Open Journal of Civil Engineering, 2023, 13, 326-341
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Numerical Modeling of the Behaviour of a Road Structure on Compressible Soil: Case of the Road Section at the Beau-Rivage-Djassin Intersection

Yémalin Daniel Agossou[1*], Judicael Agbelele[2], Peace Hounkpe[1], Daniel Djossou[1], Wilfried Hode[3], Edmond Adjovi[1]

[1]L2EGC/ENSTP-Abomey, Materials and Structure Team, National University of Sciences Technologies Engineering and Mathematics, Abomey, Benin
[2]ENSET Lokossa, National University of Sciences Technologies Engineering and Mathematics, Lokossa, Benin
[3]HAS Engenering Conseils, Abomey-Calavi, Benin
Email: *yemdag@yahoo.fr.

How to cite this paper: Agossou, Y.D., Agbelele, J., Hounkpe, P., Djossou, D., Hode, W. and Adjovi, E. (2023) Numerical Modeling of the Behaviour of a Road Structure on Compressible Soil: Case of the Road Section at the Beau-Rivage-Djassin Intersection. *Open Journal of Civil Engineering*, **13**, 326-341.
https://doi.org/10.4236/ojce.2023.132025

Received: May 1, 2023
Accepted: June 18, 2023
Published: June 21, 2023

Abstract

This document presents a study of the behaviour of a pavement structure on compressible soil and the evaluation of its durability. The objective of this study is to highlight the impact of taking into account the non-linear elastic behaviour of soils and granular materials in the design process. To this end, a numerical modelling of the pavement of the beau-rivage-Djassin crossroads section in Porto-Novo was carried out, based on a compressible soil whose behaviour will be considered elastoplastic. The subgrade soil on the section is made up of several sub-layers. The layer of soft, highly plastic clay was modelled according to a modified Cam Clay behaviour, a model of swelling clay soils. The fine sand layer and the granular layers of the structure are modelled according to Mohr-Coulomb behaviour. The loading is considered to be uniformly distributed according to the assumptions of the Burmister model in the French standard. A first verification with ALIZE allowed to validate the structure on the basis of the rutting deformation at the head of the platform ε_z = 359.6*10^{-6} which remains lower than the admissible deformation $\varepsilon_{z,adm}$ = 360*10^{-6}. The numerical calculation was carried out using the finite element method, the code of which is implemented under the PLAXIS v21 software. A comparative study with the results of the ALIZE design revealed that the numerically calculated strains ε_z = 585*10^{-6} are higher than those of ALIZE. These numerical strains, which are higher than the elastic strains, do not meet the validation criteria that the strains under loading must remain below the allowable strains. An evaluation of the pavement durability was carried out and it was found that the pavement would only last under traffic for 3 years before the first fatigue deformations appeared.

Keywords

MEF, Elastoplastic Behaviour, Modified Cam Clay, Mohr Coulomb, PLAXIS, ALIZE

1. Introduction

The evolution of inter-state and inter-provincial trade has led to a considerable increase in road infrastructure. In France, there was an 11.2% increase in the number of kilometers of roads built between 1999 and 2019 [1]. In Benin, in order to facilitate exchanges between different parts of the country, the government has launched a series of 45 major road projects since 2016, which are still underway [2]. In addition, the government's 2021 action program (PAG) provides for many other road projects to revolutionize the movement of people and goods in the Republic of Benin [3]. Given the importance of roads, it is therefore important that they are built with care and efficiency to ensure durability and comfort.

The construction of a road structure requires the mastery of the geotechnical characteristics of the soil on which the pavement structure will have to rest in order to avoid premature failure of the structure [4]. Indeed, the soils cannot withstand the pressures induced by vehicle tires without damage. Whether they are slightly or highly compressible, the passage of tires compresses the soil and ruts appear, which become residual loads with repetition. These residual deformations reflect the elastoplastic nature of soils and granular materials [5]. In a pavement structure, the layers are made up of different types of materials with different behaviors, which makes the structural system a complex whole. The contribution of the layers to the total strength of the structure is therefore complicated and difficult to define. As the total function of the structure is defined by the combined response of the layers to traffic loading, it is therefore important that the characteristics and behaviour of each soil material, including the soil, are taken into account with maximum accuracy in the design process [6]. However, the existing mechanistic-empirical pavement design methods work with calculation assumptions that are far away from the actual behaviour of the materials. Yet, for soil as well as for granular materials, it is generally accepted (even before failure) that the behaviour is not linear elastic, contrary to the considerations made by design software such as Alize [7].

