

Geotechnical Analyses of Mining Waste Rocks from the Central-Western Part of Côte D'Ivoire: Use as Road Embankment

Kouakou Pierre Kouassi^{1*}, Agré Séraphin Djomo², Yapi Désiré Sosthène Ronald Atto³, Athanas Konin¹

¹Laboratoire des Sciences Géographiques, Du Génie Civil et des Géosciences (LASCIG3), Institut National Polytechnique Félix Houphouët-Boigny, Yamoussoukro, Côte D'Ivoire

²Département des Sciences de la terre, UFR Environnement, Université Jean Lorougnon Guédé de Daloa, Daloa, Côte d'Ivoire

³Département Mines et Réservoirs, UFR des Sciences Géologiques et Minières, Université de Man, Man, Côte D'Ivoire

Email: *kouassikouakoupierre@yahoo.fr, *pierre.kouassi@inphb.ci

How to cite this paper: Kouassi, K.P., Djomo, A.S., Atto, Y.D.S.R. and Konin, A. (2025) Geotechnical Analyses of Mining Waste Rocks from the Central-Western Part of Côte D'Ivoire: Use as Road Embankment. *Open Journal of Civil Engineering*, 15, 813-821.
<https://doi.org/10.4236/ojce.2025.154045>

Received: October 24, 2025

Accepted: December 12, 2025

Published: December 15, 2025

Copyright © 2025 by author(s) and Scientific Research Publishing Inc. This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
<http://creativecommons.org/licenses/by/4.0/>



Open Access

Abstract

Materials based on mining waste are increasingly used in road engineering and building construction. These mining wastes, produced in large quantities during ore mining, pollute the environment. How can this waste be used in road surfacing and construction? This study was conducted to answer this question. It aims to analyze the geotechnical characterization of mining wastes generated by gold mining operations, particularly those in Hiré, in the central-west of Côte d'Ivoire, with a view to using them in the construction of embankments for road engineering structures. Experimental laboratory tests were conducted on the mining waste rocks. These tests were based on particle size analysis, Atterberg limits, and the physical behavior of the materials. Through this analysis, the experimental results made it possible to identify these mining wastes, to determine their hydrological nature, and the quality of the wastes to carry a load (traffic). The results of this analysis reveal that these waste rocks belong to the A-1b soil category. The uniformity coefficients (C_u equal to 12.4) and curvature coefficients (C_c equal to 1.29) show that they have a semi-spread, non-uniform and well-graded grain size. The plasticity index (PI) is 5%. The dry density of these waste rocks is 2.17 g/cm^3 for an optimal water content of 8.6%. The 95% CBR values of the Modified Optimum Proctor after 4 days of immersion in water are 39.6, a value greater than 30. They constitute the S5 soils class, which are lateritic gravelly type with a CBR greater than thirty. They are usable as road bases. These Hiré mine waste rocks can be considered as potential materials for the construction of road embankments with good rigid internal stability.

Keywords

Mining Waste Rocks, Internal Stability, Embankments, Potential, Road

1. Introduction

Land use planning policy leads to infrastructure development. The construction of this infrastructure requires earthworks, which consist of cutting and filling. Mining has experienced considerable growth in recent years, both in terms of quantity and quality, in the Lôh-Djiboua region, specifically in Hiré in the central-west of Côte d'Ivoire. Hiré is a rapidly expanding urban development. However, this development also generates significant quantities of waste of no economic value, which can pose a risk to the environment [1] [2]. To prevent problems associated with mine tailings, it is possible to use them in embankments. The main objective of this work is to analyze the geotechnical potential of mine tailings with a view to their use in road construction. In keeping with the main objective, the aim will be to identify mining waste rock and understand its granular nature, determine its degree of compaction to support a load (traffic), and determine the bearing capacity of mining waste rock for use as embankments in road construction.

2. Experimental Materials and Methods

2.1. Experimental Materials

The raw material (mining waste) was taken, in accordance with site practices, from the Hiré gold mine following the geographical location in **Figure 1**. This mining waste rock is transported to the laboratory for testing.



