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Osh risk management of tank sinking procedure using bow tie analysis on the construction of a shell gasoline station in Surabaya

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ABSTRACT

Introduction: The rate of work accidents in the construction sector is still high. Such a situation has led to the need for risk management in the area of Occupational Safety and Health (OSH). This study is aimed at finding the OSH risk management of the tank sinking procedure using Bow Tie Analysis method in the construction of a Shell Gasoline Station in Surabaya.

Methods: This is a qualitative descriptive study with case study design. The subjects of the study were the employees of PT Usaha Jaya Engineering who worked on the Tank Sinking procedure in the construction of a Shell Gasoline Station in Surabaya with the minimum service period of 2 years and with a total number of 7 people. Data collection was executed using primary data derived from interviews and field observation as well as secondary data in the forms of supporting documents from the company.

Results: As many as 9 hazards were found in the tank sinking procedure in the construction of a Shell Gasoline Station in Surabaya. These hazards were caused by 5 factors, i.e., human, machine/equipment, method, material, and environment. The possible consequence of such hazards is that the employees may experience light to serious injuries and even fatality. Prevention and mitigation measures might be implemented in 4 hierarchical steps of risk management, i.e., substitution, technical management, administrative management, and personal protective equipment (PPE). This study found 6 escalation factors and the barrier of escalation factor in the tank sinking process.

Conclusion: The tank sinking procedure in the construction of a Shell Gas Station in Surabaya was a job with risks of work accident. Prevention and mitigation measures derived from the Bow Tie analysis might be implemented to prevent work accidents from occurring.

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1. Introduction

The development in construction sectors has progressed at a highly accelerated pace in line with economic development in this era of globalization. Construction is one of the most dangerous jobs and has contributed to the number of work accidents both in the world and in Indonesia. Data from the (International Labour Organization, 2018) showed that there have been as many as 374 million cases of work accidents. As high as 70% of them have led to fatalities and permanent disabilities.

The causes of such a high rate of work accidents in the construction sector are the poor risk management, design errors, and the unavailability of personal protective equipment (PPE) by the project management (Hidayat & Siswoyo, 2020). Risk management and organization factors are the "holes" (shortcomings) in the defense system of work safety. Hence, a decent system is highly required and should involve all of the components to make it capable of preventing work accidents from occurring (Simanjuntak & Praditya, 2012).

The occurrence of work accidents in a construction area would become one of the causes of the disruptions to the project activity. Wrong management could lead to the financial loss for the company (economic cost). Hence, risk management of OSH is required in order that the risks are handled properly so that the impacts could be minimized (zero accident). Therefore, it is mandatory for the execution of a construction work to implement risk management of the workplace as a form of risk planning and control in the project. The objective and target of risk management of occupational safety and health is the formulation of an OSH system which involves all components in the workplace so that work accidents can be prevented or minimized, and an efficient, productive, and safe workplace is actualized (Ramli, 2020).

Based on the data from the preliminary study conducted in October 2021 by interviewing the HSSE Manager, PT Usaha Jaya Engineering was one of the subsidiaries of PT Usaha Jayamas Bhakti whose businesses ran in the areas of contractor services and general supplier. At that time, they were engaged in the construction of a Shell Gasoline Station in Surabaya with a total workforce of 25 employees. The construction of the Shell Gasoline Station was one of the construction projects with high risk of work accidents as concluded from the results of the risk analysis by the company using HIRARC method.

One of the risk control measures by the company to prevent the occurrence of work accidents was the implementation of administrative control. The administrative control implemented was that the workers were required to identify the risks of the job to be performed using the documents of Permit to Work (PTW), Work Clearance Form (WCF), and Job Hazard Analysis (JHA). The weakness found with this measure was that the documents were written in formal language which were not made simple and were not easily understood by the employees (workers). It was with such background that the researchers were encouraged to conduct a study entitled OSH Risk Management of Tank Sinking Procedure Using Bow Tie Analysis on the Construction of a Shell Gasoline Station in Surabaya.

