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THE ROLE OF GRANULOMETRY IN THE BEARING CAPACITY OF PAVEMENT FOUNDATION LAYER

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ABSTRACT

This work aims the study of the unbound aggregates made of gravel, sand and fines, mixed in several predefined particle size configurations, which are compacted at the Proctor Optimum in order to undergo CBR punching whose purpose is to determinate the different bearing capacities depending on the granulometries. Indeed, the sensibility of the foundation layer is related to several granulometry indicators which are related to several grain size fractions. The objective is to find the granularity of the granular foundation materials with the highest CBR value, thus which corresponds with the best overall performance of the pavement.
Keywords: pavement; granulometry; tests; characteristics; bearing capacity.

RÉSUMÉ

Ce travail a pour object l'étude des graves non traitées constituées de gravier, de sable et de fines mélangées selon plusieurs configurations granulométriques prédéfinies, puis compactées à l'optimum Proctor afin de subir des poinçonnements CBR dans le but de déterminer les différentes portances en fonction des granulométries. En effet, la sensibilité de la couche de fondation est reliée à divers indicateurs granulométriques liés à diverses fractions granulométriques. L'objectif est de trouver la granulométrie des matériaux granulaires de fondation ayant l'indice CBR le plus élevé et donc qui correspond à la meilleure performance globale de la chaussée.
Mots clés: chaussée; granulométrie; essais; caractéristiques; portance.

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1. INTRODUCTION

One of the many fundamental measurable parameters of the quality and durability of a road is its bearing capacity. The higher it is, the more it can sustain important charges and traffics. There are numerous possible ways to influence the characteristics of a pavement to increase its bearing capacity. We could improve the subsoil, plan to use adequate materials treated with binders for the realisation of sublayers, ensure a proper execution of the project, etc. But it would all imply higher costs. Yet, there is a more economic process that allows to optimize the bearing capacity of a subbase, without any additives or additional work, but only with the usage of unbound materials: It consists in the modification of the granulometric curve of the material. Indeed, the granulometry effects on granular materials are various. Many studies have been conducted in order to analyse its effect on the sensitivities of materials when submited to various mechanical and physical stresses. But the induced effect on the bearing capacity is rarely treated in the research. This work aims to bring a contribution on the optimal granulometry of unbound materials for a better bearing capacity in pavement foundation layers.

2. ROLE OF THE GRANULOMETRY IN FOUNDATION LAYERS

The granulometry choice of the granular materials is a key issue in foundation layers conception. In fact, the preparation requires analyzing the range of different grain sizes and determining their proportion. Therefore it is an essential indicator to study the physical and mechanical properties of foundation layers. When this layer of granular materials is modified, its permeability, deformation, resistance and other properties are modified. [1]

2.1 Role of the foundation layer in pavements

The main role of a pavement subbase is to distribute the stresses created by the rolling loads (or possibly static) and to bring them to a level compatible with the characteristics of the natural ground on which the roadway is established [2].

A foundation layer, also called a subbase layer, is one of the two lower pavement layers constituting the substructure of a road, with the base layer. It is situated under the base layer, and above a capping layer. The pavement foundation materials are therefore, in the granulometric sense, sandy gravels or gravelly sands most of the time. These materials are generally crushed to ensure a good internal resistance and high intergranular friction. It is therefore a key structural element of a pavement, the overall performance of a road is hence closely linked to the grain size used. [3]. Indeed, it contributes to the stability and performance of this pavement layer. Its behavior depends on the properties of the grains that constitute it: size, shape, texture, angularity, durability, specific surface, absorption, tenacity and mineralogical composition. Mishra and Tutumluer [4] have studied the effects of shape, texture and angularity, fines content and moisture on the performance of unbound aggregates layer on a large scale in Illinois involving three different types of aggregates. According to Kamal et al. [5], subbase stiffness generally decreases with the increase of fines content. With regard to the granulometry, according to Theyse [6], an increase in the maximum diameter (dmax) of the particles as well as in the percentage of fine particles causes an increase in the resistance of the foundation layer.

