



Design of Claystone Selection as Surface Material for Mine Haul Roads at Pit PQRT, Berau Regency, East Kalimantan Province, Indonesia

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ABSTRACTS

Administratively, the study area is located in Samburakat, Gunung Tabur District, Berau Regency, East Kalimantan Province, Indonesia. Geographically, it lies between 117°34'30"-119°33'00" E and 02°17'30"-02°19'30" S. This study investigates the mechanisms responsible for the formation of undulating sections on mine haul roads, identifies suitable material sources based on Unconfined Compressive Strength (UCS) values, and evaluates their economic feasibility as surface course materials for mine roads. The methodology integrates field mapping of undulating road sections, material source mapping, frequency analysis of undulating areas, rainfall observation, and lithological characterization within the pit area. Laboratory testing of the physical and mechanical properties of the identified lithologies was conducted to assess their bearing capacity and performance under wet conditions. The results demonstrate that haul road surfaces constructed using sandstone are highly susceptible to the development of undulating deformation due to meteoric water infiltration, which significantly reduces material bearing capacity. In contrast, claystone exhibits superior performance as a road surface material owing to its impermeable characteristics, higher cohesion, and greater resistance to moisture-induced degradation, thereby maintaining subgrade stability and supporting haulage loads more effectively. UCS test results indicate that PQ claystone exhibits the highest strength (13,730 kPa), followed by QR claystone (11,720 kPa) and R claystone (5,028 kPa). Sandstone shows comparatively lower performance under wet conditions despite relatively high UCS values, with QR sandstone (13,550 kPa), PQ sandstone (10,670 kPa), and R sandstone (2,940 kPa). Material extraction strategies were optimized based on proximity to haul roads and UCS values to enhance operational efficiency and economic viability. The findings confirm that claystone, particularly PQ and QR units, is the most suitable material for mine haul road surface construction in the study area

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INTRODUCTION

Safe mining operations and the achievement of production targets are strongly influenced by the condition of mine haul roads that meet established engineering standards. Well-designed and properly constructed haul roads are capable of supporting heavy equipment loads and withstanding adverse weather conditions, thereby ensuring longer service life and operational reliability.

Haul roads that do not meet technical standards can be improved through engineering design to achieve acceptable performance. The selection of appropriate construction materials and haul road structure is a critical factor in ensuring adequate bearing capacity. Particular attention must be given to the selection of surface course materials, as both the mechanical strength of the material and its availability within the pit area play a crucial role in the planning and construction of mine haul roads.

Undulating deformation on haul roads tends to increase when the materials used are not compatible with their engineering properties and the functional requirements of each pavement layer.





This condition can degrade haul road quality, reduce operational efficiency, and increase the risk of production losses as well as mechanical damage to haulage equipment components.

Therefore, this study entitled “Design of Claystone Selection as Surface Material for Mine Haul Roads at Pit PQRT, Berau Regency, East Kalimantan Province” was conducted to address these commonly encountered field problems. The research aims to apply an engineering-based approach to optimize haul road surface material selection, improve road performance, achieve production targets, and minimize the potential for haul road deterioration.

METHODS

Preparation Stage

The preparation stage was conducted prior to field investigation to ensure the smooth execution of the research activities. This stage included a comprehensive literature review of previous studies relevant to the research area in order to obtain a general understanding of the geological conditions. Topographic map interpretation was also performed to identify the geomorphological and geological characteristics of the study area. In addition, research equipment and field instruments were prepared, along with administrative arrangements, including the acquisition of necessary permits and approvals.

Data Collection

The data collection stage involved the acquisition of both primary and secondary data required for the analysis. Primary data were obtained through direct field observations, including the identification and mapping of undulating areas on mine haul roads, material source mapping, frequency mapping of undulating areas, zoning of undulating sections, and zoning of economically viable material sources. Secondary data were obtained from the mining company and included geotechnical material properties, swell test results of claystone materials, and rainfall data, both daily and monthly, which were used to evaluate the influence of climatic conditions on haul road performance.

