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Assesment of Construction Safety Management System (CSMS) In Confined Space Tunnel Construction: A Case Study Of Jragung Dam

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ABSTRACT

Construction work on bypass tunnels involves work in confined spaces that pose high-risk hazards, such as toxic gases, noise, electrical hazards, and limited mobility; therefore, the implementation of a Construction Safety Management System (CSMS) is essential to minimize the risk of workplace accidents. Previous research on CMS implementation has primarily focused on open-space construction projects, while studies on confined-space construction—particularly bypass tunnels—remain limited. Additionally, several safety compliance issues were identified during the Jragung Dam project. This study aims to analyze CMS implementation, identify barriers to its adoption, and propose corrective measures in accordance with applicable regulations. The research method used is quantitative with a descriptive approach. Data were obtained through questionnaires, observations, and interviews at the Jragung Dam bypass tunnel construction project in Semarang Regency. The results of the study indicate that seven out of nine components of SMKK implementation fall into the "good" and "effective" categories, while the remaining two components fall into the "fairly good" category. The highest percentage was found in traffic signs and accessories as well as consultation with construction experts at 88%, while the lowest percentage was found in construction safety risk control activities at 75%. This study suggests that the implementation of SMKK in confined spaces needs to be carried out more effectively and in accordance with regulations so that the risk of workplace accidents can be minimized and worker safety better ensured.

1. Introduction

Diversion tunnels are an important part of dam construction that aims to direct the flow of rivers during the construction process of the main dam. The construction of the diversion tunnel for the Jragung Dam was carried out using the NATM (New Austrian Tunneling Method) approach. NATM is not just a construction method but a strategy to ensure the smooth implementation of construction activities, prioritizing safety and economy as the main principle [1]. Construction using NATM must comply with the agreed specifications, contract documents, work instructions, and other requirements. In addition, there is a need for quality assurance and occupational health safety (OHS) assurance [2]. The use of this method allows for adaptation to different geological conditions along the tunnel work site. Without proper adaptation of geological conditions, it can lead to the risk of accidents, structural failure, and delays in the implementation of construction. Structural safety assessment of tunnel layers is known that the safety factors of layers with cavities underneath based on a fuzzy comprehensive evaluation model are strongly influenced by changes in the classification of surrounding rocks, cavity locations, and depths. In contrast, changes in cavity length do not significantly affect the safety of the coating [3].

The construction of diversion tunnels is under the construction of limited space. Confined space is a work

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area that workers can enter under certain conditions, features limited entry and exit points and is not designed for continuous occupancy. Working in confined spaces has environmental limitations that can trigger hazards, such as limited oxygen, increased concentrations and contamination of toxic gases, noise, structural instability, high temperatures, equipment failure, electrical risks such as exposure to electrical sources, and limited movement [4]. If left untreated, hazards in confined space work can significantly increase the risk of workplace accidents. The construction sector is the largest contributor to work accidents. From 2011 to 2019, there were 1,030 reported deaths due to confined space work accidents. For tunnel work in confined spaces, 129 deaths were reported, mainly caused by collapse and inhalation of hazardous substances [5].

Based on observations, on-site workers are still entering and exiting diversion tunnels without wearing full personal protective equipment (PPE), there are no access restrictions for individuals entering confined spaces, there are no barriers separating confined spaces from open areas, and not all workers in confined spaces have communication devices such as walkie-talkies. The high accident rate in construction work, limited space and low awareness of worker safety demand proactive measures to minimize accidents. These steps can be achieved by implementing an ideal construction safety management system (CSMS). Every service provider and construction service user are required to implement a CSMS in the implementation of construction service activities [6]. A Construction Safety Management System (CSMS) is an integral component of overall management that includes the organizational structure, planning, responsibilities, analysis, procedures, processes, and resources necessary to implement, achieve, and maintain occupational safety and health policies [7]. The ideal CSMS includes CSMS document preparation, socialization, promotion, training, personal protective equipment (PPE), work protective equipment (WPE), insurance and permits, construction safety personnel, facilities, and medical equipment, signage and traffic equipment, consultation with construction experts, and environmental inspections [8].