2.2 Granulometry effect in pavement foundation layers

The particle size analysis, or granulometric analysis, is the set of operations that makes it possible to understand the distribution of the different granular classes in the material and to detect the size of the grains and their respective weight percentages constituting the sample. Indeed, a particle size curve contains a lot of useful informations to understand the origin of the material, it even allows to predict its mechanical and hydraulic properties, saturated and unsaturated. [7]. In fact, a coarser grain size will generally increase the strength of the material as well as its hydraulic conductivity. [8 et 9]. Conversely, a significant proportion of fine particles (i.e. more than 10% of particles less than 0.08 mm in diameter) will reduce their hydraulic conductivity [9]. It also has a great influence on the mechanical characteristics of the materials (Los Angeles, Micro-Deval, dynamic fragmentation).

For their part, Thom and Brown [10] have shown that the effect of particle size varies according to compactness. But, Dawson et al. [11] have shown that the effect of particle size is much more important than compactness. A modification of the particle size which leads to an increase in the relative density, for the same compaction effort, causes a reduction in the permanent deformation. For [12], the increase in density for a granular material composed of angular aggregates causes very significant reductions in the permanent deformation, whereas it is less significant for a rounded aggregate. Taking into account the granulometric grading, the studies carried out by [13] and [14] concluded that a soil having a well-graded granulometry will make it possible to increase the performances in terms of rigidity and resistance to erosion However, according to Thompson and Smith [15], aggregates with a more spread particle size containing fewer fine particles are less sensitive to humidity and constitute good quality road foundation aggregates. According to Douglas, [16], the coarse untreated aggregates of the foundation layer allow water to be evacuated, while forming a block sufficiently bound to prevent fine particles from migrating through this layer. By taking into account the shape of the grains in the granulometry, Lekarp et al. [17] showed that the increase in density for a granular material composed of angular aggregates causes very significant decreases in the permanent deformation whereas they are less important for rounded aggregates.

3. IDENTIFICATION OF THE STUDY MATERIALS

The material used consists of crushed gravel from the Chelghoum Laid quarry, in the Wilaya of Mila. The main characterization and road tests are carried out to determine the different properties of these granular materials. Several requirements shown by the tests (Los-Angeles [LA], Micro-Deval [MDw], Fragmentability [FR] and Degradability [DG]) must be met in order for an aggregate to be used as a granular material for foundations. In terms of granulometry, which is the main characteristic of the granular materials (GM 20) studied in the context of this work, the material must be included within the grading range defined by the norm. The results obtained in the various road tests are grouped in Table 1.

Tableau 1: Caracteristics from the road tests.

Tests nature									
Los Angeles		**Micro-Deval**		**Fragmentability**		**Degradability**		**Sand friability**	
Class	Value	Class	Value	Class	Value	Class	Value	Class	Value
4 -6.3	23.72	4 – 6.3	11.18	10- 20	1.14	10- 20	1.033	0.2-2	48.48
6.3 - 10	24.99	6.3 - 10	10.53						
10 - 14	25.78	10 - 14	3.16						

According to the obtained results, the Los-Angeles (LA) coefficients of the elementary gravel classes (4/6.3), (6.3/10) and (10/14) are all close and are between 23 and 26%. According to Table 1, this material has good to moderate resistance to abrasion. The Micro-Deval values in presence of water (MDw) in Table 1 indicate that the higher the grain size (granular class), the more the MDw coefficient decreases and the aggregates become less sensitive to wear. The MDw coefficient (%) (Table 1) of the three classes (4/6.3), (6.3/10) and (10/14), is inferior to 15%, we can therefore consider these aggregates with good appreciation. They are therefore acceptable foundation layer materials. The value of the fragmentability coefficient (FR) found is well below the threshold value of 7 proposed by the norm NF P11-300. The material can then be considered as scarcely fragmentable. The value of the degradability coefficient is almost equal to 1, which means that the tested material is scarcely degradable under the action of water stress. This sand has a friability coefficient of less than 60, which is the authorized limit, so it can be used in pavement layers.

The material studied, comprising several granular classes, is not very degradable under water stress and not very fragmentable, with a good appreciation in the Micro-deval and with a good to average resistance to abrasion in the Los Angeles test, which denotes its possibility of use in all pavement layers.