Data Processing and Analysis

The final data processing stage involved integrating and analyzing all collected data. Correlations were established between the physical and mechanical properties of lithological units and haul road stability. In addition, the relationship between rainfall frequency and the occurrence of undulating areas was analyzed to assess the impact of weather conditions on haul road bearing capacity. Based on these analyses, conclusions were drawn regarding the influence of material characteristics on the performance and quality of mine haul road surface layers.

RESULTS AND DISCUSSION

Macroscopic observations indicate that the sandstone units exhibit a fresh gray color and weather to a yellowish-brown appearance. The sandstone displays a clastic texture with medium sand grain size (1/2–1/4 mm), very thick bedding (>100 cm), and well-developed stratification.



Figure 1. Sandstone Outcrop at the Western PIT Area

In contrast, claystone units are characterized by a fresh dark gray to blackish color, weathering to yellowish-brown. The claystone shows a clastic texture with clay-sized particles (<1/256 mm), reflecting its fine-grained nature and low permeability.





Figure 2. Mudstone

The dominance of quartz minerals within the claystone is influenced by the provenance of the source material. Within the Lati Formation, claystone is commonly associated with depositional environments ranging from deltaic and fluvial to marine settings, where sediment sources originate from hinterland detrital materials. These source rocks commonly include quartz-rich lithologies such as granitic intrusions and metamorphic rocks. Quartz minerals are highly resistant to weathering and mechanical breakdown during transport, resulting in their preferential accumulation during sedimentation compared to less stable minerals such as feldspar.

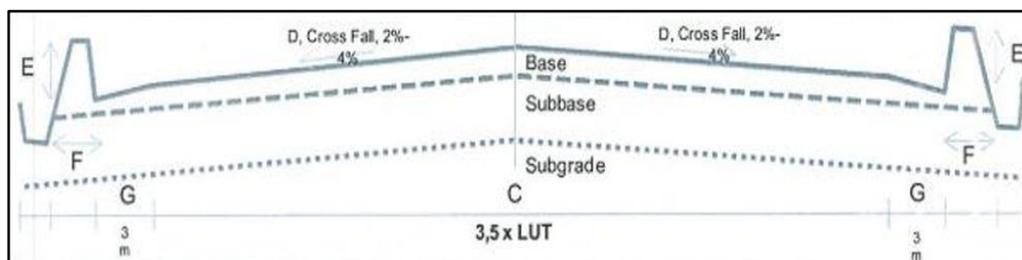


Figure 3. Mine Haul Roads structure

Mine haul roads in the study area can be classified into two categories based on the construction material used. The first category consists of haul roads that utilize claystone as the subgrade, base, and surface course layers. The second category employs sandstone as part of the haul road structure.

Claystone-based haul roads demonstrate superior performance due to the impermeable nature of claystone, which limits meteoric water infiltration. Additionally, the higher cohesion between clay particles and higher UCS values contribute to improved load-bearing capacity. These factors allow claystone-surfaced haul roads, such as those observed along the Sriwijaya haul road, to maintain optimal conditions even after rainfall events. However, claystone also exhibits swelling characteristics that may lead to subsidence and deformation if improperly selected. Therefore, swell potential testing is essential to ensure the suitability of claystone as a surface course material. Rainfall intensity and frequency remain dominant external factors influencing haul road material degradation and the development of undulating deformation.

In contrast, haul roads utilizing sandstone as the subgrade or surface layer are more vulnerable to deterioration when exposed to rainfall. Despite having moderate to high UCS values under dry conditions, sandstone possesses higher porosity and permeability, making it susceptible to water infiltration, saturation, and subsequent loss of bearing capacity.



GEOTECHNICAL MATERIAL PROPERTIES										
MATERIAL NAME	COLOR	UNIT WEIGHT (Kn/m3)	STRENGTH TYPE	COHESION (kPa)	PHI(°)	COHESION TYPE	UCS (INTACT) kPa	GSI	mi	D
Coal CHB	■	13	Generalized Hoek-Brown				3500	32	10	0
Mudstone R	■	22.2	Generalized Hoek-Brown				5028	50	4	0
Sandstone R	■	21.7	Generalized Hoek-Brown				2940	60	17	0
Sandstone QR	■	22.1	Generalized Hoek-Brown				13550	65	17	0
Mudstone QR	■	22.9	Generalized Hoek-Brown				11720	55	4	0
Sandstone PQ	■	22	Generalized Hoek-Brown				10670	65	17	0
Mudstone PQ	■	22.4	Generalized Hoek-Brown				13730	55	4	0

Figure 4. UCS of Material on PIT

Field data collection aimed at evaluating the influence of UCS values and material types on the formation of undulating areas was conducted through systematic daily observations over a three-week period. Each undulating section along the haul roads was mapped, and changes in frequency were recorded.

