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ORIGINAL ARTICLE

Hazard Identification and Risk Assessment of Sensor Maintenance Work Activity on The Suramadu Bridge Steel Box Girder Area

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ABSTRACT

Introduction: The steel box girder of Suramadu Bridge is a confined work area with sensor maintenance activities and potential hazards. The purpose of this study was to determine the potential hazards and risk levels in the Suramadu Bridge steel box girder work area. **Methods:** This descriptive study involved cross-sectional data collection. This study used a qualitative risk assessment method. The primary data used in this research included interviews with informants, which consisted of five key informants from experts and five main informants from technicians. The secondary data of the study include a job safety analysis document issued by the Suramadu Bridge Structural Health Monitoring System (SHMS). Risk assessment was performed by determining the level of likelihood and consequences using a risk analysis matrix. Data processing techniques and analysis are based on job safety analysis documents and interviews, whereas the risk analysis table is based on AS/NZS 4360 (2004). **Results:** The study results show that sensor maintenance work in the steel box girder area involves eight activities, 15 potential hazards, and 19 risks. **Conclusion:** The study concludes that, Out of the 19 identified risks, three risks (16%) were in the low-risk category, 15 risks (79%) were in the medium-risk category, and one risk (5 %) was in the high-risk category with the potential for fire.

Keywords: hazard identification, risk assessment, sensor maintenance work, Suramadu Bridge, steel box girder

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INTRODUCTION

In carrying out project work, one of the important points of concern is the implementation of occupational safety and health in every work aspect from the planning, implementation, and evaluation stages. Manpower is a company-owned resource that plays an important role in the operation of the production process. Therefore, the health and safety of employees must be protected by the company. The implementation of OHS in a company can help minimize the occurrence of work-related accidents and occupational diseases through an occupational health and safety management system. According to the International Labor Organization (ILO), occupational health and safety aims to promote and maintain the highest degree of physical, mental, and psychosocial safety in all types of work to prevent occupational health problems and protect workers in every job from risks arising from potential hazards that can interfere with health, placing and maintaining workers in a work environment that is in accordance with their physiological and psychological conditions, as well as creating compatibility between workers and their work (Rahayu *et al*., 2022). Occupational health and safety is a means of preventing accidents, disabilities, and death due to work accidents. Prevention measures include the provision of personal protective

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equipment, machine maintenance processes, and reasonable working hours (Hasibuan *et al*., 2020).

The purpose of occupational safety and health is to protect workers' rights to safety in carrying out their work, ensuring the safety of everyone in the workplace, and maintaining production resources so that they can be used safely (Rahayu *et al*., 2022). Based on Law No.1 (1970) on Work Safety, Article 3, paragraph 1 concerning Occupational Safety states that one of the objectives of work safety is to prevent and reduce accidents.

A work accident is an unwanted event that can injure humans, damage property, and harm production processes (Mahawati *et al*., 2021). Construction is one of the sectors in Indonesia with the highest number of occupational accidents. The theory developed by Heinrich in 1941 suggests that 85% of work accidents are caused by human factors (Malau, 2022). Furthermore, Frank Bird, through the International Loss Control Institute in 1972, put forward the theory of the loss causation model and stated that management factors were the background of the causes of accidents (Poetra, 2021). Research conducted by Kristiana *et al*. (2018) discovered that 90% of human factors from project owners caused work accidents during the construction of the Taman Anggrek Residence project owing to careless behavior and work habits. The same study also found that 94.19% of accidents occurred because of human factors from consultant teams. Soekiswara (2020) stated that the factors influencing the occurrence of work accidents from an equipment perspective include equipment conditions, tool placement, maintenance, and unfeasible equipment. Every workplace has a potential source of danger. Danger cannot be eliminated, but can be controlled (Ramli, 2010).

Hazards can result in injuries to humans and damage to equipment and the environment (Sumarna *et al*., 2018). Risk is the likelihood of exposure of a person or device to a work hazard (Sumarna *et al*., 2018). Work accidents can be prevented by identifying and assessing the risks to hazards at work. By identifying hazards and evaluating risks, a company or industry may determine various risks of a certain job, which can be controlled to reduce the risk of hazards in the workplace through follow-up efforts.

Hazard identification is an attempt to determine, recognize, and estimate the existence of a hazard in a workplace system, such as equipment, work environment, work regulations, and procedures (Candrianto, 2020). Hazard identification activities include diagnosing and finding hazards, recognizing processes and sequences of work activities, and paying attention to the possible causes and effects of hazards that may arise in the workplace (Candrianto, 2020). Risk assessment in occupational safety and health is a method to conduct a more careful assessment of the potential risks that exist in the workplace to ensure and protect the safety and health of workers through control efforts (Fitra, 2021). The purpose of risk analysis is to determine whether the risks in the workplace are within an acceptable and controllable level.

