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VARIATION OF GEOTECHNICAL PARAMETERS IN THE MIXTURE OF CRUSHED AND ROUNDED GRAVELS IN THE NORTH WEST REGION OF CAMEROON BY THE WEIGHT MASS METHOD

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Abstract

We study the geotechnical parameters (void ratio and hydraulic conductivity) of two types of mixtures of particles (crushed gravel and rounded gravel), and determine the porosity *n* (or the void ratio *e*) along with the permeability or hydraulic conductivity by the weight mass method. A progressive evolution of the void ratio of the three

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granular classes is established starting with completely crushed gravel to the fully rounded gravel. We establish a dependency of the void ratio in function of the size range for each grain size.

The study of the permeability or the hydraulic conductivity enables to see a decrease in the evolution of the permeability of different granular classes in function of the shape of the grains. Fully crushed gravels have a higher permeability. We rely on the fact that the values of permeabilities do not follow that of the void ratio and we have established a difference between porosity and drainage which is a function of the stack and grain shape. And then we have established a relationship between the measured values and the predictive values of Chapuis [4].

I. Introduction

The quality of granular materials used in various civil engineering works such as drainage layers of paved roads, bottoms of household waste storage centers, cement or bituminous concrete, and asphalt layers requires good knowledge of some of their geotechnical parameters such as porosity, permeability, and angle of friction. Controlling these parameters enables us to carry out an efficient selection of materials. To meet up with standards, we identified and analyzed several studies specifically the ones that take into account the factors such as the angularity of the grains, the size and shape of grains and distribution of grains in the granular milieu.

Several research works were carried out in order to determine the factors that influence the granular milieu or changes in the geotechnical parameters of gravel. It is apparent that the different shapes and distributions of the grain used to define the sphericity is the ratio of the specific surface of the particle and of the sphere; both the parameters contained in the same volume $\Psi = s/S$ (Wadell [34]). The improved Wadell method for the calculation of sphericity by using the particle's inscribed and circumscribed diameter in its more precise equation shows the influence of grains (Riley [22]). The original approach introduces circularity on which a relationship between the area enclosed by the particle and that of the circle obtained from the diameter of the largest delimited side is established (Pentland [20]). The most recent studies introduce the concept of bridging phenomenon which demonstrates how grains having an elongation create high voids ratio between grains of the granular matrix (Santamarina and Cho [24]). Other researchers have developed a way to calculate the curvature, the form factor of grains and connectivity of gravel for concrete using the method of digital image (Mora and Kwan [17]), while some others have shown that we can determine the shape of the grains based on their means of transportation or on their origin especially for clays (Mitchell and Soga [16]). These studies gave the influence of particle shape on the mechanical behavior of gravel, namely hardness, workability, shear, and fatigue in bitumens (Arasan et al. [1]). Regarding the angularity and shape of the grains, with empirical methods and by analyses, the images and numerical calculation of grains, calculation techniques of the factors influencing the parameters of porous melieu have been developed (Tickell [32], Lees [13], Shergold [28], Mirghasemi et al. [15], Nouguier-Lehon et al. [18] and Sukumaran and Ashmawy [31]). Apart from the intrinsic factors of the grains, two other key parameters that regulate the structure of the granular materials were established, namely the stack of grains and their interconnectivity (Santamarina and Cho [24]).

Depending on the origin of the grains, their shapes, angularity and distribution differ. Therefore, the stack differs affecting geotechnical parameters such as void ratio or porosity and hydraulic conductivity (Rousé et al. [23] and Shinohara et al. [29]). To reach these conclusions, they used the Powers' classification [21] which is in six groups. By bringing together the different groups to form a gravel, a composite material characterized by parameters such as the porosity, the void ratio and permeability is obtained.

