

Hazard and Risk Analysis Using Hirarc and Hazop Methods on Erection Girder Work

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Abstract. Superstructure work of the toll flyover construction is one of the works that have a high level of risk, especially when the erection girder work passes over the existing toll road. This study aims to identify hazards on erection girder work using the HIRARC and HAZOP methods. Using these two methods requires the implementation of questionnaire and surveying, using at least 30 respondents with 34 respondents is successfully gathered. The results showed that there were 36 possible hazards where 11 hazards were identified as moderate risk and 25 hazards identified as low risk. Then an interview was conducted with occupational health and safety (OHS) experts on site to validate the results of this research. Efforts are being made to carry out inspections of heavy equipment before use, only operators who have SIO that are appropriate and competent to do, conduct toolbox meetings, install warning signs, use PPE, and coordinate and cooperate with existing toll owners.

1 Introduction

The activities carried out on construction projects involve a lot of labor and have a high work intensity and the use of various work equipment. Work accidents on construction projects are undesirable for both the contractor and the workers [1]. If a work accident occurs, the impact of the accident can cause losses in the form of costs, time, and quality of work as well as individual disability and even death. Currently, the parties that involved in construction projects are increasingly aware of the importance of monitoring risk issues because errors in handling risks will have a negative impact on construction projects, either directly or indirectly.

In the toll road construction project, there are toll flyover construction works which consist of six scopes of work including drainage works, earthworks, substructure work, superstructure work, and other [2]. The superstructure work is one of the jobs that has a high level of risk [3], especially during erection girder work that passes over the existing toll road. Therefore, to prevent things that can cause work accidents, a hazard identification method is needed at the erection girder work steps [3]. This study was analyzed using the HIRARC method where the data obtained from observations and interviews that have been conducted by researchers to determine the comparison with the HAZOP method [4]. The use of two methods is carried out to determine which method is appropriate in identifying hazards on the erection girder work stage.

1.1 Objectives

The objective of this paper is:

- To identify hazards in erection girder work using the Hazard Identification, Risk Assessment and Risk Control (HIRARC) method.
- To identify hazards in erection girder work using the Hazard and Operability Study (HAZOP) method.
- To find out the comparison of identification results between the Hazard Identification, Risk Assessment and Risk Control (HIRARC) method and the Hazard and Operability Study (HAZOP) method.

Previous studies also discussed similar topics and were used in this study, the following are previous studies:

- Previous research was conducted on a bridge project built over the Surabaya River using heavy equipment launching gantry and identified 15 hazards during the launching girder work [5].
- Previous research used the 2013 PMBOK risk management method which was sharpened by Monte Carlo simulation to see the frequency and sensitivity and identified 7 hazards in erection girder work [3].
- Previous research was conducted at the Captain Tendean Flyover project using heavy equipment launching gantry and identified 4 hazards during the launching girder work [6].

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2 Literature review

2.1 Occupational health and safety

According to the International Labor Organization (ILO), occupational safety and health is developing and maintaining the highest degree of physical and mental well-being of all workers and of social welfare in all types of work, preventing health problems caused by work, protecting workers from risks posed by other factors. factors that can interfere with health in every job, placing workers in a work environment that is in accordance with the physiological and psychological conditions of workers to realize the compatibility between workers and work in accordance with their duties [7].

2.2 Erection girder

Girder is a beam that is between two supports in the form of a pier, pierhead or abutment on a bridge or fly over [8]. The girder on the bridge will support the loads acting on the bridge.

Erection girder is a work of installing precast girder beams that are mounted on a pedestal in the form of a rubber bearing or commonly known as an elastomeric bearing pad. The use of cranes in erection girder work can make the work faster and more efficient, so that the time required is less and less practical [9].

2.3 Hazard identification risk assessment and risk control (HIRARC)

A work activity on a project often has hazards and risks of work accidents, so efforts are needed to analyze these hazards and risks (Karundeng, Doda, & Tucunan, 2018). One of the methods used to analyze risk in preventing and minimizing work accidents is HIRARC. HIRARC stands for Hazard Identification Risk Assessment and Risk Control which is the process of identifying hazards or risks that may occur in a job on a project, then a risk assessment is carried out based on the identified hazards or risks to determine the high or low value of the hazard or risk. After a risk assessment has been carried out, then hazard control is planned so that these hazards can be reduced, and accidents do not occur in every work on the project [5].