2. Research Method

This is a qualitative descriptive study with a case study design. A qualitative study is designed to inform the researchers of how (process) and why (meaning) a phenomenon takes place (Cooper & Schindler, 2017). This study applied the purposive sampling method to select the research subjects. This method is a technique of determining the samples with certain consideration in accordance with the researcher's objectives (Mamik, 2015). The research subjects were the employees of PT Usaha Jaya Engineering who worked on the Tank Sinking procedure in the construction project of a Shell Gasoline Station in Surabaya with a minimum service period of 2 years and consisted of 7 people. The risk analysis was performed using the method of bow tie analysis. Bow Tie Analysis is a method which is applied to identify the risks with easily understood visualization by combining the causes and the consequences (British Standard Institution, 2018). Edgar Dale in the book entitled "Audiovisual Method in Teaching" states that humans would obtain 3x (three times) better understanding with the use of visual media compared to reading (Brissel et al., 2013). The primary data of the research were collected using observations and interviews. Whereas, the

secondary data were derived from the information provided by PT Usaha Jaya Engineering. The secondary data used were those of work accidents, man hours, sickness absenteeism report, Job Hazard Analysis (JHA) documents, Permit to Work (PTW), Work Clearance Form (WCF), company profile, and other supporting information. The data collected from the observation and interviews on the risks of occupational safety and health in the tank sinking procedure were presented in the bow tie section.

3. Results and Discussion

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can be drawn.

3.1. Results

Tank sinking procedure consisted of 5 stages, i.e. preparation, excavation, iron framework installation, tank lifting and lowering, and burying.

3.1.1. OSH risk management at preparation stage

There were 2 hazard risks at this stage, i.e hazard from grinding blades which might cut through the hands and hazard from the exposure to sunlight and UV light which might cause dehydration and fatigue to the workers. The first cause of the hazard was the workers' failure in wearing PPE and the possible impacts were that the workers would lose time and the work would be disrupted. The second cause was the climate factor in which hot weather was existent. This factor could cause the workers to experience fatigue and loss of concentration at work. In relation to the first hazard, the preventive and mitigative measures that could be taken were inspection of the workers by the OSH team, application of PPE, development of safe operational procedure by the OSH team, and provision of first/medical aids. For the second hazard, there were 4 preventive or barrier measures to deal with, i.e., preparation of an effective break (rest) schedule for the workers, application of PPE, provision of first aid, and provision of drinking water for the workers by the company. The escalating factors at the preparation stage were the workers refusal to apply PPE and errors in the development of operational procedures. For each of the escalating factors, the preventive measures to take consisted of organizing OSH campaigns, inspection by OSH team, and monitoring by supervisors in the formulation of operational procedures.

