Journal of Civil, Construction and Environmental Engineering
2024, Vol. 9, No. 3, pp. 84-97
https://doi.org/10.11648/j.jccee.20240903.14

Research Article

Optimising Pavement Performance in Douala City Using a Mixture of Clay and Sand Fractions

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Abstract

Pavements are complex structures composed of multiple layers, designed to withstand various types of stress, including mechanical, organic, and climatic. The pavement is constantly subjected to cyclic, dynamic-mechanical actions caused by road traffic and different axle loads. Classified as engineering structures, the standard theoretical durability of this type of construction is generally estimated to be around one hundred years. However, this objective may not be achieved if the designer does not take into account certain specific factors that are endogenous and exogenous to the structure. Therefore, the durability of a road can be achieved through an optimized design that meets the needs defined by the public authorities and the context of its socio-economic framework. This passage discusses the factors that affect the performance of pavements, including soil type, machinery used, users, and climatic conditions. Exceeding axle loads, which form the basis of pavement design calculations, is also a disruptive factor from a civic perspective. A pavement consists of multiple layers, each made up of materials that must meet strict quality criteria and respect the anthropological, economic, social, and natural environment. It is important to consider all of these factors when constructing a pavement to ensure its longevity and avoid any negative impacts on the surrounding area. Additionally, it is crucial to maintain the pavement to prevent any loss of economic or infrastructural development opportunities. Several road infrastructures in urban and inter-urban areas experience issues that result from a combination of causes, each with varying degrees of impact. Douala is one such city where civil engineering projects are subject to an environment that is not conducive to the longevity of infrastructure, especially road infrastructure. The city is situated on a surface layer covered by a predominantly sandy-clay soil. This study aims to propose a proportional mixture of clay and sand soil fractions to create an anvil effect during compaction. The objective is to create a hybrid backfill material that can achieve a high compaction rate. Good compaction is crucial for achieving optimal pavement layer performance. The thickness of the material to be laid is greatly affected by this characteristic, which in turn affects the volume of equipment depreciation and user comfort. This has a significant impact on a wide range of socio-economic benefits. Based on soil mechanics and geotechnical tests, a new material is proposed to combat the early onset of disorders such as potholes, ruts, erosion, or pavement collapse in bad weather or heavy traffic.

Keywords

Pavements, Applied Loads, Bearing Capacity, Hybrid Backfill Material, Geotechnics

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Received: 12 May 2024; **Accepted:** 27 May 2024; **Published:** 21 June 2024

1. Introduction

Douala, the economic capital of Cameroon, has a road network of approximately 1,500 kilometers, including access roads [3]. The city's industry is closely linked to the transportation of people and goods by heavy and light vehicles, particularly due to its port location. The Douala-Bangui corridor sees around 1.2 million trucks crossing it annually [4], and the number of registered heavy goods vehicles in the city is constantly increasing. Between 2010 and 2023, the growth rate increased steadily from 44% [4, 10]. The road infrastructure sector, which is the key driver of economic development, consists of a vast network split up under several institutional designations. The sector is affected by increased climatic constraints, high temperatures, and abundant rainfall throughout the year. The design of sustainable pavements poses numerous challenges for the infrastructural development of the city. Therefore, it is essential to explore new technologies that can better respond to environmental changes [7, 9]. This article examines a technology in the field of soil mechanics and geotechnics. The article argues for the mixing of clay and sand fractions to improve the mechanical, hydraulic, and environmental properties of backfill soils. This will also contribute to the development and sustainability of road infrastructure in the country's economic capital. The current network is defective and not conducive to optimal development. It is well known that 'where the road goes, development follows.'

2. Materials and Methodology

2.1. Method for the General Formulation of the Optimization Problem

The selection of references, including realistic objectives, relevant constraints, correct mathematical models, adequate load and safety parameters, has a fundamental effect on the results of optimization. However, discussing this topic requires an in-depth study. The search for the conditions under which a given function reaches an optimum, which is most often presented as an extremum, is crucial. To achieve the optimum, a certain merit function, such as an objective or economic function, must be maximized. This process can address a range of concerns, including physical, mechanical, technical, and economic factors. It is important to maintain a clear and concise writing style, avoiding complex terminology and ornamental language [8]. The optimisation of reinforced concrete elements aims to determine the optimal properties and corresponding minimum cost of materials used in construction. Additionally, the use of passive tone and impersonal construction is recommended, and first-person perspectives should be avoided unless necessary. The text should adhere to style guides and maintain consistent formatting, including citation and footnote styles. Finally, it is crucial to ensure grammatical correctness and avoid introducing new content beyond the scope of the original text. The purpose of optimisation in construction is to identify the best solution to a problem. The development of optimisation methods has refined our understanding of the project, identified applications, and restructured many sub-processes involved in project design.

