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Influence of E-CBR Relationship in Linear Finite Element Modeling of CBR Test: Application on Unbound Granular Materials from Senegal

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Abstract

CBR is an essential parameter in the design of flexible pavements in tropical countries. It is used to determine the bearing capacity of materials and to predict the stiffness moduli of untreated granular materials. However, determining it in the laboratory requires a great deal of effort and time. This naturally leads us to a numerical simulation of this test. This article presents the finite element simulation of the CBR test using cast3m, studying the influence of the E-CBR relationship. The results show that the correlation relations overestimate or overestimate the force-displacement curves. This shows that these relationships are not valid for all materials and must be used very carefully in our roads to avoid premature deterioration.

Keywords

CBR, Tropical Countries, Over-Predites, Finite Elements, cast3m

1. Introduction

One of the major problems observed on some Senegalese roads is their premature state of failure. This situation is due to a problem with the adaptation of certain standards and the use of inappropriate sizing methods [1]. Uncertainty over the choice of modules is the main cause of this deterioration [2]. Furthermore, the moduli used to calculate stresses and strains are estimated on the basis of correlation relationships established by CEBTP [3] and LCPC [4]. These relationships are only valid under very specific conditions and for very specific materials. However, the use of these relationships tends, as a function of the CBR, to over-predict the modulus [5]. The use of high moduli leads to the use of low thicknesses and therefore to undersizing [1]. Solving the choice of modulus, therefore, comes down to solving the problem of the relationship between E and CBR. The latter is determined in the laboratory over a period of 96 hours and requires a great deal of tedious work. An alternative is to simulate the test numerically. The work undertaken in this article is to simulate the CBR test using the E-CBR relationships in order to study the influence of these relationships on the force-displacement curves of the CBR test and to propose some ideas on the use of these correlations on our roads.

2. Background

Materials characterisation plays an important role in pavement design [4]. However, the performance of a road depends largely on the stiffness of the materials [6]. The values of moduli of elasticity taken into account for the verification of stresses and strains vary according to the authors and depend on the CBR index [3]. Heukelom and Klomp [7] studied the relationship between E and CBR and proposed the following Equation (1):

$$E(MPa) = 10 \times CBR \tag{1}$$

This correlation is valid only for fine soils with a CBR after immersion of less than 100% [8]. Another study was developed by Naasra [9] considering a prediction interval according to the value of the CBR index. He established the following relationships 2 and 3:

- For a CBR lower than 5:

$$E(MPa) = 16.2 \times CBR^{0.7} \tag{2}$$

- For a CBR below 5:

$$E(MPa) = 22.4 \times CBR^{0.5} \tag{3}$$

Powell *et al.* [10] propose Equation (4):

$$E(MPa) = 17.6 \times CBR^{0.64} \tag{4}$$

In tropical countries, CEBTP [3] specifies that the dynamic moduli measured *in situ* with a vibrator or by means of wave propagation or in the laboratory, on intact samples, can be estimated, as a first approximation, from the following empirical relationship 5:

$$E_{dyn}(bars) = 100 \times CBR \tag{5}$$

It also establishes the following relationships 6 and 7 for static moduli measured by in-situ plate tests or by crushing tests in the laboratory.

- For coarse-grained materials

$$E_{stat}(bars) = 50 \times CBR \tag{6}$$

- For materials with a high fine fraction

$$E_{stat}\left(bars\right) = 30 \times CBR \tag{7}$$

The Laboratoire Centrale des Ponts et Chaussées (LCPC) [4] recommends relation 8, equivalent to relation 6 of the CEBTP. This relationship is expressed in MPa and becomes:

