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Improvement of Lateritic Gravelly Soil Using Cement and Litho-Stabilization and Its Application Case of Main Road Artery on the City Side of the New Ouagadougou-Donsin airport

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Abstract: *Innovative techniques like litho-stabilization enhance the quality of lateritic gravel for road construction. Our experiment incorporated varying percentages of crushed gravel with native lateritic gravel. Results revealed that adding 25% and 30% crushed gravel achieved excellent compaction energy, while 20% crushed gravel mixture surpassed natural laterite in density, water content, and plasticity. California Bearing Ratio (CBR) values were notably high, reaching 90%, 95%, and 98% for 20%, 25%, and 30% crushed gravel blends. This research showcases litho-stabilization's potential in fortifying lateritic gravel, yielding resilient and long-lasting road networks.*

Keywords: *California Bearing Ratio (CBR), crushed 0/31.5 base course, optimum proctor modified (OPM), litho-stabilization*

1. Introduction

In Burkina Faso, as in other parts of the world, transport plays a crucial role in regional integration and development [1]. Lateritic gravels are extensively used in road construction, serving as fill material or as the primary component for the subgrade [2; 3; 4; 5; 6; 7]. Therefore, it is essential to ensure the sustainability of this network. To enhance air transport competitiveness in Burkina Faso, improve the quality of life in Ouagadougou city, and establish better connectivity between the city center and southern districts, the Burkina Faso government decided to relocate the airport to Donsin, approximately 30 km north of the capital.

However, these materials cannot be used for the sub-base layer due to their poor load-bearing characteristics, as stated in the pavement design guide for tropical countries, CEBTP [8; 9; 10]. Recently, litho-stabilization has gained popularity in various sub-Saharan African countries. The technique was introduced in Burkina Faso through the National Laboratory of Buildings and Public Works (LNBTP) during the Ouagadougou-Yako Road development project [11]. Pierre LOMPO further developed and implemented the technique [12], and he concluded that gravel can be used as a road base. Therefore, it is necessary to explore alternatives to improve the properties of such gravel for rational use in road construction. The study demonstrated that the lateritic gravel from the construction site can serve as a base course for road sublayers when stabilized with 25% crushed stone content, following the specifications of the CEBTP guide [8] and the revised version [9].

2. Study Area

2.1 Ouagadougou - Burkina Faso

Located in the heart of West Africa, the main links between Burkina Faso and the rest of the world are the road, rail and air networks. The city of Ouagadougou, the main administrative and economic center of the country, has an international airport located in the city center.

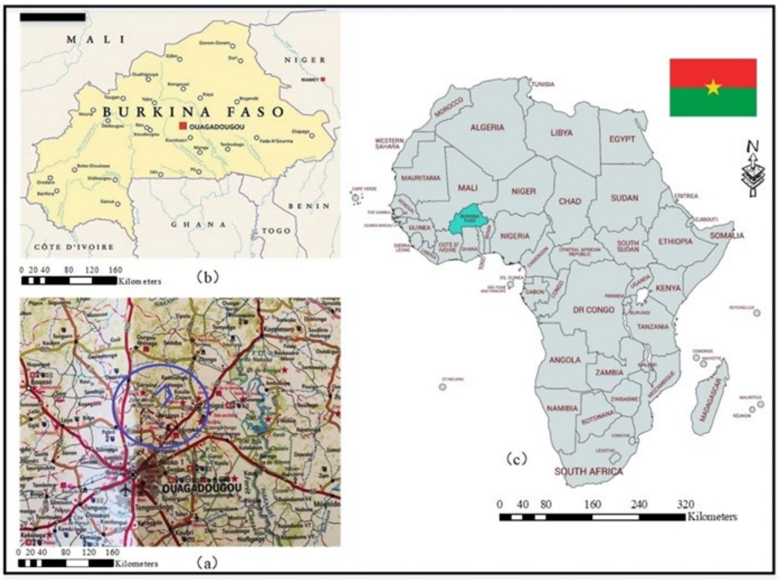

Figure 1: Study Area (a) Location of the project in Ouagadougou b) Burkina Faso Map showing Ouagadougou (c) Map of Africa Showing Burkina

The new airport project is situated in the municipality of Loumbila, within the central plateau region. Specifically, the project site is located in the village of Donsin, around 9km from the center of Loumbila, covering an area of approximately five thousand hectares. The precise location of the project area is indicated on the map depicted in Figure 1.