2.2. Characterisation and Sizing of Pavement Layer Materials is the Problem Formulation

Research on clays and sands has been limited to a few isolated articles, which do not always provide fixed elements of appreciation for soils composed of clay and sand. To adopt a geotechnical analysis that is as close as possible to local variations, it is important to establish the difference between sandy clay and clayey sand. To adopt a geotechnical analysis that is as close as possible to local variations, it is important to establish the difference between sandy clay and clayey sand. This remains a major question. To adopt a geotechnical analysis that is as close as possible to local variations, it is important to establish the difference between sandy clay and clayey sand. In the case of Douala city, where pavements are deteriorating prematurely, a better understanding of the sandy clays and clayey sands that predominate in the city's soils is necessary to ensure the durability and longevity of the structures to be built there. Therefore, considering the proportion of clay and sand fractions in the soil found throughout the city, we developed an experimental protocol based on the table below for measuring the volume variation of clay and sand samples using weighing.

***Table 1**. Laboratory experimental protocol.*

Series of 10 tests per level	Proportion by volume of clay in test sample	Volume proportion of sand in the test sample	Observation
1	100%	0%	Clay sample only
2	90%	10%	
3	80%	20%	

Series of 10 tests per level	Proportion by volume of clay in test sample	Volume proportion of sand in the test sample	Observation
4	70%	30%	
5	60%	40%	
6	50%	50%	
7	40%	60%	
8	30%	70%	
9	20%	80%	
10	10%	90%	
11	0%	100%	Single sand sample

2.2.1. Parameters for Characterising Soils for Roadway Backfill

The physical, mechanical, and chemical parameters influence the characterisation of pavement layers. For our study, we present proportional ranges defined by a 10% step, as shown in Table 1. The tests carried out relate to two types of characterisation: intrinsic properties such as grading, Atterberg limits, plasticity index, and volume weight; and properties that depend on the soil's natural or operating environment, such as the sand equivalent test, the Proctor test, and the test to determine the CBR index. It is important to note that all evaluations presented are objective and free from bias.

The tests were conducted at LABOGENIE, which is the main body for soil investigations in the sub-region and is affiliated with the Cameroonian state.

2.2.2. Selection of Clay Extraction Quarry in Douala

Several quarries in and around Douala, including BAKOKO, YASSA, NYALLA, MALANGUE, YOUPWE, and NDOGBONG, were investigated. After a preliminary study aimed at identifying the most clay-rich quarry in the town, the MALANGUE quarry was selected. Our approach identified a weight refusal of 87% of grains < 80μ for the MALANGUE quarry.

2.2.3. Selection of Quarry for Sand Collection in Douala

The sand sample was taken without the use of any special procedure, as it was visually identifiable due to the presence of quarries in and around the town. The BONAMOUANG quarry (AKWA-NORD) was selected for its accessibility and the availability of a large reserve of sand capable of supplying major works in the town and beyond. This quarry is characterised by a continuously graded sand material, which justifies its large-scale exploitation [1, 3, 5].

3. Presentation of Soil Characterisation Tests

All tests were conducted following French standard references.

The physical and mechanical tests used to determine the optimal clay and sand mixture for mechanical performance in Douala are presented below. These tests include determining grain density, Atterberg limits, particle size analysis, the Proctor test, and the CBR index.

3.1. Proctor Test

The Proctor compaction characteristics of a material are determined using tests known as the Normal Proctor Test or the Modified Proctor Test. Both tests follow the same principle, with the only difference being the values of the parameters that define the compaction energy applied. The tests involve moistening a material with varying water contents and compacting it using a conventional process and energy for each water content. For each water content value, the material's dry density is determined, and the curve of density variations is plotted against water content. This curve, known as the Proctor curve, generally shows a maximum dry density value for a specific water content value. These two values are referred to as the optimum normal or modified Proctor compaction characteristics, depending on the test performed.

3.2. CBR Test

The test aims to measure the forces required to penetrate a material sample at a constant speed using a cylindrical punch. The values of the two forces causing conventional indentations are compared to those observed on a reference material with the same indentations. The index sought is defined as the greater value of the two ratios calculated in this way, expressed as a percentage. The CBR and IPI indices are not inherent properties of soil. Although these values are partially influenced by the soil's nature, they are primarily dependent on its water content, dry density, and degree of saturation. These are state characteristics that are influenced by usage conditions and the environment. When designing a pavement, the CBR index must be taken into consideration. The designer should choose the soil characteristics based on the project's specific requirements.

The following values are then calculated:

$$\frac{\text{Penetration force at a depth of 2.5 mm (in km)}}{23{,}35} \times 100$$

$$\frac{\text{Penetration force at a depth of 5 mm (in km)}}{19{,}93} \times 100$$

By convention, the preferred index is the larger of the two values.