The Suramadu Bridge is one of the icons of the East Java Province, which continues to be maintained to preserve its longevity. Its maintenance process includes not only the exterior but also the interior part of the bridge to maintain its reliability and safety. The Suramadu Bridge is a cable-stayed bridge of 5,438 m that spans the Madura Strait and connects Java Island to Madura Island. The bridge has several areas whose construction and operation involve personnel, namely, the bridge deck, steel box girder, pylon, and pile cap. To ensure safety and reliability, the Suramadu Bridge features a facility called the Structural Health Monitoring System (SHMS), which can detect damage. The monitoring work is carried out by Structural Health Monitoring System (SHMS) components, which include sensors, data acquisition devices, data transmission systems, databases, data processing, and data presentation.

The steel box girder bridge is a part of the Suramadu Bridge with a sensor component, whose maintenance work involves human factors. The steel box girder area has several sensors including an accelerometer, Fiber Bragg Grating (FBG), Atmospheric Temperature and Relative Humidity (ATRH) sensors, and Global Positioning System (GPS) sensors. Sensors are routinely monitored, maintained, and repaired to avoid anomalies in data detected by these sensors. Sensor maintenance is performed by humans. This is a special concern because there are dangerous conditions caused by human and equipment factors in the steel box girder area, which may result in work accidents and occupational diseases.

The steel box girder area has limited access, with only one entrance and one exit. Because it is restricted and there are hazards originating from components in the area, work environment, and unsafe behavior, hazard identification and risk assessments are necessary. This study aimed to

identify potential hazards, conduct a risk assessment, and determine the level of risk. Hazard Identification and Risk Assessment (HIRA), which is part of the HIRADC, can be used as a basis for determining controls to minimize the consequences of potential hazards that threaten the safety and health of workers who carry out work in the steel box girder area of the Suramadu Bridge.

METHOD

A qualitative risk assessment method was adopted in this study with the collection of primary and secondary data. Secondary data were obtained from the job safety analysis (JSA) document issued by the Operational Service of the Suramadu Bridge's Structural Health Monitoring System (SHMS). Job safety analysis is a document that contains an analysis of hazards and risks that arise owing to potential hazards in a job to identify hazards before an incident occurs. In this study, job safety analysis was used as the basis for hazard identification and risk assessment (HIRA) because it explains the potential hazards and risks in sensor maintenance in the steel box girder area of Suramadu Bridge. After the compilation of hazard and risk identification based on the job safety analysis document, the next step was to assess the risks in hazard identification and risk assessment (HIRA) from the primary data obtained from interviews with informants.

The informants in this study were key informants, consisting of five experts and main informants involving five technicians. Key informants were selected based on the inclusion criteria of experts who had participated in the preparation of job safety analysis documents and had carried out sensor maintenance in the steel box girder area. Meanwhile, the main informants were selected based on the inclusion criteria of technicians who had carried out sensor maintenance work in the steel box girder area of the Suramadu Bridge. This study is descriptive research that provides an overview of certain conditions. Based on the data collection, this study used a cross-sectional analysis. The variables in this study included hazard identification, risk assessment, and risk level determination in the maintenance work of the steel box girder area of Suramadu Bridge. This study was approved by the Health Research Ethics Commission of the Faculty of Public Health, Universitas Airlangga, with an ethical test number of 152/EA/KEPK/2022.

A risk assessment was performed by determining the level of likelihood and consequences using a risk analysis matrix. The data processing techniques and analyses were based on secondary data, observations, and interviews. The risk level was obtained from a risk analysis table based on AS/NZS 4360:2004 (Ramli, 2010) in Table 1.

In conducting a risk assessment, it is necessary to first determine the likelihood or opportunity criteria and consequence criteria. The criteria for likelihood include events that are almost certain,

Table 1. Risk Matrix

Likelihood	1	2	3	4	5
A	H	H	E	E	E
B	M	H	H	E	E
C	L	M	H	E	E
D	L	L	M	H	E
E	L	L	M	H	H
	Consequences				

Source: AS/NZS 4360:2004 (Ramli, 2010)

Table 2. Likelihood Criteria

Level	Criteria	Description
A	Almost certain	May occur at any time
B	Likely	Often occurs
C	Possible	May occur occasionally
D	Unlikely	Less likely to occur
E	Rare	Almost never/ rarely occur

Source: Likelihood Criteria AS/NZS 4360:2004 (Ramli, 2010)