In order to highlight and evaluate the impact of taking into account the non-linear behaviour of soils and granular materials in the design of roads and engineering structures, several studies have already focused on modelling their behaviour. Adel Djellali [8] studied the behaviour of flexible pavements on a swelling support. The study was carried out on an Algerian flexible pavement. The results showed that the combination of the Mohr-Coulomb model in the pavement body and the soft soil model for the supporting soil gives a good stress distribution when compared to the cracking evaluated on the pavement and on the shoulder. The choice of soil behaviour model severely affects the stress distributions, and it extends to the resilient deformations. The same author in his thesis [9] carried out the modelling of pavements on expansive soils. Flemond Dolin [10] carried out thermomechanical modelling of flexible pavements with application to the prediction of rutting of the subgrade treated with local plant binders. Schmitt [11] carried out a study to take into account the non-linearity of the behaviour of soils subjected to small deformations for the calculation of geotechnical structures. Ijel [12] analyzed the non-linear behaviour of soils using hyperbolic laws. The influence of non-linearities of soil behaviour on the design of underground structures is analyzed through an example. Rizi [13] in a study of the behaviour of soils and granular materials, a numerical modelling of the triaxial test on an analogue material was carried out. Khemissa [14] studied the behaviour of fine soils under homogeneous stresses. This work deals with the modelling of the behaviour of soft clays and soft clayey rocks under homogeneous loads. Castonguay [15] carried out an evaluation of the NorSand-aUL law, an improved behavioral law for modelling sands under static and cyclic loading.

These studies, although similar to the present one in the sense that they analyze the deformation of elastoplastic soils under loading, have not been able to present the real impact of this deformation on the modelled structures: it is the durability of these structures. Thus, the present study highlights the impact of taking into account the linear inelastic behaviour of the soil and granular materials in the design of the pavement structure of the beau-rivage-Djassin crossroads section resting on a compressible clay soil. This study involves numerical modelling of the structure and the supporting soil. The objective is firstly a comparative study of the numerical deformations with the solicitations calculated under the assumption of elastic deformation, then an evaluation of the durability of the pavement based on the calculated numerical deformations.

2. Materials and Methods

2.1. Study Area

The section of road to be developed crosses a swampy area with very compressible soil between KP 0 + 850 and KP 1 + 275. It will be built next to an existing platform. The following **Figure 1** shows its location.

The geotechnical campaign carried out (core drillings) revealed that the soil in this area is predominantly clay, which made the pressure meter drillings very difficult.

2.2. Materials

The foundation soil on which the structure rests is a multi-layered mass consisting

Figure 1. Google earth location of the study area.

of a sub-layer of soft compressible clay encountered from 6 m to 22 m depth. This is topped by a sub-layer of fine sand from 6 m to 1 m depth as it rises to the surface. A surface layer of 1 m of fill lies on top of the other two layers.

The structure implemented on this soil is flexible and consists of a subgrade of lateritic gravel (GL) topped by a sub-base of cement-enhanced moistened reconstituted gravel (GRH-A). The base course is made of bitumen gravel (GB) and the surface of bituminous concrete (BB).

Reconstituted gravel is obtained by mixing three granular classes of crushed stone. The mixture consists of 48% 0/5 crushed sand, 20% 5/10 crushed sand and 32% 10/20 crushed sand.

The following Figure 2 shows a sample of lateritic gravel.

The complete soil and structure profile considered in the modelling is provided in Table 1. The table provides information on the thickness of the layers and the behavioral modes considered for each layer.