Curves are constructed from the experimental data, which are a function of the mixture and compaction energy. It is important that these curves do not have an inflection point near the origin. The test results are used to determine the CBR index coordinates for a Modified Proctor Optimum (OPM 95%) at the molding [2, 4], drying, and punching stages, at different compaction energies. The following diagrams illustrate the equipment utilized in the aforementioned test.

Figure 1. *Module BR.*

Figure 2. *Form and Lady Proctor.*

Figure 3. *Pointing device.*

Figure 4. *Baack dip flask.*

Figure 5. *Subm erged material.*

Figure 6. *Weighing the sample.*

4. Essay Results

The table presents a summary of the results from standardised tests.

Table 2. Presents a summary of the test results.

N	Test Designtion	Norm	Package	% ingredients		Value
				Clay	Sand	(γ_s)
				10	90	2.68
				20	80	2.68
01	Grain density	NF 94-054	$\gamma_s = \frac{P}{\frac{P_2+P-P_4}{d}}$	30	70	2.68
				40	60	2.68
				50	50	2.67
2	Atterberg limits		L_l, Lp, Ip			
				10	90	27.79
				20	80	20.79
2.1	Liquidity limit		L_l = Fissure /1-2cm	30	70	12.90
				40	60	20.65
				50	50	0
		NF P94 051		10	90	0
		March 1993		20	80	0
2.2	Plastic limit		L_p = W%/ 10-15 cm	30	70	9.9
				40	60	14.15
				50	50	14.29
				10	90	0
				20	80	0
2.3	Plastic index		$L_p = L_l - L_p$	30	70	3
				40	60	6.5
				50	50	13.5
				Sieves %; $0.08 \le \varphi \le 5$		
		NFX501		10	90	100
			$\%T = 100 - \left[\left(\frac{R_i}{M_S}\right) x\ 100\right]$	20	80	100
3	A. Granulmetric			30	70	100
				40	60	100
				50	50	100
				10	90	W_{op}=7.8%, γ_d =1.65 t/m^3
		NF P94-093	$W_{op} = \frac{W_W}{W_S} x\ 100,\ \gamma_S = \frac{W_s}{V_s}$	20	80	W_{op}=8.03%, γ_d =1.85 t/m^3
4	PROCTOR			30	70	W_{op}=9.3%,

N	Test Designtion	Norm	Package	% ingredients Clay	Sand	Value (γ_s)
						$\gamma_d = 1.861\,t/m^3$
				40	60	W_{op}=9.43%, $\gamma_d = 1.86\ t/m^3$
				50	50	W_{op}=9.408% $\gamma_d = 1.87\ t/m^3$
				10	90	25
				20	80	28
5	CBR rating	NF-P. 94-078	$d_s = \frac{P_s}{v}$ $p_s = \frac{100Ph}{100+\omega}$ γ *for* : (100%, 90%90%)	30	70	31
				40	60	31
				50	50	31

5. Curves Showing the Mechanical Behavior of Mixture Fractions

5.1. Proctor

The document includes five Proctor curves ranging from 10% clay to 50° clay (pages 6 to 7) for 95% of the OPM.

5.2. Boring Indice (cbr)

Five (05) curves from 10% clay to 50° clay.

5.2.1. Classification of Mixtures of Clay and Sand Fractions in the City of Douala

The table presents the results of mechanical characterisation for fine soils (Proctor and CBR) and physical characterisation (granulometric analysis and Atterberg limits) together. The standard HRB table includes criteria for classifying embankments, allowing the sandy clays and clayey sands studied to be included in the parameter values obtained (refer to the classification table).

5.2.2. Analysis of Test Results

The interpretations derived from testing at different compaction energy levels and varying soil types are as follows:

Although sandy-clay and clayey-sand are not yet classified separately in most Highway Research Board (HRB) or RTR classifications, their respective thresholds allow for their inclusion as distinct materials.

The graph on page 12 shows the Proctor water contents curve, which includes levels ranging from 10 to 50% clay. The abscissa represents the mixtures, and the ordinates represent the water contents, as given in the table above.

Additionally, there is a curve for the CBR index values, limited to the coordinates of levels 6, 7, 8, 9, and 10.

6. Mathematical Formulation of the Pavement Optimization Problem

Consider a concrete pavement with a slab formwork height of 'h'. The cost of a unit strip of pavement is denoted by $C_T(h)$.

Hypothesis for basic simulation and optimization

1) The roadbed is stable dimensionally.
2) The road will be surfaced with micro-concrete paving blocks.
3) The maximum load and,
4) Daily flow are yet to be specified.