$$E\left(MPa\right) = 5 \times CBR \tag{8}$$

The CEBTP and LCPC relationships are frequently used in the design of roads in tropical countries. In addition, the importance of the CBR index has inspired some authors to simulate the test numerically. The work of Sukumaran *et al.* [11] shows a three-dimensional simulation of CBR test based on finit element simulation. The mould and piston are made of steel; these characteristics are defined in standards NF P 94-093 and NF P94-078. The characteristics are derived from experimental tests. The simulation is carried out using the ABAQUS software (HKS 2000). The CBR values obtained were used to estimate the modulus of elasticity of the clays. Yohannes *et al.* [12] used the discrete element method to simulate the CBR test. In this simulation, the sample is composed of 3500 spherical granite particles with an equivalent diameter of 10 mm. The results show that the force increases as an exponential function with the depth of indentation and serve to validate the experimental results. Putri *et al.* [13] also used the fine element method to model the CBR test. Cosmosworks software is used to model the CBR mould, the base and the loading piston. The input parameters are density, modulus of elasticity and fish coefficient. The finite element simulation is carried out with a modulus of elasticity varying from 1. 106 Pa to 1. 107 Pa to obtain the load-displacement curves.) The CBR is determined from this curve by considering the penetration forces at 2.5 mm and 5 mm indentation. Kumar *et al.* [4] study the simulation of the CBR test considering a Mohr-Coulomb model while analysing the effect of friction angle and cohesion.

3. Methodology

The aim of the numerical simulation is to correlate the experimental results of the CBR test with the numerical results obtained from the E = k CBR correlations. To this end, the materials used, such as Bargny and Bandia limestones and Diack basalt, were sampled. The experimental study concerns grading, compaction and the CBR test in accordance with current standards. The CBR test was modelled using cast3m on these three materials, the characteristics of which are given in **Table 1**. Several numerical models were tested in order to approximate the real experimental model. Cast3m coding was carried out for the CBR test using a material with linear elastic behaviour to better simulate the E = k × CBR relationship used in our correlations. The modelling is carried out in several stages:

- Choice of geometry and mesh;
- Definition of the mathematical model and boundary conditions;
- Solving the discredited problem;
- Analysis and post-processing of results.

Table 1. Granulometric and compaction characteristics of the materials in the study.

Materials	Particle size characteristics			Compaction characteristics		
	<0.08 mm	<4.75 mm	USCS	W_{opt} (%)	γ_{dmax} (kN/m^3)	CBR
Bargny limestone	2.5	48	GW	8.9	20.6	32
Bandia Limestone	4	38	GP	6.9	20.83	138
Diack Basalt	2.7	34	GW	4.4	22.05	86

The material is placed in the CBR mould and then displacements are imposed. This modelling begins by meshing the piston mould and the material (Figure 1) and defining the boundary conditions, the characteristics of the materials and a loading system. The boundary conditions consist of blocking the mould and the material along the transverse direction x and y so that they do not move in these directions, allowing them to move only along the vertical (z). The mould is also blocked at the bottom to prevent any movement of the mould base along (z). The piston is boxed along z at its lateral face to facilitate movement along the vertical. The mould and piston are made of steel; these characteristics are defined in standards NF P 94-093 and NF P94-078.

- CBR mould height H = 116.5 mm
- cylinder diameter Φ = 101.5 mm
- piston with a diameter of 49.5 mm
- E = 210GPa
- V = 0.3
- density $\gamma = 7800$ kg/m^3

