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CBR-based optimization of rain barrier operation

Jérémie Madjadoumbaye[1], Marceline Blanche Manjia[1], Jacques Rémy Minane[1,*], Valentin Makomra[2], Patient Nana[1]

[1](Department of Urban and Civil Engineering,National Advanced School of Engineering of Yaounde (Polytechnic),University of Yaounde I, P.O. Box 8390 Yaounde, Cameroon)
[2](Department of Civil Engineering, National Advanced School of Publics Work, Yaounde, Cameroon)

Abstract:
Poorly drained rainwater is the cause of early deterioration of earth pavements. The random nature of the current management of rain barriers, coupled with a lack of knowledge of the geotechnical and mechanical properties of the pavement layers, poses a problem with regard to the effectiveness of these protective devices. This study is aiming to determine the optimal closure duration of rain barriers based on the soil CBR index. To achieve this objective, our methodology consisted of the sampling of the identified soil, the characterization (physical and geotechnical) and subjecting it to rain simulation and then drying under unfavorable conditions. CBR values are measured as a function of drying time. The characterization of initial lateritic soil revealed that the CBRequals to 28.5%. The CBRs obtained at drying times of 0h, 1h, 2h, 3h and 4h after rain simulation were respectively 17%, 19%, 22.5%, 27% and 27.5%. Based on these results, we found that the time that best corresponds to 95% of the initial CBR is 3h, which reduces the regulatory shutdown time by 25-50%.

Background*: Rainwater is one of the major causes of deterioration of dirt roads in African countries. In addition, deterioration accelerates especially when maintenance is not carried out. Thus, the use of rain barriers remains a serious alternative to compensate for the early deterioration of dirt roads. During rainfall, the bearing capacity of earth roads decreases sharply and therefore it is necessary to interrupt vehicle traffic on these roads. In this study, it was a question of determining the optimal time for reopening the rain barriers in order to restore traffic flow and allow users to circulate comfortably without damaging the pavement.*

Materials and Methods*: During this research, a lateritic soil was identified, sampled and characterized (grain size distribution, liquidity limit, modified proctor test, CBR, etc.) in the laboratory according to the test standards in force. The simulation of a 2-hour rainfall was carried out on the identified soil and the CBR was determined after the drying times of 0 h, 1 h, 2 h, 3 h and 4 h. The CBR values obtained after drying were compared to those of the original floor.*

Results: *The CBR test obtained on the initial lateritic soil is 28.5%. CBR values obtained after 0h, 1h, 2h, 3h and 4h after the rainfall are respectively 17%, 19%, 22.5%, 27% and 27.*

Conclusion:*In order to preserve the rapid deterioration of roads and to ensure the safety of road users, 3 hours remains the suitable time to the opening the rain barrier.*

Key Word*:Rain Barrier, CBR, optimization, earth road, drying time*

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I. Introduction

In most African countries, roads remain the most widely used means of transporting goods and people. Earth roads are rapidly deteriorating under the combined influence of several factors such as the incivility of users, traffic, climate, pavement structure and especially rainwater. The phenomenon often takes an extremely rapid pace when the frequency of maintenance is not controlled.

Thus, in the maintenance strategy for earth roads, the use of rain barriers is required to compensate for early pavement deterioration. Indeed, when the soil is exposed to the influence of heavy downpours, it loses its bearing capacity and it is necessary to interrupt traffic to a certain category of vehicles to prevent the road from being damaged. This basic activity is carried out using rain barriers that ensure the protection of nearly 110,000 km of roads out of a total of 122,222 km of the national network [1]. Despite the existence of these devices, statistics in 2016 indicate that only 11% of earth roads are in good condition [2], and that between 2012 and 2016 the number of rain barriers fell considerably from 1835 to 1099, which may be due to their poor management [3]. It is therefore clear that the non-existence of these devices on our roads would have enormous consequences, both in terms of loss of income for users and in terms of reconstruction or rehabilitation expenditure. It is on the strength of these stakes that, for several years now, the protection of roads in rainy weather has been an issue that has been the subject of sustained reflection within the Ministry of Public Works in Cameroon. The main problem is, first of all, the uncontrolled passage of vehicles at rain barriers, the lack of a tool to measure the time of passage of these vehicles during and after a rainfall; and on the other hand, the purely empirical nature of their operation which indicates the reopening of the barrier 4 to 6 hours after a rainfall [4].

