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Implementation Of The Construction Safety Management System (Smkk) For Soft Soil Road Improvement Works At Km 28 Batuah, Kutai Kartanegara

***Yanti[1], Syapril Janizar[2]**
Program Studi Teknik Sipil, Universitas Muhammadiyah Kalimantan Timur, Samarinda, Kalimantan Timur[1]
Program Studi Teknik Sipil, Universitas Winaya Mukti, Bandung[2]

*) Email: yy229@umkt.ac.id[1]

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Abstract

This study discusses the implementation of the Construction Safety Management System (SMKK) in road construction work on soft soil at KM 28 Batuah, Kutai Kartanegara Regency, East Kalimantan. The study aims to analyze geotechnical parameters and construction safety risks under soft soil conditions. The research variables include California Bearing Ratio (CBR), settlement, slope stability, probability, severity, and construction work risk levels. The research methods consisted of field observations, laboratory testing, literature review, and risk analysis using the HIRADC approach within the SMKK framework. The results showed that the soil CBR value ranged from 3–5%, field settlement reached 30–80 cm, and the slope safety factor under saturated conditions was less than 1.0, indicating unstable conditions. Risk analysis identified the main hazards as slope failure, heavy equipment sinking, surface deformation, and occupational accidents, with medium to high risk levels. The probability level was categorized as frequent due to high rainfall intensity, poor drainage conditions, and heavy traffic loads. The implementation of SMKK through technical and administrative controls, personal protective equipment, geotechnical monitoring, and emergency response systems is necessary to minimize occupational accidents in road construction on soft soil.

Keywords: SMKK, soft soil, settlement, slope stability, construction safety.

Abstrak

Penelitian ini membahas penerapan Sistem Manajemen Keselamatan Konstruksi (SMKK) pada pekerjaan jalan di atas tanah lunak di KM 28 Batuah, Kabupaten Kutai Kartanegara, Kalimantan Timur. Penelitian bertujuan menganalisis parameter geoteknik dan risiko keselamatan kerja konstruksi pada kondisi tanah lunak. Variabel penelitian meliputi nilai California Bearing Ratio (CBR), settlement, stabilitas lereng, tingkat kekerapan (probability), tingkat keparahan (severity), dan tingkat risiko pekerjaan konstruksi. Metode penelitian dilakukan melalui observasi lapangan, pengujian laboratorium, studi literatur, serta analisis risiko menggunakan pendekatan HIRADC dalam kerangka SMKK. Hasil penelitian menunjukkan nilai CBR sebesar 3–5%, settlement lapangan mencapai 30–80 cm, dan faktor keamanan lereng pada kondisi jenuh kurang dari 1,0 sehingga menunjukkan kondisi tidak stabil. Analisis risiko menunjukkan potensi bahaya utama berupa longsor lereng, amblasnya alat berat, deformasi permukaan kerja, dan kecelakaan tenaga kerja dengan tingkat risiko sedang hingga tinggi. Tingkat kekerapan risiko berada pada kategori sering akibat pengaruh curah hujan tinggi, drainase yang buruk, dan dominasi kendaraan berat. Penerapan SMKK melalui pengendalian teknis, administratif, penggunaan alat pelindung diri, monitoring geoteknik, dan sistem tanggap darurat diperlukan untuk meminimalkan risiko kecelakaan kerja pada konstruksi jalan tanah lunak.

Kata kunci: SMKK, tanah lunak, settlement, stabilitas lereng, keselamatan konstruksi.