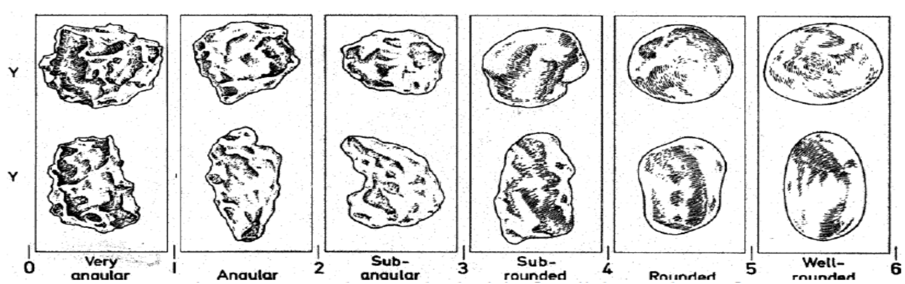


Figure 1. Sphericity - qualitative circularity of the Powers' diagram [21].

In the case of voids ratio, to define the porosity, several studies were performed to predict the porosity of the materials from different mixtures of known particle sizes. These studies are essentially based on two methods: one is focused on the arrangement of particles (Clarke [8]). This method takes into account the arrangement of the grains of a binary mixture that can be obtained in two ways. The first method is by the arrangement of coarse aggregates where the smaller particles lodge between the larger particles and the second method is by another arrangement where the larger particles are isolated between the smaller particles. Clarke's method has witnessed some improvements from the assumption that the diameter of the small particles must be less than the void ratio, and that the volume of the mixture must be equal to the volume of larger particles (Koltermann and Gorelick [12]). We also have the mixing method, which is based on a vision at the macroscopic scale of the association of particles of materials. The formula for calculating the void ratios of the mixture is $e_m = e_f F + e_c(1 - F)(1 - RmF)$ (Gutierrez [9]). This formula assumes that the void ratio will be based on the fractions of smaller particles of the mixture: it uses the miscible blends method. An analysis of this formula shows the non-inclusion of Clarke's ideal mixture. Indeed, the particle shape can be a limiting factor to the non-accuracy of the results related to the bridging factors created during the particle arrangement.

As for permeability, several studies were used to develop predictive methods which are based on the void ratio and the compliance coefficient of the particle diameter of the aggregates (Scheidegger [25-27], Bear [3], Vukovic and Soro [33], Mbonimpa et al. [14] and Aubertin et al. [2]). For the determination of the permeability, other researchers used different empirical methods based on capillary action, statistics, and on the theories of hydraulic ratios (Chapuis and Aubertin [5]). Other studies used methods that take into account several other factors such as the nature of the materials, the shapes of particles, particle size, and the particle distribution (Sperry and Peirce [30] and Chapuis [4]). The nature of the fluid passing through the particles, the uniformity of grains, and the effective diameter were identified as key parameters (Hazen [10]). Thus, $k = C_u D_{10}^2 \text{cm/s}$, the modified Carman-

Kozeny (MCK) equation. Chapuis and Montour [7] and Chapuis and Aubertin [5] developed a method based on Kezony-Carmann and linked to Hazen for the estimated calculation of the saturated hydraulic conductivity. This method takes into account other factors such as the tortuosity of the flow channels which is a function of pore formation and void ratio. So

$$k_{sat} = C_g \frac{\gamma_w}{\mu_w} \frac{e^{B+x}}{1+e_m} C_u^{1/3} D_{10}^2 \text{ cm/s}.$$

The advantage of this formulation is that it takes into account most of the factors influencing gravel. The results, however, showed that there are still major differences between the calculated values and in some cases the measured values. In order to obtain an approximate solution, studies carried out with the help of the expansion equation of Kozeny-Carman and of Hazen, established another equation that takes into account not only the void ratio but also the effective diameter d10 (Chapuis [4]). These are parameters that take into account the arrangement of grains and their diameters and not the nature and shape of the grains defined by

$$k = 2{,}4622\left[\frac{d_{10}^2 \theta^3}{1+\theta}\right]^{,7825}.$$

The advantage of this method is that environmental conditions are no longer important, but it reflects the arrangement of the particles which is one of the major factors in the formation of voids in the gravel as shown by Clarke's method.

During this study, we admitted that the granularity, the nature and shape, and the distribution vary the geotechnical parameters of gravel in a linear model and the permeability is related to a predictive equation.

