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(Research Article)

Stabilization of lateritic soil with Portland cement and crushed granite for pavement base courses

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Abstract

The aim of this work is to propose reconstituted materials, by cement-based improvement of lateritic gravels and joint cement improvement and lithostabilization, that are technically suitable for use in base courses. The study focused on two (02) different lateritic gravels, LG1 with a fine content of 24% and LG2 with a fine content of 15%. For lithostabilization, 0/25 granite crushed stone was used and the cement used was CEM II/B-LL 42.5. For cement improvement, three (03) cement contents (1%; 1.5% and 2%) were studied, and for joint stabilization, the granite crushed content was set at 10%, with only the cement content varying by 1%, 1.5% and 2%. The mixes were obtained by adding the cement mass calculated from the total gravel mass collected and the cement rate studied to the raw gravel or to a mixture of 90% gravel and 10% granite crushed stone. The results of physical-mechanical tests such as the Atterberg limits, Modified Proctor and California bearing index of stabilized materials were analyzed in comparison with the initial values of raw materials without stabilization. The results show that cement increases the plasticity index but improves the bearing capacity of lateritic gravels better than joint stabilization. However, joint stabilization does improve gravel bearing capacity compared with untreated raw gravel. For use as a base course in accordance with CEBTP specifications [3], in addition to the 10% granite crushed content, LG1 must be upgraded to at least 1.5% cement and LG2 to 1%.

Keywords: Lateritic gravel; Lithostabilization; Cement improvement; Physical-mechanical properties; Base course

1. Introduction

Optimizing the construction of any infrastructure is based on the principle of quality/cost ratio. In road construction, this objective is all the more important in view of the enormous quantities of materials required for the pavement structure. The use of untreated natural materials in pavements is one way of reducing the cost of road projects. For a long time, the use of natural laterite gravel as sub-base and base course materials was widespread in many parts of sub-Saharan Africa, such as Burkina Faso. Laterites are soils found at shallow depths, widespread throughout the inter-tropical regions of Africa. The word laterite was first suggested by the geologist Buchanan in 1807 to designate a ferruginous material used in the mountainous regions of Malabar in India to make mud bricks for construction [1, 2]. This material, which has the appearance of a ferruginous deposit with a vesicular morphology, lies at shallow depths in the soil in the form of cuirasses, indurated laterite and gravelly material [1]. Lateritic gravel is a loose soil with a grain size of 0/20 to 0/40 mm, containing 10 to 35% fines passing through an 80 µm sieve and a "skeleton" (refusal on the 2 mm sieve) of 20 to 60%. Mortar passing through a 0.425 mm sieve has a plasticity varying between 10 and 35% [3]. According to the HRB (Highway Research Board) classification, lateritic gravels cover several classes, including A-2-4 to A-2-7 and A-7-5 to A-7-6 for the most clayey [4].