Table 3. Consequence Criteria

Level	Criteria	Description
1	Insignificant	No injuries occur, minor financial loss
2	Minor	Mild damage, moderate financial loss
3	Moderate	Moderate injuries, medical treatment needed, major financial loss
4	Major	Severe injuries to more than one person, major financial loss, interruption of production
5	Severe	Fatality > one person, massive loss and extended impact, all activities halted

Source: : Consequence Criteria AS/NZS 4360:2004 (Ramli, 2010)

likely, possible, unlikely, or rare. The consequence criteria can be categorized as insignificant, minor, moderate, major, or severe. After determining the likelihood and consequence criteria, the level of risk in the steel box girder area, observed through the risk matrix in Table 1, was determined. The likelihood and consequence criteria are listed in Tables 2 and 3, respectively.

RESULTS

In this research, the job safety analysis method was used as the risk identification technique, in which the documents were issued by the operational services of the Structural Health Monitoring System of the Suramadu Bridge. Job safety analysis documents can help determine potentially hazardous events in the work carried out by workers in the steel box girder work area. In addition to applying job safety analysis, interviews with experts and technicians who frequently visited and worked in the steel box girder area were conducted to determine the conformity between the field parameters and existing documents. Hazard identification was performed from the worker mobilization process to work completion in the steel box girder area. This study identified 15 potential hazards in a steel box girder work area.

Based on the risk assessment results presented in the form of a diagram in Figure 1, there are 3 (three) risk levels identified in sensor maintenance work in the steel box girder area of Suramadu Bridge, namely low risk (16%), medium risk (79%), and high risk (5%).

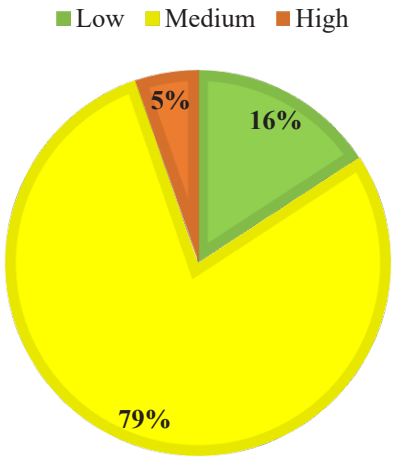

Figure 1 Risk Category Diagram

Worker Mobilization

The identified hazard during worker mobilization to the manhole steel box is high-speed motorists, which results in the risk of workers being hit. The mobilization of workers leaving the Suramadu Bridge is carried out in the morning between 09.00 a.m. - 10.00 a.m. Meanwhile, the mobilization of workers back from the Suramadu Bridge to the office occurs between 02.00 p.m. and 03.00 p.m. There is a risk of workers being hit by vehicles that fall into the level E likelihood criteria and level three consequence criteria with a medium risk level.

Opening Manhole Steel Box Girder

The identified hazard during the opening of the steel box girder manhole was the weight of the manhole door. Another identified danger involved in opening the manhole steel box girder door is the incorrect position of the worker when opening it. In this activity, there is a risk of injury due to the potential danger of heavy loads on the manhole door, which falls into the level E likelihood criteria and level three consequence criteria with a medium risk level. On the other hand, the potential danger of wrong work position when opening the manhole door with the risk of injury falls into the level E likelihood criteria and level three consequence criteria with a medium risk level.

Entering Steel Box Girder Area

The hazard identified during the activities of workers entering the steel box girder area is when workers descend the steel box girder manhole ladder. The slippery manhole stairs often cause workers to slip. When entering the steel box girder area, there is a risk of falling when descending the manhole ladder with level E likelihood criteria and level two consequence criteria at a low-risk level. This risk arises as a result of the potential hazard of the slippery manhole steel box girder ladder.

Walking To Sensor Location

The activity of Walking to the sensor location is an activity where workers walk in the steel box girder area to the sensor location to perform sensor maintenance based on the established work plan. The identified hazards were the presence of steel components at the top of the steel box girder, the

presence of iron components at the bottom of the steel box girder, and limited oxygen in the steel box girder, which is a confined space area.

In this activity, the risk of head injury falls into the level B likelihood criteria and level one consequence criteria with a medium risk level. There is also a tripping risk with level B likelihood criteria, and level one consequence criteria with a medium risk level. In addition, there is a risk of respiratory distress with level C likelihood criteria and level two consequence criteria with a medium risk level. There is another risk of workers experiencing dizziness with level C likelihood criteria and level two consequence criteria with a medium risk level.

Working on Sensor Maintenance

The hazard identified during sensor maintenance activities is the presence of an electrical source and limited oxygen in the steel box girder, which is a confined space area. Confined space areas have the same entrance and exit; therefore, the oxygen is limited.