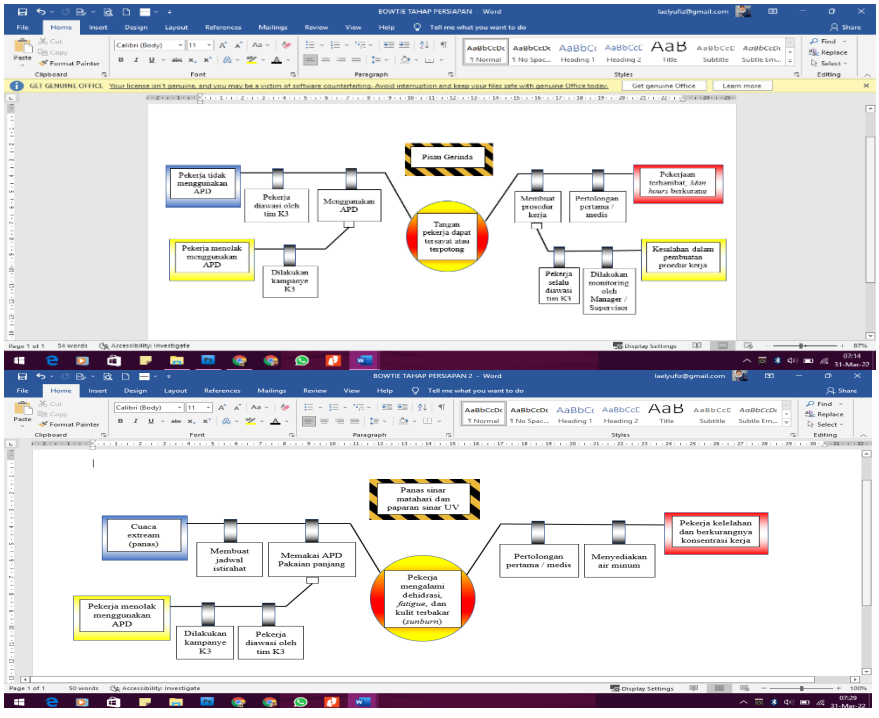

Figure 1. OSH risk management of preparation activity

3.1.2. OSH risk management at the excavation stage

This stage presented 3 hazards, i.e., fall of dug soil, use of excavator, and exposure to dust. These three hazards might end up in the peak incident of excavator mired into the digging, workers suffering from severe headache, low back pain, deafness, respiratory infection, and eye irritation. The first hazard might be attributed to soil stability, pressure on the digging area from the surrounding buildings, and type of excavator in operation. The possible impacts included (1) operators hitting the excavator cabin, being hit by the falling excavator or falling dug soil, and fatality, (2) distraction on workers' concentration, (3) workers suffering from breathing difficulties and eye irritation. The second hazard was related to 2 factors, i.e., exposure to vibration/shaking and noise from the engine of the excavator. The possible impacts included the distraction on workers' concentration and the operator's inability to listen to the flagman's instructions. The third hazard was mainly due to the arid/barren area of the project so that the possible impacts include workers' breathing difficulty and eye irritation.

The preventive barrier measures to deal with the dug soil falling hazard might include application of *cone penetration test,* use of long boom type of excavator, distance arrangement of excavator placement, and installation of double piles. The preventive barrier measures for the hazards from the operation of the excavator might include preparation of effective work schedule, application of vibration damper on the operator seat, and wearing of PPE of earplugs. Whereas, the preventive barrier measures for the hazards from the exposure to dust could be the application of masks and glasses. The escalating factors in the excavation stage would be the excavator breakdown. The preventive measure would be the inspection of the excavator before the operation.