Figure 1. Geographic location of the Hiré mining waste rock sampling site.

This mining waste rock is transported to the laboratory for testing.

2.2. Experimental Methods

The methodological approach is based on:

- Particle size analysis, which involves passing a representative borrowed sample of the waste rock through stacked sieves with opening diameters decreasing from top to bottom. The largest particles therefore remain trapped on the larger diameter sieves to produce the rejects or retained particles, while the finer particles move to the smaller diameter sieves and constitute the passing particles. When the masses retained on each sieve become constant, the sieving process is complete, and all the rejects are weighed. The mass of each reject is then compared to the initial total mass of the sample collected in the laboratory, which allows the calculation of the cumulative passing reject percentages. The results are plotted on a semi-logarithmic graph using an arithmetic scale ranging from 0% to 100% on the ordinate and modules expressed on a decimal logarithmic scale on the abscissa for small values ranging from 0.2×10^{-6} meters to 2 meters where they construct a granulometric curve according to in **Figure 2**.

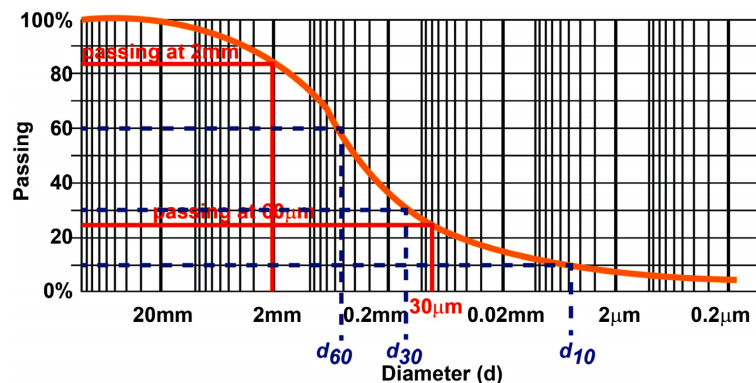


Figure 2. Grain size distribution curve of waste soils [3].

From this grain size distribution curve, the HBR (High Research Board) classification of mine waste rock is performed, the designation of waste soils is identified, and the curvature coefficient $C_c = (d_{30})^2 / ((d_{60})d_{10})$ and the uniformity coefficient $C_u = ((d_{60}) / (d_{10}))$ are calculated to characterize the rigid internal stability of mine waste rocks [4] [5] **Table 1**.

Table 1. Soil designations according to soil type proportions.

Proportion of Soil Types	Terminology	Examples
>35%	gives the name of the soil	Gravel, sand, silt, etc
20% to 35%	gives the adjective	Gravelly, sandy, etc
10% to 20%	A little	With traces of clay silt, etc.
<10%	defines the Trace	

- Determination of the Atterberg limits (liquidity limit LL using the Cassagrand cup, plastic limit LP using a roller [6]. The plasticity index IP is the difference between LL and LP, *i.e.*, the extent over which the mine waste soils are malleable. It characterizes the water content of the waste rock [7].
- Physical characterization using the modified Proctor method to determine the dry density and optimal water content, followed by the CBR test for the CBR at 95% of the OPM after 4 days of immersion in water, according to standards NF P 94-093 [8] and NF P 94-078 [9], respectively, for the degree of compaction and the CBR bearing capacity of the mine waste soils.

3. Results, Interpretations, and Discussion

3.1. Results and Interpretations

- **Granulometry of the Hiré mining waste rock**

The size distribution of the different grains in the Hiré mining waste rock is shown in **Figure 3**. The distribution of the proportions of the different grains of the Hiré mine waste soils. The analysis shows that these Hiré mine waste soils are composed of 10% pebbles, 36% gravel, 44% sand and 3% silt. These soils have a dominant coarse fraction (sand and gravel) at 80% with 10% large elements then a small fine fraction (silt and clay) equal to 3%. This grain distribution shows the homogeneous distribution of the different grain sizes. The Hiré mine waste soils can be identified as pebbly gravelly sand with a trace of silt. The determination of the parameters $C_c = 1.29$ between 1 and 3 and $C_u = 12.9 > 6$ suggest that the Hiré mine waste gravelly sands have well-nested grains, exhibit high internal stability and natural compaction.