We need to explore how the granularity, the nature and shape, and the distribution govern geotechnical parameters? Another thing to find out is what is the predictive equation of permeability which linked the gravel?

To address these concerns, we will use the method of volumic weight by determining the permeability and porosity of the samples from the three major groups of mixing rounded and crushed granularity: $d/D = 20/63$, $25/63$, $31.5/63$. We will then deduct the different equations that govern these mixtures. Then we will calculate the values for samples of different gravel groups by the methods of predictions mentioned above. The verification is made by establishing an equation between the measured values and those obtained by the prediction equation. The difference between these two values must be minimal.

II. Materials and Experimentation

II.1. Materials

There are several varieties of granular media in Cameroon. The varieties depend on the region of origin and in the manner of extractions (crushed manually or mechanically or rolled by washing). The materials used in this work are in three groups of sizes: $d/D = 20/63; 25/63; 31.5/63$ for the manually crushed gravel of the North West region of Cameroon and two groups of sizes: $d/D = 20/63; 25/63$ for rounded gravel from the same region. We used a mixture of aggregates with rounded and crushed shapes in suitable ratios for the composition of proportions for each granular class.

Table 1. Composition of materials in percentages

Materials nature	100/0	90/10	80/20	70/30	60/40	50/50	40/60	30/70	20/80	10/90	0/100
Crushed gravel	100	90	80	70	60	50	40	30	20	10	0
Rounded gravel	0	10	20	30	40	50	60	70	80	90	100

Figure 2. Crushed gravels.

Figure 3. Rounded gravels.

II.2. Experimentation

II.2.1. Particle analysis

The particle size analysis is carried out on two sources of rounded granular and crushed granular in a stack of a series of sieves ranging from 63mm to 20mm according to the EN 933-1 standard. By introducing the aggregates in the 63mm sieve after shaking at the vibrating table, the particles will be distributed in the different sieves that make up the series of diameters. Then the collection will be done by grouping sieves of different sizes starting with the largest diameter sieve. The retained on each sieve will be any particles that have not gone through that particular sieve and all the particles passing through the sieves will be called *passings*. The following formulas will be used for the calculation of superior sieves and sieve in each refusal:

cumulative passings in a sieve *i* is (Tci) = Sum of retained below sieve *i*,

cumulative retained *i* (Rci) = Sum of retained above sieve *i*, it can also be calculated as 100-Tci.

II.2.2. Permeability test

The test of hydraulic conductivity or permeability was conducted using the constant head permeameter form in accordance with the UNE 103403; BS 1377 standards. It consists of causing water to flow through a sample of length *L* in a cylinder of cross sectional area *S* in proportion of the mixtures of crushed and rounded gravels of the different compositions. The test was carried out using equipments such as a reservoir, a graduated ruler, a scale balance, a stopwatch, a permeameter of constant head of code of practice UNE 103403, a thermometer, and a 200ml container. The permeability is obtained by combining the mixture and gravel and vibrating in order to obtain a better particle arrangement followed by placing the container at a suitable height to the water supply valve and connecting to the permeameter with the help of a tube, then we measure the height of the free surface water in the container and its connection point at the permeameter, and with another tube, we connect the water outlet of the permeameter to a graduated container. We open the tap on the container and that of the permeameter pending, we can have a permanent water flow and place there the graduated container. From the moment water starts flowing, we stop the chronometer and then read the time elapsed for the volume of water collected in the graduated container, and we close the tap and the permeameter filling the container. Finally, we determine the permeability *k* by Darcy formula:

$$k = \frac{QL}{S\Delta H},$$

$Q =$ flow through the sample of gravel,

$L =$ the height of the sample through which the water in the cylinder passes,

$S =$ the cylinder cross sectional area at its base,

$\Delta H =$ the height between the different equilibrium surfaces of the water entering and leaving.

II.2.3. The test on the void ratio

The test of the void ratio is performed to determine the proportion of voids that can be found between the particles in the case of gravel when viewed as granular soil. It is produced by the method of the graduated cylinder. The equipments used are a scale, a measuring tube or a measuring container, and a container of water. To determine the void ratio, water is filled to a certain level or the 200ml container of graduated tube read h_1, then we introduce the gravel in the water-containing container and read the new displacement h_2 in the graduated tube. We calculate the volume of solid particles $Vs = h_2 - h_1$, later we calculate the void volume $Vv = 2h_1 - h_2$, finally, the void ratio $e = \frac{Vv}{Vs}$.