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The use of lateritic gravel in road construction is governed by numerous standards, most of which are empirical rules. Specifications may vary from one country to another. In Burkina Faso, the use of lateritic gravel for sub-base courses is subject to compliance with the CEBTP, the Practical Guide to Pavement Design for Tropical Countries [3]. For example, to be used as a base course, lateritic gravel must have a plasticity index of less than 15% and a CBR index of over 80%, according to CEBTP [3]. According to studies by Pierre LOMPO [5], lateritic gravel from Burkina Faso is a highly variable raw material, both in terms of deposit thickness and the clayey or sandy nature of the mortar (<0.425 mm). Class A-2-4(0) to A-2-6(0), they are characterized by a percentage of fine particles varying between 5 and 30% by mass, a refusal at 2 mm between 50 and 80% by mass, a plasticity index between 10 and 30%, a maximum dry density of the OPM (modified Proctor optimum) between 1.90 and 2.30, an optimum water content varying between 7 and 12% and a CBR bearing capacity at 95% of the OPM varying between 15 and 100 [5, 6]. Thus, according to CEBTP specifications [3], some lateritic gravels can be used in their natural state as base courses, but others can only be made suitable for use by modifying their nature and/or condition using an appropriate technique. In recent years, increasing road traffic and axle overloads have meant that the geotechnical characteristics of natural lateritic gravel no longer meet the requirements for use in base courses. As a result, quarries of good quality lateritic gravel are becoming increasingly rare, difficult to locate and more costly to obtain. The use of soil improvement techniques is becoming more and more systematic, and the choice of a technique is always based on a technical-economic analysis. Improvement techniques involve chemical, physical or mechanical treatments, the general aim of which is to ensure the suitability of soil that does not initially have the required characteristics for a specific use. Physical or mechanical treatments consist in seeking a soil with a better CBR index, either by correcting the particle size by adding sand and/or gravel [7, 8, 9, 10], or by installing a drainage system using geotextiles, or by compaction. One of the most widely used physico-mechanical treatments in Burkina Faso is lithostabilization, which consists in mixing lateritic gravel with a granular material usually obtained by crushing massive rocks such as granite, basalt, etc. This method gives good results. A study by Mbengue et al [7] on the lithostabilization of lateritic gravel with 0/31.5 granite crushed rock showed a maximum increase in CBR of 273% with the addition of 30% granite crushed rock. They also showed an increase in Young's modulus and unconfined compressive strength of 309% and 140% respectively. Grehoa et al [9] analyzed the influence of the granular class of natural aggregates on the performance of laterites. They incorporated rates of 15%, 20%, 30% and 40% of classes 0/5, 0/15 and 5/15 into laterite soil. The results obtained show that whatever the granular class considered, the optimum rate is 30%, and the best improvements are obtained with the 0/15 granular class. Jemal et al [10] have shown that to improve the CBR index of an expansive clay soil for use as a base course, the optimum rate of granite waste to be used is 30% to 35%. It should be noted, however, that some materials remain unsuitable for use as base courses despite a clear increase in CBR index after lithostabilization. In the work of Mbengue et al, the 273% increase in CBR index enabled the value to rise from 11% to 41%. As far as chemical treatment is concerned, chemical stabilizers such as cement, lime or bituminous emulsions are used [11, 12, 6, 13, 14]. In Burkina Faso, cement is the most widely used chemical treatment. It considerably improves the physico-mechanical parameters of soils. However, cement stabilization generally results in high stiffness and makes the soil weak, which is undesirable under dynamic loading conditions such as pavement systems [15]. Furthermore, the use of cement as a stabilizer can lead to cracking due to thermal and desiccation shrinkage [15]. Increasing the amount of cement increases stiffness and the risk of cracking [15, 16]. CEBTP [3] has differentiated between cement improvement and cement stabilization of soils. The former concerns cases where the cement content used is low enough to still allow the soil to behave flexibly, whereas in the latter, the cement content used results in appreciable soil rigidity.

The overall aim of the present work is to propose reconstituted materials, by cement improvement of lateritic gravel and joint cement improvement and lithostabilization, that are technically suitable for use in base courses. Specifically, the study consists in identifying and analyzing the physical and mechanical properties of two different lateritic gravels, and then analyzing the influence of cement improvement and joint improvement with cement and lithostabilization on the physical and mechanical properties of the lateritic gravels

2. Material and methods

Two lateritic gravels were used in this study. The first (LG1) was taken from a quarry in central-eastern Burkina Faso, used to treat critical points on the Kampoaga-Loukou-Godin runway in Tenkodogo, and the second (LG2) from a quarry in northern Burkina Faso, used for periodic maintenance operations on the RN2: Ouahigouya-Gourcy. For lithostabilization, 0/25 granite crushed stone from the KF quarry (KANAZOE et Frères) was used, and for cement stabilization, CEM II/B-LL 42.5 cement from CIMAF was used.