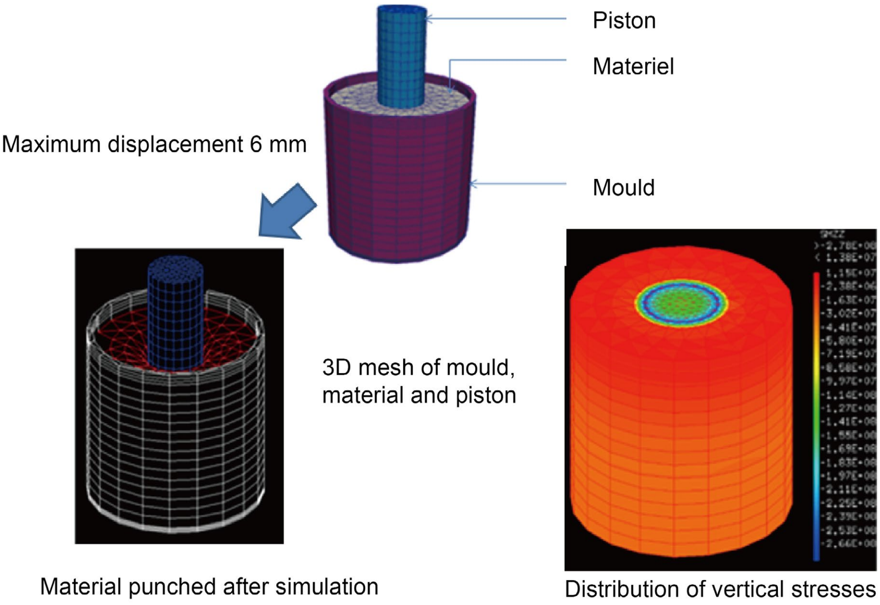

Figure 1. Mesh of the mould, piston and material.

The characteristics of soils are derived from experimental tests. The simulation is carried out using the moduli derived from the E = k CBR correlations. For each modulus value, a simulation is carried out, each time imposing a maximum displacement of 6 mm. An imposed displacement stress of up to 6 mm is applied. Using the PASAPAS operator, we can find the different values of the forces as a function of the indentation and thus conclude on the behaviour associated with the material after simulation.

4. Results and Discussions

Once all the simulations have been run, the force-displacement curves can be collected and compared with the experimental curve. For each material, we look to see for which relations E = k × CBR (k = 100; 50; 10; 7; 5) the experimental curve is overestimated, underestimated or estimated normally (**Figures 2-7**). Generally speaking, the results showed that there is a large gap between the experimental curve and the curves derived from the correlations (E = 100.CBR, E = 50.CBR, E = 10.CBR, E = 5.CBR). However, this difference is very large for the force-depth curves (E = 100.CBR, E = 50.CBR and E = 10.CBR). Only the E = 7.CBR curves (**Figures 5-7**) are predicted to the experimental curve. The E = 100.CBR, E = 50.CBR and E = 10.CBR curves overestimate the experimental curve. The deviation from the experimental curve is even greater for the E = 100.CBR and E = 50.CBR relationships (**Figures 2-4**). For the E = 5.CBR curves, the experimental curve is underestimated. The relationships E = 100.CBR and E = 50.CBR are those established by CEBTP (1984) and the results obtained have shown that these relationships overestimate the experimental curves. Consequently, these relationships should be used with great care as they tend to over-predict the moduli. The use of high moduli in pavement design inevitably leads to the use of low pavement thicknesses, resulting in premature deterioration of roads due to under-design.

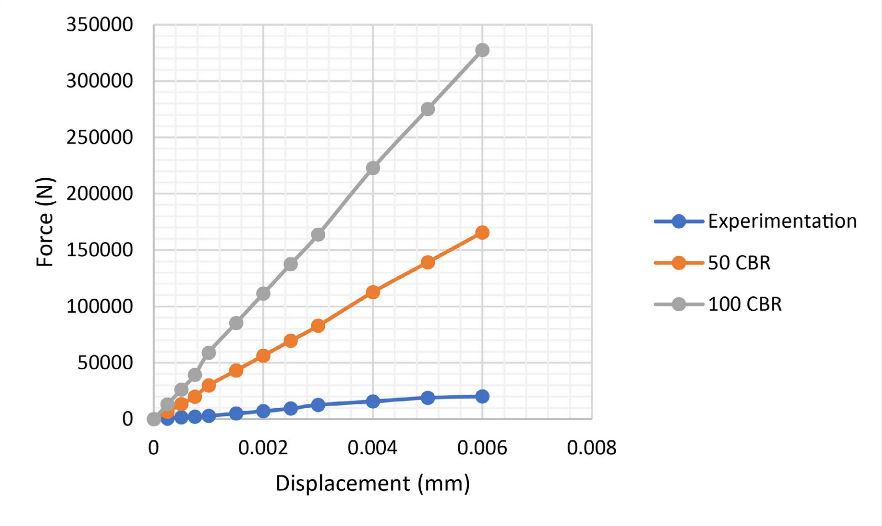

Figure 2. Force-displacement curves for Diack basalt for k = 50 and 100.