The main objective of our study is to optimize the closing time of rain barriers by analysing the results of the CBR tests.

II. Material And Methods

2.1 Observations

A road is built to carry a certain amount of traffic. Therefore, once implemented it has in theory adequate characteristics to fulfil this function. The particularity of earth roads is their high sensitivity to water.

When rain falls, the following steps are progressively observed:

a) The first raindrops raise light dust;

b) After a certain time, depending on the intensity of the rain, the fine particles present on the surface are washed away by the water running down the roadside;

c) The soil increasingly acquires a smooth paste texture. Especially in the most traffic-prone areas, this paste becomes denser until it becomes very firm. The surface is smooth;

d) Prolonged rainfall causes the soil to become waterlogged. It is noticeable that the passage of vehicles leaves clear deformations. Sloughs are likely to be created;

e) The texture of the soil is gradually getting closer to mud that sticks to the wheels. Cars are skating on the road. Water stagnates in the small crevices formed. At this stage, the deformations are irreversible.

After observation, we look for the right moment just before state d) which will represent the time of closure of the rain barrier. This time, relative to the principle of the Proctor test, will correspond to the time when the soil has an optimal water content. During the rainy season, the starting point is an initial soil moisture content below the optimum moisture content. In order to reach the optimal moisture content, we will need information on the intensity of rainfall, infiltration, runoff, percolation and evaporation of water in the soil. Unfortunately, the present study was carried out during the dry season and we did not have all these data for the whole country.

Assuming that we have this closing time which is the time between the beginning of the rain and the time when the soil reaches its optimal water content. A problem may arise for vehicles that will have crossed the rain barrier just at the beginning of the rain and will continue to drive to the next barrier as the rain intensifies. These vehicles will not only accelerate the degradation of the road, but will also be exposed to accidents. All this is caused by the fact that in Cameroon, after crossing a rain barrier; another one is encountered 30 km or more away and there are urban networks where only one rain barrier is encountered [3].

Faced with all these difficulties, we deemed it necessary to make the problem simpler by taking as closing time equal to the time provided for by law; that is to say, at the beginning of the rainfall. Traffic will be reopened when the ground has lost enough water to return to an almost good condition and can receive traffic again, this time will depend on the duration of the rain and the time the ground regains sufficient bearing capacity. The determination of this time will therefore be the subject of our experimental study at the Laboratory.

2.2 Hypothesis

Our hypotheses take into account the period during which this study was conducted (dry season), as well as the behavior of a earth road during and after rainfall when vehicles pass. These assumptions are as follows:

- The road is in "good" condition at the beginning of the study: the presence of further damage on the road would have an impact on the road's behaviour;
- Before the rain, the soil has a moisture content lower than its optimal moisture content;
- The duration of the rain is set at two hours; (average rainfall duration in the Central Region of Cameroon) [5];
- The road will be assumed to be sufficiently drained so that rainwater does not stagnate on the road ;
- The phenomenon of water run-off into the ground is not taken into account; (the aim is to have a nearly saturated material after the rain simulation);
- The rain simulation will consist of a possible immersion of the soil sample in water for 2 hours;
- The closing time of the rain barrier corresponds to the beginning of the rain;
- No swelling of the material after the two hours of rain;
- After a rain, the sun does not come immediately (unfavorable conditions) and the time elapsed for it to rain again is enormous (six hours minimum).

Let D_c be the duration of closure of the rain barrier to be studied, this duration represents the time elapsed between the moment of closure (beginning of the rain by hypothesis) and the moment of opening (moment when the ground has sufficient bearing capacity to receive traffic again) of the rain barrier. We can write the following equations:

$$D_c = t_{off} - t_{on} \qquad (1)$$

$$D_c = D_r - D_s \qquad (2)$$

D_c: rain barrier closing time (hour)
t_{off}: time of closure of the rain barrier (hour)
t_{on}: time of opening of the rain barrier (hour)
D_r : Duration of rain (hour)
D_s : Time needed on the ground to regain a starting lift (hour)

Since the duration of rain is known, optimising the closing time of a rain barrier would only optimise the time needed for the ground to regain its initial bearing capacity after the rain. This duration will be the subject of our experimental study through geotechnical tests in the laboratory.