Two (02) types of improvement were analyzed in this study on the two (02) kinds of lateritic gravel. These were cement improvement and joint stabilization of granite crushed stone and cement. For cement improvement, three (03) cement contents (1%; 1.5% and 2%) were studied on the two (02) gravels. For joint stabilization, the granite crushed content was set at 10% and only the cement content was varied by 1%, 1.5% and 2%. The cement mixes were obtained by adding the mass of cement obtained from the total mass of gravel taken and the cement rate studied. For joint stabilization, the cement mass corresponding to each rate is added to a mixture of 90% LG and 10% granite crushed stone. After addition, the mixture is carefully homogenized before the various tests are carried out. The results of physical-mechanical tests such as Atterberg limits, Modified Proctor and California bearing index of stabilized materials were analyzed in comparison with the initial values of raw materials without stabilization. In addition, identification parameters specific to granite crushed materials, namely the flattening coefficient, Los Angeles coefficient and Micro-Deval coefficient, were determined. Table 1 shows the identification of the various mixes studied.

Granulometric analysis by sieving according to NF EN ISO 17892-4 [17] was carried out to determine the weight distribution of grains according to their size in each material before stabilization. The effect of stabilization on gravel plasticity was analyzed by studying the results of the Atterberg limits performed in accordance with standard NF EN ISO 17892-12/A2 [18] on the fraction passing through a 0.4mm sieve. The Modified Proctor test carried out in accordance with standard NF P94-093 [19] on the fraction passing through a 20mm sieve was used to determine the optimum water content (OWC) for obtaining the maximum dry density (MDD) of the materials. The CBR test, which evaluates the bearing strength of the various materials, was carried out in accordance with standard NF P94-078 [20] on fractions passing through a 20mm sieve. In this study, the CBR index determined is that after 4 days of immersion, as it represents the most unfavorable case in the study area. The CBR index was studied for a compaction level of 95% of the maximum Proctor density. For granite crushed material, the flattening coefficient, measured in accordance with standard NF EN 933-3 [21], was used to characterize the more or less massive shape of the aggregate. Obtained from a double sieving process, the flattening coefficient is an important parameter for aggregates used in pavement layers, which must be sufficiently compacted to provide good mechanical resistance to the stresses to which the pavement is subjected. The fragmentation and wear resistance of crushed aggregates has been assessed using the Los Angeles test in accordance with standard NF EN 1097-2 [22] and the Micro Deval test in accordance with standard NF EN 1097-1 [23].

Table 1 Identification of the studied mixtures, LG: Lateritic Gravel, Li: Lithostabilization and Ce: Cement

Identification	Rate	
	Lithostabilization	**Ciment**
LG-Li0Ce0	0	0
LG-Li0Ce1	0	1
LG-Li0Ce1,5	0	1.5
LG-Li0Ce2	0	2
LG-Li10Ce1	10	1
LG-Li10Ce1,5	10	1.5
LG-Li10Ce2	10	2

3. Results and discussion

3.1. Raw material characterization

3.1.1. Lateritic gravels

Fig. 1 shows the grain size curves for LG1 and LG2 inserted in the base course granular spindle prescribed by CEBTP [3]. While LG2 fits perfectly into the spindle, LG1 leaves the spindle for grain diameters below 0.16mm. The fine element content would be slightly higher than that prescribed by CEBTP [3], which requires that gravels used in base courses have a percentage of particles smaller than 0.08mm to be less than 20%. The data in Table 1 show that the percentage of elements smaller than 0.08mm is 24% and 15% for LG1 and LG2 respectively.