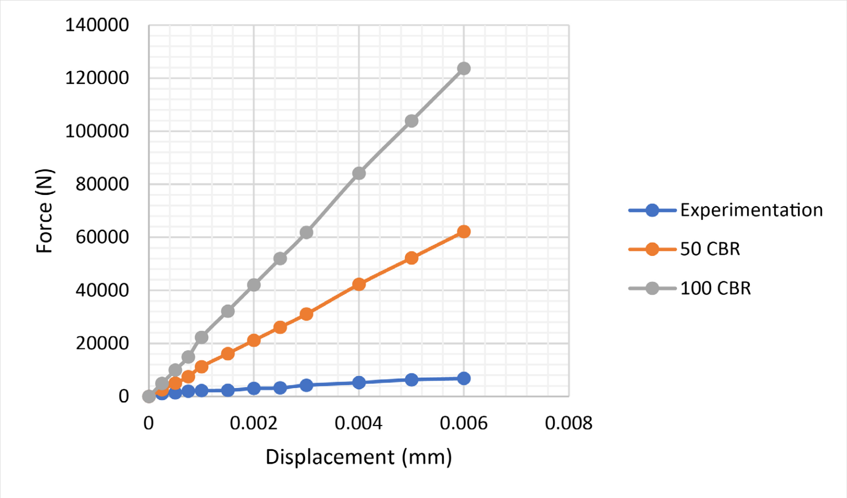

Figure 3. Force-displacement curves for Bargny limestone for k = 50 and 100.

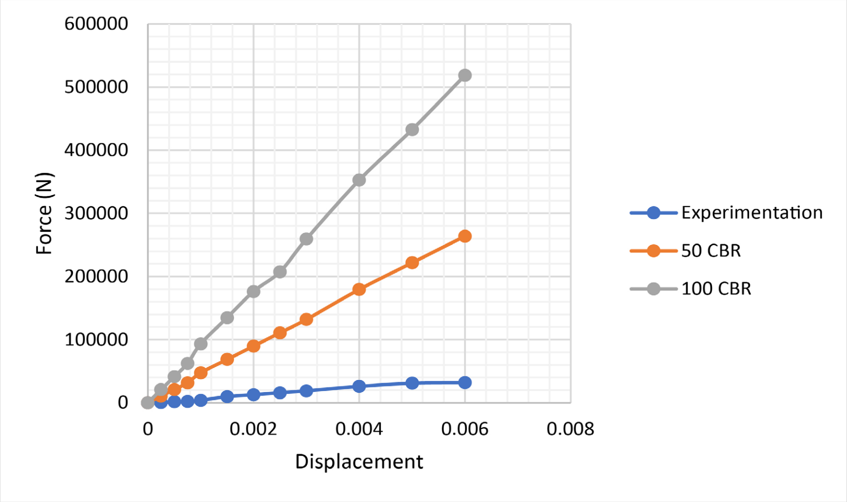

Figure 4. Force-displacement curves for Bandia limestone for k = 50 and 100.

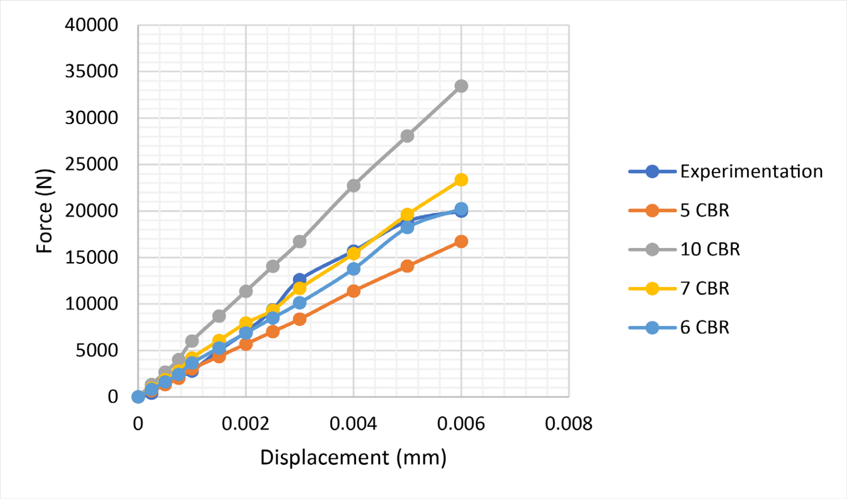

Figure 5. Force-displacement curves for Diack basalt for k = 5; 6; 7; 10.