3.1 Selected granulometries

In order to test the influence of the granular classes on the bearing capacity, we have chosen 6 different granulometries, while modifying the percentages of the three main granular classes gravel (2/25), sand (0.063/2) and fines (0/0.063) , which are themselves composed of nine secondary granular classes (25 - 20); (20 – 14); (14 – 10); (10 – 6.3); (6.3 – 4) and (4 - 2) for gravel, (2 - 1); (1 - 0.5); (0.5 - 0.063) for sand and (0.063 - 0) for fines. The selected granulometries are then obtained with different percentages of gravel, sand and fines within the limits of the normalized grading range. The different granulometries chosen are restricted to the limits of the specification range described by norm NF EN 13285 relating to the dimensioning of road base and subbase layers. This grading range is determined according to the requirements that the foundation materials must meet according to the norm.

The choices of the different gravel, sand and fine passings are presented in Table 2 and the granulometric curves are grouped together in Figure 1.

Table 2: Mass percentages attributed to each class for the different granulometries.

Granular classes	Average (normal Proctor)	More Sand	More fines	More gravel	More fines and less sand	More sand and less fines	More fines, more sand and less gravel
Gravel (2/25)	**64%**	**50%**	**63%**	**77%**	**78%**	**50%**	**50%**
Sand (0.063/2)	**29.5%**	**43.5%**	**28%**	**16.5%**	**13%**	**46%**	**41%**
Fines (0/0.063)	**6.5%**	**6.5%**	**9%**	**6.5%**	**9%**	**4%**	**9%**
Sum	100%	100%	100%	100%	100%	100%	100%