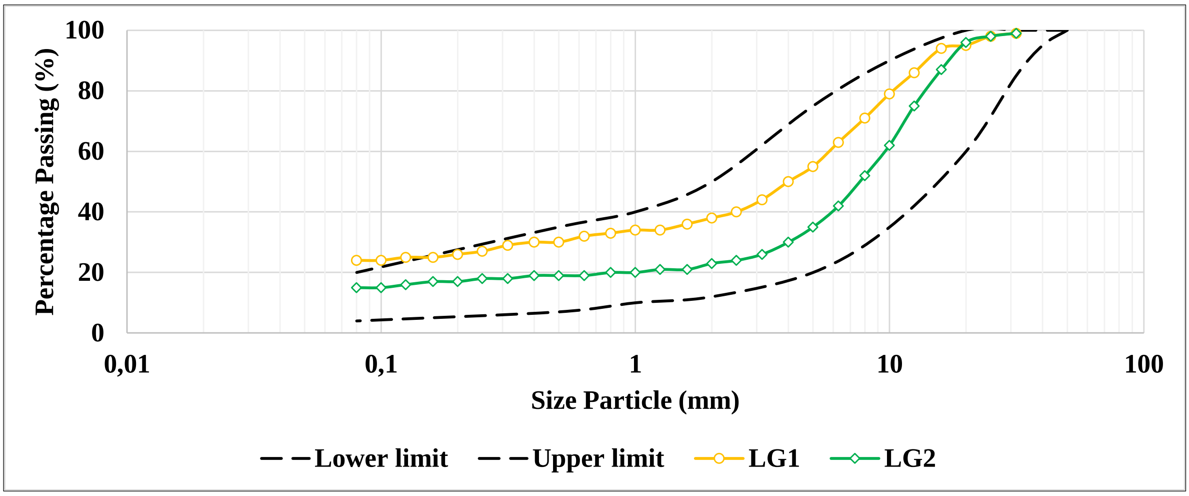

Figure 1 Grain size distribution of LG1 and LG2 and comparison with the CEBTP [3] criteria for the application in base layer

Evaluation of the Atterberg limits shows that the plasticity indices of LG and LG2 are 21% and 18% respectively. The two (02) lateritic gravels thus have a plasticity higher than that prescribed by CEBTP for use in base courses. According to HRB classification [24], LG1 is class A-2-7 and LG2 class A-2-6. The maximum dry density (MDD) at the Proctor optimum prescribed by CEBTP [3] is respected by both gravels, with a value of 2.01g/cm^3 for LG1 and 2.11g/cm^3 for LG2. Optimum water content (OWC) is 8.6% and 8% for LG1 and LG2 respectively. The CBR indices of LG1 and LG2 gravels are 25% and 35% respectively. Thus, the use of these materials in base courses requires upgrading or pre-treatment in accordance with CEBTP specifications, which prescribe a CBR value of 80% [3]. According to CEBTP, when lateritic gravel is treated with cement, the material is said to be improved when its CBR index exceeds 160% [3].

Table 2 Geotechnical characteristics of lateritic gravel LG1 and LG2 compared with CEBTP specifications [3]

Samples	**Grain size distribution (%)**		**Atterberg limit**			**Proctor test**		**CBR index at 95% OPM**
	0,08 mm	**2 mm**	**Liquidity limit (LL)**	**Plasticity limit (LP)**	**Plasticity index (Ip)**	**Wop (%)**	**ρ_d (g/cm^3)**	**%**
LG1	24	38	42	21	21	8,6	2,01	25
LG2	15	36,5	36	18	18	8	2,11	35
CEBTP Specifications								
Base layer	< 20	-	-	-	< 15	-	> 2	> 80

3.1.2. Granite crushed stone

The grain size curve of the granite crushed stone used is shown in Fig. 2. The grain size of the crushed material, which is spread out and well graded with a Cu uniformity coefficient of 30 and a Cc curvature coefficient of 2.13, falls within the range prescribed by CEBTP [3]. The Los Angeles and Micro Deval tests yielded coefficients of LA = 22.6% and MDE = 6.2% respectively. From the point of view of resistance to fragmentation and wear, granite crushed stone also complies with the criteria set by the CEBTP guide: LA < 30% and MDE < 12%.