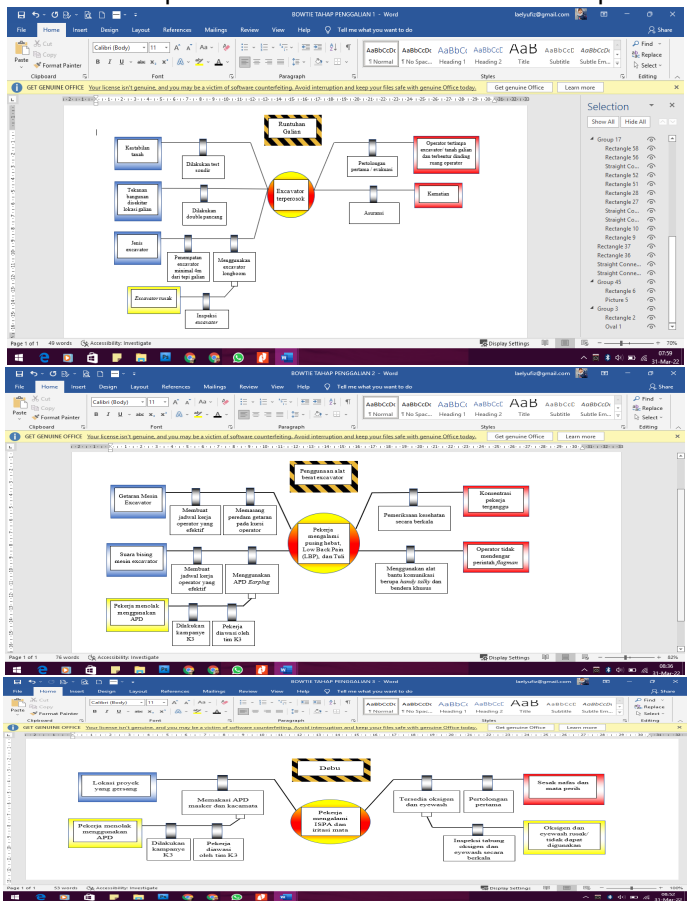

Figure 2. OSH risk management of excavation activity

3.1.3. OSH risk management of iron frame installation

There were 3 hazards at the iron frame installation, i.e., exposure to H2S gas, falling of dug soil, and use of iron wire-mesh iron. The possible peak incidents included the workers being pinched in the wire-mesh, buried under digging soil, gas poisoning, and fatality. The first hazard was caused by the natural factor of abrupt emission of dangerous gas from the digging area. The inhalation of the gas by the workers might cause nausea, vomiting, headache, and hypoxia. The second hazard was caused by soil consistency which may lead to injury and fatality of the workers. The last hazard at this stage was caused by the workers' loss of concentration or fatigue which may lead to the loss of man hours and delay of work.

The preventive barrier measure which could be done in relation to the first hazard was the inspection of the gas level in the digging area using a gas detector from the time before the workers start the job until they finish it. Whereas, the mitigation measures included the provision of first aid and provision of respirator gas masks as the PPE. The preventive barrier measures for the second hazard might include the installation of geotextile and installation of double piles. Whereas, the preventive barrier measures for the third hazard might include the preparation of efficient break schedules by the OSH team and periodical health inspection for the workers. The escalating factors at this stage might include invalidity of the gas detector and workers refusal to wear the PPE. For such cases, the preventive barrier measures might include periodical calibration of the measurement device and OSH campaign and inspection by the OSH team for the workers.

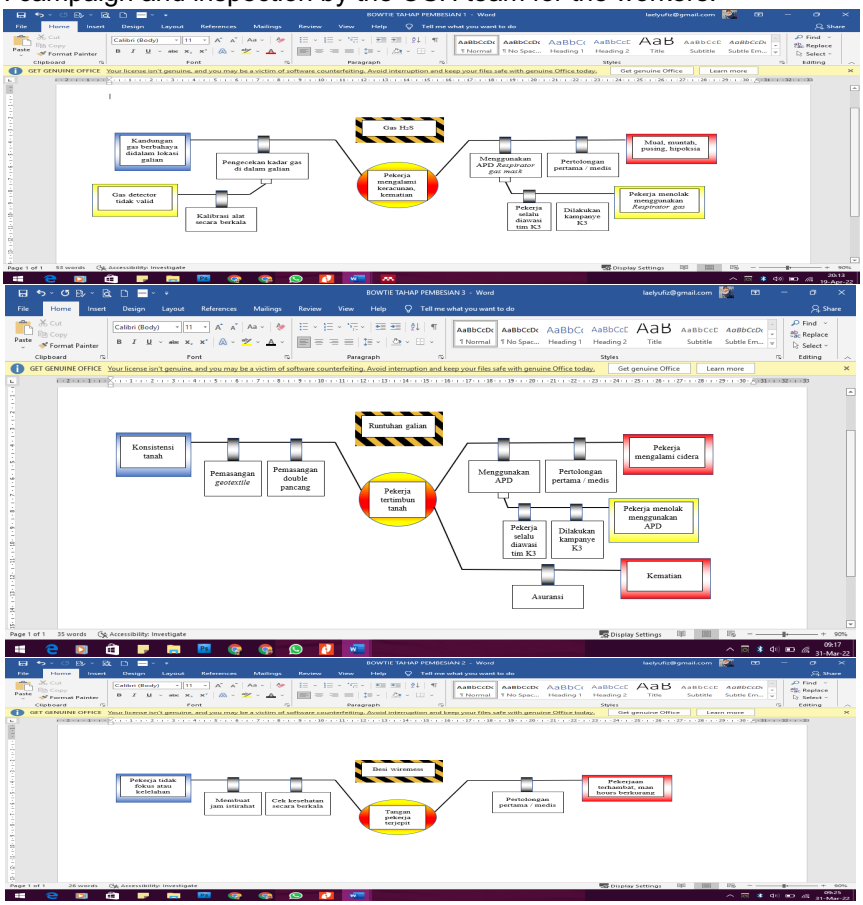

Figure 3. OSH risk management of iron frame installation

3.1.4. OSH risk management of tank lifting and lowering

Lifting and lowering of the tank stage presented the hazard from the use of crane heavy equipment with the peak incident of rollover/collapse. The risk was caused by failure in the lifting plan, failure in crane inspection, type of soil, and incompetent operator. The possible impact would be the workers hit by falling load, hit by the crane body, and fatality. The barrier preventive measures to be done were monitoring of lifting plans by the consultant team, monitoring of heavy equipment