As previously described, in the practice of implementing CSMS in limited space in the Jragung Dam diversion tunnel construction project, there are still some shortcomings in meeting the construction safety aspect. Given the specific hazards in confined spaces, which are different from open spaces, ignoring these shortcomings in meeting the safety aspects of construction can significantly increase the risk of construction accidents in confined spaces. Additionally, non- compliance with CSMS in the space can damage the company's reputation and reduce the trust of project owners and other stakeholders. Remedial measures and increased oversight are required to ensure that the construction of the Jragung Dam diversion tunnel is aligned with the specific specifications for the CSMS Analysis component.

In line with that, from 2012 to 2022 in China, it was obtained that the concept of safety management was not implemented in the chemical industry in China. This can be seen in a study that observed that 14 major chemical accidents in China had poor safety cultures, inadequate accident investigations, inadequate training, and a lack of poor safety personnel, deliberate violations [9]. Therefore, the effectiveness of CSMS is highly dependent on the involvement of all stakeholder's interests, policy support, and adoption of safety technology and culture. The implementation of OHSMS in South Korea has shown significant success, with a 67% reduction in accidents and a 10.3% decrease in fatal accidents in the period 2006–2011. However, the difference in perception between general managers and K3 managers towards these systems shows the importance of harmonized understanding in safety management [10].

Hong Kong has implemented the Safety Management System (SMS) through formal regulations since 1999. The system integrates 14 safety elements and is closely supervised by the Labour Department, making Hong Kong a successful regulatory model in the implementation of construction safety [11]. Malaysia has not had comprehensive regulations for construction safety since the pre-construction stage. Recent studies highlight the need for safety indicators at the preconstruction stage as a preventive measure [12]. Norway sees good overall management of construction projects as having a positive impact on safety management. The results advocate the implementation of safety management as an integral aspect of all management activities within a project rather than as a disconnected subsystem. This work is new by empirically demonstrating the impact of the project management aspect on safety management in construction projects [13].

This study was conducted with the aim of analyzing the CSMS analysis in the limited space of the diversion tunnel construction project at the Jragung Dam and providing recommendations to improve CSMS compliance and reduce the risk of work accidents. The study not only seeks to protect workers' welfare but also aims to improve the overall efficiency and sustainability of the project. The findings of this study are expected to provide insight into the ideal CSMS Analysis in confined spaces for similar projects in accordance with applicable regulations [6] and [4]. The novelty of this research lies in its focus on the construction of confined spaces, while other research has been conducted on the construction of open spaces. In addition, evaluations are conducted on nine elements of the CSMS as set forth in the specific CSMS specification CSMS is a part of construction project management designed to ensure safety during the execution of work. Occupational Health and Safety (K3) in the construction sector encompasses all measures taken to protect workers from the risk of accidents and illnesses associated with their work. This effort involves preventive measures to prevent work incidents and maintain the health of workers during construction projects [14]. According to the safety management system as an increase in the speed of the safety management system in the form of external and internal inspections of the safety management process is the core of process safety management (PSM) and is an important opportunity to improve operational solutions [15]. To ensure the realization of construction safety, it is necessary to apply targets in the implementation of CSMS in construction projects. The following are the objectives in the implementation of construction safety [16]:

a) Ensuring the fulfillment of safety, safety, health, and sustainability standards in the study, planning, design, and implementation of construction projects;
b) Maintaining the health and safety of workers and other individuals at the construction site;
c) Ensure the safety, health, efficiency, and effectiveness of any materials and tools used;
d) Ensure the smooth completion of construction work;
e) Ensure safe and efficient use and maintenance of construction products.