INTRODUCTION

Road infrastructure development plays an important role in supporting regional connectivity, logistics distribution, and economic growth. The KM 28 Batuah road section in Kutai Kartanegara Regency, East Kalimantan, is a strategic transportation corridor connecting Samarinda, Balikpapan, and the Nusantara Capital City (IKN). However, the site is predominantly characterized by soft clay soil with low bearing capacity and high compressibility, which increases the risk of settlement, pavement deformation, and slope instability [5],[13]. Laboratory testing based on ASTM D1883-21 [15] indicated that the California Bearing Ratio (CBR) values ranged from 3–5%, indicating poor subgrade conditions. Soft soil conditions also exhibit a high potential for long-term settlement and slope failure due to consolidation behavior [13]. These conditions have resulted in permanent deformation, road subsidence, longitudinal cracking, and slope failures that endanger both road users and construction workers. Based on geotechnical investigation results, the slope Safety Factor (SF) under saturated conditions was found to be below 1.0, indicating unstable slope conditions. Construction safety management has become an essential aspect of infrastructure development projects because construction activities involve various occupational hazards and complex working conditions [1]. Construction safety climate assessment is important to improve worker awareness and reduce unsafe behavior during infrastructure project implementation [2]. In Indonesia, construction safety implementation is regulated under Law No. 2 of 2017 concerning Construction Services and Ministerial Regulation of PUPR No. 10 of 2021 concerning the Construction Safety Management System (SMKK) [17], [18]. Several previous studies have discussed safety risks and geotechnical problems in soft soil infrastructure projects. Zhang et al. [5] reported that repeated traffic loading significantly affects embankment deformation and stability on soft clay soils. Huang et al. [10] emphasized that continuous geotechnical monitoring is essential to reduce safety risks during soft soil construction works. In addition, Rahman et al. [3] explained that HIRADC-based risk assessment is effective in identifying occupational hazards in road construction projects. However, previous studies mainly focused on geotechnical performance or occupational safety separately, while limited studies integrated geotechnical analysis with SMKK implementation in soft soil road projects. The novelty of this study lies in the integration of geotechnical analysis and SMKK implementation using the HIRADC approach for soft soil road construction projects. Therefore, this study aims to analyze construction safety risks through the integration of geotechnical conditions and SMKK implementation.

The implementation of SMKK in the KM 28 Batuah road handling project is necessary because the construction activities involve intensive heavy equipment operations, risks of landslides and ground subsidence, high traffic loading, saturated soil conditions, and potential occupational accidents caused by slope instability and inadequate drainage systems. Previous studies reported that road construction projects on soft soil conditions involve significant risks related to slope instability, heavy equipment operation, traffic interaction, and unsafe working environments [5].

Therefore, a comprehensive study regarding the implementation of SMKK in accordance with the geotechnical characteristics of the site is required to ensure that construction activities can be carried out safely, effectively, and sustainably.

Safety Risks in Soft Soil Construction Works

Hazard identification and risk assessment are essential components of construction safety management systems, particularly in high-risk geotechnical environments [3].

Soft soil is characterized by low bearing capacity, high compressibility, high water content, and significant susceptibility to settlement and slope failure. In the KM 28 Batuah road project, field investigations revealed that ground settlement reached approximately 30–80 cm, while the saturated slope condition exhibited a Safety Factor (SF) of less than 1.0, indicating unstable slope conditions. In addition, the soil was classified as CH (Clay of High Plasticity), which is highly sensitive to changes in moisture content and loading conditions. These geotechnical conditions substantially increase construction safety risks, including heavy equipment subsidence, embankment slope failure, worker accidents, and road body collapse.

Construction hazards in soft soil road works generally include slope failure that may result in worker injuries or fatalities, excessive settlement that can cause heavy equipment overturning, water ponding that increases the risk of slips and workplace accidents, heavy equipment traffic that may lead to collisions, inadequate drainage causing erosion and road subsidence, as well as embankment material instability that may result in workers being buried by collapsed material.

In the implementation of the Construction Safety Management System (SMKK), risk control is carried out through a hierarchical approach consisting of elimination, substitution, engineering controls, administrative controls, and the use of Personal Protective Equipment (PPE). This approach is intended to minimize occupational risks and improve construction safety performance, particularly in high-risk geotechnical conditions such as those encountered at the KM 28 Batuah road section.