2.3. Laboratory Tests

A set of standard characterization tests were conducted on the lateritic gravel, the soil support and the crushed gravel that was used in the improved material. These tests include sieve analysis, Atterberg limits, direct box shear, oedometer test and compression test.

- **Particle size analysis after washing:** The test to determine the grain distribution of a sample was carried out on a sieve range of 40 mm to 80 µm.
- **Atterberg limits:** This test for liquidity and plasticity limits was carried out on the passing of a 400 µm sieve soil sample.
- **Direct box shear:** This is the test for obtaining the angle of friction and cohesion of granular materials.
- **The oedometric test:** It reproduces the conditions of deformation of the soil in the case of a massif with a horizontal surface loaded by a uniform pressure and where the soil can only move vertically.
- **The OPM test:** The Modified Proctor Optimum is used to find the Proctor compaction characteristics, *i.e.* the optimum moisture content and the maximum dry density of a material. These characteristics are also essential for the CBR test.

Figure 2. Lateritic gravel sample.

Table 1. Soil and structure profile.

	Material	*Mode of behavior*	Thickness (cm)
Surface	BB	Elastic	6
Base	GB	Elastic	10
Foundation	GRH-A	Elastic	20
Form	GL	Mohr Coulomb	20
	Backfill	Mohr Coulomb	100
Soil foundation	Fine sand	Mohr Coulomb	500
	Soft clay	Cam Clay Modified	1600

- **The CBR test:** The Californian Bearing Ratio is a quantity used to characterize a soil or a material developed as a support or constituent of a pavement structure. For this study, the CBR index was carried out after immersion. It is used to characterize the bearing capacity of the material (*i.e.* the load it can support without breaking), but also to measure the suitability of a pavement in the event of heavy rain. The CBR index is a dimensionless number expressing in percentage terms the ratio between the pressures producing a given amount of sinking in the material studied on the one hand and in a reference material on the other. This index is also used to estimate the modulus of granular or improved materials by means of an empirical formula in the pavement design guide for tropical countries of the Centre d'Essais du Bâtiment et Travaux Publics (CEBTP) [16].

- **Compression test:** This test is particularly performed on improved moistened reconstituted gravel specimens and allows to evaluate their compressive strength.

The following **Figure 3** shows the course of a compression test on GRHA.

Table 2 below provides a summary of the characteristics of the supporting soil.

In addition, the test results were used to classify the materials based on the criteria of the GTR [17]. The value of the Ip and the grading of the clayey subsoil

Figure 3. Compression test on GRH-A.

Table 2. Characteristics of the supporting soil.

Features	Values
Passing 80 µm (%)	85
Plasticity Ip	75
Drained cohesion Cu (KN/m^2)	40
Friction angle φu (˚)	0
Compression index C_c	1.2
Recompression index C_s	0.24
Cam Clay's compression index λ	0.140
Cam Clay swelling index k	0.028
Expansion angle ψ (˚)	0

allows it to be considered as a class A4 material, which is the class of very plastic clays and marly clays. These parameters also make it possible to classify the lateritic gravels as being of class B4, which is the class of gravels with little clay. The crushed materials found in Benin are of volcanic or magmatic origin (granites, basalts, etc.), so the GRH will be recognised as being of class R6.

Table 3 below shows the characteristics of the fine sand, fill and lateritic gravel modelled using a Mohr Coulomb model.

The following Table 4 shows the characteristics of bituminous and improved materials that are considered elastic.

2.4. Additional Calculation Data

The average annual daily traffic is 533 trucks. A geometric growth rate of 4% is considered. The design is based on a 20-year life span of the road.

2.5. Calculation Tools

The calculation software used is ALIZE and PLAXIS. ALIZE is used to carry out

Table 3. Mohr Coulomb characteristics.

	Fine sand	*Backfill*	GL
Young's modulus E (MPa)	50	75	150
Poisson's ratio v	0.35	0.35	0.35
Cohesion C (KN/m^2)	3	5	5
Friction angle φ (˚)	32	35	28
Expansion angle ψ (˚)	0	0	0

Table 4. Elastic characteristics.