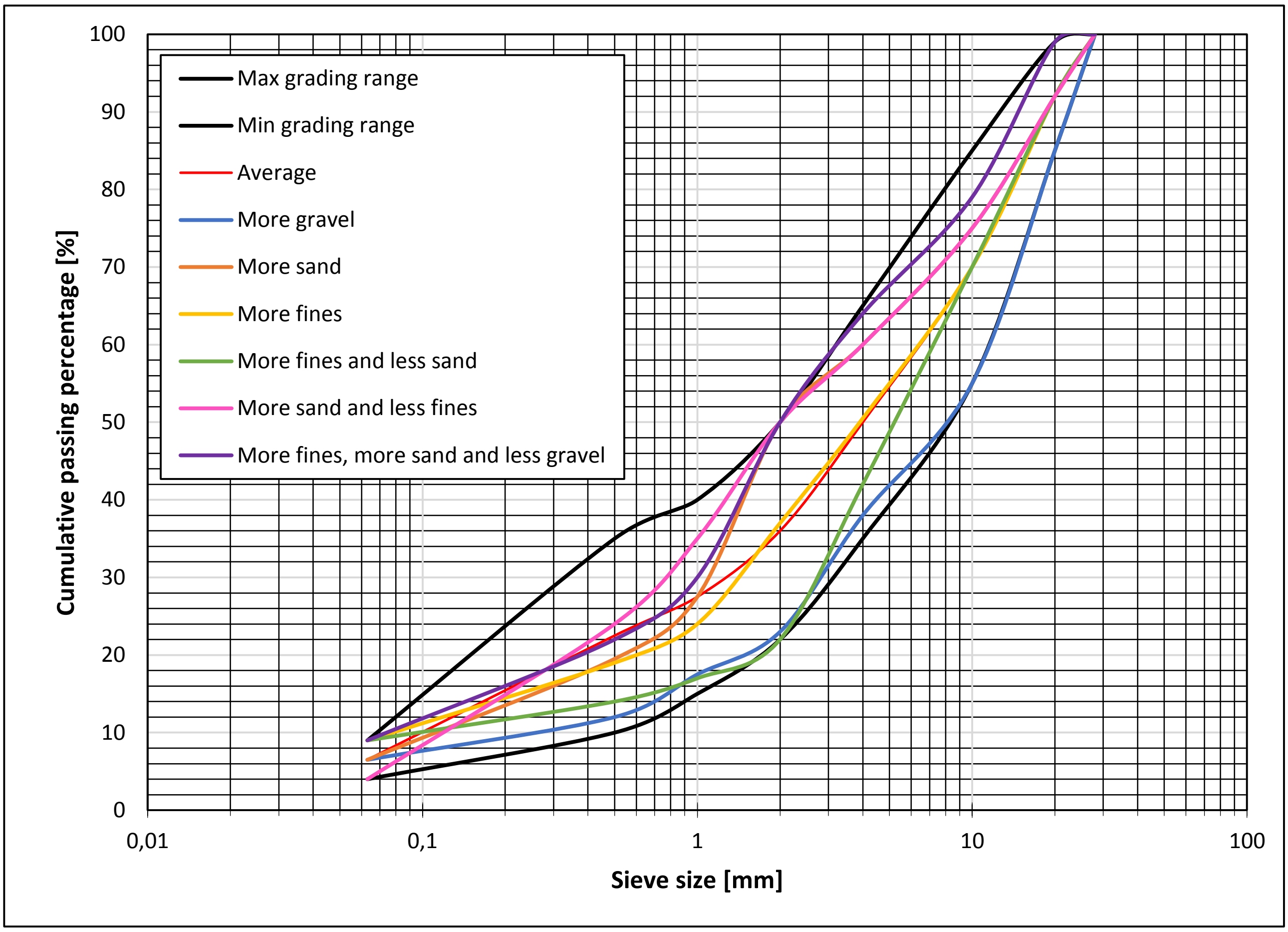

Figure 1: The granulometric curves studied grouped in the normalized grading range.

In order to decide on the validity of the different particle sizes, the uniformity and curvature coefficients are calculated and grouped in Table 3.

The coefficient (Cu) informs us about the uniformity of the granulometry. A particle size is considered uniform for Cu values below 5. For our work, uniform soils are prohibited and Cu values greater than 5 are therefore sought, in order to obtain a granular material with maximum bearing capacity. In addition, the coefficient (Cc) makes it possible to determine the spread of a particle size curve. Cc values between 1 and 3 indicate that the granulometry of a soil is well spread.

Table 3: Cc and Cu characteristics of the differents granulometries curves.

Nature of the granulometry	Cu	Cc	Conclusions
Average granulometry	65	2,8	Granulometry well graded and spread
Granulometry with more gravel	48	2,61	Granulometry well graded and spread
Granulometry with more sand	40	3,025	Granulometry spread and poorly graded
Granulometry with more fines	81,25	4,33	Granulometry spread and poorly graded
Granulometry with more fines and less sand	73	10,35	Granulometry spread and poorly graded
Granulometry with more sand and less fines	33,33	1,17	Granulometry well graded and spread
Granulometry with more fines, more sand and less gravel	42,67	4,17	Granulometry spread and poorly graded

The granulometries carried out in the laboratory sweep the grading range used and therefore prove to be valid in order to be able to eventually compare them with the average granulometry. These granulometries all include gravel, sand and fines with significant uniformity coefficients greater than 30; therefore they are non-uniform and all spread. However for the curvature coefficient; the values are very dispersed, which shows that the granular classes are all present and various from the fines to the biggest gravel used.

4. PROCTOR AND CBR TESTS AND RESULTS INTERPRETATION

The purpose of the Proctor test is to determine the optimum moisture content for a given granular material under fixed compaction conditions. This optimum water content allows for a more efficient compaction which results in the achievement of the highest dry density of the granular material. The California Bearing Ratio (CBR) test allows to know the mechanical bearing of a compacted material with optimal density and water content. The maximum bearing capacity of the material in question can thus be achieved. In this way, it is possible to determine the stiffness of the material. This test makes it possible to determine two indicators: The unsoaked, or immediate bearing ratio, and the soaked bearing ratio, or bearing ratio after immersion. The CBR was used by [18] to determine, in a relative way, the influence of the quantity and quality of the fine particles on the bearing capacity of a pavement. Osouli et al. [19] demonstrated that the CBR decreased with the increase in the percentage of fines.

4.1 Results presentation and interpretation

The Proctor curves obtained from the different granulometries are represented in Figure 2. The dry densities and the optimum water contents are grouped in Table 4.

