cables inducing electric current	2	Perform routine checklists and perform periodic servicing to ensure the equipment is in good condition
	3	Oxygen or LPG cylinders explode	3	Use the trolley for LPG gas bins to keep them standing
	4	Crushed oxygen cylinder	4	Oxygen cylinders and LPG cylinders must use an aristor flashback
	5	Burns caused by sparks from welding.	5	Use PPE and provide Work Safety Tools (APKs) before starting work.
			6	Workers at height are required to use *a good and correct* safety harness *and* life line.
Unstable displacement of heavy materials	1	Physical injury due to being trapped or mired while moving heavy or unstable loads	1	All lifting equipment and accessories used in the project such as cranes, cranes, chain blocks must be optimized, maintained and certified by a third party in accordance with the Lifting Equipment Standards of PT. PP.
	2	Damage caused by tipping over or contact with structures/equipment that cause financial and production losses.	2	Performing soil compaction/layer repair in material transfer areas
			3	Conducting a work site inspection before carrying out activities.
Lack of maintenance of equipment, accessories & certifications	1	Production and financial losses due to heavy equipment repairs	1	Lifting equipment and accessories must be fit for purpose, certified by a third party and tested in accordance with the requirements applied by the lifting work stamdar in accordance with the applicable regulations.
	2	Failure of equipment resulting in injury/death	2	Perform a checklist before using the appliance.
	3	Heavy equipment accidents due to not running properly due to lack of maintenance.	3	All workers must use the correct PPE (Personal Protective Equipment).
TOTAL	**62**	***Risks that can arise***	**85**	***Recommendations for safe conditions based on regulations***

Safe conditions based on regulations

Following the identification of 62 risks stemming from 19 unsafe conditions, an analysis was conducted using the applicable regulations and standards. This analysis resulted in 85 recommendations for improving safety conditions. The largest number of recommendations, totaling 12, addresses unsafe conditions related to the use of non-standard crane vehicles. The bar

diagrams illustrating the 62 identified risks and the 85 safety recommendations based on these regulations are shown in Figures 4 and 5 below.