2.2 Materials Characteristics

2.2.1 Natural Lateritic Gravelly

Laterite can be defined as a residual soil or rock that forms as a result of rock decomposition [13; 14; 15; 16]. This material finds extensive use in road construction. Prior to attempting to enhance the characteristics of lateritic gravel, it is essential to assess the material's properties.

Table 1: Properties of the natural lateritic gravel from borrow area after some Laboratory test

Nature	Atterberg Limits		Granulometric Analysis (Sieve in mm)										OPM		CBR		
	WL	IP	0,08	0,5	1	2	4	6,3	10	20	31,5	40	W	Ds	90%	95%	98%
Natural Lateritic Gravelly	27	12	19,5	26,5	30,5	36	50	68,5	86	97	100	100	8,0	2,19	22	38	57

Table 1 provides the data necessary to represent the granulometric curve, Proctor curve, and CBR curve in Figures 2, 3 and 4.

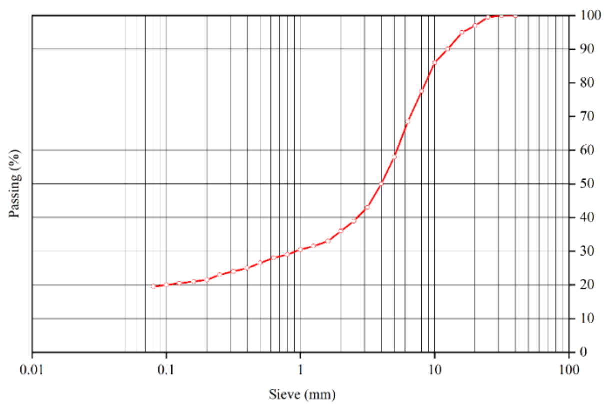

Figure 2: Granulometric curve of natural lateritic gravelly

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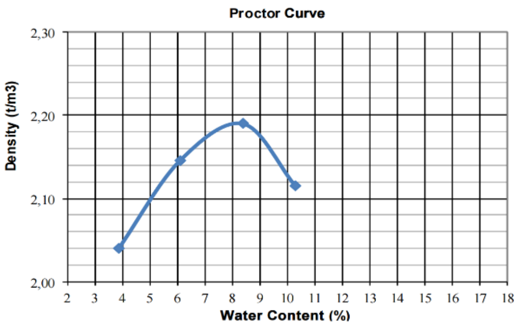

Figure 3: Proctor curve of natural lateritic gravelly

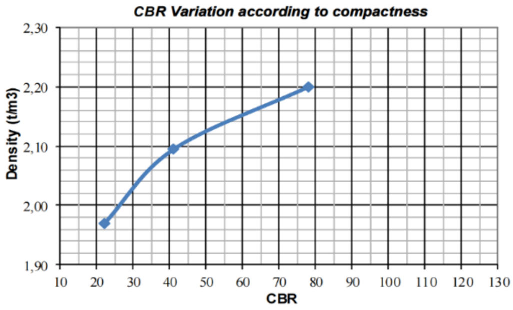

Figure 4: CBR curve of natural lateritic gravelly

2.2.2 Comments

Based on these results, it is evident that in accordance with the CPT (Technical Clause of the site), we have %0.08 = 19.5, which is less than 20. Additionally, the IP is 12.5, also falling below 15, and the Cc is 1.5, which exceeds 1, indicating a soil in the solid state. However, when considering the bearing capacity at 95% and 98% of the OPM, we observe values of 38 and 58, respectively, which are far from satisfactory for a base course. These values do not meet the requirements specified by the CPT, where a CBR of 95% of the OPM > 60 and a CBR of 98% of the OPM > 80 are expected. In conclusion, the bearing capacity characteristics of the lateritic clayey gravel do not align with the specifications outlined by the CPT. Thus, improvements will be necessary.

2.2.3 Crushed gravel

Crushed gravel is a naturally occurring material in Burkina Faso, and it is abundantly found in Ziniare, the area where our tests were conducted. It is obtained by crushing rocks to meet the specific dimensions required. Laboratory test was conducted on this material.