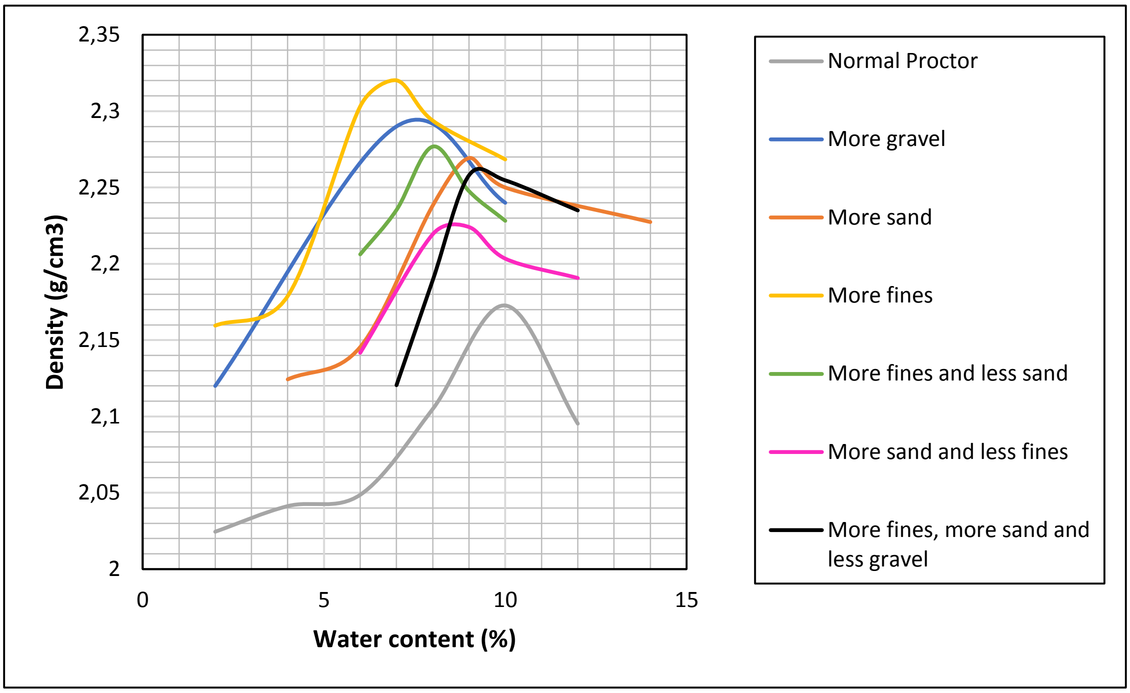

Figure 2: Proctor curves for the different granulometries

Table 4: Summary of the Proctor test results

Granulometry	Optimum water content (%)	Optimum dry densitiy [g/cm^3]
More gravel (77%) - 16,5% sand – 6.5% fines	7.2	2.298
More sand (43.5%) – 50% gravel – 6.5% fines	9	2.2693
More fines (9%) – 63% gravel – 28% sand	6.9	2.322
More fines (9%) less sand (13 %) - 78% gravel	8	2.2768
More sand (46%) less fines (4%) - 50% gravel	8.5	2.2241
More fines (9%), more sand (41%) and less gravel (50 %)	9.25	2.265

The granulometry with more fines, more sand and less gravel has the highest optimum water content, the classes (0/0.063) and (0.063/2) being classes with the elements absorbing the most water. The granulometry with more gravel is the one presenting at the optimum the lowest water content, due to the low percentage of fine elements. It was noticed during handling that demoulded specimens containing more fines have a greater tendency to keep the shape of the mould. Moreover, when dried, they also take the form of large lumps that are difficult to crumble. The fines therefore serve to make the material cohesive by filling all the voids and to cement the aggregates into blocks. This is the reason why they have the highest densities.

The granulometry with more fines gave the maximum density. This particle size is ideal provided it is moistened to a minimum content. The granulometry with more gravel has the second highest density due to the weight of its elements, as long as a minimum of sand and fines is present as defined by the grading range in the norm.

These choices will make it possible to study the influence of each of the granular classes on the California Bearing Ratio. We varied the amounts of fines, sand and gravel in the different granulometries in order to find the granulometry that will provide the highest bearing.

Table 5 : Summary of the unsoaked CBR and soaked CBR.