The period during that we carried out this study did not allow us to have a real rainfall, this is why the simulation of a rainfall consisted in immersing our material (compacted respectively at 10, 25 and 55 strokes) in water for a duration of 2 hours. We also assumed the non-swelling of our material during these two hours.

2.3 Experimental study

Lateritic gravel is collected from the quarry of the Yaounde-Douala highway and transported to the geotechnical laboratory of the National Advanced School of Engineering (Yaounde-Cameroon) to perform various tests. The sampled soil was characterized in accordance to the French legislation. The standard regulations used in this investigation are reported in Table 1.

Table 1: Physical and geotechnical parameters of sampled soils.

Test	Method	Reference
Water content	NF P 94-050	[6]
Grain size distribution	NF P 94-056	[7]
Atterberg limits	NF P 94-051	[8]
Proctor tests	NF P 94-093	[9]
CBR	NF P 94-078	[10]

The CBR test (10, 25 and 55 strokes) will be carried out after determination of the optimal water content and the sample will be immersed in water (rain simulation, about 2 hours). After this immersion, it will be put in the sun (under unfavorable conditions) and after each drying time (0h, 1h, 2h, 3h, etc...); its CBR index will be determined until it reaches 95% of the initial soil CBR_i index. The CBR_k indexes will be determined after k hours of drying. The figure 1 shows the samples after 2h of immersion.

Figure 1: Soil samples after rain simulation

This situation represents the state where the soil has a very bad bearing capacity and corresponds to the end of the rain.

After obtaining the CBR of the soil directly after the rain (CBR_0), we will observe the behavior of the soil over time until the soil regains an admissible bearing capacity (95% of the initial soil), at which time we will open our rain barrier. The immediate consecutive CBR tests of the soil from hour to hour after the rain with the corresponding moisture content values are determined (CBRk; k≠0). To have successful results, the determination of these CBRs are independent of each other. Indeed, having quarried our material, we proceed as follows:

- We sampled 18 kg of soil material corresponding to the CBR of the first moment, i.e. after 1 hour of drying after the rain;
- It is compacted to the optimal water content in the different moulds according to the protocol of the CBR test (10, 25 and 55 strokes);
- It is immersed in water for 2 hours (rain simulation hypothesis);
- Then it is exposed to the sun in unfavorable conditions for 1 hour (in the morning, or in the shade if the sun is intense after immersion);
- We punch and determine the CBR at that time. It is noted CBR_1,
- This process is repeated to obtain the CBR after 2, 3 or 4 hours of drying in the sun after the rain, which is noted as CBR_2, CBR_3, CBR_4.

The figure 2 shows the appearance of the samples after one hour of drying:

Figure 2: Soil samples after 1h of rain

After obtaining the values of the different CBR, we can establish a linear correlation between the CBR and the drying time, and determine from this graph the time that best corresponds to 95% of the initial soil CBR.

III. Results

3.1 Water Content

Table 2 shows the results of water content of sampled soil and the obtained value is 12.90%.

Table 2: Initial Soil Moisture Content Results

Tare No	**A4**
Weight of wet material + tare weight (g)	77,1
Weight of dry material + tare weight (g)	71
Weight of tare (g)	23,7
Weight of dry material (g)	47,3
Weight of wet material (g)	53,4
Weight of water (g)	6,1
Moisture content w (%)	**12,90**

3.2. Particle Size distribution

The grain size distribution of sampled soil is reported in Figure 3. The HAZEN coefficients C_u and C_c are calculated as follows as:

$C_u = d_{60}/d_{10} = 3.50$; (3)

$C_c = (d_{30})^2 / (d_{60} * d_{10}) = 1.14$ (4)

With $d_{60} = 12.55$ mm; $d_{30} = 7.17$mm and $d_{10} = 3.59$ mm

According to the Unified Soil Classification System (USCS), the identified soil is a clean and poorly graded gravel (GM) because the HAZEN coefficients do not verify the conditions of Well Graded (Cu > 4 and 1< Cc < 3).