Using the data provided in Table 2, we will depict the particle size distribution curve of the crushed material in figure 5.

Table 2: Summary of the tests carried out on the crushed 0/31.5

Sieve Opening (mm)	40	32	20	10	6.3	4	2	1	0.5	0.1	Micro Deval	Los Angeles
Percentage by weight of passers by	100	100	73	46	36	27	19	13	10	6	10.6	23.7

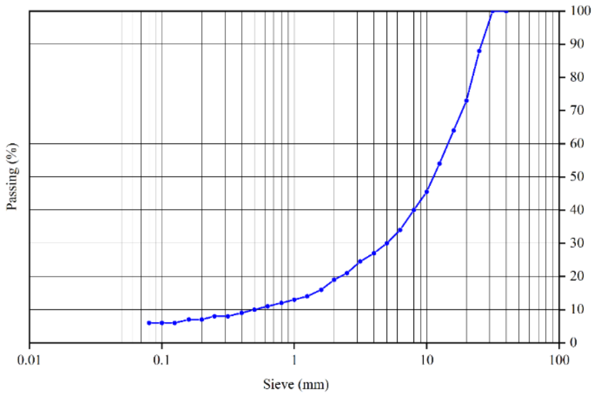

Figure 5: Granulometric analysis of the crushed material

2.2.4 Comments

The particle size analysis reveals that the material consists of a minimal amount of fines (% <0.08 equals to 6%) and exhibits a uniform grading. It is important to note that for it to be utilized in the base course, the Quality Assurance Plan mandates an LA value of less than or equal to 25 and an MDE value of less than or equal to 20. Granite crushed stone fulfills these requirements. Its properties render it suitable for enhancing the lateritic gravels investigated in this study.

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3. Method

In the production of high-performance materials, it is common practice to incorporate good quality crushed granite materials into the inferior natural lateritic gravel as part of the litho-stabilization process [2]. To characterize these materials, various tests are conducted, including granulometric analysis [17], Atterberg limits [18], and experiments such as the Proctor, CBR [19; 20], and the Los Angeles [21], and Micro Deval [22] which explore the significance and impact of material composition [23].

3.1 Sampling

The aterial is mixed, sieved using a 5mm sieve, and exposed to sunlight for five hours. Sampling involves quartering method for heterogeneity, and a sampler is used for materials under 50 kg.

3.2 Particule size

The Particle size analysis studies grain distribution by size/weight. Methods include sedimentometry (small particles) and sieving (large particles). Material divided, sieved, percentages calculated, and visual representation generated.

The material is first oven-dried and then submerged in water for 24 hours. After a wash through a 0.08 sieve, it is steamed for another 24 hours [17]. The material is then sorted from top to bottom, arranging square-mesh sieves in decreasing mesh size order. Vibrations are applied to the sieves, and the cumulative weights of the particles retained in each sieve are measured starting from the sieve with the largest diameter.

3.3 Atterberg Limits

The behavior of soil is influenced by the amount of water present. When the water content is high, the soil behaves like a liquid, and as the water content decreases, the soil gradually transitions from a plastic to a solid state. The transition between these phases is determined by the limits of fluidity and plasticity, known as the Atterberg limits, which are geotechnical criteria used to characterize soil behavior [18].

$$I_P = W_r - W_p \tag{1}$$

$$I_C = \frac{W\mathrm{L} - W\mathrm{n}}{I_p} \tag{2}$$

Where: I_C is the Consistency Index WL is the Liquidity Limit Wn is the Natural Water Content and Ip is the Plasticity Index

The document entitled [21] gives us Table 3.

Table 3: State of the soil according to the consistency index

Consistency index Ic	State of the soil
Ic > 1	Solid
0 < Ic < 1	Plastic
Ic < 0	Liquid

3.4 Proctor test

This test aims to determine the optimal water content (Wop) and the maximum dry density (γdmax) of the soil, which will serve as a reference for compaction.

By following the procedure, the optimal water content and maximum dry density of the soil can be determined, providing a basis for achieving effective compaction.

3.5 CBR test

The CBR (California Bearing Ratio) test is used to determine the bearing capacity of a material, which indicates its ability to support loads [20]. This test allows for the determination of different indices.