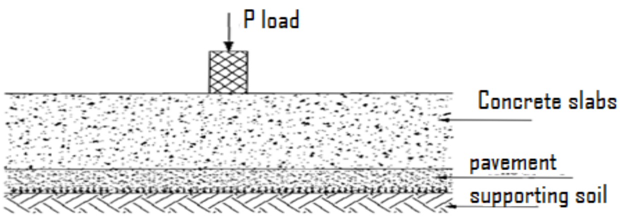

Figure 7. Pavement structures.

Formulation of optimization Problem

The objective of the optimization problem is to find an optimal value for h that minimises $C_T(h)$.

The problem is subject

1) To the non-negativity constraint: $h > 0$.
2) Slab Thickness Selection: $h_{min} \le h \le h_{max}$

3) Failing Criterion Erosion;

$0 \leq$ Damages due to erosion $D_E = \sum_{i=1}^{n} \frac{n_i}{N_{iE}} \leq 100\%$

4) Criterion for fatigue to fail:

$0 \leq$ Damages due to erosion $D_F = \sum_{i=1}^{n} \frac{n_i}{N_{iF}} \leq 100\%$

5) Verification condition of the constraint: $\sigma_{eq} \leq \sigma_{eq\ tab}$

For both types of axles (single axles with twin wheels and tandem axles)

Given the expected traffic repetition n_i and the permissible fatigue rehearsal; N_{iF}:

$$N_{iF}: \begin{cases} S_r > 0,55 \rightarrow \mathrm{Log}(N_{iF}) = \left[\frac{0,9718 - S_r}{0,0828}\right] \\ 0,45 \leq S_r \leq 0,55 \rightarrow N_{iF} = \left[\frac{4,2577}{S_r - 0,4325}\right]^{3,268} \\ S_r \leq 0,45 \rightarrow N_{iF} \quad \text{unspecified} \end{cases}$$

$S_r = \frac{\sigma_{eq}}{S_c}\left[\frac{p_i \times LSF}{4,45 \times F_1}\right]^{0,94}$ Available at

σ_{eq}; the given equivalent voltage

p_i; Load on the axle in KN

F_1; Adjustment factor for load

LSF: Security

Erosion allowable repetition:

$$\mathrm{Log}(F_2 N_{iE}) = 14,524 - 6,777\left[\left[\frac{p_i \times LSF}{4,45 \times F_1}\right]^2 \frac{10^{F_3}}{41,35} - 9\right]^{0,103}$$

F_2: Slab Edge Effect Adjustment Factor

F_3: The erosion factor specified

Equivalent stress check:

$\sigma_{eq} = \frac{6 \times M_e}{h^2} \times f_1 \times f_2 \times f_3 \times f_4 \leq \sigma_{eq\ tab}$

$\sigma_{eq\ tab}$: equivalent voltage

$$M_e = \begin{cases} -1600 + 2525 \times \log(l) + 24,42 \times l + 0,204 \times l^2 & \text{For a single axle with twin wheels} \\ 3029 - 2966,8 \times \log(l) + 133,42 \times l - 0,064 \times l^2 & \text{For use with tandem axle} \end{cases}$$

$$f_1 = \begin{cases} \left(\frac{24}{SAL}\right)^2 \times \frac{SAL}{18} & \text{For a single axle with twin wheels} \\ \left(\frac{48}{TAL}\right)^{0,06} \times \frac{TAL}{36} & \text{For use with tandem axle} \end{cases}$$

$f_1 = 1,017$ for both axle types

$$f_2 = 0,894 + \frac{h}{85,71} + \frac{h^2}{3000}$$

$$f_3 = 0,894$$

$$f_4 = \frac{1}{[1,235 \times (1-\mu)]} = 0,9531$$

$$L = 4,73 h^{0,75}$$

Calculation of the optimal cost of a strip of road and the profit made.

The optimal cost function is defined as follows

$$C_{T\ opt} = C_{b\ opt} + C_{c\ opt}$$

$$C_{T\ opt} = (b + 0,1(2+b)) \times C_{b\ u} \times h_{opt}$$

$$C_{T\ opt} = 1,634$$

The gain is:

$$G = \frac{C_T - C_{T\ opt}}{C_T} \times 100 = \frac{h - h_{opt}}{h} \times 100 = 18,096\%$$

The problem of optimization is expressed as a non-linear programming issue, and the optimization process is based on selecting an appropriate algorithm to solve a system created for the cost optimization process. The total cost of construction materials includes the cost of the pavement's concrete and the formwork used. The cost, representing the objective function, is subject to the behavioural constraints of the erosion failure and fatigue failure criteria, as well as the minimum slab thickness constraint. Upon solving the optimisation problem, we achieved a gain of 18.096%, which is a significant result and represents an economical solution that adheres to the mechanical constraints and standard rules of good execution in accordance with the business continuity plan (BCP).