	Unsoaked CBR		**Soaked CBR**	
Granulometry	**Ratio at 2.5 mm**	**Ratio at 5 mm**	**Ratio at 2.5 mm**	**Ratio at 5 mm**
More gravel (G=77% - S=16.5% - F=6.5%)	196	230	137	170
More sand (S=43.5% - F=6.5% - G=50%)	154	194	149	184
More fines (F=9% - G=63% - S=28%)	169	216	136	175
More fines and less sand (F=9 % - S=13 % - G=78%)	143	191	133	175
More sand and less fines (S=46% - F=4% - G=50%)	151	197	151	196
More fines, more sand and less gravel (F=9 % - S=41% - G=50 %)	152	198	141	183

From the unsoaked CBR (Table 5), the granulometry having the most optimal bearing capacity is that with more gravel. Indeed, the gravels being the aggregates which mainly provide the bearing function. The sample with more gravel is the most solid of all the mixtures tested, provided it is combined with a minimum of sands and fines so that the particle size curve falls within the normalized grading range. The granulometry with the less important bearing is the one with more fines and less sand. As a matter of fact, the fines cannot exercise their role of binding together all the elements of the specimen without the sand which helps to transmit the loads in a homogeneous way. The fines therefore need the intermediate element that is sand to fill the voids between the gravels and play their role of natural cement in order to fully contribute to the compactness of the material.

From the soaked CBR results (Table 5), the granulometry with the highest bearing is the one with more sand and less fines. It is the most stable of all the granulometries tested. Actually, the grains of sand will be located in the interstices created by the gravel and therefore fill part of these interstices, which has the effect of increasing the dry density and therefore reducing the percentage of voids, implying an increase of the bearing. The granulometry with the lowest bearing is the one with more gravel. It is also the most influenced by soaking (drop of more than 60% of CBR). The high presence of coarse and medium gravel with a minimum of fine material to fill the voids, provides more chances for the aggregates to undergo the flow of water and move under load. The granulometry with more fines is the one whose bearing remains among the lowest for their high water absorption. Indeed, the fines are the particles that retain a large quantity of water which causes a drop in bearing.

4.1 Correlation between Proctor characteristics and CBR

The results of the various tests show that the CBR values are mainly influenced by the compaction energy and the granulometry. In fact, Proctor characteristics have a remarkable effect on the CBR. According to [20] and [21], it is widely accepted that CBR values are extremely related to the degree of compaction and water content. Additionally, Dhurgham et al. [22] sought to correlate the CBR value of coarse-grained soils based on certain physical properties such as grain size analysis, percentage of fine particles, and fractions of gravel, sand, and fines. They showed that the coarse-grained particles are more determining than others because the correlation of the CBR value depends significantly on the value of D60, on the percentage of gravel and the percentage of sand. The observed differences in bearing ratios both unsoaked and soaked could be attributed to changes in particle size or Proctor characteristics. These results correspond well to studies carried out on unbound granular materials with more than 35% gravel and where the optimum CBR was obtained for a fines content of between 8 and 10% [23 and 24].

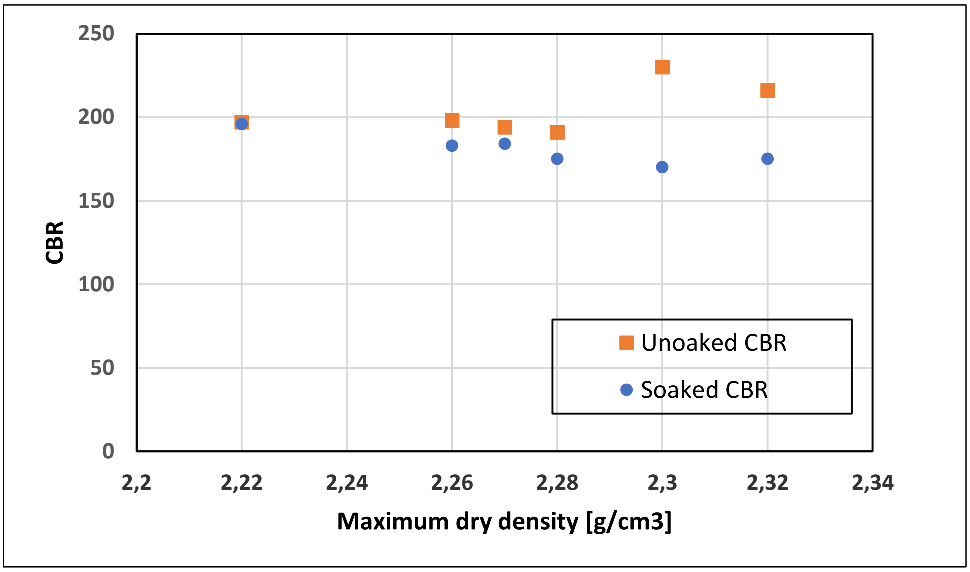

Figure 3: Evolution of the California Bearing Ratios according to optimal dry densities for each granulometry.