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These three values are used to plot the index-dry density curve, from which the CBR indices at 90%, 95%, and 98% of the maximum dry density can be determined.

3.6 Los Angeles test

This test allows for the determination of the resistance to fragmentation caused by shocks and wear due to reciprocal friction of the material's elements [21]. The test was conducted at the National Laboratory of Buildings and Public Works (LNBTP).

3.7 Micro Deval test

The purpose of this test is to measure the abrasion resistance of an aggregate through the mutual friction between the aggregates under an abrasive load [22]. This test was also conducted at the "LNBTP". The Los Angeles and Micro Deval tests are specifically applicable to crushed gravel materials. Our study will be conducted using the procedures showed in figure 6.

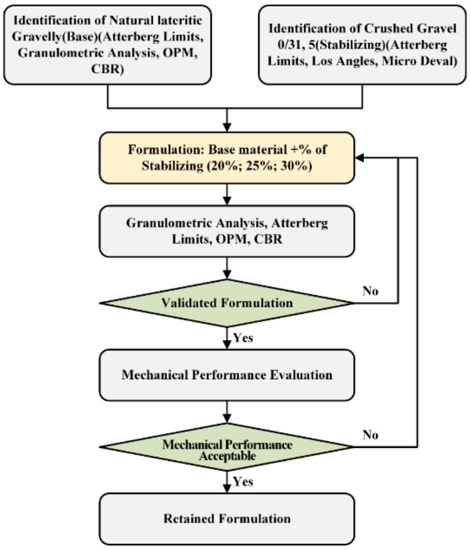

Figure 6: Flow chart of the research method

4. Results and discussion

4.1 Results of the study

Table 4: Summary of the tests carried out on lateritic gravels improved with crushed 0/31.5

Nature	Atterberg's limits		Granulometric Analysis (mm)												CBR		
	WL	IP	0.08	0.5	1	2	4	6.3	10	20	31.5	40	w	Ds	90%	95%	98%
NLG	27	12	19.5	26.5	30.5	36	50	68.5	86	97	100	100	8.0	2.19	22	38	57
NLG + 20% CG 0/31.5	20.7	8.5	16	25	28.5	35.5	52.5	71	86.5	99	100	100	7.5	2.23	14	30	68
NLG + 25% CG 0/31.5	22.1	9.4	16.5	24	28	33.5	46	74	81.5	96.5	100	100	6.6	2.27	34	79	98
NLG + 30% CG 0/31.5	21.6	9.4	14	22	25.5	33	52	70	87	100	100	100	5.8	2.24	16	22	40
NLG =Natural Lateritic Gravelly: CG = Crushed Gravel																	

The previously studied lateritic gravels have been enhanced by incorporating granite crushed stone of granular class 0/31.5, which has previously determined physical and mechanical properties. The objective of this study is to investigate how the addition of crushed stone improves the properties of the lateritic gravels, aiming to enhance the road's resistance. The mixtures were prepared in the proportions of 20%, 25%, and 30%.

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The improved samples were subjected to the following tests: Granulometric analysis, Atterberg Limits, Modified Proctor, CBR test

4.2 Discussion

4.2.1 Analysis of Granulometric Results

In general, it is observed that the granulometry of the lithostabilized GAL has improved (from 19.5 to 16, 16.5, and 14). This improvement can be attributed to the addition of the granite material, which has a lower proportion of fines and contributes coarse elements that enhance the granulometry by strengthening the structure of the improved material.

For the 25% mixture, there is a slight increase in the percentage of fines from 16 (in the 20% mix) to 16.5. This could be attributed to potential over or under-dosing during the quartering operations, resulting in a small increase in the 25% mix. It is also observed that the 25% mix has the most spread-out curve. The results obtained for upgrading with 20% crushed material are as follows in figure 7, figure 8 and 9:

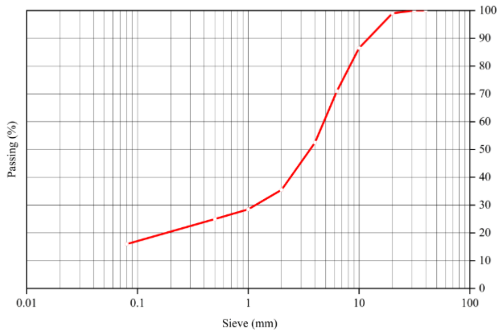

Figure 7: Granulometric analysis curve of the lateritic gravel + 20% crushed stone