In this activity, there is a risk of electric shock that falls into the level D likelihood criteria and level two consequence criteria at a low-risk level. The next risk is the occurrence of fire, which falls into the level E likelihood criteria and level five consequence criteria at a high-risk level. The risk of respiratory distress is also identified in this activity, which falls into level C likelihood criteria and level two consequence criteria with a medium risk level. Furthermore, the risk of workers experiencing dizziness falls into the level C likelihood criteria and level two consequence criteria with a medium risk level.

Walking to Manhole Door

After workers finish performing sensor maintenance, the next activity is to return to the manhole steel box girder door to exit the area. The identified hazards from this activity were steel components at the top of the steel box girder, iron components at the bottom of the steel box girder, and limited oxygen in the steel box girder.

In this activity, there is a risk of workers hitting their head, which falls into the level B likelihood criteria and level one consequence criteria with a medium risk level. The next risk is stumbling, which falls into the level B likelihood criteria and level one consequence criteria with a medium risk level. Meanwhile, the risk of respiratory distress falls into the level C likelihood criteria and level two consequence criteria with a medium risk level. The last risk is the risk of dizziness experienced by workers, which falls into the level C likelihood criteria and level two consequence criteria with a medium risk level.

Getting Out of Steel Box Girder Area

The identified hazard while exiting the steel box girder area is the climbing of stairs to the steelbox girder manhole door. When entering the steel box girder area, workers must pass through the manhole ladder to exit from the steel box girder area.

In this activity, there is a risk that falls into level E likelihood criteria and level two consequence criteria at a low-risk level. Workers must climb the same stairs to exit and enter the steel box girder area, because it is a confined space.

Closing Manhole Door

During this activity, workers close the manhole steel box girder door after completing the job. The identified hazards were the weight of the load on the manhole door and the wrong position when closing the steel box girder manhole door.

In closing the manhole door, the risk involved in this activity includes an injury risk due to the heavy load on the manhole door, which falls into level E likelihood criteria and level three consequence criteria with a medium risk level. The next risk is an injury due to an incorrect work position when closing the manhole door, which falls into the level E likelihood criteria and level three consequence criteria with a medium risk level.

DISCUSSION

The Suramadu Bridge Steel Box Girder Area

The steel box girder area is one of the areas at the Suramadu Bridge where the site can be accessed through a manhole door located between the emergency lane for cars and the bicycle lane. A ladder was attached to the manhole to reach the steel box girder area. Several sensors were installed in the steel box girder area, including an accelerometer, FBG strain, ATRH, and GPS sensors. The work activities in the steel box girder area are not carried out on a daily basis, but depend on the schedule determined in the initial work plan.

Worker Mobilization

Mobilization of workers includes travelling to the steel box girder manhole and returning to the office after completing work in the steel box girder area, and vice versa. Mobilization is carried out using motorized vehicles such as cars or motorbikes. The speed of motorized vehicles is often a cause of traffic accidents. From the results of the analysis of road traffic accident data to 2007-2016, most accidents occurred between 12.00 p.m. and 06.00 p.m. with 44% of cases since the period is a productive time for road traffic in Indonesia (Saputra, 2017). Another study on accidents based on the time of occurrence on Yos Sudarso Pekanbaru Street during the 2014-2018 period stated that the accident occurred in the morning between 06.00 a.m. - 12.00 p.m (Yandi *et al*., 2020).

Some of the factors that cause road traffic accidents are low discipline of drivers, lack of technical maintenance of vehicles by vehicle owners, lack of safety facilities in vehicles, accident-prone areas, poor bridge conditions, lack of traffic signs, and geometry in the form of cornering, downhill roads, and uphill roads (Saputra, 2017). One of the unsafe factors that causes accidents on highways is the condition of the vehicle. Company-owned vehicles used for mobilization must be in good condition, including brakes, tires, lights, rearview mirrors, and other conditions related to the physical vehicle (Sulistyowati *et al*., 2018).

Opening Manhole Steel Box Girder Door

To enter the steel box girder area of the Suramadu Bridge, the only access is through a manhole. The manhole steel box girder is located between the motorcycle and emergency car lanes. The manhole steel box girder was protected by a cover made of iron, weighing more than 20 kg. Therefore, to open the manhole door, it must be carried out by two people owing to its weight. When the manhole door is not properly lifted, it may cause injuries to the workers' hands and spine.