RESEARCH METHODOLOGY

Research Location

This study was conducted on the KM 28 Batuah road section located in Batuah Village, Kutai Kartanegara Regency, East Kalimantan, Indonesia. The study area is part of a national road corridor with a high traffic volume and a heavy vehicle proportion of approximately 30–40%, making it a strategically important transportation route connecting Samarinda, Balikpapan, and the Nusantara Capital City (IKN) area. The location has experienced significant road deformation and slope instability due to soft soil conditions and heavy traffic loading.

Research Method

The research employed a qualitative and quantitative approach through field observations, literature review on the Construction Safety Management System (SMKK), construction safety risk analysis, and geotechnical analysis based on previous soil investigation data from the KM 28 Batuah area. The study focused on evaluating construction safety risks associated with soft soil conditions and identifying appropriate mitigation measures to improve construction safety performance. Risk assessment was conducted using the Hazard Identification, Risk Assessment, and Determining Control (HIRADC) approach, which is widely applied in construction safety management systems [3].

Data Sources

The study utilized both primary and secondary data sources. Primary data consisted of field condition observations, documentation of road damage, and assessments of heavy equipment operations and working area conditions. Secondary data included geotechnical investigation data from the KM 28 Batuah research area, SMKK regulations and standards, as well as literature related to construction safety and geotechnical engineering. These data sources were used to support the analysis of construction safety risks, and the implementation of SMKK in this study also refers to occupational health and safety principles outlined in ISO 45001:2018 [16].

Analysis Method

The analysis was carried out through several stages, including hazard identification, risk assessment, risk level analysis, determination of mitigation measures, and evaluation of SMKK implementation. Hazard identification was conducted to determine potential risks associated with soft soil construction works, while risk assessment and risk level analysis were performed to evaluate the probability and impact of construction hazards. Furthermore, mitigation measures were determined based on engineering, administrative, and safety control approaches to reduce construction risks and improve occupational safety performance during project implementation.

Risk Classification Criteria

Probability Scale

Table 1 presents the probability scale used in the HIRADC risk assessment.

Level	Description	Criteria

1	Rare	Very unlikely to occur
2	Unlikely	Occasionally occurs
3	Moderate	Possible during construction
4	Likely	Frequently occurs
5	Almost Certain	Repeatedly occurs

Severity Scale

Table 2 presents the severity scale used in the risk assessment process.

Level	Description
1	Minor injury
2	Medical treatment
3	Serious injury
4	Permanent disability
5	Fatality

Risk Classification

The construction risk level was determined based on the multiplication of probability and severity values.

$$Risk\ Level = Probability \times Severity$$

Table 3 presents the risk classification criteria.

Score	Risk Level =Probability×Severity
1–4	Low
5–12	Medium
13–25	High

RESULTS AND DISCUSSION

Existing Site Conditions

Based on field investigations and laboratory testing conducted on the KM 28 Batuah road section in Kutai Kartanegara Regency, the geotechnical condition of the site was identified as soft clay soil with high plasticity characteristics (CH – Clay of High Plasticity). The soil is characterized by high moisture content, low bearing capacity, and high compressibility, making it highly susceptible to deformation and construction failure. The laboratory results indicated that the soil was classified as CH (Clay of High Plasticity), characterized by high moisture content and low shear strength [13].

Laboratory testing indicated that the subgrade soil had California Bearing Ratio (CBR) values ranging from 3–5%, based on testing procedures conducted in accordance with ASTM D1883-21 [15]. These values are below the minimum subgrade requirement of ≥ 6% according to Indonesian highway standards (Bina Marga). According to pavement design criteria, subgrade soils with low CBR values are classified as poor subgrade materials and are highly susceptible to pavement deformation under repetitive traffic loading [4]. The low CBR value indicates that the soil is unable to adequately sustain repetitive traffic loading. In field conditions, the low bearing capacity resulted in longitudinal cracking, road subsidence, surface undulation, and permanent deformation, particularly along heavy vehicle lanes.