II.2.4. Determination of the minimum values between the various values of the studied predictive models

The determination of the values of predictive models will be calculated using the formulas above.

In the case of Hazen [10], the permeability formula is:

$$k = C_u D_{10}^2,$$

where C_u is the coefficient of uniformity and D_{10} is an effective diameter.

According to Chapuis and Aubertin [5], the saturated permeability formula is as follows:

$$k_{sat} = C_g \frac{\gamma_w}{\mu_w} \frac{e^{B+x}}{1+e_m} C_u^{1/3} D_{10}^2,$$

where C_u is a coefficient of uniformity; D_{10} is an effective diameter; e is a void ratio; μ_w is a viscosity of the liquid; γ_w is a volumic weight and C_g is a compliance coefficient.

In the case of Chapuis [4], the permeability formula is as follows:

$$k = 2{,}4622\left[\frac{d_{10}^2 e^3}{1+e}\right]^{,7825},$$

where D_{10} is an effective diameter and e is a void ratio.

After calculating the permeability values with different predictive formulas, we will choose the formula whose values are closer to the measured values.

III. Results and Discussion

III.1. Analysis

The two curves show the granular continuity of two gravels used in the composition of different samples to be used for the test. For the analysis of these materials, the diameters are known and are of minimum diameter of 20mm and maximum diameter of 63mm.

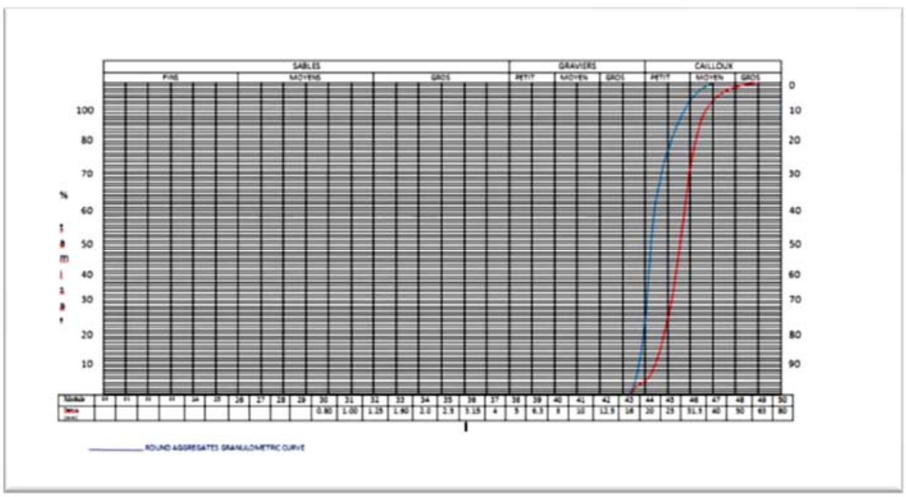


Figure 4. Particle size curves of the two gravels: rounded and crushed aggregate mixture.

III.2. Variation of void indices in function of the percentage of rounded gravel in the crushed-rounded mixture

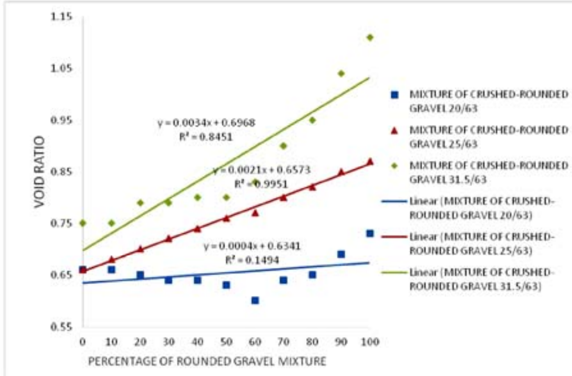


Figure 5. Variation of the void ratio mixture based on the percentage of gross rolled.