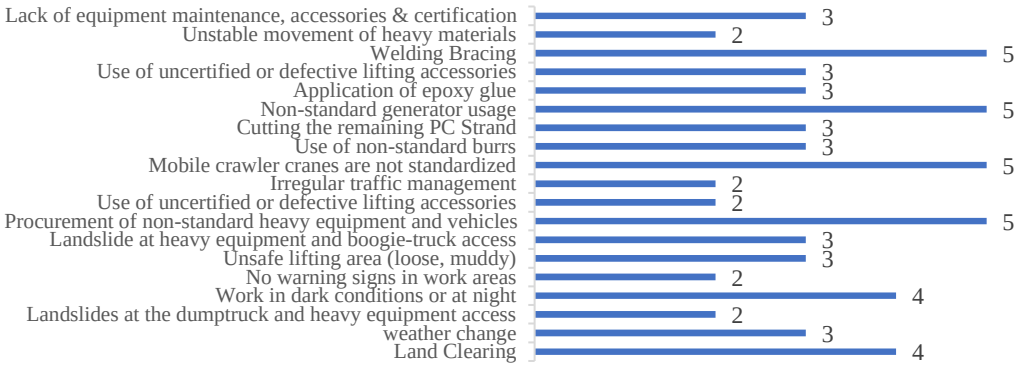

Figure 4. Bar diagram 62 possible risks

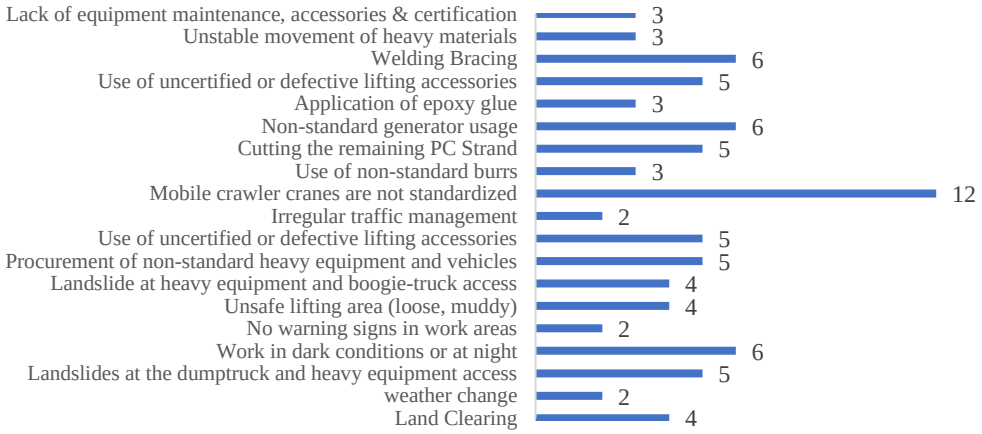

Figure 5. Bar diagram 82 recommendations for safe conditions based on regulations

Selection of PCI Girder crane method installation as hazardous area

The selection of the research object was influenced by several high-risk work accidents observed in toll road construction projects in Indonesia, particularly during the installation of girders. To further substantiate this choice, an initial interview was conducted with the Site Engineer Manager of the Bakauheni-Sidomulyo toll road construction project (Nugraha, 2022). The interview revealed that the installation of PCI girders using the crane method poses significant risks, including a high potential for fatal accidents. This heightened risk is attributed to the large dimensions and heavy weight of the materials and equipment involved, as well as the elevated heights at which the PCI girders are installed.

Regulations or standards suggested

In this study, various regulations and standards were used as references for developing recommendations for work procedures. These regulations are also applied in the Bakauheni – Sidomulyo toll road construction project to enhance safety and prevent work accidents. The key regulations and standards referenced for formulating these work procedure recommendations are outlined below:

(1) Law No.1 of 1970 CHAPTER III Article 3 concerning Occupational Safety

(2) Per.01/MEN/1980 Safety and Health of Building Construction Occupational Safety
(3) PER-05/MEN/1996 Occupational Safety and Health Management System
(4) SNI-04-0225-2000
(5) OHSAS18001: 2007
(6) SNI ISO 45001:2018

Correlation between unsafe conditions and unsafe actions

The primary causes of work accidents can be categorized into two main types: unsafe actions and unsafe conditions. Research indicates that 85% of work accidents are attributed to unsafe actions (unsafe behavior), while 10% are due to unsafe conditions, and the remaining 2% are considered to be the result of unforeseen circumstances. Unsafe conditions contributing to work accidents are not solely caused by environmental factors but are often exacerbated by unsafe actions performed by workers. These unsafe behaviors can occur not only during the task but also before and after work activities. Thus, while maintaining high safety standards for actions is crucial, it is equally important to ensure a safe working environment to mitigate risks.

This study, while focusing on unsafe conditions, also addresses the impact of unsafe actions on work procedures. It highlights the interplay between unsafe conditions and unsafe actions, showing that both factors are interrelated and influence each other.

To enhance this research and expand its applications, the following suggestions are proposed: (1) Extend work procedure recommendations to other types of work environments. (2) Include additional factors such as work quality in future studies. (3) Validate findings with quality and occupational safety certification bodies.

Conclusion

From the analysis of work procedures for PCI girder installation using the crane method, the following conclusions can be drawn:

1. Identification revealed 62 types of risks associated with unsafe conditions throughout the various stages of PCI girder installation work, resulting in 85 recommendations.
2. A flow chart detailing the work procedure for PCI girder installation using the crane method was developed, covering all stages from land preparation to welding (bracing) for the Bakauheni–Sidomulyo toll road construction project.
3. The findings of this research can be applied as recommendations not only for the construction of toll roads but also for other construction projects involving PCI girders.

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