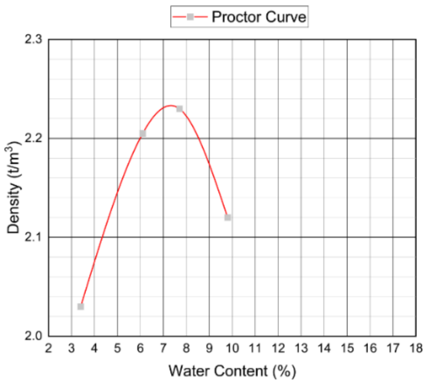

Figure 8: Proctor of the lateritic gravel + 20%CS

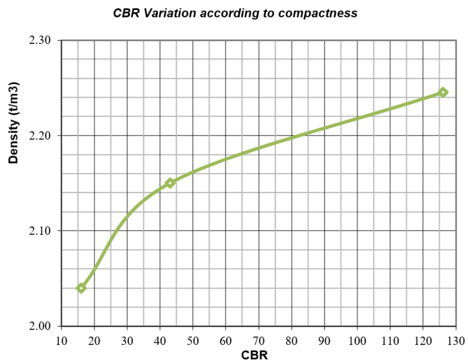

Figure 9: CBR of lateritic gravel + 20% CS

The results obtained for upgrading with 25% crushed material are as follows in figure 10, figure 11 and 12:

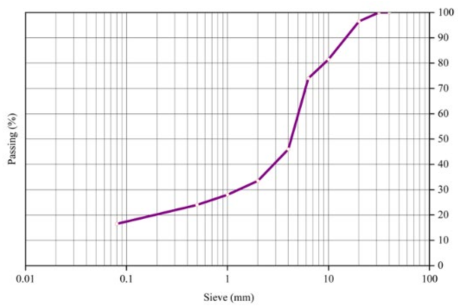

Figure 10: Granulometric analysis curve of the lateritic gravel + 25% crushed stone

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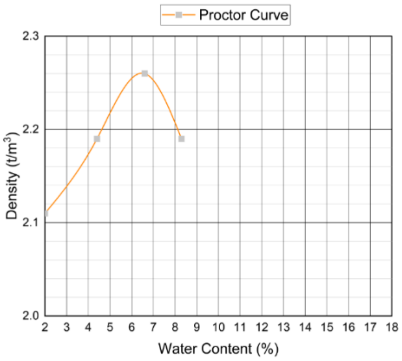

Figure 11: Proctor of the lateritic gravel + 25% CS

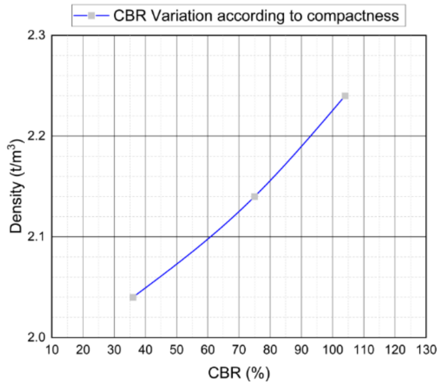

Figure 12: CBR of lateritic gravel + 25% CS

The results obtained for upgrading with 30% crushed material are as follows in figure 13, figure 14 and 15:

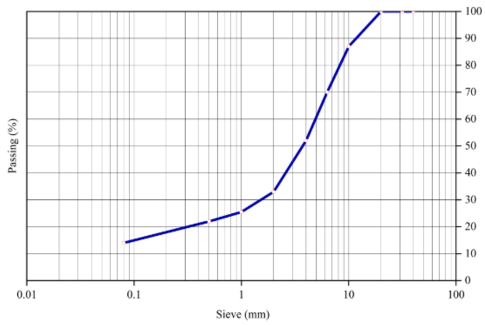

Figure 13: Granulometric analysis curve of the lateritic gravel + 30% crushed stone