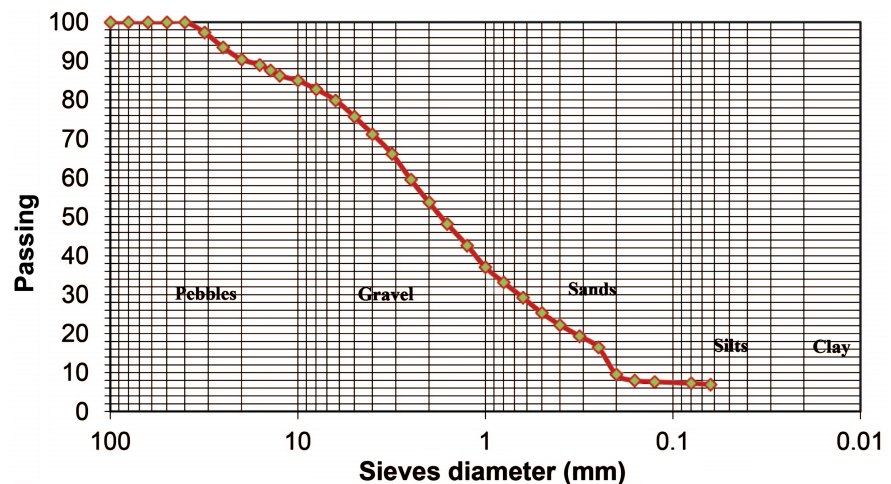


Figure 3. Average particle size curve of Hiré mining waste.

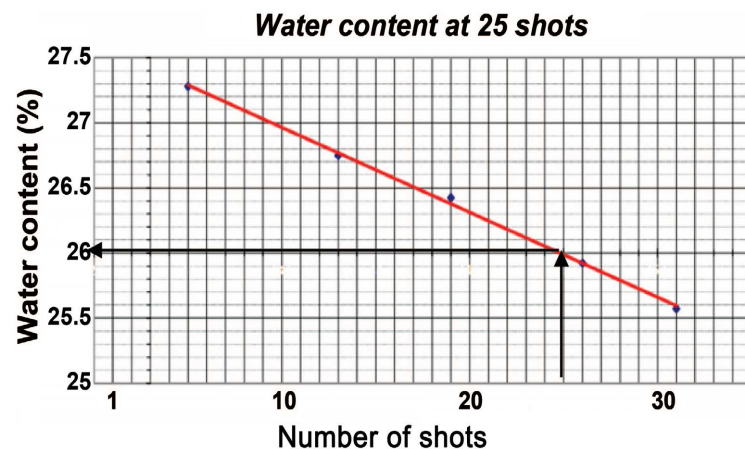
Table 2 shows that depending on the granular composition, there is a low presence of fine matrix in the Hiré mining waste with 3% of silts while the coarse matrix (80%) is dominant and consists of 36% of gravels and 44% of sands. The large elements (pebbles) are in equal proportion to 10%.

Table 2. Grain size values of Hiré mining waste.

Fraction	Granular composition of Hiré mining waste fractions (%)
Pebbles with a diameter between 20 and 100 mm	10
Gravels with a diameter between 2 and 20 mm	36
Sands with a diameter between 0.2 and 2 mm	44
Silts with a diameter between 0.02 and 0.2 mm	3

- **Atterberg limits and Water content**

Figure 4 represents the diagram for determining the liquidity limit (LL) of the Hiré mining waste gravelly sands which is a constant that allows the soil to pass from a plastic state to the corresponding liquid state on the semi-logarithmic scale at n strokes equal to 25. The water content corresponding to 25 strokes is the liquidity limit $LL = 26\%$. The plasticity limit (PL) on the role of the fine fraction 10 cm long thinned and which breaks around 3 cm in diameter gave the laboratory results with $WP = 25\%$, therefore $PI = 5\%$. The plasticity index (PI) is low for these soils. The Hiré mining waste gravelly sands are moderately plastic and stable to water variation and they can be used as backfill in road technology.