The results indicate a noticeable increase in the frequency of undulating areas during the first and third weeks of observation. When correlated with rainfall data, the frequency of undulating deformation shows a direct relationship with rainfall occurrence. Increased rainfall frequency corresponds to a higher number of undulating areas, demonstrating the significant role of water infiltration in haul road degradation.

WEEK 1					
Date	Sriwilaya Road	Indrapura Road	Singhasari Road	Bone Road	Total
29/09/2024	9	6	1	5	21
30/09/2024	3	4	3	7	17
1/10/2024	5	4	8	3	20
2/10/2024	6	10	3	4	23
3/10/2024	7	8	8	3	26
4/10/2024	3	8	4	3	18
					125

Figure 5. Weekly Frequency of Undulating Deformation (Week 1)

WEEK 2					
Date	Sriwilaya Road	Indrapura Road	Singhasari Road	Bone Road	Total
5/10/2024	4	4	2	5	15
6/10/2024	6	4	6	3	19
7/10/2024	4	2	6	2	14
8/10/2024	5	3	6	4	18
9/10/2024	3	2	5	4	14
10/10/2024	4	3	6	3	16
					96

Figure 6. Weekly Frequency of Undulating Deformation (Week 2)



WEEK 3					
Date	Sriwijaya Road	Indrapura Road	Singhasari Road	Bone Road	Total
11/10/2024	4	8	7	7	26
12/10/2024	4	6	6	4	20
13/10/2025	3	6	5	4	18
14/10/2025	5	8	7	4	24
15/10/2025	3	3	8	5	19
16/10/2025	7	6	7	4	24
					131

Figure 7. Weekly Frequency of Undulating Deformation (Week 3)

Analysis of Undulating Areas

The study focused on haul roads within PIT PQRT, including the Sriwijaya, Indrapura, Singhasari, and Bone haul roads, which serve as primary routes for overburden and coal transportation. Field observations reveal that haul road construction practices often prioritize efficiency and cost-effectiveness, resulting in the use of locally available materials without prior evaluation of their physical and mechanical properties.

This practice has led to frequent water ponding on haul road surfaces, indicating inadequate construction methods and unsuitable material selection. Such conditions accelerate haul road deterioration, reduce hauling efficiency, and negatively impact production performance.

The application of claystone as a surface course material is considered appropriate based on its impermeable properties, which inhibit rainwater infiltration into the haul road structure and subgrade. This characteristic helps preserve haul road bearing capacity and reduces the occurrence of undulating deformation.