A study by Okello *et al*. (2020) on the prevalence and predictors of work-related musculoskeletal disorders among workers of a gold mine in South Kivu, Democratic Republic of Congo, revealed a high prevalence of work-related musculoskeletal disorders associated with workers who carry out heavy lifting. Meanwhile, a study conducted by Rumangu *et al*. (2021) indicated a relationship between work positions and musculoskeletal complaints among palm sugar farmers in Rumoong Atas Village, Tareran District. The work positions of farmers when lifting weights can cause injuries to their hands and spine.

Entering Steel Box Girder Area

After opening the manhole door, the next step to reach the steel box girder area is to descend the stairs, which have a height of approximately 3 m. A study by Muhlis *et al*. (2021) highlighted that a total of 50 respondents (42%) indicated that the cause of falling or slipping from stairs was slippery stairs.

According to the Regulation of the Ministry of Manpower (2016) No. 9 on Occupational Health and Safety in Work at Height, working at height is a work activity carried out by workers at workplaces on the ground or in waters with different heights and potential falls that can cause injury or death. the Ministry of Manpower in 2014 stated that of the total work accidents experienced by construction workers, 26% were falls from heights (Safitri and Evi, 2017). Working at height must satisfy health and safety requirements, such as planning, work procedures, and Personal Protective Equipment (PPE) (Trianto, 2020).

Walking to Sensor Location

Inside the steel box girder area, particularly at the top and on the sides of the steel box girder. The narrowing of the space in the steel box girder occasionally caused workers to hit the steel component at the top of the steel box girder. A study by Amaliah *et al*. (2021) conducted PT. Nusa Raya Cipta Tbk stated that one type of work accident that occurred was a head bump. Work accidents such as head bumps are caused by unsafe actions. There is a relationship between supervision, motivation, perception, and work instructions and unsafe acts on workers who work at heights at PT. Nusa Raya Cipta Tbk (Amaliah *et al*., 2021).

In addition to the risk of head bumps when walking toward the sensor location for maintenance, there is also a risk of tripping owing to potential hazards, namely iron components or other components in the area under the steel box girder. Huda *et al*. (2021) examined factors related to work accidents in building construction projects involving PT. X in 2020 and discovered that one of the most frequent work accidents is tripping. The study also stated that one of the factors related to the accident was unsafe actions, such as rushing to work, joking and disturbing other workers, and drowsiness.

The steel box girder area is a confined space area in which there is only one way in and out, namely, the manhole. One of the dangers of confined spaces is the limited amount of oxygen, which may cause workers to experience respiratory problems and dizziness (Sulardi and El-Ridho, 2019). The steel box girder area was located along the main bridge of the Suramadu Bridge. The duration to reach the intended sensor depends on the distance between the sensor and manhole door.

Working on Sensor Maintenance

After arriving at the intended sensor location, the workers perform sensor maintenance. During sensor maintenance work, there is a potential hazard, namely, the presence of an electrical source; hence, the risk that can occur is an electric shock. Ariyani *et al*. (2021) examined potential work accidents at PT. PLN (Persero) Sumbawa discovered that the potential danger of electric shock occurs due to a lack of vigilance and knowledge among workers when carrying out work procedures, causing inappropriate actions. In addition to the danger of being electrocuted, fire hazards can occur during sensor maintenance. The interviews conducted during the study indicated that workers occasionally committed unsafe acts in the work area, such as smoking. Research conducted by Huda *et al*. (2021) found that one of the causes of work accidents is unsafe behavior, in this case smoking. Smoking in an inappropriate place, particularly in the steel box girder area, which has many sensors and electrical cables, can trigger a fire.

Fire risk was included in the high-risk category. Based on the concept of As Low As Reasonable Practicable (ALARP), high risk is unacceptable Ramli (2010), hence it is necessary to take preventive measures to reduce the level of risk to an acceptable level.

The steel box girder area is a confined space area; therefore, it has only one entry and exit path. If emergency response efforts are not optimal, a fire will cause huge losses, including the loss of life. In addition, if a fire occurs, the asset loss will include many assets, such as sensor components in the steel box girder area. A fire is an emergency situation that causes various types of losses, namely human loss, property loss, productivity loss, and social loss (Mangindara *et al*., 2021).

From the results of the interviews, it was discovered that there were workers who carried out unsafe actions that could potentially cause fires, namely smoking, in the steel box girder area. Based on the interview results, cigarette butts were found to be left behind in the steel box girder area, indicating that there were workers smoking in the steel box girder area. In this area, many sensor components and electrical cables are prone to explosion if there is a heat source, such as a lit cigarette butt. Workers who carelessly throw cigarette butts at work can trigger fires and explosions in the workplace(Fajrin, 2019). In a study conducted by Asilah (2020) analyzing the analysis of factors causing work accidents in tofu industry, it was found that 63.6% of workers smoked while doing work. Smoking is a form of unsafe action that potentially endangers workers or other people and causes work accidents (Amanah Ramadhany and Pristya, 2019). Factors related to unsafe actions include knowledge, attitudes, OHS training, supervision, and availability of OHS facilities (Sangaji and Jayanti, 2018).