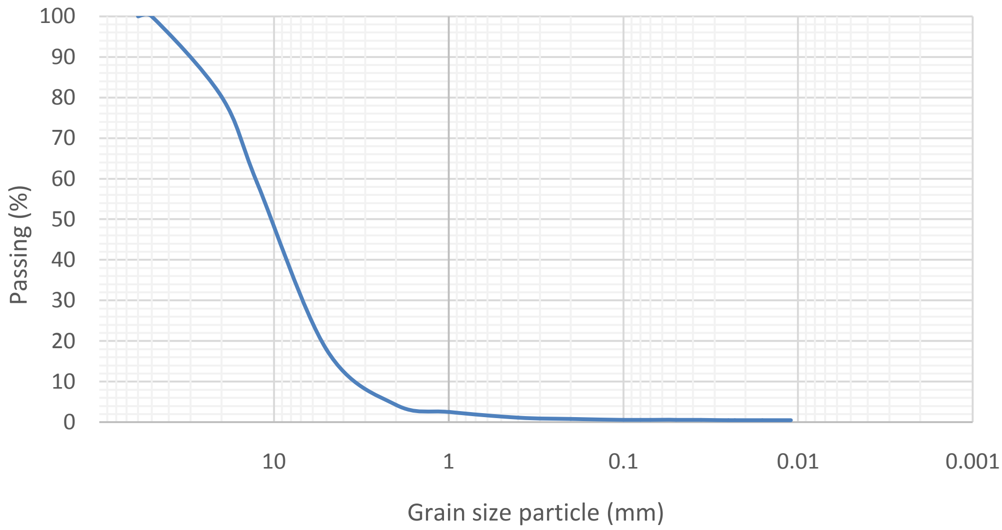

Figure 3: Particle size curve of identified soil

3.3. Atterberg's limits

After plotting the curve of the different water contents on the x-axis and the number of moves on the y-axis, the liquidity limit is obtained by projecting the number of moves N=25 on the y-axis (See below Figure 4)

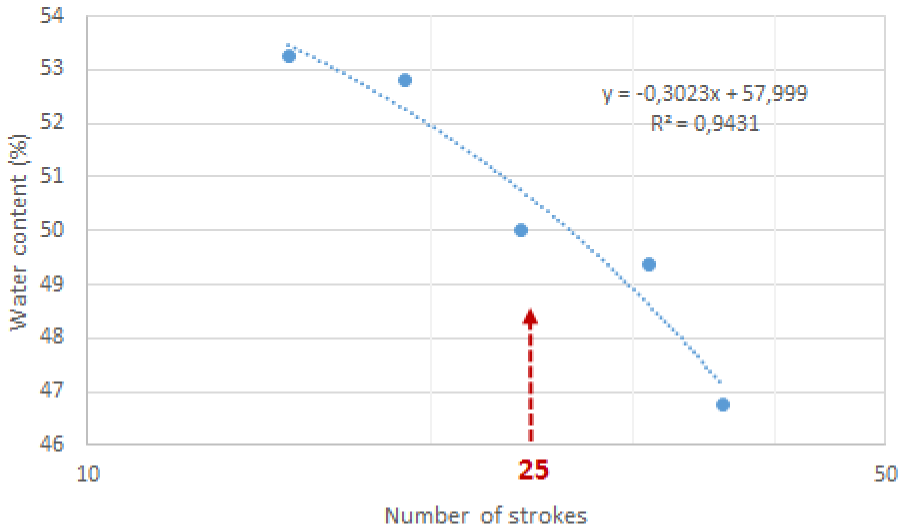

Figure 4: Moisture content as a function of the number of strokes

As it can be observed in Figure 4, the liquid limit of the soil is W_L = 50.05%. Table 3 gives the results of the plasticity limit of the identified soil.