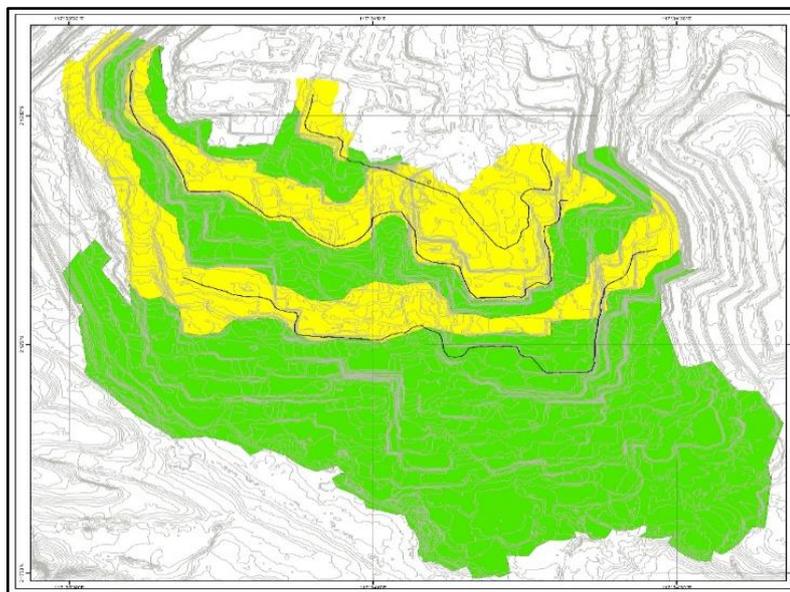


Figure 8. Spatial Distribution Map of Potential Material Sources

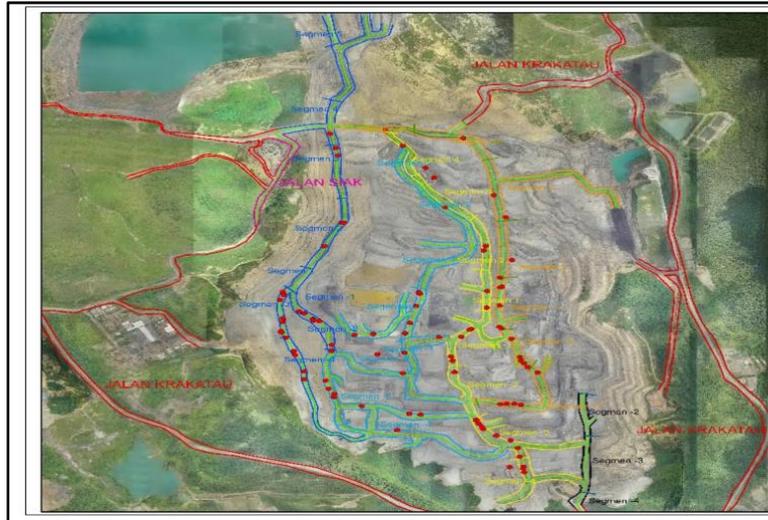


Figure 9. Weekly Frequency Map of Undulating Deformation week 1

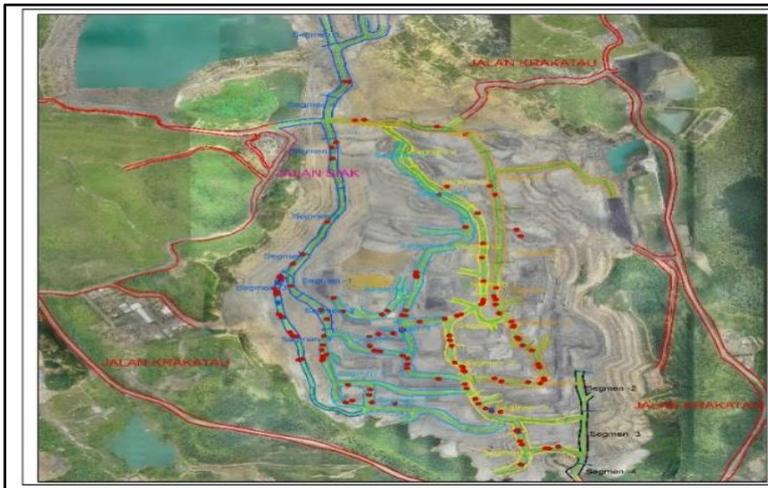


Figure 10. Weekly Frequency Map of Undulating Deformation week 2

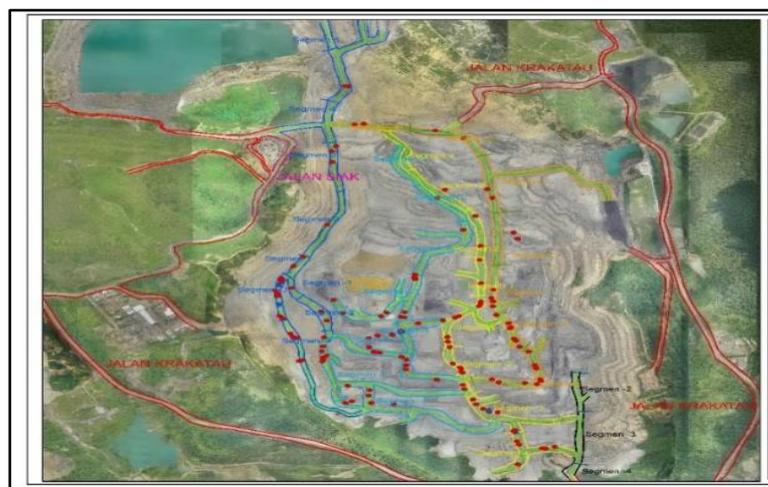


Figure 11. Weekly Frequency Map of Undulating Deformation week 3



Influence of Material Properties and UCS on Undulating Frequency

Further analysis integrating field observations and laboratory test results confirms that lithological characteristics significantly influence the frequency of undulating areas, particularly under wet conditions. Claystone units PQ (13,730 kPa) and QR (11,720 kPa), which exhibit higher UCS values, perform more effectively as haul road surface materials compared to sandstone units QR (13,550 kPa) and PQ (10,670 kPa). Although some sandstone units show relatively high UCS values, they remain more susceptible to water infiltration, saturation, and plastic deformation.

These findings support the hypothesis that the formation of undulating areas is not solely controlled by mechanical loading but is also strongly influenced by geotechnical property changes induced by rainfall. Even haul roads constructed with claystone subgrades may develop localized undulating deformation in areas with poor drainage and persistent water ponding.