In the implementation of CSMS, there are several components that must be met. The following are the components of CSMS implementation activities in accordance with a) CSP (Construction Safety Plan), containing CSMS management, project safety targets and programs, internal and external challenges in the implementation process, communication schedule, risk analysis, CSMS implementation costs, emergency response procedures, work stoppage steps when there is a threat, all aspects of safety control in construction, and monitoring and inspection schedules; b) CSU (Construction Safety Unit) In the implementation of CSMS, construction service providers must form UKK. UKK gets a mandate from the department that manages safety in construction, which is part of the service provider's highest management structure. UKK consists of leaders and members who are responsible for it; c) CSMS Implementation Fee. Service users need to ensure that the entire budget for the implementation of the CSMS has been prepared and allocated appropriately by the service provider. The CSMS implementation budget includes costs related to the implementation of CSMS in construction projects as well as costs for construction consulting services [6].

Specification of CSMS Implementation Components the components of CSMS [8] implementation activities are further explained as follows:

a) Preparation of CSMS implementation documents, including the creation of CWP (Construction Work Plan), CWQP (Construction Quality Plan), EMMWP (Environmental Management and Monitoring Work Plan), and RMLLP (Work Traffic Management Plan) documents. Creation of procedures and work instructions. Preparation of reporting on the implementation of CSMS (daily, weekly, monthly, final);
b) Socialization, promotion, and training;
c) Work protective equipment and personal protective equipment;
d) Insurance and licensing;
e) Construction safety personnel;
f) Medical facilities, infrastructure, and equipment;
g) Signs and necessary traffic or traffic management equipment;
h) Consultation with experts related to construction safety; and
i) Activities and equipment related to safety risk control.

The application of CSMS varies greatly between countries depending on regulations, work culture, and technology used. The United States uses data-driven approaches, such as predictive analytics and BIM, under OSHA oversight. Standards such as ANSI/ASSE Z10 are widely applied, with quantitative indicators such as the Total Recordable Incident Rate (TRIR) used for safety performance evaluation [17]. Systems in the UK are controlled by the Health and Safety Executive (HSE) through the Construction (Design and Management) Regulations (CDM). This model emphasizes the principle of Prevention through Design (PtD), ensuring risks are minimized from the planning stage [18]. A dedicated management framework has been developed to support construction clients to ensure their projects are safe and healthy for construction workers. Examples include the Model Client Framework in Australia [18] and the operational excellence model for OHS client engagement in the US [19]. PSM systems from jurisdictions in Asia, Australia, Europe, and North America, as well as approaches to the development of process safety performance indicators, are analyzed. The core process safety concept of an inherently safer design, the introduction of warning signs, a process safety culture, and dynamic risk assessment are also considered from the perspective of their integration in PSM [20].

In addition to technical and managerial aspects, human factors also play a crucial role in the successful implementation of construction safety management systems in confined-space tunnel projects. Several studies indicate that unsafe behavior among workers remains one of the primary causes of construction accidents, particularly in high-risk work environments such as tunnels and underground structures. Workers often underestimate the dangers due to monotonous work patterns, lack of supervision, time pressure, and low awareness of workplace safety procedures. Unsafe actions such as failing to wear complete personal protective equipment, entering confined spaces without permission, and disregarding communication procedures can increase the likelihood of fatal accidents during tunnel construction activities [21].

Human behavior regarding construction safety is greatly influenced by an organization's safety culture. Safety culture refers to the attitudes, perceptions, competencies, and collective behavioral patterns that determine a commitment to occupational health and safety management to [22]. A positive safety culture can encourage workers to follow regulations, actively participate in hazard reporting, and improve communication between supervisors and workers. Conversely, a weak safety culture can lead to negligence, rule violations, and low compliance with established safety procedures. In confined space construction work, a safety culture becomes even more critical because emergency situations can develop rapidly and potentially lead to serious consequences if preventive measures are not properly implemented.

Research conducted on underground construction projects shows that communication and monitoring systems have a significant impact on worker safety performance. Effective communication between supervisors, operators, and workers is crucial in tunnel construction because environmental conditions such as limited visibility, high noise levels, dust exposure, and restricted movement can hinder coordination during work activities [23]. Communication devices such as walkie-talkies, warning systems, emergency alarms, and monitoring equipment are essential for ensuring worker safety. Inadequate communication systems can hinder emergency response and exacerbate the consequences of accidents during operations in confined spaces.