	GRH-A	*GB*	BB
Young's modulus E (MPa)	1325	2700	1300
Poisson's ratio v	0.35	0.35	0.35

the design assuming elastic deformation of all layers. The research version is the one used. For the numerical modelling taking into account the behaviour modes listed in **Table 1**, PLAXIS version v21 is used.

3. Results

3.1. Laboratory Test Results

The particle size distributions of the subsoil, lateritic gravel and crushed stone are shown in the following **Figures 4-6** respectively.

It is noted that 85% of the soil passes through the 80 micron sieve, which confirms the very fine nature of the foundation soil.

The grading curve shows that the lateritic gravel used for the subgrade has a low proportion of fines. Referring to the French standard on the classification of materials in road construction [18] a percentage of 31% passing the 2 mm sieve makes it possible to assess the material as gravelly; this also confirms its nature. It is also noted that 11% of the material passes the 80 micron sieve, which confirms that lateritic gravels are poor in fines, in accordance with the standard.

Furthermore, **Figure 6** shows that the grading curve of the crushed materials falls within the range specified by the guide to pavement design for tropical countries of the Centre d'Essais du Bâtiment et Travaux Publics (CEBTP). This shows the conformity of the reconstituted gravel for use as a subbase.

The following **Figure 7** from the Atterberg limit test of lateritic gravels shows the number of blows causing the closure of the slot in the Casagrande apparatus test.

At the end of the test, a plasticity index of 16 and a liquidity limit of 45 were found. A comparison of the PI and the liquidity limit with the Casagrande curve of the French classification guide allows the gravels to be judged as slightly plastic clay.

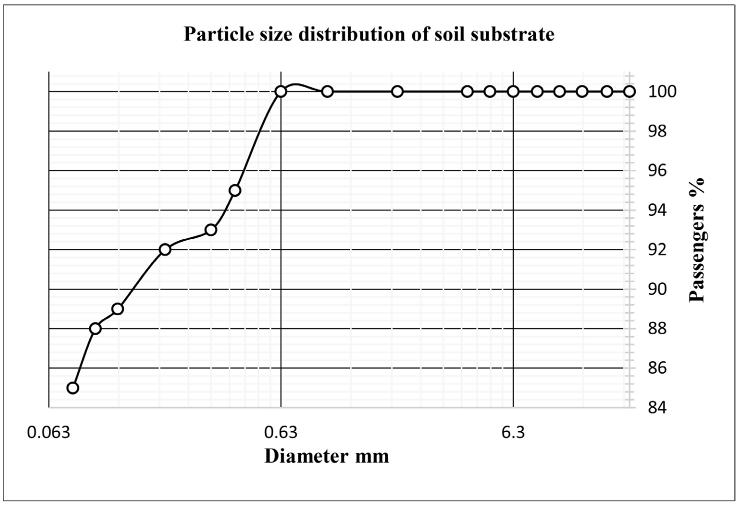

Figure 4. Particle size distribution of soil support.

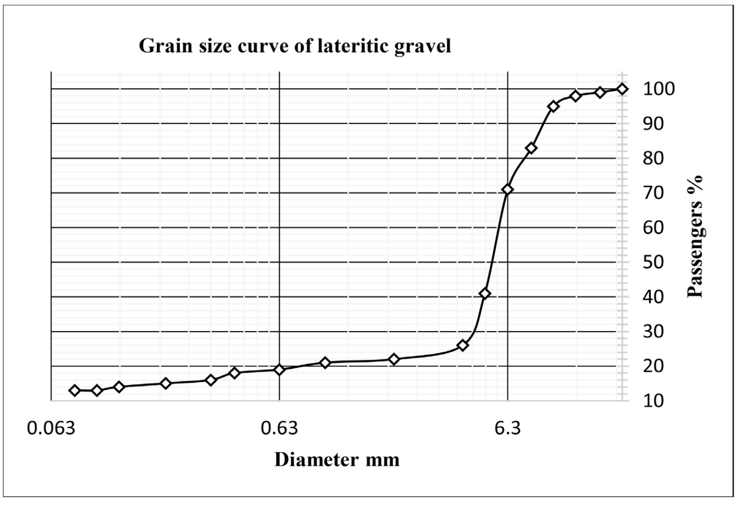

Figure 5. Grain size curve for lateritic gravel.