2.4 Hazard and operability study (HAZOP)

Hazard and operability studies or commonly known as HAZOP is a study carried out to identify potential hazards that interfere with the work process so that it can pose a risk that is detrimental to humans or facilities in the system (Setiono, 2017). HAZOP is carried out systematically and structured in identifying potential deviations from a process, examining possible causes and assessing the consequences so that prevention can be determined (IEC, 2001).

3 Methods

This research begins with conducting field observations and studying literature studies regarding erection girder work. Then collect data consisting of primary data and secondary data. Primary data consists of observations, questionnaires, and interviews, while secondary data consists of shop drawing, work stages and documentation. The primary data was gathered using survey method, questionnaire in Likert Scale. The questionnaire was collected using google form to ease the data collecting and allow an easier method of inputting questionnaire for the respondents. The secondary data are the shop drawing of the project, and work stages of the erection for girders and its documentation. The data was gathered through the help of the site project

Then the questionnaire research instrument was tested consisting of 34 respondents, namely validity test, reliability test and normality test. Furthermore, the analysis of hazard and risk identification was carried out using the HIRARC and HAZOP methods which were then compared the results of the two methods. Then validate the research results with OHS experts on the project. The conclusion of this research is knowing the stages of erection girder work and knowing the hazards and risks in the work using the HIRARC and HAZOP methods and knowing the comparison between the HIRARC and HAZOP methods.

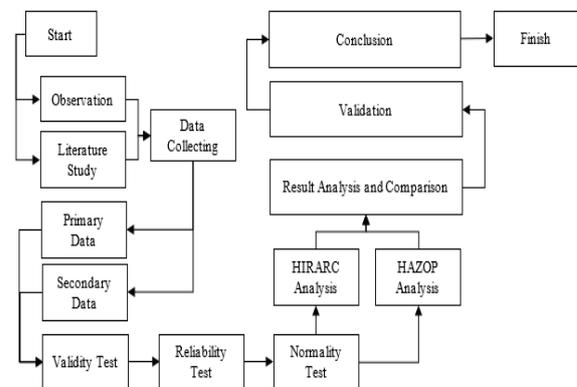


Fig. 1. Research flowchart.

Below are figures, regarding the observation on the study location.



Fig. 2. Observation documentation on location.

4 Data collection

4.1 Respondents

Data collection was done using questionnaire in google form format.

For the questionnaire, the target is 30 respondents, with the actual respondents is 34 people. Below are the characteristic of the respondents.

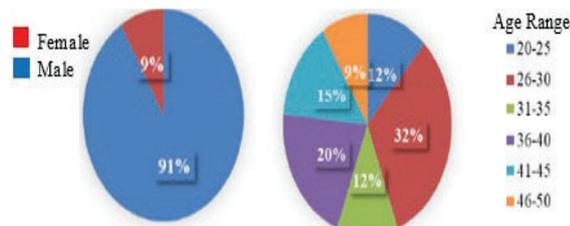


Fig. 3. Respondents characteristics (left: gender; right: age range).

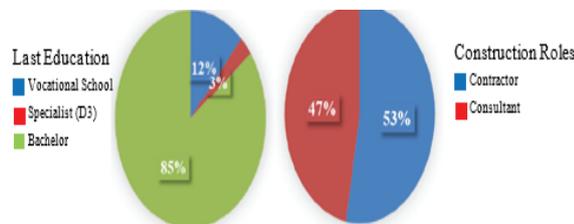


Fig. 4. Respondents characteristics (left: last education; right: construction roles).