To mitigate moisture-induced damage, the use of impermeable claystone materials for haul road surfaces should be accompanied by strict drainage system management to ensure effective surface runoff and minimize infiltration.

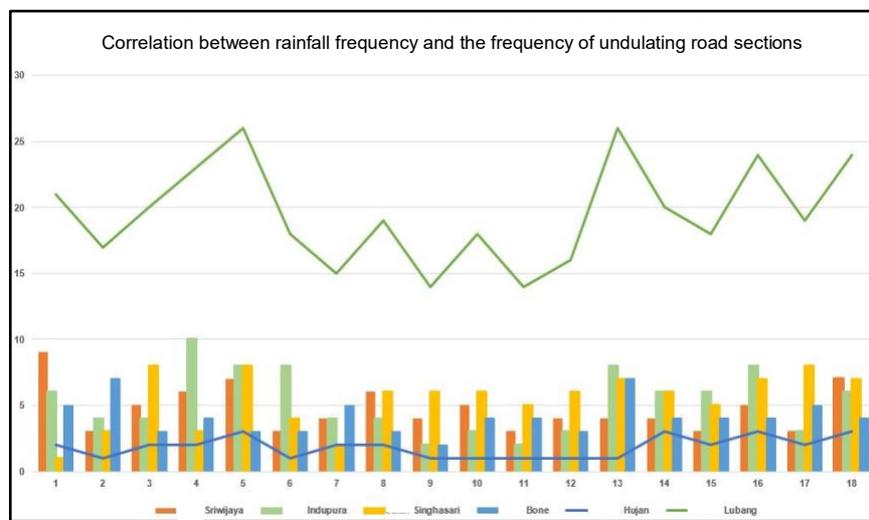


Figure 12. Correlation Diagram between Rainfall Frequency and Undulating Area Frequency

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Correlation Between Rainfall and Undulating Deformation

Correlation analysis between daily rainfall frequency and daily undulating area occurrence reveals a strong positive relationship. As rainfall frequency increases, the number of undulating areas along haul roads also rises. This trend is particularly evident on haul roads dominated by sandstone layers, which possess higher porosity, lower cohesion, and reduced UCS under saturated conditions.

The comparative analysis confirms that the application of claystone as a surface material significantly reduces rainwater infiltration, thereby decreasing the frequency of undulating deformation and improving overall haul road performance.





To ensure economic and operational efficiency, material source zoning was developed based on proximity to undulating areas and material suitability. Approximately 70% of undulating areas are concentrated within a 500 m radius of overburden zones dominated by sandstone materials, which are unsuitable for haul road surface applications.