inspection by the OSH team, implementation of cone penetration test, and inspection on workers by the OSH team. The escalating factor at the lifting and lowering of the tank would be the weather. Rainy weather would greatly impact the cone penetration test which would lead to failure. The barrier preventive measure for this escalating factor would be the installation of double piles.

3.1.5. OSH risk of burying activity

This last stage would present the hazard of incorrect physical posture and repetitive movement while the workers were using hoes which would lead to the peak incident of Musculoskeletal Disorders (MSDs). The hazard at this stage was caused by incorrect physical posture and lengthy work which eventually led to the occurrence of low back pain (LBP) suffered by the workers. The preventive barrier measures to be done would be the formulation of operational procedures and allocation of efficient work schedules. The escalating factor at the burying stage was the errors in the preparation of operational procedures so that the preventive barrier measure for this would be the monitoring of operational procedure preparation by the OSH team.

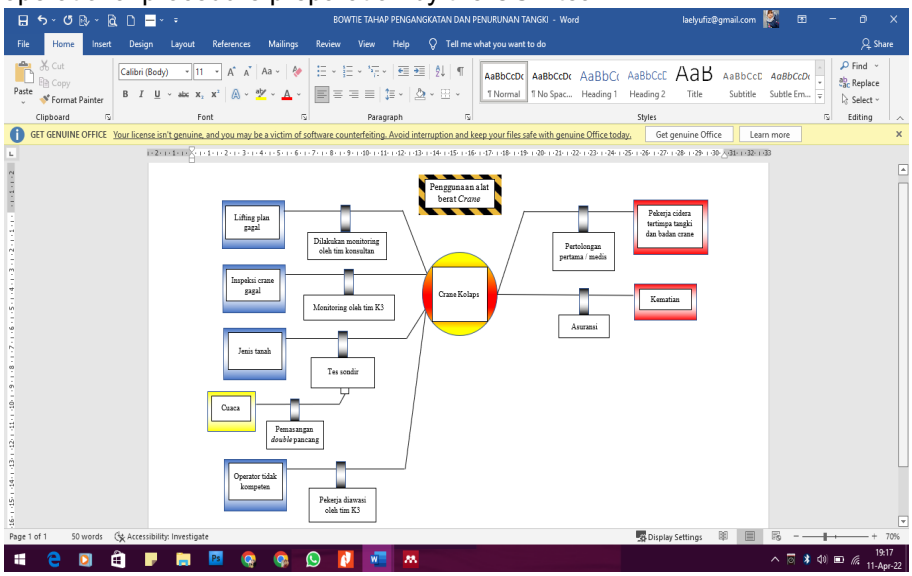

Figure 4. OSH risk management of lifting and lowering of the tank

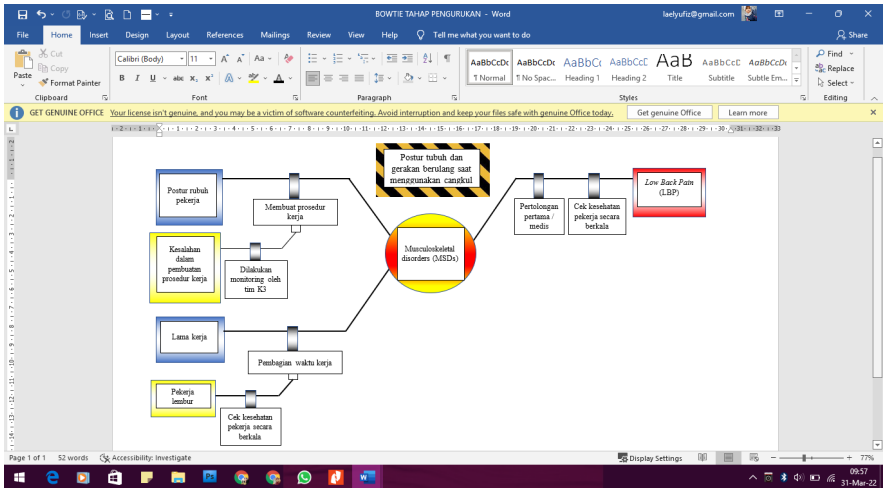

Figure 5. OSH risk management of the burying activity

3.2. Discussions

The condition of every workplace could not be separated from risks and hazards. Risks of various types could be found, from the low level to high level of risks. Work accidents could take place if the existing risks were not managed appropriately. In this study, the researchers had conducted interviews and observations of hazard and risk analysis using the method of Bow Tie

analysis on the tank sinking procedure in the construction of a Shell Gasoline Station in Surabaya. The study was aimed at identifying the hazards and the peak incidents, causing factors and impacts, preventive barriers and mitigation, and escalating factors of a tank sinking procedure. The tank sinking procedure consisted of 5 work stages: preparation, excavation, iron frame installation, tank lifting and lowering, and burying.

3.2.1. Identification of Hazards and peak incidents

The results of the study showed that each stage of work presented various hazards and peak incidents. The researchers encountered 9 hazards in the tank sinking procedure. Based on the findings of such hazards, the researchers were able to identify the possible peak incidents, i.e., hands being cut or pinched, dehydration, fatigue, sunburn, buried under dug soil, low back pain (LBP), noise induced hearing loss (NIHL), respiratory infection, dangerous gas poisoning, hit by falling tank, and musculoskeletal disorders (MSDs).