Table 3: Experimental results of the plasticity limit

Plasticity limit			
Tare No.	A1	A2	A3
Wet weight + Tare weight (g)	11,9	11,6	15,2
Dry weight + Tare weight (g)	11,5	11,1	14,7
Weight Tare (g)	10,1	9,6	13
Dry material weight (g)	1,4	1,5	1,7
Material weight Wet (g)	1,8	2	2,2
Weight of water (g)	0,4	0,5	0,5
Moisture content w (%)	28,57	33,33	29,41
Mean w (%)		**30,44**	

The plasticity limit is equal to W_P = 30.44%. The plasticity index is given by the relationship as below: $I_P = W_L - W_P$ (5)
I_P = 19.61%.
This parameter measures the extent of the plasticity range. According to the LCPC method (which uses the Casagrande Plasticity Chart), we have the coordinates of point A given by: A (I_P = 19.61%; W_L = 50.50%). Thus, the identifiedsoil is classified as a Clay with low plasticity.

3.4 The Proctor test

The modified proctor test has been preferred to normal proctor because it is the requirement for the CBR test. The obtained results are shown in Figure 5 with the water content and the optimum dry density of soil.

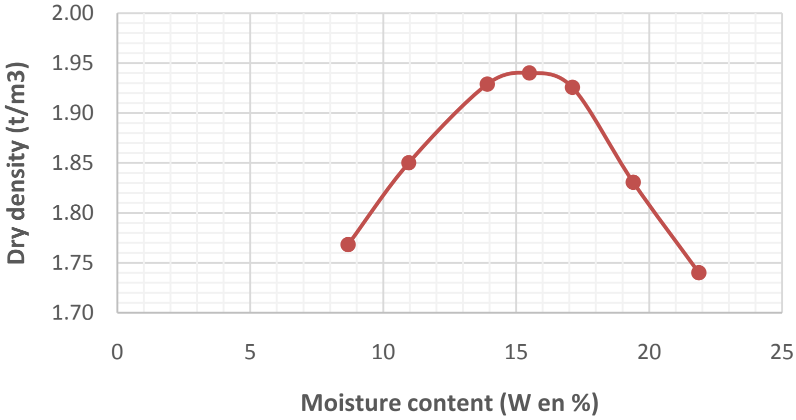

Figure 5: Proctor curve

As seen in Figure 5, the torque (W_{opt} = 15.50%, γ_{opt} = 1.94) represents respectively the optimum moisture content and the maximum dry density.

3.5. The CBR test

The initial soil is an immediate CBR depending on the context of our study, which will be used as a reference for the rest of the study. The punching results of the samples compacted at 10, 25, and 55 strokes, respectively are reported in Table 4.

Table 4: Experimental results of punching at 10, 25 and 55 strokes (initial ground)

Compacting	10 Strokes	25 Strokes	55 Strokes
C 2.5 mm	6.68	16.32	13.67
C 5 mm	12.5	30.12	35.43
CBR = max (C2.5: C5)	12.5	30.12	35.43

The curve of pressure variation as a function of the depression is shown in Figure 6.