Table 3. *Effort penetration curve coordinates (means).*

% by volume	**100% clay 0% sand**	**90% clay 10%sand**	**80% clay 20% san**	**70% clay 30% san**	**60% clay 40% san**	**50% clay 50% san**	**40%clay 60% san**	**30% clay 70% san**	**20% clay 80% san**	**10% clay 90% san**	**0% clay 100% san**
Level	1	2	3	4	5	6	7	8	9	10	11
CBR value	12	12	14	16	19	25	28	31	31	31	31

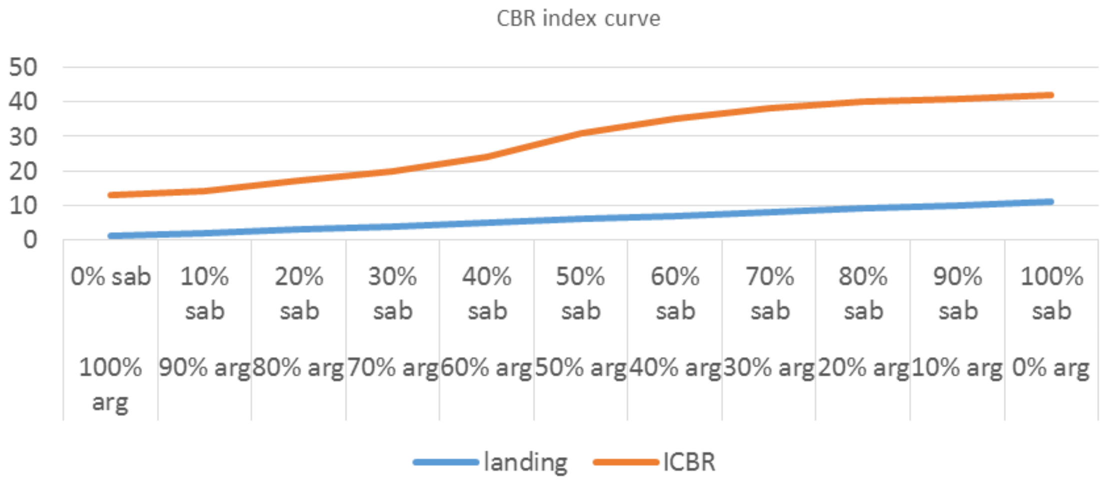

Figure 8. CBR index curve for the Proctor optimum.

Level N 3

Summary tables of CBR data (moulding-piercing)

Table 4. Varying clay and sand content.

TYPE OF MATERIAL	Clay; 80% Sand: 20%

Table 5. Optimum dry densities for different densities: Grade 3.

PROCTOR'S DATA	Level of compaction	OPTIMAL DRY WEIGHT	
		After the dive	After the dive
Dry densities optimised	100%	1,95	1,97
1,99T/m^3	95%	1,89%	1,90%
Maximum moisture 10,50%	90%	1,77	1,79

Moulding Stage

Table 6. Water content before and after soaking at different densities: Stage 3.

COMPACTION MODE		10	25	55
Moisture content	Pre-immersion	9,50	9,50	9,50
	After the dive	17,05	17,30	16,00

drying heaks

Table 7. Coordinated Effort-Penetration Curve (Means) Level 3.

E C	0,2	0,4	0,6	0,8	1,0	1,5	2	2,5	3	3,5	4	5	6	7	8
55 blows	2	5	7	8	12	18	24	29	34	39	44	50	56	65	65
25 blows	4	7	10	12	15	20	26	33	39	47	54	62	72	88	88
10 blows	2	3	4	5	6	7	8	10	12	13	15	16	18	19	22

Punching Phase: The material is punched (E) and then compacted (C).