Theoretically, exposure to a high temperature environment may lead to dehydration and fatigue of workers. Continuous exposure to a hot environment may cause sweat evaporation. Evaporation is a process inside the body to respond to the surrounding high temperature by sweat excretion to keep the temperature inside the body stable. Increasing excretion of sweat which is not compensated with sufficient intake of fluid would lead to dehydration. In addition, frequent exposure to above normal temperature may lead to fatigue, concentration loss, and increasing rate of work errors (Sultan, 2021). This is in line with a study by (Sari, 2017) that a hot work environment leads a worker to lose body fluid so that dehydration and decrease in concentration may occur.

Vibration coming from a heavy equipment is categorized in the type of whole body vibration which has a wide range of frequency of 0.1 - 10000 Hz. Whereas, human sensitivity to accept vibration is limited to the frequency range of 4 - 8 Hz. If the vibration is too strong or too frequent, then it will definitely cause pain in the back and stomach parts (Simarmata et al., 2022). This is in line with a study by (Haikal & Wijaya, 2018) that exposure to whole body vibration from an equipment may lead to fatigue, sleeping disorder, headache, and low back pain (LBP).

Theoretically, Hydrogen Sulfide (H2S) is a poisonous and dangerous gas. It is colorless, flammable, and poisonous. In general, humans are able to identify the existence of hydrogen sulfide gas in the concentration of 0.0005 - 0.003 ppm. If the gas concentration reaches above 500 ppm, then it may cause fatality. Exposure to low concentration of H2S on the skin would lead to the absorption of the gas into blood circulation which in turn could result in irritation of eyes and throat as well as breathing difficulty (U.S. Department of Health and Human Service, 2016). This is in line with a study by (Zulkarnain et al., 2018) that the dangerous gas coming from inside the soil is a result of the decomposition of organic substances by anaerobic bacteria and is disadvantageous to the health especially the respiratory system and may cause fatality.

3.2.2. Analysis of the Causing Factors and the Impacts

Upon the identification of the hazards and their possible peak incidents, it was found that there were a number of the causing factors and the impacts. There are 5 factors that have influence, i.e., human, machine/equipment, method, material, and environment. The impacts were workers' fatigue and decrease in concentration so that the work was delayed, workers' injuries due to being hit by falling excavator and dug soil, workers' breathing difficulties, eye irritation, nausea, vomiting, headache, hypoxia, and low back pain (LBP), and fatality as the most serious one.