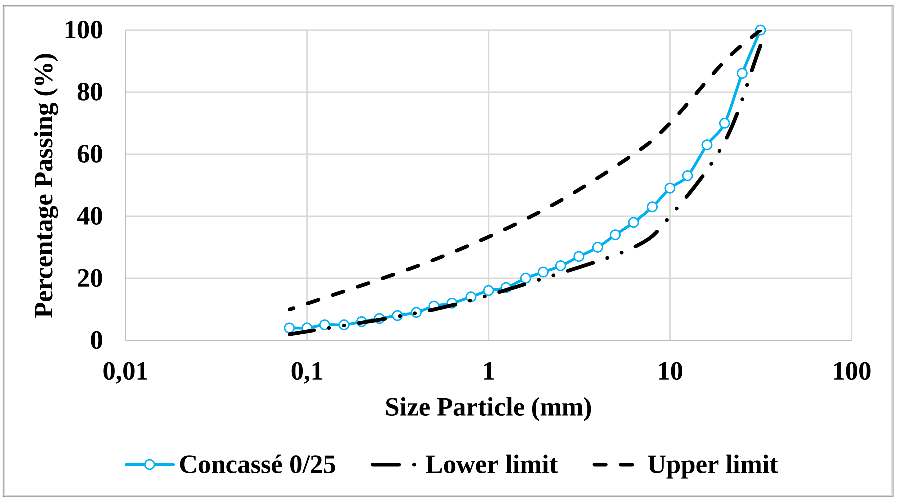

Figure 2 Particle size distribution of granite crushed material 0/25

3.2. Mixture test results

3.2.1. Plasticity index

Figs. 3.a and 3.b show the evolution of the plasticity index (PI) of the two lateritic gravels studied according to the mixes used. Generally speaking, the plasticity index of lateritic gravels increases with the addition of cement, and more so as the cement content of the mix increases. The plasticity index increases from 21% to 24% and from 18% to 21% with the addition of 2% cement for LG1 and LG2 respectively. This variation, which is in accordance with literature results [25, 26, 27], is justified by the fact that cement is a fine powder which forms a plastic paste in the presence of water.

With the addition of 10% granite crushed 0/25, the plasticity index of the mixes obtained was lower than that of mixes without crushed granite. This is explained by the addition of granite crushed material, which is non-plastic and leads to a reduction in the fine content of the mix [28]. This trend is similar to that observed by other authors in the literature [7, 29]. The PI values of cement-improved and lithostabilized mixes with 10% crushed stone also increase with cement content for LG1 and LG2. However, for the two gravel mixes studied, the values remain higher than those of unimproved raw LGs and increase with cement content. The relatively low crushed content and the presence of fine cement powder explain these trends. The use of cement does not contribute to improving the plasticity index of soils according to CEBTP specifications, but the cement's reaction, which contributes to soil stabilization, does not depend on soil minerals but only on the presence of water required for its hydration process [25, 27].