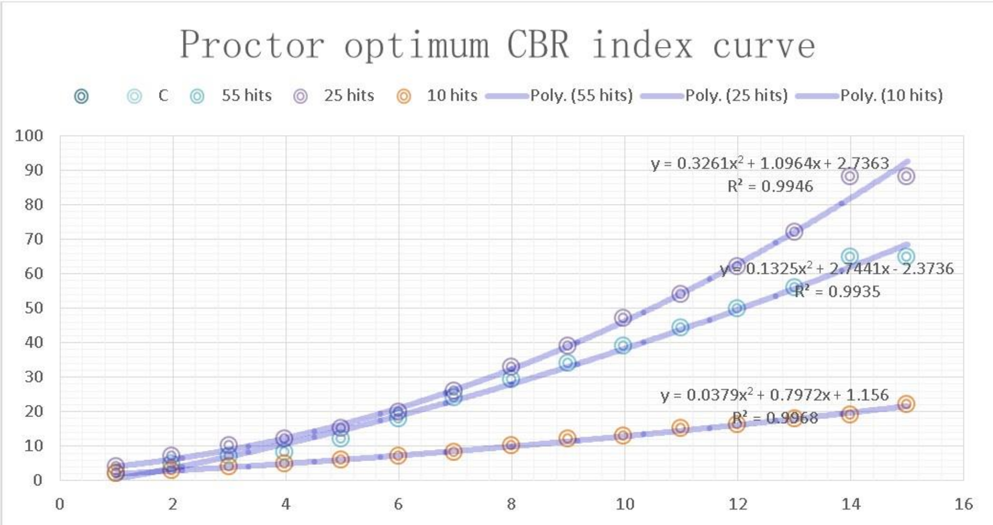

Figure 9. Shows the CBR curve as a function of compaction energy.

Data for moulding and punching are presented in Level No4.

Table 8. Varying clay and sand content.

TYPE OF MATERIAL	Clay; 70% Sand; 30%

Table 9. Shows the optimum dry density values at different degrees of compaction for evel 4 during the drying phase.

PROCTOR'S DATA	Compacting degree	OPTIMAL DRY WEIGHT	
		Pre-diving	After the dive
Dry densities optimised	100%	1,96	1,97
1,96T/m^3	95%	1,90%	1,91%
Maximum moisture 10,50%	90%	1,76	1,78

Table 10. Water content before and after soaking at different compaction levels: Level 4.

HOW TO COMPACT		10	25	55
Moisture	Pre-diving	9,43	9,43	9,43
	After the dive	17,0	16,90	15,98

Table 11. Effort penetration curve coordinate (averages); Level 4.

E C	0,2	0,4	0,6	0,8	1,0	1,5	2	2,5	3	3,5	4	5	6	7	8
55 blows	2	5	7	10	13	20	32	44	52	62	72	82	96	114	135
25 blows	2	5	7	10	13	19	35	42	50	60	69	80	92	111	123
10 blows	1	3	4	5	7	11	13	15	17	19	21	23,50	26	31	32

Punching Phase: The material is punched (E) and then compacted (C).

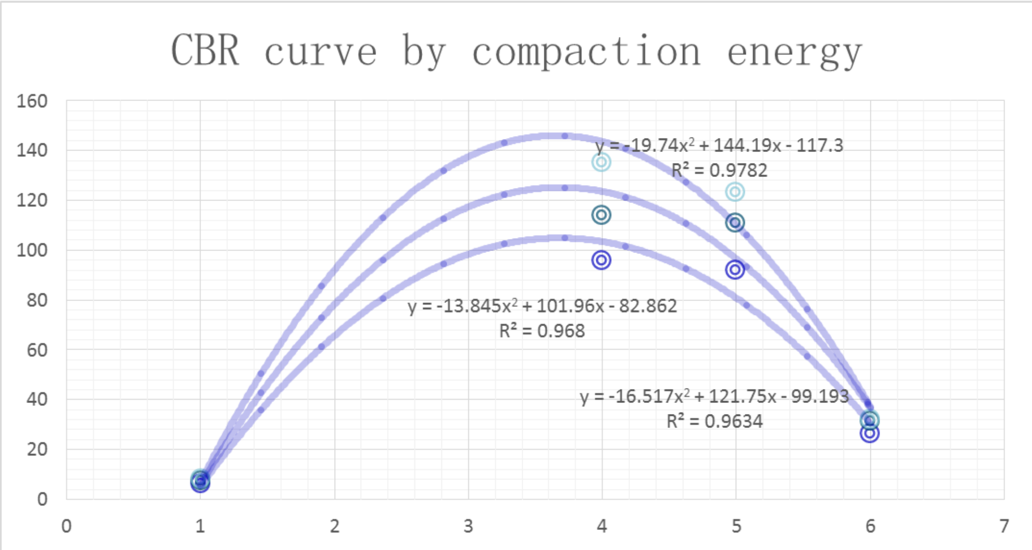

Figure 10. Shows the CBR curve as a function of compaction energy.

Data for moulding and punching are presented in Level No5.

Table 12. Varying clay and sand content.

NATURE OF THE MATERIAL	Loam; 60% Sands; 40%

Table 13. Shows the optimum dry density values at different degrees of compaction during stage 5 of the drying phase.

PROTECTORS	Compactness	Optimum dry density	
		Prior to immersion	After immersion
Optimum dry densities.	100%	1,93	1,95
1,94T/m^3	95%	1,86%	1,88%
Maximum water content. 10,44%	90%	1,74	1,75

Table 14. Shows the water content before and after immersion at different levels of compaction.

COMPACTION METHOD		10	25	55
Moisture	Pre-diving	9,3	9,3	9,3
	After the dive	16,97	16,97	15,76

Table 15. Shows the mean values for the coordinates of the effort-penetration curve at Level 5.