**Figure 4.** Result diagram of the liquidity limit of the Hiré gravelly sands.

These mine waste rocks are type A-1b soils (gravelly sands) with a moderately plasticity index (PI) of 5% according to **Table 3**. These Hiré mine waste rocks are identified as pebbly gravelly sands with traces of silt. These gravelly sands have a semi-spread grain size; the C_u value is 12.4 (range 5 to 20) and the C_c value is 1.29 (range 1 to 3). These various results show that these gravelly sands (mine waste rocks) from Hiré have strong internal stability and are well graded. The optimal average dry density is 2.17 g/cm^3 with an optimal average water content of 8.6% according to **Figure 4**. This optimal average water content made it possible to obtain, for each compaction energy at 4 days of immersion in water, the CBR bearing value curves as a function of the dry densities according to **Figure 5**.

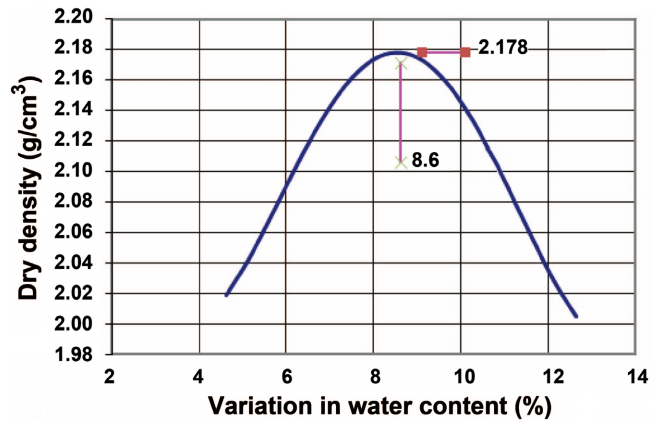


Figure 5. Curve resulting from the variation in water content as a function of the dry density of sterile gravelly sands from Hiré.

Table 3. Values of the Atterberg limits of the Hiré mining waste rock.

	Atterberg Limits
Liquidity Limit (LL) (%)	26
Plasticity Limit (PL) (%)	21
Plasticity Index (PI) %	5

The results in **Figure 6** show that 95% of the California Bearing Ratio (CBR) of the Modified Optimum Proctor (MOP) after 4 days of immersion in water is on average 39.6 higher than 30. The Hiré mine waste gravelly sands, classified as S5 soil, are suitable for use as backfill for road engineering structures [5]. Indeed, S5 soils are lateritic gravelly type with a CBR greater than thirty. They are suitable for use as road bases.

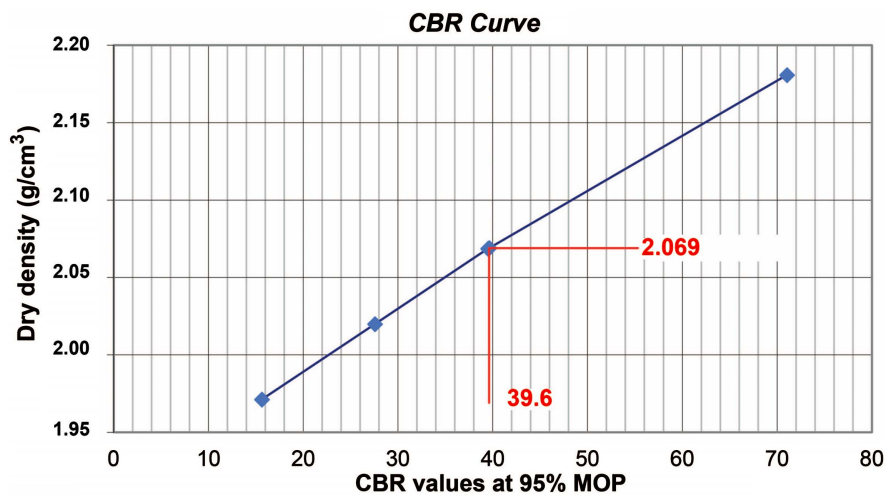


Figure 6. CBR 95% MOP result curve for the Hiré mine waste gravelly sands.