In addition, the implementation of CSMS in tunnel construction also requires a continuous hazard identification and risk assessment process. Tunnel construction involves dynamic geological conditions that can change during the excavation process. Changes in rock structure, groundwater conditions, and excavation stability can give rise to new hazards that were not identified during the planning stage. Therefore, periodic risk assessments are necessary to ensure that control measures remain effective throughout the project's implementation [24]. Continuous monitoring systems, geotechnical instrumentation, and environmental inspections are key components of tunnel safety management for detecting potential failures at an early stage.

Management commitment is another key factor influencing the effectiveness of CSMS implementation. Strong commitment from project owners, contractors, and supervisors can improve compliance with safety procedures and encourage the allocation of adequate resources for safety programs. Management commitment can be demonstrated through regular safety evaluations, the provision of safety facilities, the enforcement of safety regulations, and the implementation of training programs for workers [25]. In large-scale infrastructure projects such as dam construction, management support is essential to ensure that safety objectives are integrated into every stage of construction.

Technological advancements have also helped improve safety management practices in construction projects. Digital technologies such as Building Information Modeling (BIM), real-time gas monitoring systems, wearable safety devices, and automated warning systems are increasingly being implemented to reduce the risk of accidents in confined spaces [11]. These technologies help project managers monitor environmental conditions, worker locations, and potential hazards more effectively. In tunnel construction projects, monitoring technologies can provide early warnings regarding hazardous gas concentrations, oxygen deficiency, excessive vibrations, or structural instability. Integrating these technologies into CSMS implementation can improve decision-making processes and enhance overall project safety performance.

Although there have been advances in safety regulations and technology, the implementation of CSMS in developing countries still faces various challenges. Limited safety budgets, inadequate training, weak enforcement, and a lack of worker participation often hinder the effectiveness of safety management systems [18]. In some cases, safety programs are implemented solely to meet administrative requirements, rather than to foster a genuine safety culture. As a result, safety procedures may not always be followed during project implementation. Therefore, evaluating the implementation of CSMS in actual construction projects is crucial for identifying gaps between regulatory standards and on-site practices.

Based on these considerations, an evaluation of the implementation of the Confined Space Management System (CSMS) in the Jragung Dam diversion tunnel project is essential, as this project involves high-risk construction activities in confined spaces using the New Austrian Tunneling Method (NATM). The findings of this study are expected to contribute to the development of more effective construction safety practices, particularly for tunnel and underground construction projects in Indonesia. Additionally, this study is expected to provide recommendations for enhancing safety awareness, strengthening oversight systems, and optimizing the implementation of CSMS in accordance with applicable regulations and international best practices.

3. Methods

This study uses a quantitative method with a descriptive approach. According to [20], quantitative methods are research methods used to study certain populations or samples, where data collection is carried out using research instruments and the analysis is quantitative/statistical. Meanwhile, the descriptive approach, as defined [4], aims to describe the phenomena that occur in the object of research.

The research was carried out at the construction site of the Jragung Dam diversion tunnel package III. Geographically, the Jragung Dam is located in Candirejo Village, Pringapus, Semarang, Central Java. The sampling technique used is saturated sampling, where all members of the population are taken as samples. The sample and population in this study consisted of all workers involved in the diversion tunnel construction project, including SQM (Site QHSE Manager), QHSE staff, administrative staff, technical staff, and operational staff.

The needs analysis in this study is divided into two types: primary data and secondary data. Primary data were obtained through questionnaires, which were developed based on the components of the CSMS Analysis activities as set out in the CSMS-specific guidelines. Secondary data is collected through observation and interviews to gather additional information.

The analysis of the questionnaire results was carried out by measuring the success rate for each indicator outlined in the questionnaire. The measurement scale used in this study is the Likert scale. The Likert scale is used to measure an individual's opinion of a particular phenomenon). The criteria in Table 1 for evaluating success are presented in the table below [16].