Material source zones were divided into three priority clusters based on distance: 0–300 m, 300–600 m, and >600 m from undulating areas. The nearest cluster (0–300 m) contributes approximately 45% of suitable claystone reserves, enabling hauling cost reductions of up to 40% compared to more distant sources.

A hybrid material utilization strategy is recommended, prioritizing the nearest claystone sources for emergency road repairs, while secondary clusters (300–600 m) with high UCS values are reserved for routine maintenance. The integration of real-time mapping is proposed to balance material availability with dynamic haul road deterioration patterns.

The results demonstrate that claystone, particularly PQ and QR units, exhibits superior performance as a mine haul road surface material due to its impermeable nature and high UCS values. The findings emphasize the importance of integrating geotechnical properties, rainfall characteristics, and material logistics in the design and maintenance of mine haul roads to minimize undulating deformation and optimize operational efficiency.

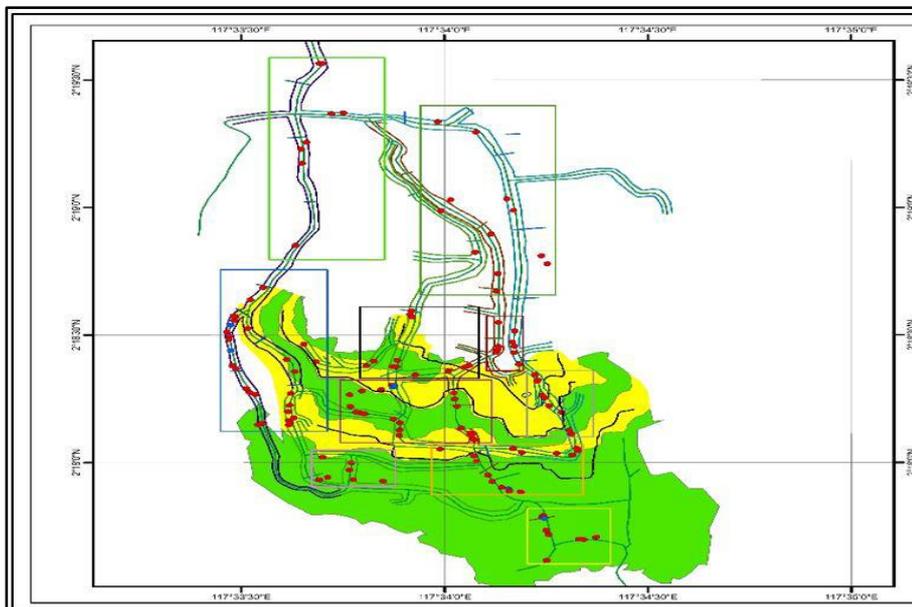


Figure 13. Clustering of Material Sources for Mine Haul Road Surface Construction

CONCLUSIONS

The selection of materials used for mine haul road surfaces significantly influences the frequency of undulating deformation. Haul road surfaces constructed using sandstone tend to develop undulating areas due to meteoric water infiltration, which leads to material saturation and a reduction in bearing capacity. In contrast, haul road surfaces utilizing claystone exhibit a lower tendency for undulating deformation because of the impermeable nature of claystone, which effectively restricts water infiltration. This characteristic enables the subgrade to maintain its bearing capacity and adequately support haulage equipment loads.

Analysis of materials within the pit area indicates that claystone exhibits higher UCS values compared to sandstone. The UCS values of claystone range from PQ claystone (13,730 kPa), QR claystone (11,720 kPa), to R claystone (5,028 kPa), while sandstone exhibits UCS values of QR sandstone (13,550 kPa), PQ sandstone (10,670 kPa), and R sandstone (2,940 kPa). Based on these results, PQ and QR claystone units are identified as the most suitable materials for mine haul road surface construction due to their high strength and impermeable properties.

To ensure economical and efficient material utilization, a material source zoning approach was developed using clustering based on proximity and material quality. The zoning strategy recommends prioritizing claystone sources located nearest to undulating areas to minimize hauling distances and





costs, while designating secondary sources as reserves to maintain continuity of road maintenance operations. Overall, the integration of material properties, UCS values, and spatial clustering provides an effective framework for improving mine haul road performance and reducing undulating deformation in the study area.

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