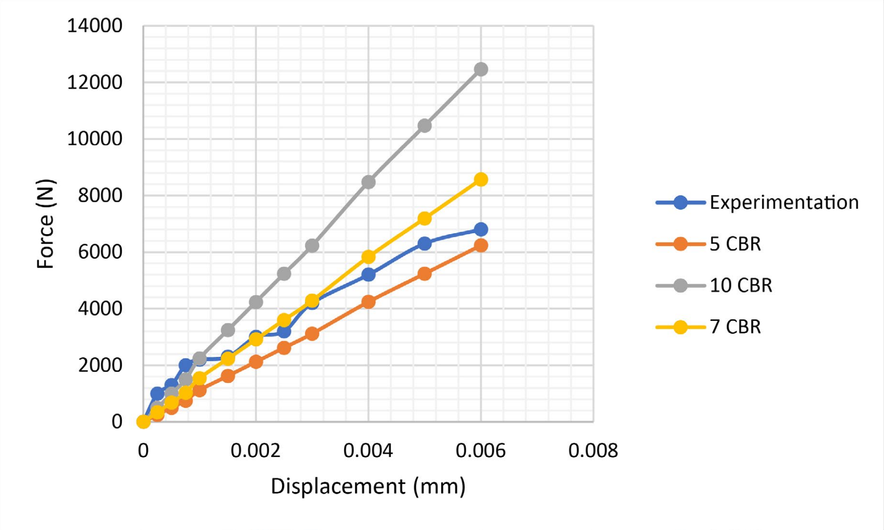

Figure 6. Force-displacement curves for Bargny limestone for k = 5; 6; 7; 10.

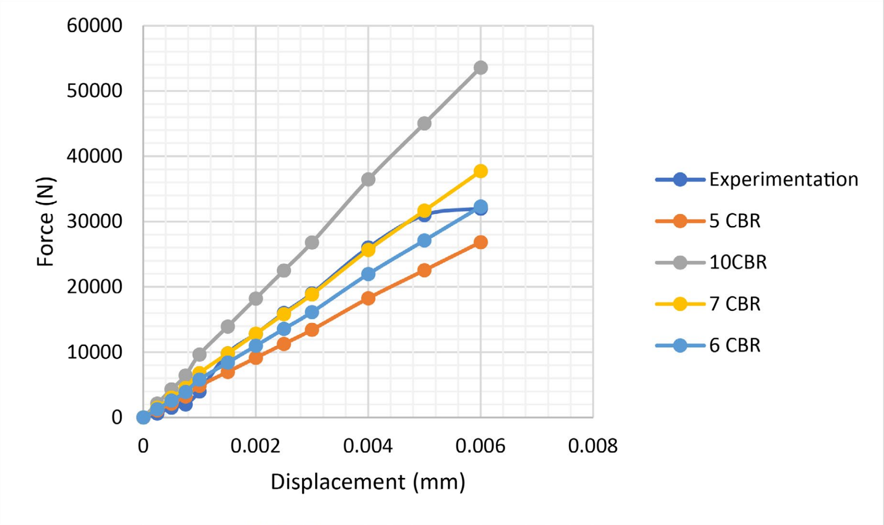

Figure 7. Force-displacement curves for Bandia limestone for k = 5; 6; 7; 10.

5. Conclusion

The simulation shows that the correlation relationships established by CEBTP cannot be used to predict the CBR test numerically. They give an over-prediction of the force-displacement curves. This shows that the E-CBR relationships used in tropical countries are not valid for all materials, and are valid only under specific conditions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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