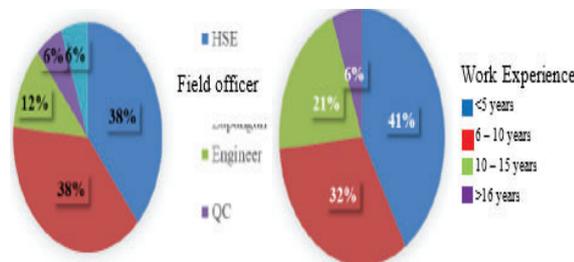


Fig. 5. Respondents characteristics (left: roles in project; right: work experience).

4.2 Research variables

The following are the variables obtained through the results of observations and literature studies in this study.

Table 1. Research variables for the questionnaire.

No.	Potential Hazard	Notes and References
X1	Lifting girders from stock yard to multi axle using crane service	Erection Girder Work Step 1
X1.1	Crane service is not working optimally	Observation
X1.2	Crane service over swing	(Khalima 2018)
X1.3	Worker hit by girder when girder is moved to multi axle by crane	(Egar 2017)
X1.4	Girder falls or falls off the crane	(Komaraningsih and Sjaaf 2013)
X1.5	Sling crane broke	(Kholida et al. 2020)

X2	Multi axle runs across the existing toll road to get to the lifting location	Erection Girder Work Step 2
X2.1	Multi axle not working optimally Girder	Observation
X2.2	Falling or detaching from multi axle	(Komaraningsih and Sjaaf 2013)
X2.3	Worker hit by multi axle	(Egar 2017)
X2.4	The median of the existing toll road is damaged	Observation
X2.5	Existing toll road crossing is active	Observation
X2.6	High speed vehicle	Observation
X3	The girder is linked to the main crane sling	Erection Girder Work Step 3
X3.1	The jawara, remove from girder	Observation
X3.2	Sling crane broke	(Kholida et al. 2020)
X4	Lifting girder by main crane Main	Erection Girder Work Step 4
X4.1	Crane not working optimally	Observation
X4.2	Crane base ground is unstable	(Khalima 2018)
X4.3	Main crane over swing	(Khalima 2018)
X4.4	Sling crane broke	(Kholida et al. 2020)
X4.5	Girder falls or falls off the crane	(Komaraningsih and Sjaaf 2013)
X4.6	Worker is crushed by material when lifting girder	(Kholida et al. 2020)
X4.7	Workers caught in girders when placing on bearing pads	(Egar 2017)
X4.8	Existing toll road crossing is active	Observation
X4.9	High speed vehicle	Observation
X5	Bracing girder	Erection Girder Work Step 5
X5.1	Workers fall from a height	(Khalima 2018)
X5.2	Workers are crushed by material when bracing girders	Observation
X5.3	Welding equipment is not functioning optimally	Observation
X5.4	Eye irritation from incandescent light when welding	(Egar 2017)
X5.5	Burns due to welding	(Egar 2017)
X5.6	Sling crane broken or loose	(Kholida et al. 2020)
X5.7	Existing toll road crossing is active	Observation
X5.8	High speed vehicle	Observation
X6	Release slings and cranes back to where they started	Erection Girder Work Step 6
X6.1	Workers caught in slings during release	(Egar 2017)
X6.2	Overswing crane	(Khalima 2018)
X6.3	Worker hit by crane	(Kholida et al. 2020)
X6.4	Crane base ground is unstable	(Khalima 2018)
X6.5	Existing toll road crossing is active	Observation
X6.6	High speed vehicle	Observation

The research variable above are also the questions that will be implemented into the questionnaire.

5 Results and discussion

5.1 Validity test

Validity can be interpreted as a measure that shows the levels of validity of an instrument. The purpose of the validity test is to check whether the contents of the questionnaire have been understood by the respondents [10].

If the value of r count $>$ r table, then the question items have a significant correlation with the total score and are declared valid. To put it simply, validity test purpose is to determine whether each variables in the questionnaire is being measured by an accurate measuring tool, which in this case is the questionnaire itself.

In this study using Corrected Product Moment Pearson Correlation with the value of r table obtained from table r with $df = n-2$ and the critical rate of 5% and the number of respondents 34 people, then the obtained r table is, $df = 34 - 2 = 32$. Value r table (N) $32 = 0.349$, with r count is 0.364 showing r count is indeed higher than r table. Meaning that all variables are valid.