Furthermore, settlement analysis showed that field settlement reached approximately 30–80 cm, which is considered excessive for road pavement structures, as the acceptable settlement tolerance for road pavements generally ranges from 2–5 cm. The significant settlement occurred due to the high compressibility of the soft soil, influenced by high water content and long-term consolidation processes. Greater settlement values directly increase the risk of pavement deterioration and construction-related accidents.

Monitoring activities included visual inspection of cracks, settlement measurements, groundwater observations, and slope condition evaluations during construction activities. Geotechnical monitoring is an essential component of SMKK because soil conditions may change due to rainfall intensity and repetitive traffic loading [10]. Consequently, these geotechnical conditions substantially increase the risk of heavy equipment subsidence, worker accidents, embankment failure, and pavement collapse during construction activities.

Overall, these existing conditions demonstrate that construction activities at the KM 28 Batuah site involve a high level of safety risk for workers, heavy equipment operators, and road users.

Construction Safety Risk Analysis

a. Slope Failure Risk Analysis

The slope stability analysis showed that the Safety Factor (SF) under saturated conditions ranged from 0.60–0.95. In soil mechanics, slope conditions are generally categorized as safe when SF ≥ 1.5, critical when SF ranges from 1.0–1.5, and unstable when SF < 1.0. Since the SF values at the study location were below 1.0, the slopes were classified as unstable and highly susceptible to landslides. Similar slope instability problems on expansive and soft soil conditions were also reported in previous studies [12].

According to soil mechanics principles, increased pore water pressure significantly reduces effective stress and soil shear strength [14]. In addition, soft clay soils generally exhibit low bearing capacity and high compressibility [13]. During rainfall events, water infiltration further increases pore water pressure, making the slopes more vulnerable to failure This condition results in a substantial decrease in soil shear strength. During rainfall events, water infiltrates the soil pores and increases pore water pressure, thereby reducing effective stress and soil shear strength. As a result, the slopes become more vulnerable to failure. From a construction safety perspective, slope failure may cause workers to be buried, heavy equipment overturning, temporary structural damage, and disruption of project traffic access. According to the SMKK risk matrix, slope failure is classified as a high risk due to its high probability and fatal consequences.

b. Heavy Equipment Subsidence Risk Analysis

The CBR value of 3–5% indicates extremely low soil bearing capacity. Under such conditions, the contact pressure exerted by heavy equipment exceeds the soil's capacity to support the imposed loads. For example, crawler excavators typically impose ground pressures ranging from 40–80 kPa, while loaded dump trucks may generate pressures exceeding 100 kPa. Permanent deformation in soft soil foundations may increase significantly under cyclic traffic loading conditions [8]. These conditions may result in heavy equipment instability, overturning, project delays, and serious occupational accidents within the construction area.

Due to the high water content and large void ratio of the soft soil, heavy equipment at the site is highly susceptible to subsidence, loss of stability, and overturning. The field settlement of 30–80 cm further indicates that soil deformation is still actively occurring, creating unstable working surfaces for construction activities. Repetitive traffic loading significantly increases permanent deformation and instability in weak pavement subgrade soils, particularly under complex stress conditions [4]. Heavy equipment subsidence may result in operator injuries, equipment damage, project delays, and chain-reaction accidents within the construction area. Therefore, mitigation measures such as working platforms, geotextile reinforcement, geogrid installation, and restricted heavy equipment routes are required.

c. Traffic Accident Risk Analysis

The KM 28 Batuah road section is classified as a national highway with traffic volumes ranging from approximately 8,000–15,000 vehicles per day, of which 30–40% are heavy vehicles. The high traffic intensity significantly increases the interaction risk between public vehicles and construction activities. Unsafe working conditions and insufficient safety supervision may significantly increase accident probability in construction projects [1].