III.2.1. Influence of the nature and shape of gravel

The void ratio of the 20/63 gravel mixture shows a minimum value of 0.66 when the material is fully crushed and 0.75 when the material is rounded. This gives a variation of about 0.09 points. An observation of the curve shows a very small standard deviation that is close to 0. This shows a notable gap from the measured values represented by the trend curve *y* and shows a growth of the void index as the used rounded gravel.

The void ratio of the 25/63 gravel mixture shows a minimum value of 0.66 when the material is fully crushed and a value of 0.88 when the material is rounded. This gives a variation of about 0.22. An analysis of the curve shows a standard deviation of 20% closer to 1, indicating a very close approximation of the values found represented by an average curve of the trend *y*. As for the 20/63 gravel mixture, the same increase in the void ratio is observed by changing the nature of the gravel from crushed to rounded.

The void indices of the 31.5/63 gravel mixture show a minimum value of 0.75 when the material is fully crushed and a value of 1.11 when the material is rounded. This gives a variation of about 0.36. An observation of the trend curve gives a standard deviation close to 1. This shows a very close approximation of the values measured with respect to *y* of the predictive values.

In general, we observe a large variation in the void ratio of gravel mixtures, depending on the nature and form, between 25 and 33% of the voids in the mixture.

III.2.2. Influence of gravels granularity

We observe that the trend lines of the three classes of granularity have increased void ratio which increases with different rates. The largest is that of the mixture of the gravel 31.5/63 and the smallest is the mixture of gravel 20/63. These equations are all linear. This allows us to think in linear model in the evolution of the void ratio of each granularity class.

III.2.3. Influence of gravels distribution

From the results obtained, we observe that the contribution of small grains in granular class increases the density of the gravel while reducing porosity. The evolution of the void ratio of crushed aggregates rounded different classes of aggregates is governed by a linear or polynomial relationship which always increases as the mixture tends towards a larger mixture of rounded aggregates. If we consider the relationship of the crushed/rounded gravels between 0 and 1, we can establish an appropriate function as defined in Figure 5. We can estimate that the change in the void ratio is a polynomial function of the form $e = \alpha x^2 + \beta x + \gamma$ (see the method of least squares).

III.3. Change in permeability according to the percentage of rolled gravel in the mixture

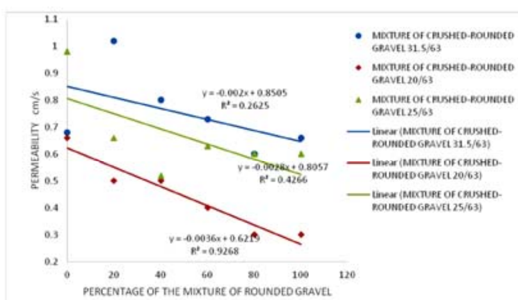


Figure 6. Permeability variation of the mixture based on the percentage of rounded gravel.

III.3.1. The influence of the nature and form of gravels

The variation of the permeability of the 20/63 has the following indicators: a maximum value 0.66 for the crushed gravel and a minimum value 0.35 for fully rounded gravel. The gap between the different minimum and maximum values is 0.31. The trend line shows a standard deviation close to 1, which shows a great combination of measured values such that they can belong to the same function.

The permeability curve of 25/63 gravel shows a dispersion of results. Mainly, the result of the first value which is 0.98. This value forms a very concave curve and far from its different measurements. It seems to present a reading error relative to the concentration of other points. The small standard deviation shows a very weak type of measurement from the trend curve. This indicates a large variation in permeability between the sample groups. The change in permeability in entirely crushed gravels is large compared to rounded gravel. This shows a change in the probable behavior related to the mode of arrangement of rounded and crushed particles in the connectivity of particles or other phenomena such as bridging.

The dispersion of permeability values in this class shows us the desire that the permeability increases gradually as the particles become larger. And likewise, the permeability is no longer easily defined because the gaps between the particles cause them to develop hydraulic behaviors that are very uniform. The curve shows a phase where the behavior changes with the contribution of rounded particles which instead increases the permeability. In general, the trend lines are linear which can be explained by the fact that the model of permeability is linear.