5.2 Reliability test

The reliability test is an index that shows the level of reliability of the data obtained from an instrument to-

-ensure the consistency of the research instrument [11]. This test was used to test the reliability of the questionnaire data results obtained from the instrument used (the questionnaire).

A variable is said to be reliable if the Cronbach's Alpha > 0,6 [12].

Based on the results of the reliability test analysis using the IBM SPSS Statistics 23 computer program for each statement item in the table above, it shows that the Cronbach's Alpha value is greater than 0.6. From these results indicate that all items are declared reliable because they meet the reliability test.

5.3 Normality test

[13] said that Normality test is an important aspect in econometrics or statistical analysis because statistical or econometric model are based on normality test. It's very essential to test the randomness of a random number. A generalization of the familiar bell-shaped normal density to several dimensions plays a fundamental role in multivariate analysis. It assumes that data were generated from multivariate normal distribution. It is mathematically tractable and gives nice results [13].

According to another, normality test is a data test to find out that the distribution of research data obtained is normally or not normally distributed [14]. Normality testing in this study used the Kolmogorov-Smirnov statistical test analysis. Normality test is done by comparing the significance value, if the significant value is > 0.05, then the data distribution is normal. If significant < 0.05, then the data distribution is not normal. A normality test is used to determine whether sample data has been drawn from a normally distributed population.

Based on the results of the analysis of the normality test for each statement item in the table above, it shows that the data is likely to be normally distributed because the significant value of the variable is greater than 0.05, which is 0.2, as well as the severity data is normally distributed because it has a significant value of the variable greater than 0.05 which is 0.2.

5.4 Data analysis using HIRARC method

5.4.1 Hazard identification of HIRARC

Literature study is the first step in risk identification. This is done to find out what occupational safety and health risks can occur in erection girder work. The literature that was used can be seen on table 1 and from previous research. In addition, interviews were conducted with resource persons, namely workers involved in erection girder work. This is done to complete data that is not recorded in the OHS risk

variable in the work under study. The following are examples of hazard identification results in erection girder work.

Table 2. Hazard identification on erection girder work.

Job Description	Potential Hazard	Causes	Hazard Classification
Lifting girders from stock yard to multi axle using crane service	Crane service is not working optimally	Crane service not inspected	Safety
	Crane service over swing	Incompetent operator	Safety
	Worker hit by girder when girder is moved to multi axle by crane	There is a miscommunication between workers; Lack of supervision	Safety

The identification above is an example of the HIRARC identification on one of the main variables (variable X1: Lifting girders from stock yard to multi axle using crane service).

5.4.2 Risk assessment HIRARC

After obtaining valid and reliable items, then the data is processed so that the probability value and severity value of each risk are obtained. Risk assessment is carried out by calculating the relative risk value and using the likelihood × severity matrix. The matrix is used to determine the level of risk in determining risk control. The following is an example of a risk assessment on erection girder work:

Table 3. Risk assessment on erection girder work.

Job Description	Potential Hazard	Risk Assessment		Risk Level
		Possibility	Severity	
Lifting girders from stock yard to multi axle using crane service	Crane service is not working optimally	2 (Remote)	3 (Serious)	6 (Medium)
	Crane service over swing	1 (Inconceivable)	4 (Fatal)	4 (Low)
	Worker hit by girder when girder is moved to multi axle by crane	1 (Inconceivable)	4 (Fatal)	4 (Low)

The assessment above is an example of the HIRARC assessment on one of the main variables (variable X1: Lifting girders from stock yard to multi axle using crane service).

5.4.3 Risk control HIRARC

Risk controls carried out include elimination, substitution, engineering control, administrative control, warning system and use of personal protective equipment. [12]. Examples of controls recommended by researchers to minimize the risks that exist in erection girder work are as follows:

Table 4. HIRARC form.