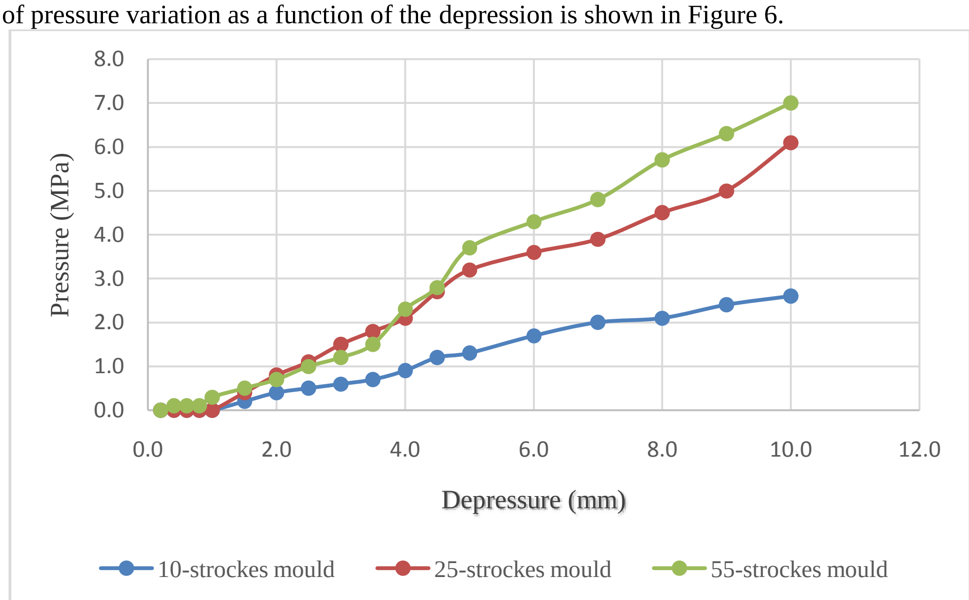

Figure 6: Curve of pressure variation as a function of the depression (initial soil)

In principle, as the number of strokes increases, the soil compaction increases. The figure shows exactly how the curves increase with increasing number of strokes, which satisfies this principle. It could be observed that between 2 mm and 4 mm of depression, the curve of the 25-shot mould is slightly higher than that of the 55-shot mould, which can be explained by possible handling errors. However, it could be seen that beyond 4 mm, the curves respect the principle of pressure growth as a function of the sink rate and the number of strokes.

Figures 7 and 8 show respectively the curves of the number of strokes as a function of the CBR index and the dry density as a function of the CBR index:

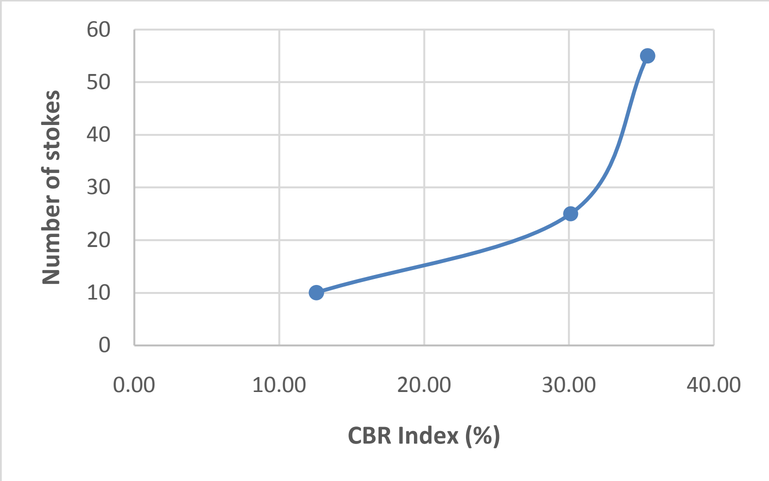

Figure 7 : Number of strokes as a function of the CBR index (initial soil)

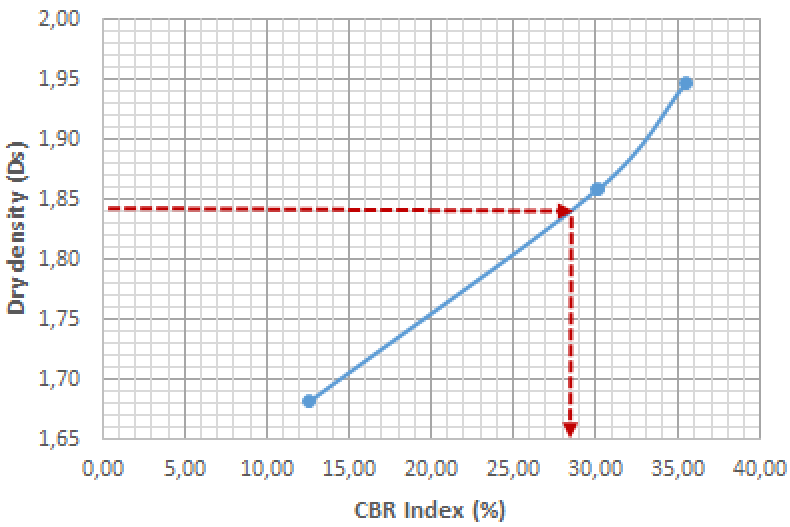

Figure 8. Dry density as a function of the CBR index (initial soil)

The final CBR is obtained by projecting on the x-axis of the above curve, the y-axis corresponding to 95% of the maximum dry density obtained in the modified Proctor test. Regarding in the Figure 8, CBRi equal to 28.50% with maximum dry density D_{Smax} = 1.94 that corresponding to 1.84 at 95% of compacting optimum.