Some of the causes of fires include cigarettes and electricity Rahmat *et al*.(2018), while other factors that may cause fires are the electrical components themselves. In the steel box girder area, many electrical components can potentially cause fires. The potential danger of short circuits of electric currents, unprotected wiring, and untidy cables that can cause short circuits or other damage to wires can potentially cause fires (Andu, 2019).

In addition to the previously mentioned hazards, other potential hazards in sensor maintenance include respiratory problems and dizziness. Similar to walking to the intended sensor location, sensor maintenance can also trigger respiratory problems and dizziness, especially if workers work for a long time. One of the potential hazards found in confined spaces is the lack of oxygen experienced by workers (Sulardi and El-Ridho, 2019). Another study by Ramdan (2017) on hazard identification and risk assessment in the boiler division using the hazard identification, risk assessment, and risk control (HIRARC) method found that one of the physical hazards in the boiler division, which is also a confined space, is respiratory distress.

Based on the interviews, respiratory problems were often felt by the workers. Occasionally, they also experienced dizziness during work, especially after a prolonged period in the steel box girder area. This may occur because workers are in a confined space; therefore, they have limited oxygen. Oxygen is a basic requirement for living organisms. If a person experiences a lack of oxygen, the condition is referred to as hypoxia Limanan *et al*. (2020) and can

be detected by checking oxygen saturation. If oxygen saturation decreases, there is less hemoglobin that binds to oxygen; hence, a person can feel a sense of tightness, dizziness, and restlessness (Bagus *et al*., 2019).

Walking to Manhole Steel Box Girder Door

After the workers have completed sensor maintenance work, they proceed to walk toward the manhole door to leave the steel box girder area. Similar to walking to the sensor location, potential hazards are steel components at the top of the steel box girder, which may cause head bumps. At the same time, the presence of steel, iron, or other elements in the walking area as well as the manhole door, depending on the location of the sensor being worked on, may cause workers to trip. Work accidents such as tripping are not fatal. However, companies must minimize the occurrence of more serious accidents (Huda *et al*., 2021). Other potential hazards include respiratory problems and dizziness due to limited oxygen in the steel box girder work area. Andrizal *et al*. (2020) found that the most common potential hazard in confined spaces is the lack of oxygen experienced by workers.

Getting Out of Steel Box Girder

Similar to entering the steel box girder area, workers must go through the manhole by climbing the manhole ladder. The potential danger of this activity is climbing stairs toward the manhole door, which may increase the risk of falling from the stairs. Based on the results of the interviews, workers were occasionally in a hurry or not fully concentrating because they were tired; they were not careful when climbing the stairs, causing a fall or near a fall from the stairs. One of the causes of work-related accidents is unsafe action. Unsafe actions can be affected by fatigue (Bangun and Indriasari, 2021). Fatigue at work is a vital aspect because it plays a role in decreasing workplace concentration, as it can endanger workers (Ningsih and Nilamsari, 2018).

Closing Manhole Steel Box Girder Door

After all workers on duty leave the manhole steel box girder, the next step is to close the manhole door, which is similar to the opening of the manhole door. When closing the door, the two workers shared the load from the manhole door. If workers do not have sufficient knowledge on how to lift the load correctly, injuries to the wrist or spine can occur. When a person or a few people move a work object manually and it is not done ergonomically, work accidents may occur, resulting in tissue damage due to excessive load (Wahyu Oktavia *et al*., 2018).

CONCLUSION

In this study, 15 potential hazards were identified in the sensor maintenance work in the steel box girder area of Suramadu Bridge. Meanwhile, the risk assessment identified 19 risks, including three risks with a rate of 16% (low-risk category), 15 risks with a rate of 79% (medium category), and one risk with a rate of 5% (high-risk category). The potential hazard included in the high-risk category was the presence of fire risk.

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REFERENCES

Amaliah, S. *et al*. (2021) 'Faktor-faktor yang Berhubungan dengan Unsafe Action pada Pekerja Ketinggian di Proyek Pembangunan Apartement PT Nusa Raya Cipta TBK - Tangerang Tahun 2021', *Nuevos Sistemas de Comunicación e Información*, 18(September), pp. 2013–2015.