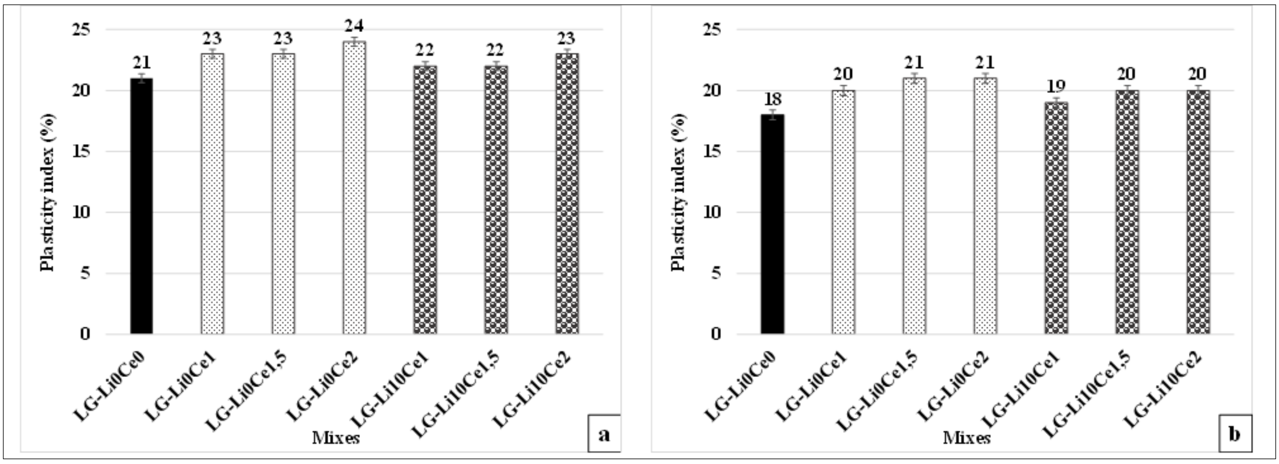

Figure 3 Plasticity index of mixes with a) LG1 and b) LG2

3.2.2. Compaction parameters

The evolution of maximum dry density (MDD) and optimum water content (OWC) of lateritic gravels after the various improvements is shown in Figs. 4.a and 4.b. While an increase in optimum water content is observed with the increase in cement content in LG1, a decrease is observed with LG2 compared to raw materials without addition. Indeed, the addition of 2% cement leads to an increase in OWC from 8.6% to 9.4% for LG1 and a decrease from 8.0% to 6.9% for LG2. According to Rohmatun et al. the addition of cement to sandy silty soils leads to a decrease in OWC, but increases that of sandy clay soils [30]. According to the percentage of fine elements below 0.08 mm and the plasticity index values, LG1 is more clayey than LG2 and this could explain the divergent evolution of the OWC of the two gravelly soils. This suggests that the evolution of the optimum water content of cement-stabilized gravels depends on the type of soil used, in terms of grain size and plasticity. The increase in OWC with cement content obtained with LG1 is explained by the increase in fine element content with the addition of fine cement grains. This trend was also observed by Saleh et al. who obtained an increase in OWC from 15.7% to 17.15% when the cement content was increased from 0% to 10% [31]. Shinde et al [25] also claim that soil stabilization with cement leads to an increase in OWC.

The addition of 10% crushed 0/25 also results in an increase in the optimum water content compared with cement mixes at LG1 (fig.4.a). But with LG2, the optimum water content decreases with the addition of 10% crushed 0/25 compared with cement-based mixes (fig.4.b). With LG1 improved with 2% cement, the OWC value rises from 9.4% to 10.4% when 10% crushed 0/25 is added. For LG2 improved with 2% cement, lithostabilization with 10% granite crushed stone reduces the OWC from 6.9% to 6.6%. There is also a divergence in OWC evolution with lithostabilization, depending on soil type. The literature shows that stabilization with crushed rock leads to a decrease in the optimum water content of soils [7, 32] compared with raw material. The opposite trend observed with LG1 could be explained by the presence of cement in the mixes.

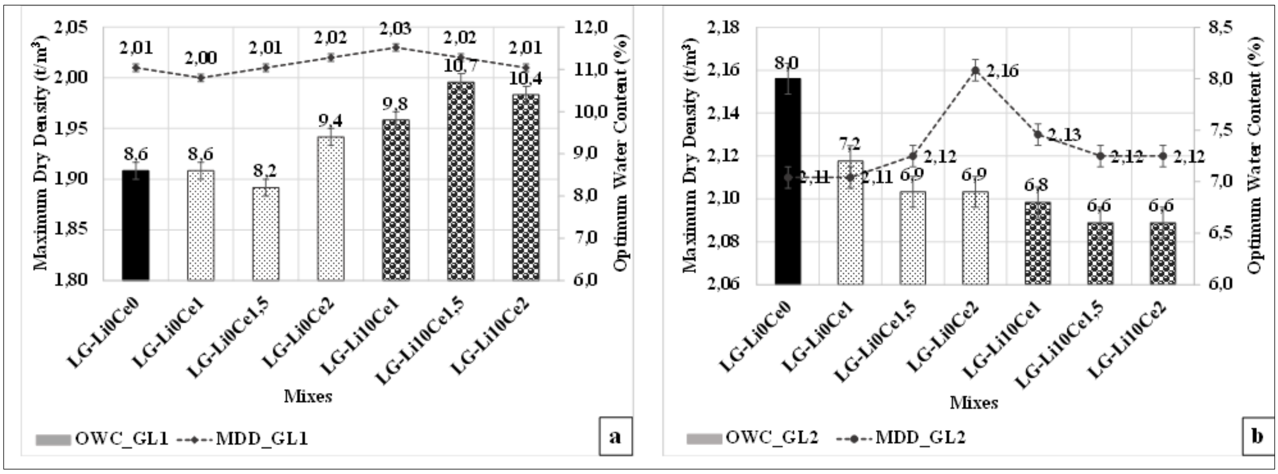

Figure 4 Optimum Water Content and Maximum Dry Density of mixes with a) LG1 ant b) LG2