Table 1. Classification of CSMS analysis success

Classification	Score
Very Precise	4
Quite Precise	3
Less Accurate	2
Inappropriate	1

The scores obtained for each questionnaire point were then processed using univariate analysis. Univariate analysis is a type of data analysis that involves only one variable at a time. To assess the success of the Construction Safety Management System Analysis (CSMS) in the confined space of the Jragung Dam tunnel construction project, a central tendency measurement formula was applied, calculating the average value as follows [23].

Table 2. Classification of success in CSMS analysis

No	Total Value Range	Description
1	$Y_r >$ Mi + 1.5 Sbi	Good and effective
2	Mi < ≤ Million Mr . 1,5 SbiY_r	Quite good and effective
3	Miss 1,5 Sbi < ≤ MiY_r	Poorly implemented
4	$Y_r \leq$ Mi – 1.5 Sbi	Unsuccessful/failed
5	$Y_r >$ Mi + 1.5 Sbi	Good and effective

$$Y = \Sigma yi = Y1 + Y2 + Y3 \ldots + Yn \qquad (1)$$

The results of the univariate analysis are then categorized based on a predetermined range. Table 2 is a success range for the Construction Safety Management System Analysis (CSMS).

3. Results and Discussion

3.1 Construction Safety Management System (CSMS) Analysis

Based on the analysis of the questionnaire results, the percentage and category of success of the CSMS (Construction Safety Management System) Analysis component in the construction of the Jragung Dam diversion tunnel are presented in the Table 3.

Based on the results, the Construction Safety Management System (CSMS) Analysis in the construction project of the limited space of the Jragung Dam diversion tunnel is included in the good and effective category. Seven components were categorized as good and effective, while two items were classified as quite good and effective. The highest percentage of 88% is observed in indicators for traffic signs and additional traffic devices, as well as consultation with relevant construction experts. In contrast, the lowest percentage of 75% is recorded in the indicators for activities and equipment related to construction safety risk control.

3.2 Shortcomings and Obstacles Along with Solutions for CSMS

This study also aims to identify the shortcomings and constraints of the Construction Safety Management System (CSMS) Analysis in the limited space of the Jragung Dam diversion tunnel construction project. Table 4 are some of the shortcomings and solutions obtained from observations and interviews. The practical implications for addressing shortcomings and obstacles in the implementation of CSMS are in line with applicable regulations and standards. This means that every step taken must be in accordance with the norms and standards set by the relevant authorities. One of the measures that can be adopted is to conduct daily inspections to ensure that all workers perform their duties according to established procedures and wear complete Personal Protective Equipment (PPE). In this way, the safety of workers can be maintained while on the job site. In addition, it is also important to document all components of the CSMS according to the forms provided, which include entry clearance forms for restricted areas, CSMS audits, inspections conducted, and documents stating that workers are free from exposure to hazards. Proper and systematic documentation not only aids in regulatory compliance but also serves as an important record for future evaluations and improvements.

Table 3. Components of CSMS analysis success

Not	Indicator	Percentage	Success Categories
1	CSMS Analysis Document	86%	Good and effective
2	Socialization, Promotion, and Training	87%	Good and effective
3	Protective Equipment	84%	Good and effective
4	Insurance	82%	Good and effective
5	Construction Safety Personnel	85%	Good and effective
6	Health Facilities, Infrastructure, and Equipment	81%	Quite good and effective
7	Traffic signs and complementary Equipment	88%	Good and effective
8	Consultation with a Construction Expert	88%	Good and effective
9	Activities and Equipment Related to Construction Safety Risk Control	75%	Quite good and effective

Table 4. Disadvantages and constraints of CSMS analysis

No	Indicator	Disadvantages and Barriers	Solution
1	CSMS Analysis Document	Lack of special permissions to enter restricted spaces	Creating a work permit Conduct special training for workers in confined spaces
		CSMS reporting is only done weekly	Improve CSMS reporting on a daily, weekly, and monthly basis
2	Socialization, Promotion, and Training	Safety induction is still common; No special safety induction for workers inconfined spaces	Perform special safety induction for workers in confined spaces
		No socialization about HIV/AIDS	Providing socialization about HIV/AIDS to all workers, both in limited spaces and outside, with the help of related agencies
		Lack of enthusiasm among workers	Provide a comfortable atmosphere and facilities