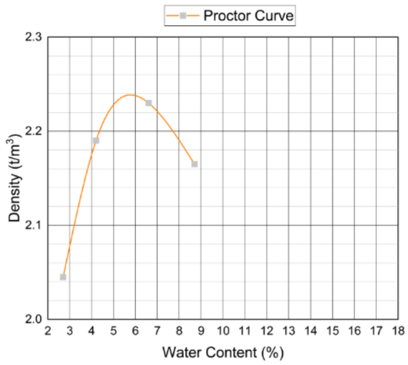

Figure 14: Proctor of the lateritic gravel + 30% CS

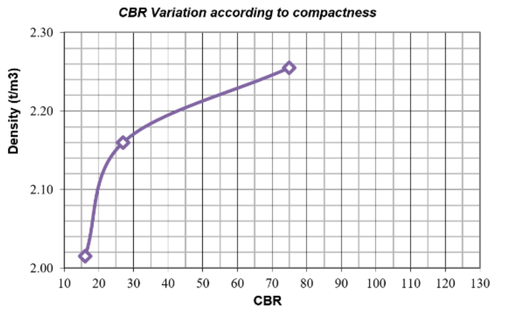

Figure 15: CBR of lateritic gravel + 30% CS

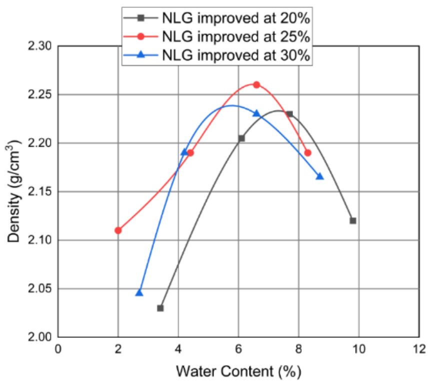

Figure 16: Proctor of Lithostabilized GAL

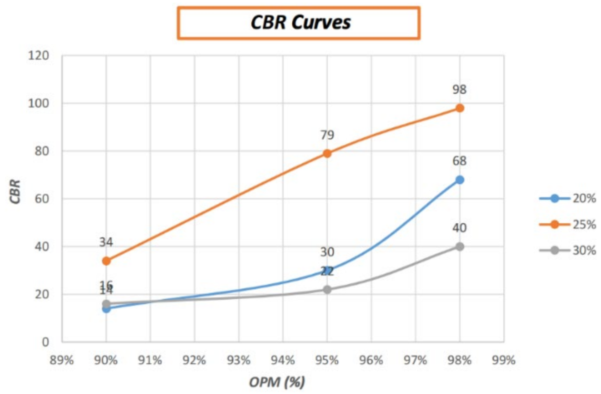

Figure 17: CBR as a function of the OPM percentage

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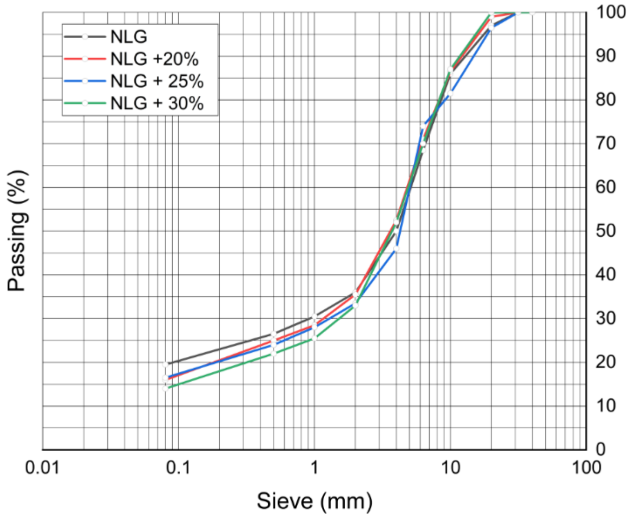

Figure 18: Curves of the granulometric analysis of the lithostabilized GAL

4.2.2 Atterberg Limits results analysis

In the case of the Atterberg Limits, it is observed that the liquidity limit decreases progressively from 27 to 20.7, then 22.1, and finally 21.6. Similarly, the plasticity index decreases from 12 in the natural state to 8.5, and then stabilizes at 9.4 for the 25% and 30% proportions. This can be attributed to the presence of fines in the added crushed material. It is worth noting that for all three scenarios, the plasticity index is lower than the required limit of 15.