Theoretically the causing factors and the impacts found in this study were in line with the fishbone theory that explains the cause and effect of an issue. In this case, the issue was the hazards in each of the procedures of the work. The main causing factors in the fishbone theory consist of 4M + 1E, i.e., machine, man, method, material, and environment.

3.2.3. Preventive Barrier and Mitigation Analysis

The existing hazards could be controlled with risk management. Risk management hierarchy is the steps taken to prevent and control possible hazards. The steps in the risk management hierarchy are elimination, substitution, technical control, administrative control, and provision of personal protective equipment (PPE) (Sari, 2017).

3.2.4. Escalating Factor and Barrier Factor Analysis

In this study, 6 escalating factors had been encountered, i.e., incorrect formulation of operational procedures, workers' refusal to apply PPE, excavator breakdown, dysfunctioned oxygen flask and eyewash appliance, invalid gas detector, and extended working hours. Each of the escalating factors had been analyzed and the preventive barrier measures included the monitoring of the formulation of operational procedures by the OSH team, OSH campaign regarding PPE application, inspection of work tools/equipment, gas detector calibration, and periodical monitoring of occupational health. According to the theory, Bow Tie Analysis basically focuses on the disrupting factors between the causes and the risks, and the risks and the impacts (British Standard Institution, 2018).

4. Conclusion

The results of the occupational safety and health risk analysis of the overall procedures of tank sinking in the construction of a Shell Gasoline Station in Surabaya revealed that:

a. There were 9 possible hazards, i.e., use of grinding machine, exposure to sunlight, falling of dug soil, use of heavy equipment excavator, exposure to dust, exposure to H2S gas, installation of iron wire-mesh, crane collapse, and body posture and repetitive movements in using hoes. In relation to these hazards, there would be the risks of peak accidents which included the hands being cut or pinched, dehydration, fatigue, sunburn, buried under dug soil, low back pain (LBP), noise induced hearing loss (NIHL), respiratory infection, dangerous gas poisoning, being hit by falling tank, and musculoskeletal disorders (MSDs).
b. The causing factors and impacts in the tank sinking procedures were the workers' non-compliance with the application of PPE, decrease in workers' concentration, unsafe acts such as incorrect body postures, tool/equipment factors such as hoe, excavator, crane, grinding machine, etc., failure in lifting plan, high temperature weather, soil stability, presence of dangerous gas in the digging area, and the dry soil condition in the project area. Whereas, the possible impacts were workers' fatigue and decrease in concentration so that the work was delayed, workers suffering from injuries from being hit by falling excavator and dug soil, workers suffering from breathing difficulties, eye irritation, nausea, vomiting, headache, hypoxia, low back pain (LBP), and fatality as the most serious impact.
c. The prevention and mitigation measures in the tank sinking procedure could be implemented in 4 ways. The first was the substitution method, i.e., the use of a long-boom type of excavator for digging work. The second was the technical control or engineering which consisted of cone penetration test, installation of double piles, installation of vibration damper on the operator seat of the excavator, inspection of gas level in the digging area, and installation of geotextile. The third was the administrative control which consisted of the formulation of operational procedures, arrangement of workers break schedule, monitoring by consultant and OSH teams. The last was the application of PPE consisting of gloves, long wearpacks, safety helmet, masks, safety glasses, earplugs, and safety shoes.
d. With regards to the escalating factors and the barrier measures, as many as 6 escalating factors were identified in the construction of the Shell Gasoline Station in Surabaya. They were the errors in the formulation of operating procedures, workers' refusal in the application of PPE, excavator breakdown, dysfunctioned oxygen flask and eyewash appliance, invalid gas detector, and extended working hours. Analyses of the barrier measures had been conducted on each of the escalating factors, resulting in the following measures: monitoring of operating procedure formulation by the OSH team, OSH campaign regarding the importance of PPE application, inspection of tools/equipments, calibration of gas detector, and periodical monitoring of workers' health.

Declaration

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Conflicts of Interest: The researchers declare that there is no conflict of interest in this research.

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