No	Indicator	Disadvantages and Barriers	Solution
		to attend training	Offer challenges and competitions with attractive incentives or prizes
		Inadequate and outdated information media	Conducting audits of construction safety information media Replacing and updating inadequate and outdated information media
3	Personal protection equipment	Safety lines have not been installed around the tunnel excavation area: Workers still wear inadequate PPE	Install safety lines to delimit between elevated and lower areas: Evaluate this issue Replace inadequate PPE Conduct training on the importance of wearing PPE
		Workers do not use complete PPE	Socializing the importance of using PPE Sentencing Severe Check the completeness of the PPE before starting work in the tunnel
4	Insurance	Equipment, heavy equipment, electrical, and other inspections are only carried out occasionally, not routinely before starting work	Perform inspections of heavy equipment, electrical equipment, and other tools whenever work in confined spaces begins
5	Construction Safety Personnel	Insufficient safety personnel, especially environmental management.	Add personnel for environmental management and emergency respons
		Officers and emergency response personnel	Providing training and certification for safety officers
6	Health Facilities, Infrastructure, and Equipment	Sanitation facilities are not yet available in the work area	Provides sanitation facilities such as portable stations with running water, and waste disposal sites
7	Traffic Signs and Auxiliary Devices	Heavy equipment mobilization is sometimes not supervised by flag guards	Set flagmen according to the SOP. Flagmen must be certified and trained according to their job description and use communication devices for coordination.
		No roadblocks on the road access to diversion tunnel works	Installing roadblocks at high-risk points on access roads to diversion tunnel works
8	Consultation with Related Construction Experts	No consultation has been carried out with earthquake and electrical experts	Consult with an earthquake and electrical expert both before and during the diversion tunnel construction process
9	Activities and Equipment Related to Construction	Ambient air quality inspections are not routine due to limited equipment	Companies should coordinate further and target routine inspections in the morning, afternoon, and evening, both at the inlet and exit.
10	Safety Risk Control	Environmental vibration tests and tests on motor vehicle vibration levels are only carried out at the beginning of tunnel work	Apply periodic vehicle vibration and vibration tests throughout the project.
		Ambient air quality documentation and river water quality checks are still lacking	Improve documentation, especially the results of ambient air quality inspections. The results should be transparent, allowing workers to access them, so they can know which results are poor or that exceed threshold values.

4. Conclusions

Based on the calculations that have been made, the findings are obtained in accordance with the research problem and in the form of recommendations. Of the nine ideal components for CSMS implementation, there are seven that fall into the category of good and effective. The remaining two components, including the advisory component, infrastructure, and medical equipment as well as the components of construction safety risk control activities and equipment are included in the category of quite good and effective. From the results of the analysis, it was found that the largest percentage of CSMS implementation, which is 88%, is in traffic signs and complementary indicators as well as consultation with construction-related experts. Meanwhile, the lowest percentage of 75% is in activity indicators and equipment related to construction safety risk control. According to the results of interviews and observations, the majority of shortcomings and obstacles in the implementation of CSMS come from within, such as management and limited resources. The solutions used in overcoming shortcomings and obstacles are adjusted to applicable regulations. The implementation of CSMS implementation solutions can be in the form of daily inspections before work to check that workers have worked according to procedures and are wearing complete PPE. In addition, documenting the components of the CSMS according to the available forms such as admission forms, CSMS audits, inspections, and free exposures. This study highlights the importance of strengthening operational safety controls in confined space tunnel construction projects. Future improvements should focus on increasing routine environmental monitoring, improving worker compliance with PPE usage, enhancing emergency preparedness systems, and providing adequate safety personnel and supporting facilities. Strengthening these aspects can help minimize occupational accidents and improve the sustainability of construction safety management implementation in high-risk infrastructure projects.

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