E C	0,2	0,4	0,6	0,8	1,0	1,5	2	2,5	3	3,5	4	5	6	7	8
55 hit	6	12	25	35	45	70	90	113	136	160	175	186	192	200	
25 hit	10	20	31	43	51	71	92	108	122	140	152	160	170	190	
10 hit	2	6	8	11	13	16	19	22	24	26	28	31	33	34	

Punching Phase: The material is punched (E) and then compacted (C).

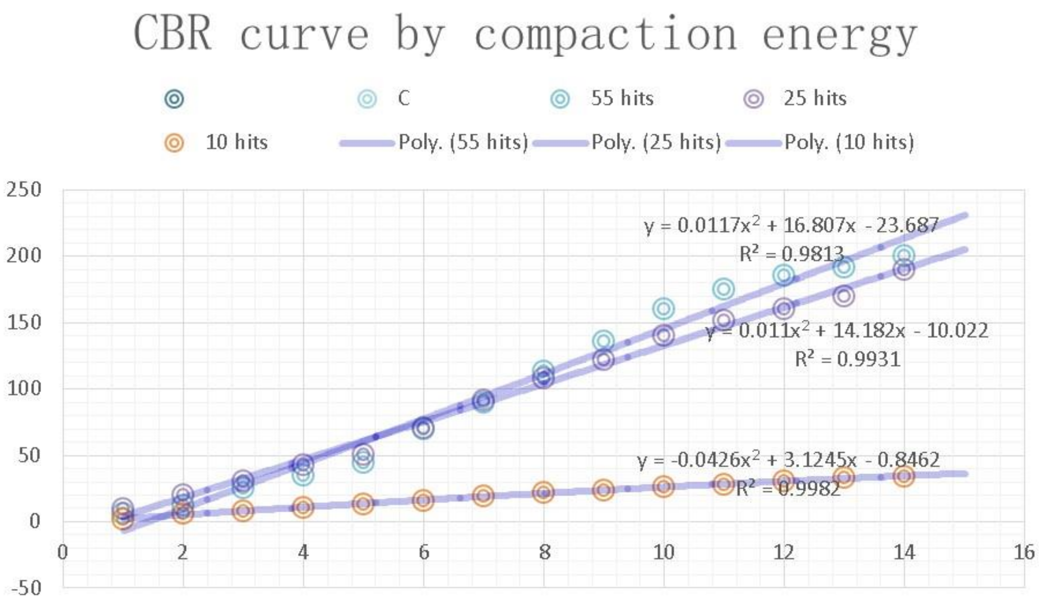

Figure 11. Shows the CBR.

curve for Bearing No. 6 as a function of compaction energy.

The summary tables present the CBR data for moulding and punching.

Table 16. *Varying clay and sand content.*

MATERIAL PROPERTIES	Loam; 50% Sand; 50%

Table 17. *Shows the optimum dry density values at different degrees of compaction during stage 6 of the drying phase.*

PROTECTORS	**Compacting degree**	**OPTIMAL DRY WEIGHT**	
		Pre-diving	**After the dive**
Optimum densities in the dry state	100%	2,01	2,02
2,02T/m^3	95%	1,90%	1,92%
Maximum moisture 9,45%	90%	1,76	1,77

Table 18. *Shows the water content before and after immersion with different degrees of compaction for bearing 6.*

HOW TO COMPACT		**10**	**25**	**55**
Moisture	Pre-diving	9,1	9,1	9,1
	After the dive	16,96	16,7	15,7

Table 19. *Shows the mean values for the coordinates of the effort-penetration curve at Level 6.*

E C	**0,2**	**0,4**	**0,6**	**0,8**	**1,0**	**1,5**	**2**	**2,5**	**3**	**3,5**	**4**	**5**	**6**	**7**	**8**
55 hit	1,5	2,3	3,5	5,5	7	11	17	22,5	28	36	42	49	54	67	72
25 hit	1,1	2	4,5	6	8	13	16,5	24	28	31	34,5	38	40,5	45	47,5
10 hit	1	1,5	3	4,5	6	8	10	12,5	14,5	16	17	19	21	23	24

Punching Phase: The material is punched (E) and then compacted (C).