Work Activity	Hazard Identification		Risk Analysis			Risk Control	
	Hazard	Causes	Possibility	Severity	Risk	Recommended Control	PIC
Lifting girders from stock yard to multi axle using crane service	Crane service is not working optimally	Crane service not inspected	2 (Remote)	3 (Serious)	6 (Medium)	Administrative Control: Inspect before use;	SHE, Inspector
	Crane service over swing	Incompetent operator	1 (Inconceivable)	4 (Fatal)	4 (Low)	Elimination: No one is allowed to work in the swing area of the heavy equipment; Administrative Control: - Only operators who have an appropriate SIO and competent are hired; - Operators have attended standard safety training in operating the tool; - The heavy equipment is equipped with an alarm (honk, siren);	SHE, Inspector
	Worker hit by girder when girder is moved to multi axle by crane	There is a miscommunication between workers; Lack of supervision	1 (Inconceivable)	4 (Fatal)	4 (Low)	PPE: Use of safety shoes, project helmets and vests Administrative Control: Conducting toolbox meeting supervised by SHE; Warning System: Installation of warning signs; PPE: Use of safety shoes, project helmets and vests	SHE, Inspector

The form above is an example of the HIRARC form on one of the main variables (variable X1: Lifting girders from stock yard to multi axle using crane service).

5.4.4 HIRARC conclusion

Based on the results of risk control carried out, it shows that there are 5 types of control methods used in erection girder work based on the Malaysia HIRARC Guidelines [15] which include elimination, substitution, engineering control, administrative control and the use of personal protective equipment.

5.5 Data analysis using HAZOP method

5.5.1 Hazard identification of HAZOP

The examination process begins with determining the nodes of study, then selecting guide words to state the deviations that occurred and the causes and consequences of these deviations [16]. Hazards identification is carried out based on literature studies (the literature can be seen on table 1 and from previous research), and the results of interviews with resource persons involved in erection girder work. The following is an example of hazard identification in erection girder work:

Table 5. Hazard identification on erection girder work.

Process	Guide words	Deviation	Possible Causes	Consequences
Lifting girders from stock yard to multi axle using crane service	No	Crane service is not working optimally	Crane service not inspected	Work can't be done
	More	Crane service over swing	Incompetent operator	Workers are injured; Girder fell and cracked
	As well as	Worker hit by girder when girder is moved to multi axle by crane	There is a miscommunication between workers; Lack of supervision	Workers injured

The identification above is an example of the HAZOP identification on one of the main variables (variable X1: Lifting girders from stock yard to multi axle using crane service).

5.5.2 Risk control HAZOP

After analyzing the hazard identification of the erection girder work, then appropriate and effective action is taken against deviations in the work. The following are examples of actions recommended by researchers to minimize risks in erection work:

Table 6. Hazop worksheet.

Process	Guide words	Deviation	Possible Causes	Consequences	Risk Control	PIC
Lifting girders from stock yard to multi axle using crane service	No	Crane service is not working optimally	Crane service not inspected	Work can't be done	Inspect before use	SHE, Inspector
	More	Crane service over swing	Incompetent operator	Workers are injured; Girder fell and cracked	<ul style="list-style-type: none"> No one is allowed to work in the swing area of the heavy equipment; Only operators who have an appropriate SIO and competent are hired. Operators have attended standard safety training in operating the tool. The heavy equipment is equipped with an alarm (honk, siren); Use of safety shoes, project helmets and vests 	SHE, Inspector
	As well as	Worker hit by girder when girder is moved to multi axle by crane	There is a miscommunication between workers; Lack of supervision	Workers injured	<ul style="list-style-type: none"> Conducting toolbox meeting supervised by SHE. Installation of warning signs. Use of safety shoes, project helmets and vests 	SHE, Inspector

The workset above is an example of the HAZOP worksheet for risk control on one of the main variables (variable X1: Lifting girders from stock yard to multi axle using crane service).

5.5.3 HAZOP conclusion

The rules and control for the HAZOP risk results follow the guideline from the British Standard - HAZOP Studies Application Guide [16].

5.6 Comparison between HIRARC and HAZOP

Based on the results of research that has been carried out using the HIRARC and HAZOP methods, below is a comparison between the two methods, they are the standards used and the work accident risk analysis process.

Table 7. Comparison of Hirarc and Hazop method.