III.3.2. Influence of granularity of gravel

The influence of granularity in the phenomenon that we observe decreases the permeability within three granularity groups in areas of high rate of void ratio of rates. The different permeabilities vary the granularity from 0.55 to 0.35cm/s when considering a different increase rate.

III.3.3. Influence of crushed gravel

Variations of permeability or hydraulic conductivity of the mixtures of rounded and crushed gravels gave the following values in the table:

Table of permeability variation in cm/s

Granular class	Minimum	Maximum
20/63	0.30	0.66
25/63	0.60	0.98
31.5/63	0.68	0.97

The observation of these permeabilities from different distributions shows an almost identical behavior of permeabilities by straight lines which almost have the same negative coefficients. This decrease of the trend curve allows us to demonstrate that the increase in rounded gravel in a mixture of crushed-rounded gravel decreases the permeability of the newly obtained gravel. But above all, we deduce that the more particles are tightly packed, the more the permeability increases.

We can then calculate the permeability constant with a variable for each type of mixture and deduce the other parameters.

IV. Determination of the Permeability Values of Some Predictive Methods and Choice of Minimum Variation of the Predictive Model to the Measured Values

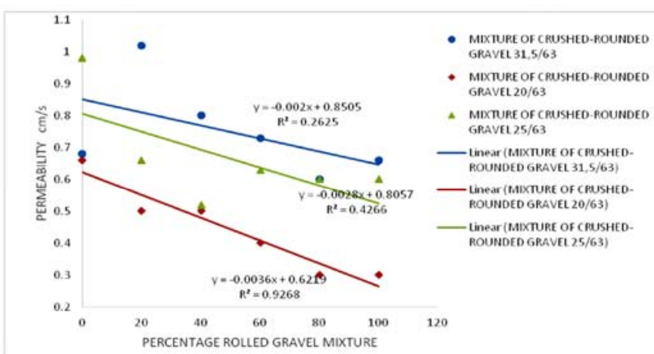


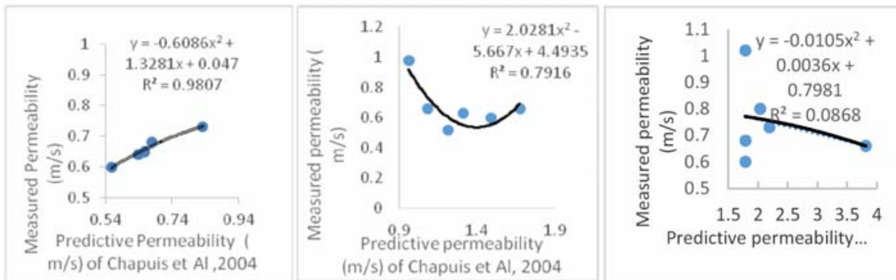
Figure 7. Determination of permeability values of rolled gravel mixture.

Table 2. Determination of permeability values of some predictive methods

Nature of gravels	Composition of the mixture rounded-crushed	Permeability K measured in m/s	Permeability K in m/s (Hazen [10])	Permeability K in m/s (Chapuis [4])
20/63	100/0	$6{,}8 \times 10^{-1}$	8	$6{,}7 \times 10^{-1}$
	80/20	$10{,}2 \times 10^{-1}$	8	$6{,}57 \times 10^{-1}$
	60/40	$8{,}0 \times 10^{-1}$	8	$6{,}37 \times 10^{-1}$
	40/60	$7{,}3 \times 10^{-1}$	10	$5{,}58 \times 10^{-1}$
	20/80	$6{,}0 \times 10^{-1}$	10	$5{,}58 \times 10^{-1}$
	0/100	$6{,}6 \times 10^{-1}$	8	$8{,}32 \times 10^{-1}$
25/63	100/0	$9{,}8 \times 10^{-1}$	10	$1{,}445 \times 10^{-2}$
	80/20	$6{,}6 \times 10^{-1}$	10	$1{,}629 \times 10^{-2}$
	60/40	$5{,}2 \times 10^{-1}$	12,5	$1{,}822 \times 10^{-2}$
	40/60	$6{,}3 \times 10^{-1}$	12,5	$1{,}974 \times 10^{-2}$
	20/80	$6{,}0 \times 10^{-1}$	12,5	$2{,}239 \times 10^{-2}$
	0/100	$6{,}6 \times 10^{-1}$	10	$2{,}535 \times 10^{-2}$
31,5/63	100/0	$6{,}8 \times 10^{-1}$	20	$2{,}11 \times 10^{-2}$
	80/20	$10{,}2 \times 10^{-1}$	15,67	$1{,}989 \times 10^{-2}$
	60/40	8×10^{-1}	15,67	$2{,}462 \times 10^{-2}$
	40/60	$7{,}3 \times 10^{-1}$	15,67	$3{,}909 \times 10^{-2}$
	20/80	$6{,}0 \times 10^{-1}$	15,67	$3{,}183 \times 10^{-2}$
	0/100	$6{,}6 \times 10^{-1}$	15,67	$2{,}429 \times 10^{-2}$