Potential accidents include collisions between vehicles and heavy equipment, vehicle skidding caused by damaged pavement surfaces, and accidents resulting from inadequate traffic management. Settlement and pavement deformation also reduce vehicle stability, particularly during rainy seasons. This risk category is considered high due to the moderate-to-high probability of occurrence and the potential for severe injuries or fatalities. Consequently, traffic management systems, flagmen, warning lights, barriers, and construction safety signs are necessary to minimize accident risks.

d. Water Ponding and Drainage Risk Analysis

The drainage system at the research location was unable to effectively discharge surface water, resulting in ponding around embankment and shoulder areas. Water ponding increases infiltration into the soft soil and raises pore water pressure levels. Geotechnically, increased moisture content reduces effective cohesion and internal friction angle while simultaneously increasing settlement potential. Poor drainage systems increase infiltration and pore water pressure, which directly affect soil stability and construction safety performance [13].

As a consequence, slopes become unstable, road embankments experience subsidence, and heavy equipment operations become more difficult. From a construction safety perspective, standing water also increases the risk of slips, electrical hazards, and vehicle skidding within the project area. Therefore, drainage control is considered a critical component in the implementation of the Construction Safety Management System (SMKK).

Implementation of the Construction Safety Management System (SMKK)

a. Construction Safety Planning

According to the Indonesian Ministry of Public Works and Housing Regulation No. 10 of 2021, construction projects are required to prepare safety-related documents, including the Construction Safety Plan (RKK), Hazard Identification Risk Assessment and Determining Control (HIRADC), Job Safety Analysis (JSA), and Emergency Response Plan (ERP). At the KM 28 Batuah project, these documents are essential due to the high-risk geotechnical conditions. HIRADC was used to identify hazards, assess risk levels, and determine appropriate control measures for activities such as embankment works, heavy equipment operations, and drainage excavation. Effective SMKK implementation requires safety planning, worker competency, supervision systems, and continuous risk monitoring throughout project execution [6]. Occupational safety management practices in Indonesian road construction projects also emphasize the importance of supervision, worker participation, and safety compliance [11].

b. Personal Protective Equipment (PPE)

The use of Personal Protective Equipment (PPE) was mandatory because the project area involved high-risk construction activities. The PPE used included safety helmets, reflective vests, safety boots, gloves, and full-body harnesses. In slope areas, safety harnesses were particularly important to prevent workers from falling due to slippery soil conditions and localized slope failures.

c. Work Area Control

Work area control measures included the installation of barricades, restriction of landslide-prone areas, dedicated heavy equipment routes, and temporary road opening-and-closing systems. These measures aimed to reduce interaction between public traffic and construction equipment while minimizing traffic-related accidents within the project zone.

d. Monitoring of Slope Conditions and Settlement

Excessive settlement in soft clay soils may also reduce pavement serviceability and accelerate structural deterioration under continuous traffic loading. Differential settlement occurring along the road alignment can create uneven pavement surfaces, increasing the risk of vehicle instability and traffic accidents. In construction areas, ongoing soil deformation may reduce the stability of working platforms and negatively affect heavy equipment operations. These conditions indicate that soft soil behavior affects not only structural performance but also construction safety and occupational risk levels. Continuous geotechnical monitoring is necessary because soil conditions may rapidly change due to rainfall intensity and repetitive traffic loading [10].

Routine monitoring activities included settlement measurements, crack inspections, road elevation monitoring, and drainage inspections. If settlement increased significantly, construction activities were temporarily suspended to prevent construction failure. In addition, integrated safety management systems are necessary to improve safety performance in high-risk highway construction projects on soft ground [9].

e. Drainage Control

Temporary drainage systems were constructed to reduce water ponding, control surface runoff, and maintain slope stability. In soft soil construction, drainage systems play a significant role in construction safety because they directly influence pore water pressure and overall soil stability.

Construction Safety Risk Assessment

Table 4 presents the construction safety risk assessment for the KM 28 Batuah project based on the HIRADC probability and severity matrix.