Amanah Ramadhany, F. and Pristya, T.Y. (2019) 'Faktor-Faktor yang Berhubungan dengan Tindakan Tidak Selamat (Unsafe Act) pada Pekerja di Bagian Produksi PT Lestari Banten Energi', *Jurnal Ilmiah Kesehatan Masyarakat*, 11(2), pp. 199–205.

Andrizal, Yani, P.I. and Antonisfia, Y. (2020) 'Monitoring Dan Kontrol Kadar Co2 Dalam Ruangan Berbasis Sistem Penciuman Elektronik', *in Seminar Nasional Terapan Riset Inovatif (SENTRINOV)* Ke-6, pp. 388–395.

Andu, F.A. (2019) 'Kajian Pengawasan Listrik Dalam Penanggulangan Kebakaran', *Jurnal Ilmiah Media Engineering*, 9(1), pp. 1–10.

Ariyani, R., Suarantalla, R. and Mashabai, I. (2021) 'Analisa Potensi Kecelakaan Kerja Pada PT. PLN (PERSERO) Sumbawa Menggunakan Metode Hazard and Operability Study (HAZOP)', *Jurnal Industri dan Teknologi Samawa*, 2(1), pp. 11–21.

Bagus, D. *et al*. (2019) 'Sistem Deteksi Gejala Hipoksia Berdasarkan Saturasi Oksigen dan Detak Jantung Menggunakan Metode Fuzzy Berbasis Arduino', *Jurnal Pengembangan Teknologi Informasi dan Ilmu Komputer*, 3(2), pp. 1925–1933.

Bangun, S. and Indriasari, I. (2021) 'Faktor-faktor yang Berhubungan dengan Tindakan Tidak Aman pada Pekerja di Proyek Pembangunan Apartemen Evencho Margonda', *Jurnal Teknik*, 10(1), pp. 133–146.

Candrianto (2020) *Pengenalan Keselamatan dan Kesehatan Kerja*. Malang: Literasi Nusantara.

Fitra, M. (2021) *Analisis Risiko Keselamatan Dan Kesehatan Kerja (ARK3)*. Jakarta: Azkiya Publishing.

Hasibuan, A. *et al*. (2020) *Teknik Keselamatan dan Kesehatan Kerja*. Medan: Yayasan Kita Menulis.

Huda, N. *et al*. (2021) 'Faktor-Faktor Yang Berhubungan Dengan Kecelakaan Kerja Pada Proyek Pembangunan Gedung Di PT.X Tahun 2020', *Jurnal Kesehatan Masyarakat*, 9(5), pp. 652–659.

Kristiana, R. *et al*. (2018) 'Identifikas Penyebab Kecelakaan Kerja Pada Proyek Konstruksi Bangunan Gedung Tinggi', *Jurnal Forum Mekanika*, 7(1), pp. 20–28.

Limanan, D., Ferdinal, F. and Yulianti, E. (2020) 'Pengaruh Hipoksia Sistemik Kronik terhadap Aktivitas Spesifik Enzim Katalase pada Darah dan Paru Tikus Sprague Dawley setelah diberi Daun Ara', *Tarumanagara Medical Journal*, 3(1), pp. 55–62.

Mahawati, E. *et al*. (2021) *Keselamatan Kerja dan Kesehatan Lingkungan Industri*. Medan: Yayasan Kita Menulis.

Malau, P. (2022) Corporate Crime Kecelakaan Di Tempat Kerja.Sidoarjo: Zifatama Jawara.

Mangindara, Samad, M.A. and Andriani, R. (2021) Kesiapsiagaan Rumah Sakit Dalam Upaya Penanggulangan Bencana Kebakaran. Makassar: Tohar Media.

Ministry of Manpower (2016) Peraturan Menteri Ketenagakerjaan No.9 Tahun 2016 Tentang Keselamatan dan Kesehatan Kerja dalam Pekerjaan pada Ketinggian. Jakarta: Ministry of Manpower of The Republic of Indonesia

Muhlis, D.Q., Umam, K. and Tirta, A. (2021) 'Pengendalian Resiko Bahaya Naik Turun Tangga Dengan Memasang Anti Toe Slip Dan Penerapan Three Point Contact Di Area Sru Pertamina RU IV Cilacap', *Jurnal TAMBORA*, 5(1), pp. 55–59.

Ningsih, S.N.P. and Nilamsari, N. (2018) 'Factors Relating To Work Fatigue in Locomotive Dipo Workers Pt. Kereta Api Indonesia (Persero)', *Journal of Industrial Hygiene and Occupational Health*, 3(1), pp. 69-82.

Okello, A. *et al*. (2020) 'Prevalence and predictors of work-related musculoskeletal disorders among workers of a gold mine in south Kivu, Democratic Republic of Congo', *BMC Musculoskeletal Disorders*, 21(1), pp. 1–10.