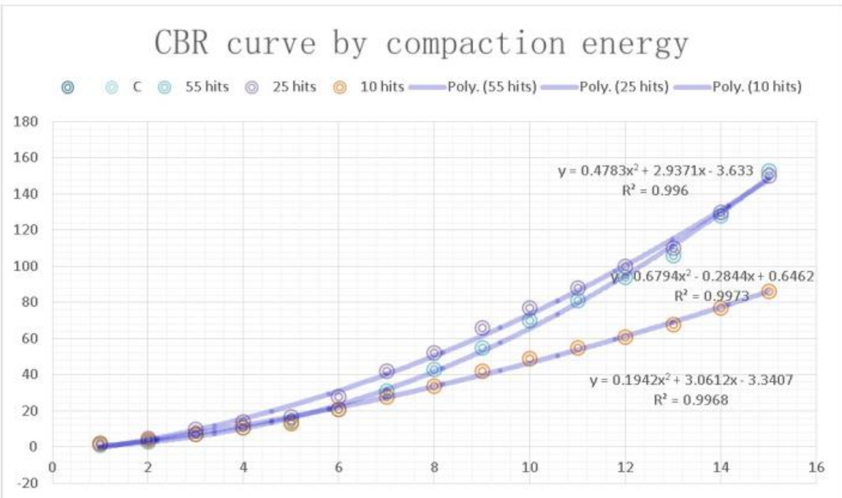

Figure 12. *Shows the CBR curve as a function of compaction energy.*

Data for moulding and punching are presented in Level No7.

Table 20. Varying clay and sand content.

MATERIAL PROPERTIES	Loam: 40% Sand: 60%

Table 21. Optimum dry density values at different degrees of compaction: Storage 7.

PROTECTORS	Compaction degree	OPTIMAL DRY WEIGHT	
		Pre-diving	After the dive
Dry densities optimised	100%	1,86	1,87
1,86T/m^3	95%	1,8%	1,81%
Maximum moisture 9,43%	90%	1,68	1,69

Table 22. Shows the water content before and after immersion with different degrees of compaction for bearing 7.

HOW TO COMPACT		10	25	55
Moisture	Pre-diving	9,01	9,09	9,01
	After the dive	16,80	16,30	15,50

Table 23. Shows the mean values for the coordinates of the effort-penetration curve at Level 7.

EC	0,2	0,4	0,6	0,8	1,0	1,5	2	2,5	3	3,5	4	5	6	7	8
55 hit	1	3	7	11	14	21	31	43	55	70	81	94	106	128	153
25 hit	2	5	10	14	17	28	42	52	66	77	88	100	110	130	150
10 hit	2	4	7	11	13	21	28	34	42	49	55	61	68	77	86

Punching Phase: The material is punched (E) and then compacted (C).

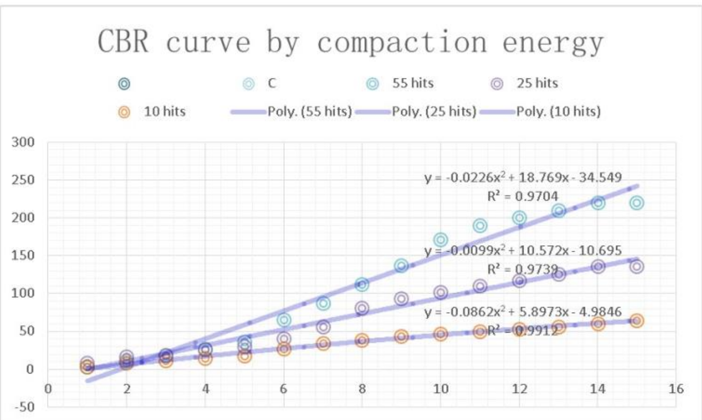

Figure 13. Shows the CBR curve as a function of compaction energy.

7. Conclusions

The tests conducted allowed for the physico-mechanical classification of the soils studied. These soils were selected for their predominance in the coastal zone of Cameroon, specifically in the economic city of Douala. While sandy-clays and clayey-sands are not yet classified separately in most Highway Ressac Board (HRB) or 'Guide de Terrassement Routier' (GTR) classifications [1, 3, 6], their thresholds enable their inclusion as sandy-clay and clayey-sand materials. The test results and simulations indicate that a mixture of 30% clay and 70% sand can produce a clayey sand with mechanical properties that allow for a dry density of 29 t/m^3 at a water content of 31%. The simulated loading hypothesis suggests that high axle loads do not compromise the durability of the city's roads and road network. The cost of the project is determined by the objective function, which is subject to the behavioural constraints of the erosion failure and fatigue failure criteria, as well as the minimum slab thickness constraint. After solving the optimisation problem, a gain of 18.096% was achieved. This result is economically viable and adheres to mechanical constraints and current rules of good execution in accordance with the business continuity plan (BCP). The problem presented in this article has been solved, and users such as the State, companies, and public road users can apply this optimal mix solution to the design of pavements in the city of Douala.

Abbreviations

HRB	Highway Ressac Board
CBR	California Bearing Ratio
BCP	Business Continuity Plan
IPI	Industrial Production Index

Conflicts of Interest

The authors declare no conflicts of interest.

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