Risk	Probability	Severity	Score	Risk Level
Slope failure	5	5	25	High
Heavy equipment subsidence	5	4	20	High
Traffic collision	4	4	16	High
Water ponding	4	3	12	Medium
Falling materials	3	3	9	Medium

The probability values were determined based on field conditions, rainfall intensity, traffic loading, and the frequency of hazardous events during construction activities. Severity values were assessed according to the potential impact on workers, heavy equipment, project operations, and public traffic safety. Risk levels were classified using the HIRADC matrix based on the multiplication of probability and severity values.

Based on the analysis above, slope failure represents the highest construction safety risk due to its fatal consequences and significant potential for structural damage. Slope failure may also trigger secondary hazards within the construction area. Landslides can obstruct project access routes, damage temporary drainage systems, and interrupt material transportation activities. In addition, slope instability may increase the probability of traffic congestion and vehicle collisions in active construction zones. Therefore, slope failure in soft soil construction projects should be considered not only as a geotechnical problem but also as a major construction safety issue requiring integrated risk management.

Risk Mitigation Measures

a. Technical Mitigation

Technical mitigation measures included the installation of geotextiles and geogrids, preloading combined with Prefabricated Vertical Drains (PVD), temporary sheet piles, and drainage improvements. Geotextiles were used to improve embankment stability and load distribution, while PVD accelerated soft soil consolidation processes.

b. Administrative Mitigation

Administrative mitigation measures consisted of toolbox meetings, safety inductions, safety patrols, and permit-to-work systems. Toolbox meetings, safety inductions, and routine safety patrols improve worker awareness and safety compliance during project implementation [7]. These activities aimed to improve worker awareness regarding construction hazards and occupational safety procedures.

c. Emergency Mitigation

Emergency mitigation measures included evacuation routes, assembly points, emergency response teams, and project ambulances. Emergency preparedness systems are essential because landslides may occur unexpectedly, particularly during periods of heavy rainfall.

Evaluation of SMKK Implementation

The implementation of the Construction Safety Management System (SMKK) in soft soil road construction projects must be integrated with geotechnical analysis because most hazards originate from unstable soil conditions. Based on the study results, low CBR values increase the risk of heavy equipment subsidence, excessive settlement causes pavement deformation, and SF values below 1.0 significantly increase slope failure potential. The effectiveness of SMKK implementation depends on the integration between geotechnical monitoring, technical mitigation, safety supervision, and management commitment [6].

The effectiveness of SMKK implementation in this study can also be observed from the integration between geotechnical monitoring and safety management practices. Continuous monitoring of settlement, slope deformation, and drainage performance enabled early identification of hazardous conditions before major failures occurred. This preventive approach is essential in soft soil construction projects because geotechnical conditions may change rapidly due to rainfall intensity and repetitive traffic loading.

Furthermore, the combination of technical mitigation measures and administrative safety controls contributed to improving overall project safety performance. The implementation of toolbox meetings, safety patrols, and traffic management systems increased worker awareness regarding construction hazards and reduced unsafe working practices within the project area.

Effective implementation of SMKK can minimize occupational accidents, improve work area stability, increase project productivity, and reduce the probability of construction failure. Therefore, SMKK implementation in soft soil road construction projects should not only be considered an administrative requirement but also an essential component in ensuring construction safety and overall project success.

CONCLUSION

The KM 28 Batuah road section was identified as having high construction safety risks due to soft soil conditions, excessive settlement, low bearing capacity, and unstable slope conditions. The implementation of the Construction Safety Management System (SMKK) is essential to minimize occupational accidents and improve construction safety performance in road construction projects on soft soil areas. The major risks identified in this study include slope failure, heavy equipment subsidence, traffic accidents, and water ponding caused by inadequate drainage systems. Technical mitigation measures, administrative controls, geotechnical monitoring, drainage improvement, and the use of personal protective equipment are necessary to reduce construction risks and improve occupational safety performance. The integration of geotechnical analysis and SMKK implementation proved effective in supporting safer, more reliable, and sustainable road infrastructure development on soft soil conditions.

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