4.2.3 Analysis of dry densities at the Modified Proctor Optimum

Dry densities generally increase after improvement, while moisture contents gradually decrease (see Table 4 and Figure 16). This effect is particularly evident in the 25% mixture, which exhibits a density of 2.265. The increase in density can be attributed to the reinforcement of the natural material structure and the reduction in fines content through the addition of granite crushed material.

However, it is important to note that the density of litho-stab is not solely determined by the percentage of crushed material used for improving the lateritic gravel. During compaction, there is a possibility of particle segregation, especially with larger diameter particles. Therefore, the relationship between density and the percentage of crushed material is not straightforward.

4.2.4 Analysis of evolution of the CBR indices

Regarding the CBR bearing capacity, the 20% mixture has a lower CBR bearing capacity and dry density than the 30% mixture, which is also lower than the 25% mixture. It has been noticed that in the 30% mixture, the CBR has relatively decreased compared to the 25% mixture. It is the same for its dry density. This is also due to a poor distribution of materials during the quartering operation.

It can be seen that at 25%, our material achieves a CBR bearing capacity of 79 to 95% of the OPM and 98 to 98% of theOPM, which would be higher than the requirements requested by the CPT (respectively 60 and 80) (see Table 4 and Figure 17). These results can be explained by the fact that there were very few voids in the material after compaction, and the reinforcement of the skeleton allowed the improvement of the CBR indices. Therefore, the proportion to be retained here is 25%. The relationship between the dry density at the Modified Proctor Optimum and the CBR index is due to the fact that the denser the material is, the fewer voids it contains. This makes the material very consolidated. Punching then requires more and more force and this is felt in the CBR index.

4.2.5 Analysis report

The particle size analysis improved as the percentage of fines decreased, and the plasticity index of the material decreased when upgraded with a granite crusher according to the Figure 18. From a road engineering perspective, the improvement of lateritic gravel with a granite crusher resulted in a CBR index exceeding 80 (98) at a mixture of 25%.

The conducted study indicates that the best results in terms of the CBR bearing index were obtained when using 0/31.5 crushed stone at a proportion of 25%.

5. Project Application

a) *b)*

Figure 19: Mixture of the lateritic gravelly soil with the crushed (a) Before mixing (b) After mixing

The implementation of litho-stabilization is relatively easy and quick. It also has few noticeable disadvantages. However, it requires strict material control before and during implementation.

During the implementation process, when the lateritic and crushed gravel mixture is deemed homogeneous and nearly ready for adjustment and compaction, granulometry tests are conducted to ensure homogeneity and assess the dosage of crushed material.

After compacting the litho-stab, the compactness is verified using a membrane densitometer, which measures the density of the layer directly on the ground (see Figure 19). This allows for the determination of the layer's compactness.

6. Conclusion and Future works

This research paper enabled us to conduct a formulation study through experimental analysis to determine the characteristics of each material used. It deepened our understanding of litho-stabilization formulations and involved an analysis of the obtained results. We have concluded that a material intended for use as a base layer must meet specific criteria. In general, a base course should have a CBR-bearing capacity index equal to or greater than 80 to 98% of the OPM. To achieve this, we have implemented a technique called litho-stabilization, which involves the mixture of laterite and crushed 0/31.5 at various proportions, namely 20%, 25%, and 30%.

The laboratory studies focused on a type of lateritic material that cannot be utilized in its natural state as a base course. These tests allowed us to analyze the physical and mechanical properties of natural lateritic gravel and lateritic gravel enhanced with crushed 0/31.5 gravel. The CBR index ranges from 38 to 95% of the OPM and 57 to 98% of the OPM. The objective of these studies was to observe how the percentage of crushed material influences the evolution of the CBR bearing index.

Based on our analysis, it is evident that the laterite improved with a 25% proportion of crushed material would be a judicious choice for our project. From our study, it is clear that relying solely on laterite would be insufficient for ensuring the road's durability. Therefore, the addition of crushed stone provides significant support for achieving a suitable bearing capacity. Our study has yielded improved results by enhancing natural laterite gravel with 0/31.5 crushed stone at a 25% proportion.

Acknowledgments

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