Poetra, R.P. (2021) *Pengantar Kesehatan Dan Keselamatan Kerja (K3)*. Makassar: Tohar Media.

President Republic of Indonesia (1970) Undang-Undang No.1 Tahun 1970 Tentang Keselamatan Kerja. Jakarta: President Republic of Indonesia.

Rahayu, E.P., Ratnasari, A.V. and Wardani, R.W.K. (2022) *Kesehatan dan Keselamatan Kerja*. Edited by M.A. Susanto. Sukoharjo: Pradina Pustaka.

Rahmat, A., Prianto, E. and Sasongko, S.B. (2018) 'Studi Evaluasi Model Bentuk Atap Dan Fenomena Kebakaran Penyebab Listrik Pada Rumah Tinggal Menengah Ke Bawah Di Pemukiman Padat', *Jurnal Arsitektur ZONASI*, 1(2), pp. 112–122. Available

Ramdan, F. (2017) 'Identifikasi Bahaya Dan Penilaian Risiko Pada Divisi Boiler Menggunakan Metode Hazard Identification, Risk Assesment And Risk Control (HIRARC)', *Journal of Industrial Hygiene and Occupational Health*, 1(2), pp. 161–177.

Ramli, S. (2010) *Pedoman Praktis Manejemen Risiko Dalam Perspektif K3 OSH Risk Management*. Jakarta: Dian Rakyat.

Rumangu, O., Paturusi, A. and Rambitan, M. (2021) 'Hubungan Posisi Kerja Dengan Keluhan Musculoskeletal Pada Petani Gula Aren Di Desa Rumoong Atas', *PIDEMIA: Jurnal Kesehatan Masyarakat Unima*, 2(2), pp. 38–43.

Safitri, N. and Evi, W. (2017) 'Penerapan Risk Management pada Pekerjaan di Ketinggian Berdasarkan SNI ISO 31000: 2011', *Higeia Journal of Public Health Research and Development*, 1(2), pp. 77–88.

Sangaji, J. and Jayanti, S. (2018) 'Faktor-Faktor Yang Berhubungan Dengan Perilaku Tidak Aman Pekerja Bagian Lambung Galangan Kapal PT.X', *Jurnal Kesehatan Masyarakat*, 6(5), pp. 563–571.

Saputra, A.D. (2017) 'Studi Tingkat Kecelakaan Lalu Lintas Jalan di Indonesia Berdasarkan Data KNKT (Komite Nasional Keselamatan Transportasi) Dari Tahun 2007-2016', *Warta Penelitian Perhubungan*, 29(2), pp. 179–190. Available

Sekar Candra Sulistyowati, S. *et al*. (2018) 'Analisis Faktor Penyebab Kecelakaan Dalam Hubungan Kerja PT X Berdasarkan Teori Loss Causation Model (Studi Kasus Pada Karyawan Bagian Warehouse)', *Jurnal Kesehatan Masyarakat*, 6(5), pp. 635–642.

Soekiswara, T.E.F. (2020) 'Faktor Kecelakaan dan Keselamatan Kerja Pada Penggunaan Crane di Proyek Konstruksi', *Jurnal Menara*, 18(2), pp. 42–50.

Sulardi, S. and El-Ridho, N.K. (2019) 'Hazard Identification and Prevention Methods on Work in Confined Spaces', *Jurnal Ilmiah Keselamatan, Kesehatan Kerja dan Lindungan Lingkungan*, 5(2), pp. 142–151.

Sumarna, U., Sumarni, N. and Rosidin, U. (2018) *Bahaya Kerja Serta Faktor-Faktor yang Mempengaruhinya*. Sleman: Deepublish Publisher.

Trianto, W.M. (2020) 'Bekerja di Ketinggian pada Pekerjaan Konstruksi – Peraturan dan Tindakan Pencegahan', *Majalah Ilmiah Swara Patra*, 10(1), pp. 39–50.

Wahyu Oktavia, C., Suprata, F. and Prasetya, W. (2018) 'Sosialisasi Perbaikan Metode Kerja Untuk Menghindari Terjadinya Low Back Pain Dan Meningkatkan Produktivitas Kerja Pada Pangkalan Elpiji Puskop Bintara', *Jurnal Pengabdian Kepada Masyarakat MADANI*, 4(2), pp. 92–96.

Yandi, T., Lubis, F. and Winayati (2020) 'Analisis Karakteristik Kecelakaan Lalu Lintas pada Jalan Yos Sudarso Kota Pekanbaru', *Jurnal Teknik*, 14(1), pp. 17–21.