IV. Discussion

4.1. CBR and Drying Time

The CBR index at drying times respectively of 0h, 1h, 2h, 3h and 4h has been performed by using the same approach described in section 3. The results of 10, 25 and 55 shot CBRs as well as the final CBRs are mentionned in Table 5.

Table 5: Summary of CBR results at drying times 0h, 1h, 2h, 3h and 4h

	10-strokes mould	25-strokes mould	55-strokes mould	Final
Time (h)	CBR (%)	CBR (%)	CBR (%)	CBR **(%)**
0	2,23	17,36	32,39	17,00
1	3,86	20,52	25,21	19,00
2	5,29	21,34	35,94	22,50
3	8,57	25,90	48,52	27,00
4	11,29	26,83	55,43	27,50

After 4 hours of drying, a CBR of 27.50% is obtained, slightly higher than the CBR after 3 hours of drying time. This value is already higher than 95% of the initial soil value (27.50 >CBRi = 0.95*28.5 = 27.075), so we have exceeded the state corresponding to the value to be reached. The soil is already in a good condition where it can receive traffic again, so we will determine by optimizing this time from the curve of the CBR as a function of the drying time.

4.2 Summary of the variation of the moisture content as a function of time

The evolution of the moisture content as a function of the drying time is reported in Table 6.

Table 6: Evolution of moisture content with drying time

10-strockes mould		25-strockes mould		55-strockes mould	
Time (h)	Water content (%)	Time (h)	Water content (%)	Time (h)	Water content(%)
0	21,56	0	18,81	0	18,22
1	19,41	1	17,89	1	17,16
2	17,76	2	16,95	2	17,07
3	15,96	3	15,68	3	15,2
4	14,96	4	14,59	4	14,6
initial	15,57	initial	15,49	initial	15,48

The evolution of water contents with the drying time is shown in Figure 9.

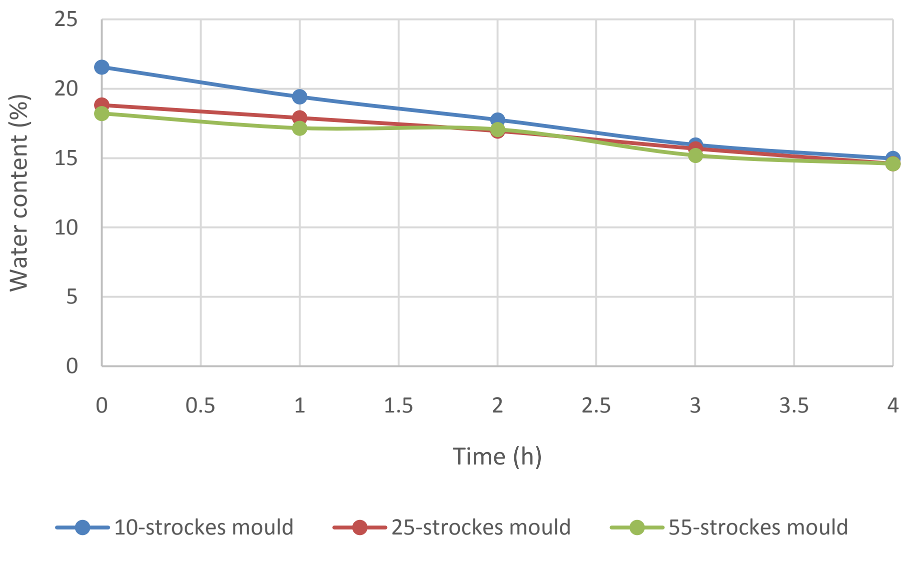

Figure 9: Evolution of water contents with the drying time

Moisture levels decrease over time, and are close to the moisture content of the original soil. The curve of the evolution of the CBR as a function of the drying time is reported in Figure 10.