3.2. Discussion

The Hiré mine wastes are gravelly sand-type soils with some pebbles, including a

trace of silt, *i.e.*, 10% pebbles, 36% gravels, 44% sands, and 3% silts. The recommended particle size for the road surface is generally composed mainly of gravel and sand with a lower fraction of fine particles ($d < 0.08$ mm). A soil with a spread grain size will increase performance in terms of rigidity and resistance indicating a potential for internal stability of this soil to erosion according to [10]. Our work is consistent with that of [11] [12]. According to [13], a soil with a CBR between 20 and 50 is a very slightly deformable support, which is confirmed by [14]. The results of physical tests on sterile gravelly sands from the Hiré gold extraction show that these mining wastes can be reused for embankments in road techniques for low to medium traffic, which remains in agreement with the work of [4]. The CBR at 95% MOP greater than 30 and C_c equal to 1.29 is between 1 and 3 and C_u equal to 12.9 greater than 6 would mean that the coarse matrix of the mining waste of Hiré is well graded which reflects an internal stability in terms of sufficient rigidity and our results are similar to those of the work of [15] on the valorization of laterites of Côte d'Ivoire. The absence of clay and the weak fine matrix shows that the sterile gravelly sands of Hiré do not retain water they are draining with a low water content 8.6% and a low plasticity index PI 5%. From a plasticity point of view, the soils studied are not too sensitive to water, therefore they could be useful in road construction. The distribution of grains in a soil influences the rigidity of this soil. Our results corroborate those of the work of [16].

4. Conclusion

We characterized the Hiré mine waste rock in the Lôh-Djiboua district of Côte d'Ivoire in the laboratory. In terms of grain size, these soils are gravelly sand. The PI is equal to 5%, which shows that our waste rocks are moderately plastic and well-drained. Regarding the physical nature, we note that the mine waste rock has a CBR of 39.6, which indicates that these soils can withstand any load and deform little. The analyzed waste rock can be used in embankments for road construction. In a sustainable development policy, these waste rocks could constitute the raw material for road construction, and the results can be integrated into embankment design guides for road engineering. However, the use of mining waste can cause environmental problems due to the drainage capacity of this type of soil, which could contaminate the aquifer with non-breakable molecules usable by the mining industry. Studies could be conducted in this regard.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Malaoui, R., Harkati, E.H., Soltani, M.R., Djellali, A., Soukeur, A. and Kechiched, R. (2023) Geotechnical Characterization of Phosphate Mining Waste Materials for Use in Pavement Construction. *Engineering, Technology & Applied Science Research*, **13**, 10005-10013. <https://doi.org/10.48084/etasr.5493>
- [2] Tebiri, B. (2023) Caractérisation géotechnique de différents stériles miniers pour leur