Comparison	HIRARC	HAZOP
Standards	Malaysia HIRARC Guidelines (2008)	British Standard - HAZOP Studies Application Guide (2001)
Analysis Result	1. Hazard Identification 2. Risk Assessment 3. Risk Control	1. Hazard Identification 2. Risk Control

Work accident risk analysis using the HIRARC method, begins with describing the stages or work processes, then identifying hazards and risks that may occur in the work process, then a risk assessment is carried out in order to determine the high or low value of these hazards and risks. After a risk assessment has been carried out, then hazard control is planned so that these hazards can be reduced, and accidents do not occur. Based on the HIRARC Guidelines [15], the risk controls carried out include elimination, substitution, engineering control, administrative control, warning system and use of personal protective equipment. Next, document the identification results into the HIRARC Form.

While the risk analysis of work accidents using the HAZOP method, begins with describing the study points studied, then based on the British Standard [16] determines guide words that state deviations that occur in the study points studied, then identifies the causes and impacts of deviations. so that the HAZOP method is more detailed in identifying hazards. Then determine appropriate and effective actions so that these hazards can be reduced, and accidents do not occur. Next, document the identification results into the HAZOP Worksheet.

Based on previous research conducted by [4], called the "Analysis of the Application of the HIRARC (Hazard Identification Risk Assessment and Risk Control) and HAZOPS (Hazard and Operability Study) Methods in the Identification of Potential Hazards and Risks in the Unloading Unit Process at PT. Toyota Astra Motor", stated that the comparison between the HIRARC and HAZOPS methods through field studies, namely HIRARC has a simpler form, faster identification time and is applicable, but is less easy to read, less detailed and more dominant to the man factor, while the Hazops method is easier to read by the operator, detailed in identifying hazards, more dominant on equipment but the form is more complicated, requires longer identification time and is less easy to use.

5.7 Validation through interview results

According to OHS experts in the field, the research results are in accordance with the conditions in the field, but there are differences in the level of risk that occurs in each hazard, where HIRARC in the field has a high level of risk. However, the results of the HIRARC study show that there is no hazard that has a high risk. HIRARC in the field has a high level of risk so that all parties involved in construction work, namely erection girder work, have the awareness to follow the existing OHS rules so that accidents can be reduced or even zero accidents and HIRARC in the field is made by mutual agreement between HSE and inspectors.

Also, according to OHS experts in the field, the HIRARC method is more recommended than the HAZOP method in identifying hazards in erection girder work, because in the HIRARC method there is a risk assessment used to determine the level of risk, whether high, medium, or low. So that it can determine which risks must be controlled first.

6 Conclusion

6.1 Conclusion

Based on the results and discussions that have been carried out, the following conclusions can be drawn:

- The steps in the erection girder work are: first, lifting the girder from the stock yard to the multi axle using a crane service; second, multi-axle running across the existing toll road to the lifting location; third, the girder is attached to the main crane sling; fourth, lifting girder by main crane; fifth, bracing girder; sixth, release the sling and crane back to the starting place.
- Hazard identification results using the HIRARC method:
 - Identified 36 hazards and risks which are divided into 6 sub-steps of work.
 - The results of the risk assessment carried out from all steps of the erection girder work using the HIRARC method, there are 11 hazards with moderate risk levels and 25 hazards with low risk levels.
 - The results of risk control on erection girder work using the HIRARC method, carried out 5 types of control including: Elimination, Substitution, Administrative Control, Engineering Control, Warning System, and Personal Protective Equipment (PPE).
- Hazard identification results using the HAZOP method:
 - Identified 36 hazards and risks which are divided into 6 sub-steps of work.
 - The results of risk control on erection girder work using the HAZOP method, including inspecting heavy equipment before use, only operators who have SIO that are appropriate and competent to do so, conduct toolbox meetings, install warning signs, use PPE, and coordination and cooperation with existing toll owners

6.2 Suggestion

- Based on the results of the work accident risk analysis research on the erection girder work that has been carried out, the suggestions that researchers can give are:
 - It is necessary to do further research on the causes of the difference between the theoretical results and the situation in the field.
 - It is necessary to do further research on the analysis of the budget for the SMK3 plan in this study.

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