Several studies have shown that the dry density has a significant impact on the results of unsoaked and soaked CBRs for both fine and coarse materials [25 and 26]. From our results, Figure 3 shows that the granulometries with fines contents of the order of 4% (minimum content) give unsoaked CBRs and soaked CBRs practically confounded; this shows that this content of fines does not influence the dry density and the immersion has no influence on the fines or on the other granular classes. On the other hand, the more the percentage of fines increases with the percentage of gravel, the more the dry density increases and the difference between the two ratios becomes significant. The variation in CBR values is not only related to the content of fine particles, but also to the percentage of sand and gravel.

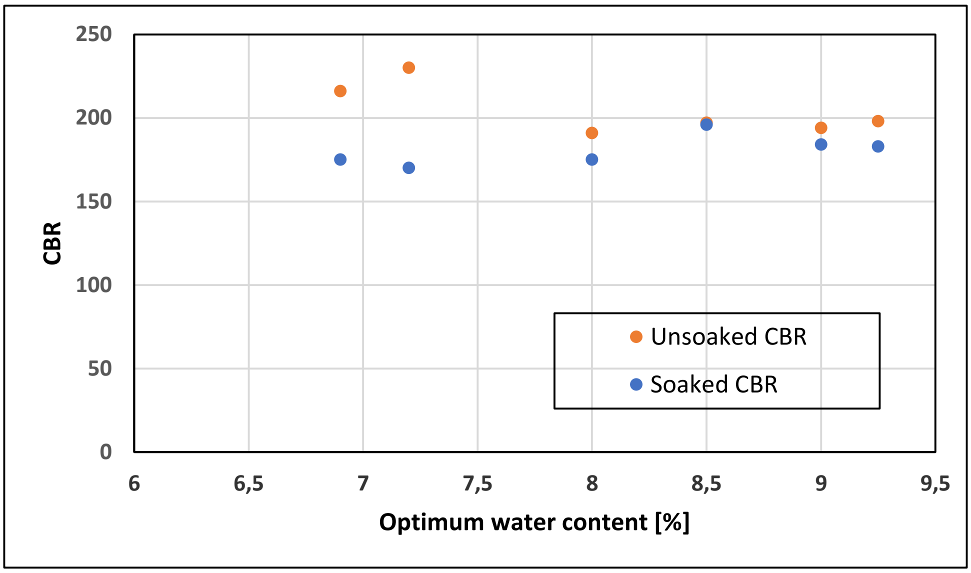

Figure 4: Evolution of the CBR according to the optimum water content for the different granulometries.

Figure 4 shows that granulometries with fine contents of around 4% (minimum content) give unsoaked CBRs and soaked CBRs that are practically the same. This shows that the immersion did not influence the CBR values. The difference between the CBRs becomes more and more important when the percentage of fines increases and the percentage of sand decreases.

5. CONCLUSION

The analysis of the experimental data showed that the CBR values obtained gave clear indications on the Proctor characteristics according to the different particle sizes used. Certainly, the percentages of gravel, sand and fines in a given granulometry play a key role in the bearing capacity of the pavement foundation layer. From the main results obtained, we can retain:

- The percentages of gravel, sand and fines in the granulometries studied influence the Proctor characteristics (optimum dry density and optimum water content) and both unsoaked and soaked CBRs;
- The values of the CBRs are linked to the compaction characteristics (optimum dry density and optimum water content);
- The fine particles influe on the Proctor characteristics and CBR only when they exceed a percentage of 4%;
- The lack of sand in sufficient quantity in the granulometries reduces the characteristics of both Proctor and CBR;
- Coarser pzarticules sizes give better values for both unsoaked and soaked CBRs;

- Soaked CBR generally decreases with increasing fines content;
- Unsoaked CBR generally increases with increasing sand content.

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