For maximum dry density (MDD), it can be seen that cement improvement leads to an increase in MDD as the cement content of the mix increases. This trend was observed with the two (02) gravel mixes studied. Thus, the MDD increases from 2.01 t/m3 to 2.02 t/m3 and from 2.11 t/m3 to 2.16 t/m3 when the cement content increases from 0% to 2% for LG1 and LG2 respectively. This evolution is in accordance with the results obtained in the literature and would be due to the filling of voids in the soil by cement grains [33, 31, 27, 34]. Saleh et al [31] found in their study that with the addition of 3%, 6% and 10% cement, the MDD of the soil increased from 1.83 to 1.84, 1.85 and 1.88 respectively.

Lithostabilization of cement-improved gravel with 10% 0/25 granite crushed stone results in a decrease in MDD compared with cement-improved gravel alone. This could be explained by the additional porosity created by the addition of the crushed stone. Compared with unimproved raw gravel, joint stabilization results in an increase in maximum dry density at 1% and 1.5% cement, but at 2%, MDD decreases. The increase in dry density with the addition of crushed stone is explained by the increased skeleton, which creates pores that the fines fill with compaction [35]. The combined action of 0/25 granite crushed stone and cement would help improve mix density, but only up to a certain cement content. Nevertheless, the MDD of all the mixes studied comply with CEBTP [3] specifications for use in base courses.

3.2.3. CBR bearing capacity

The evolution of the CBR index of LG1 and LG2 after the various improvements is shown in Figs. 5.a and 5.b. Cement enhancement of lateritic gravels leads to a clear increase in CBR index, which increases with the cement content. However, the rate of increase is greater with LG1 than LG2. It is 160%, 588% and 784% for LG1 and 129%, 374% and 746% for LG2 when 1%, 1.5% and 2% cement are added respectively. The increase in CBR index is mainly explained by the bonds created between soil particles by cement hydrates [27, 30, 26]. The greater increase in CBR index in LG1 could be explained by a complementary reaction between the portlandite resulting from cement hydration and the soil particles (silica, alumina) [30].

Lithostabilization of LG1 cement-improved gravel with 10% crushed stone (fig.5.a) results in a reduction in the CBR index compared to cement-only improved gravels. The CBR index drops from 65%, 172% and 221% to 64%, 109% and 161% respectively for 1%, 1.5% and 2% cement after lithostabilization. Okonkwo et al [36] found similar results when they jointly stabilized A-2-7 laterite with cement and sand. When they added 15% sand to the cement-stabilized laterite, they obtained a decrease in CBR index from 80% and 175% to 74% and 75% respectively for 3% and 6% cement.

For LG2 (fig.5.b), the CBR index increases after lithostabilization in association with cement improvement for cement contents of 1 and 1.5%. For the 2% cement content, lithostabilization with 10% crushed material results in a lower CBR index than for cement-only improved material. The CBR index goes from 80%, 166% and 296% to 95%, 171% and 211% after lithostabilization at 1%, 1.5% and 2% cement respectively. The low fine particle content in LG2 could explain this improvement, unlike LG1, and justify the drop in CBR when 2% cement is added, which increases the fine particle content of the dry mix. However, for both LG1 and LG2, the CBR values of the improved materials remain higher than those of the unimproved raw LGs. Also, when considering the three (03) joint mixes lithostabilized and improved with cement, we note an increase in the CBR index with the cement content.