- usage en remblais. Ph.D. Thesis, Université Echahid Cheikh Larbi Tébessi-Tebessa.
- [3] Gouba, B. (2023) Traçage de la courbe granulométrique et la détermination des coefficients de Hazen par la méthode analytique. *Revue Internationale de la Recherche Scientifique*, 1, 21-31.
- [4] Benzaazoua, M., Bois, D., Belem, T., Ouellet, S. and Fall, M. (2003) Utilisation du remblai en pâte Comme Support de Terrain, Partie II: Comportement à court, à moyen et à long terme. *Colloque Après-Mine 2003*, Nancy, 5-7 Février 2003, 1-13.
- [5] CEBTP (1984) Guide pratique de dimensionnement des chaussées pour les pays tropi-caux. Ministère des relations extérieures, Coopération de développement, République Française, 157 p.
https://www.francescomiceli.com/blog/Guide_pratique_dimensionnement.pdf
- [6] NF P 94-051 (1993) Sols: Reconnaissance et Essais-Détermination des limites d'Atterberg—Limite de liquidité à la coupelle—Limite de plasticité au rouleau. AFNOR, 15 p.
<https://www.boutique.afnor.org/fr-fr/norme/nf-p94051/sols-reconnaissance-et-essais-determination-des-limites-datterberg-limite-d/fa020765/11080#AreasStore-ProductsSummaryView>
- [7] Ouazir, K., Belmahi, S. and Benferhat, R. (2025) Manuel de travaux pratiques de la mécanique des sols I. Université Ibn Khaldoum de Tiaret, Faculté des sciences appliquées, Département génie-civil, 50 p.
<https://fsa.univ-tiaret.dz/images/doc/COURS/Polycopie-ManuelTP-MDS1-OUAZIRKhatima.pdf>
- [8] NF P 94-093 (2014) Sols: Reconnaissance et essais—Détermination des références de compactage d'un matériau—Essai Proctor Normal—Essai Proctor modifié. AFNOR, 28 p.
<https://www.boutique.afnor.org/fr-fr/norme/nf-p94093/sols-reconnaissance-et-essais-determination-des-references-de-compactage-du/fa185491/43924#AreasStoreProductsSummaryView>
- [9] NF P 94-078 (1997) Sols: Reconnaissance et essais indice CBR après immersion—Indice CBR immédiat—Indice portant immédiat. Mesure sur échantillon compacté dans le moule CBR. AFNOR, 12 p.
<https://www.boutique.afnor.org/fr-fr/norme/nf-p94078/sols-reconnaissance-et-essais-indice-cbr-apres-immersion-indice-cbr-immedia/fa042054/11055#AreasStore-ProductsSummaryView>
- [10] Amrani, M., Taha, Y., Kchikach, A., Benzaazoua, M. and Hakkou, R. (2019) Valorization of Phosphate Mine Waste Rocks as Materials for Road Construction. *Minerals*, 9, Article 237. <https://doi.org/10.3390/min9040237>
- [11] Tannant, D.D. and Regensburg, B. (2001) Guidelines for Mine Haul Road Design. University of British Columbia Library, 111 p.
- [12] Thompson, R.J. and Vissera, T. (2000) The Functional Design of Surface Mine Haul Roads. *The Journal of the Southern African Institute of Mining and Metallurgy*, 100, 169-180.
- [13] GTR (2023) Guide des terrassements, Des remblais et des couches de forme, Fascicule N°1. *Editions Cerema*, 118 p.
https://www.ensemble77.fr/images/outils/gestion_domaine_public/Guide_terrassements/gtr_2023_fascicule_1_compressed.pdf
- [14] Hao, S. (2021) Experimental Measurement, Mathematical Description, and Machine Learning Prediction of the Mechanical Properties of Waste Rocks for Mine Haul Roads.

Ph.D. Thesis, Polytechnique Montréal. <https://publications.polymtl.ca/9479/>

- [15] Assandé, A.A. (2007) Valorisation des latérites de la Côte d'Ivoire: Fabrication des briquettes de parement à base de latérite stabilisée à froid à l'aide de liant hydraulique: Le ciment Portland. Master's Thesis, Université de Cocody, UFR STRM.
- [16] Reiffsteck, P., Nguyen Pham, P.T. and Arbaut, J. (2007) Influence de la répartition granulométrique sur le comportement mécanique d'un sol. *Bulletin des Laboratoires des Ponts et Chaussées (BLPC)*, **268-269**, 83-104.
https://www.ifsttar.fr/collections/BLPCpdfs/blpc_268-269_83-103.pdf