The calculated values of the different predictive models have led us to retain that of Chapuis [4] as the one giving the closest values to the measured values. But the granularity of classes 25/63 and 31.5/63 has a large difference compared to the predicted values. This difference shows the improvement that the mixture of gravel can bring in the permeability of this new established draining material (crushed-rounded gravel). This gravel can be defined by a model linked to that of Chapuis [4] by an equation that will give us a predictive model of the crushed-rounded mixture of the gravel of the Northwest region of Cameroon by granularity.

V. Relationship between Measured Permeabilities and Predictive Permeability Model



(a) (b) (c)

(a) Relationship between measured and predictive permeability of Chapuis and Al 20/63 mixture of gravel.

(b) Relationship between measured and predictive permeability of Chapuis and Al mixture of gravel 25/63.

(c) Relationship between measured and predictive permeability of Chapuis and Al mixture of gravel 31.5/63.

Figure 8. Relationship between measured permeabilities and predictive permeability model.

The various graphs of permeability of Figure 8 show increasing and decreasing trends of the trend curve. A fully symmetrical behavior (Figure 8(b)) resembles the curve shown by Hernandez [11]. But in the case of a comparison with predictive models, Figure 8(a) shows a close link between the permeability of measured gravel and that of Chapuis and Aubertin [6]. For Figure 8(c), there are great differences between the measured values of permeability and trend line. The analysis of these results leads us not to take into account some of its very remote values. These curves have very similar variants to one another even when the mixtures are different in terms of granularity, nature, shape and distribution of the grains in the mixture.

After comparing between the hydraulic conductivity and predictive conductivity or measured permeability, we noted that there are differences between the two values. This is a proof that not all the parameters are taken into account when developing the Chapuis and Aubertin [6] prediction equation. However, from this equation, we can design a model of the gravel of the Northwest Region of Cameroon with correlation factors with the Chapuis model where the trend line gives us that opportunity. Thus, the model of Chapuis, being a linear model, is correlated. This model will also be a linear model with variables those of Chapuis and Aubertin [6].

VI. Conclusion

In the present work, we showed the influence of particle size, shape nature and the distribution of grains by weight method for two kinds of gravel on the model of geotechnical parameters. This study shows that the changes in the geotechnical parameters in the mixture of rounded or crushed gravel obtained manually or with the machine are based on the nature and form of gravel, granularity and distribution of gravels. At the end of our study, we demonstrated that the choice of a type of gravel mixture as building materials or as a draining material has a number of advantages including:

- Technically, obtaining the crushed material requires a lot of financial means or generates too much hardships and their mixture as construction materials will be a means of production time savings.

- Economically, this study will encourage the exploitation of the local river for gravel career that rolled less expensive for the various projects.

- With a judicious choice of gravel, these results are used to assess the estimated permeability values depending on the void ratio and the effective diameter in the area concerned.

Despite the differences observed in the experimental model, this study constitutes a contribution in the optimal use in gravel drainage of fluids. It would be of great importance in the choice of drainage material in the region of Northwest Region Cameroon where crushed or rolled gravels are relatively rare.

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