Finally, for use as a base course in accordance with CEBTP specifications [3], LG1 must be upgraded to at least 1.5% cement and LG2 to 1%. With joint improvement, a cement content of 1.5% is still required for LG2, with a reduction in bearing capacity compared with simple cement improvement, and a cement content of 1% is required for LG1, with an increase in bearing capacity compared with simple cement improvement.

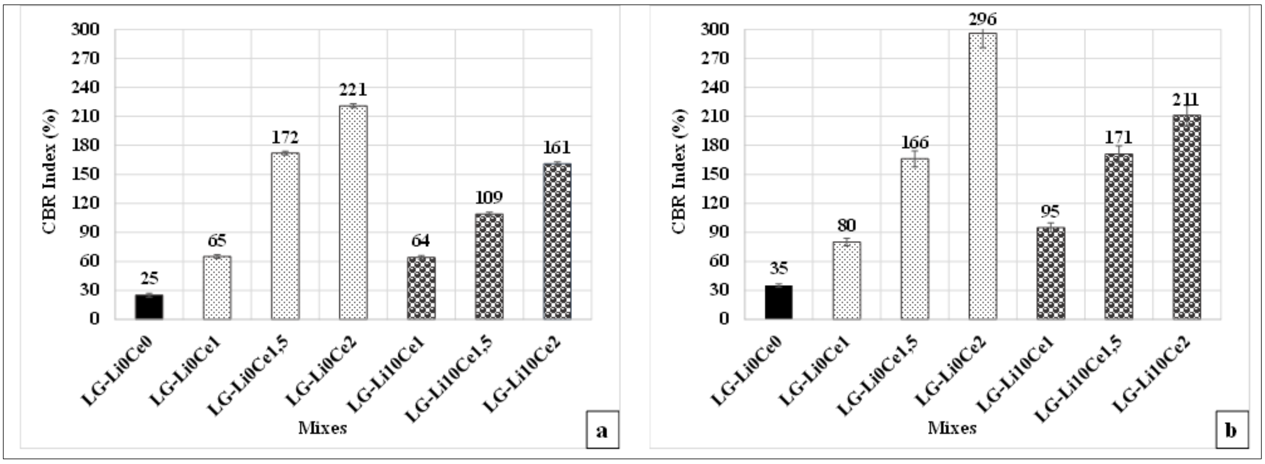

Figure 5 CBR index of mixes with a) 1 and b) LG2

4. Conclusion

The improvement of lateritic gravel with cement and joint stabilization with cement and granite crushed stone were analyzed in this study. From the results obtained, the following conclusions can be drawn:

- The addition of cement to the lateritic gravel results in an increase in the plasticity index of the gravel, which decreases with joint stabilization. However, the plasticity index after joint stabilization remains higher than that of raw gravel without stabilization.
- As far as compaction parameters are concerned, cement improvement leads to different evolutions in terms of optimum content, depending on the type of gravel used. Indeed, the addition of cement leads to an increase in OWC for clay soils, but a decrease for silty soils.

- Maximum dry density increases with cement improvement compared to raw material, due to pore filling by fine cement grains. With lithostabilization combined with cement improvement, MDD decreases compared to cement-only stabilized materials, but remains higher than that of unimproved raw gravel.
- Upgrading lateritic gravels with cement results in an increase in bearing capacity, characterized by an increase in CBR index. The rate of increase depends on the type of gravel used. In this study, the gravel with the highest plasticity index achieved the highest rate of increase in CBR, and this may be linked to the type of minerals contained in this material, which would have reacted with the portlandite in the cement to give other binding compounds in addition to those resulting from the hydration of the cement.
- Joint stabilization of cement and lithostabilization at 10% results in a decrease in the CBR index compared with the cement-only improved material, which nevertheless remains higher than that of the unimproved raw gravel.
- Combined stabilization of gravel with cement and 10% granite crushed stone therefore improves gravel bearing capacity. For use as a base course in accordance with CEBTP specifications [3], LG1 must be upgraded with at least 1.5% cement and LG2 with 1% cement, in addition to lithostabilization with 10% granite crushed stone.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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