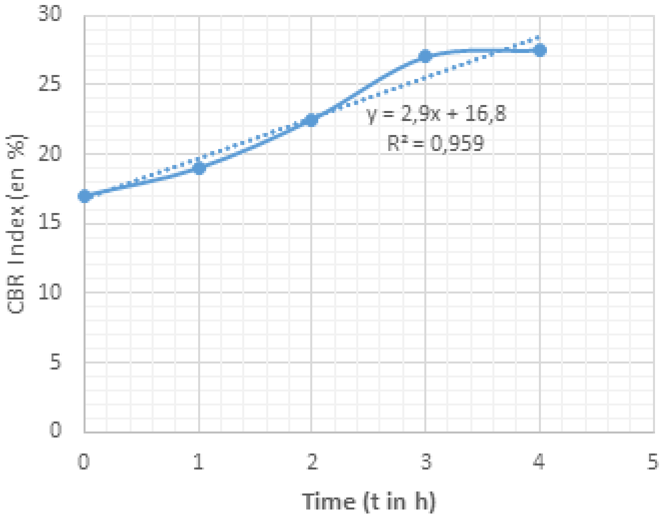

Figure 10: Evolution of the CBR as a function of the drying time

The regression line has a strong correlation with a coefficient R = 0.97 close to 1. Hence, there is a very good linear correlation between CBR and drying time.

Having the equation of the line in this graph, we will look for the time that corresponds to 95% of the initial CBR in order to the optimizing and getting users passed.

Let y_{exp} = 95% (initial soil) = 0.95*28.5 = 27.075%;

and

$x_{exp} = t_{exp}$; the time corresponding to this value of the CBR ;

Let the point A_{exp} (t_{exp} ;y_{exp}) belonging to the regression line of the figure above, we have :

$y_{exp} = 2.9x_{exp} + 16.8$ (6)

and

$x_{exp} = t_{exp}$ = 3.54 hours

The aim is being to optimize, and given the fact that the value of the CBR at 3h of drying is equal to 27% which is roughly equal to y_{exp} = 27.075%. Therefore, we can easily adopt: $x_{exp\ opt} = t_{exp\ opt} = 3$ hours

Finally, it is suitable to open the rain gate 3 hours after the rain regarding to the obtained results. This time is suitable because the water content values at that time are approximately equal to the initial water content (see table 6). But, below of 3 hours after the rain, the CBR is certainly close to 95% of the initial CBR but the water content is higher than the initial water content. So, the soil is not in a sufficiently satisfactory condition to receive the traffic again.

V. Conclusionand perspectives

This paper aimed to optimize the closure time of the rain barriers in Cameroon by using the process of CBR test. A methodology has been performed according to the scientific approach. An initial soil has been identified, characterized in accordance to the French regulation and the CBR test has been performed. After immersion for 2 hours (rain simulation), the soil material was exposed to the sun under unfavorable conditions. The CBR index of the soil was performed at each drying time (0h, 1h, 2h, 3h and 4h). With the obtained values, a linear correlation between the CBR and the drying time was established and the time that corresponds at best to 95% of the initial soil CBR was deduced. The time that correspond to the opening of the rain barrier is determined.

The following conclusions were made:

- The CBR index of initial soil equal to 28.5%;
- The CBRs obtained at the drying times 0h, 1h, 2h, 3h and 4h after simulation of 2 hours rainfall were 17%, 19%, 22.5%, 27% and 27.5% respectively;
- The linear correlation between the CBR and the different drying times, and found that the time that best corresponds to 95% of the initial CBR is 3 hours for the material used. So, 3 hours remains the suitable time to the opening the rain barrier.

However, the methodology used only allows for special circumstances (dry season) and to a well-defined material.

Further analysis should be investigated in order to ensure an objective continuity of this research: i) the study in the rainy season by varying the duration of the rain (more than 3 hours) as well as its intensity, taking into account the phenomena of infiltration and water run-off in the soil. The swelling of the material will therefore be studied; ii) the linear correlation between the swelling of the material and the drying time; iii) Carry out in-situ bearing capacity tests to concretize the methodology, as it is limited to the Laboratory.

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