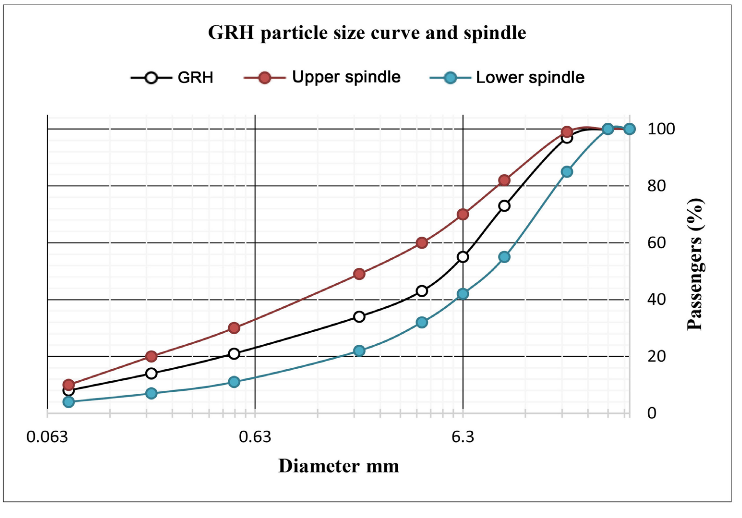

Figure 6. GRH particle size curve.

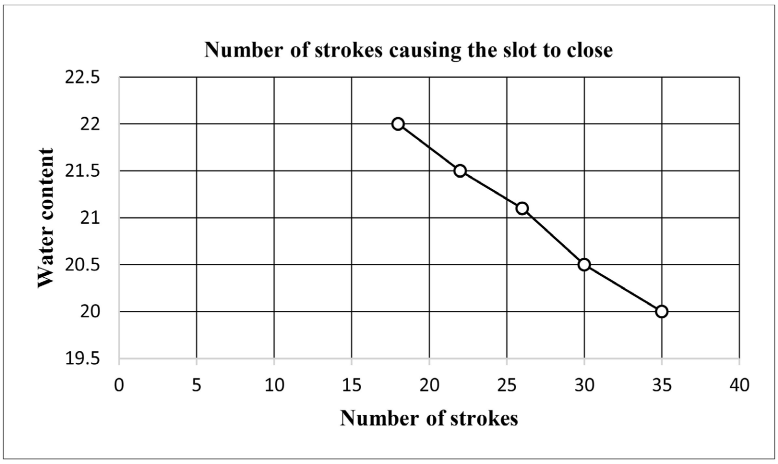

Figure 7. Graph of the casagrande box test.

The following **Figure 8** and **Figure 9** show the OPM test graphs for lateritic gravel and moistened reconstituted gravel.

The maximum dry density at the end of the test is 2.08 t/m^3 and the optimum moisture content is 11.2%.

At the end of the test, the maximum dry density is 2.19 t/m^3 and the optimum moisture content is 7%.

The compaction characteristics determined for both materials allowed the CBR test to be carried out.

The following **Figure 10** and **Figure 11** show the stress-strain curves for lateritic and reconstructed gravel in the CBR test.

The CBR value for lateritic gravel at 95% OPM after immersion at 96 hours is 60.

The CBR value for GRH at 95% OPM after immersion at 96 hours is 265.

3.2. Elastic Sizing ALIZE

The ALIZE design results show that the structure is verified at all layers. The verification is done on the value of rutting deformation ε_z at the surface of the soft layers and the subgrade; and on the value of tensile deformation at the base ε_t of the bituminous layers.

The following **Table 5** shows the values of these deformations and the verification.

The table shows that the calculated values under standard 13t axle loading are well below the permissible values.

3.3. Digital Modelling

For the numerical modelling, the behaviour of all inelastic layers is drained due to the installation of vertical drains to drain the soil. The water table is assumed to be located 1 m from the subgrade surface. The load of 0.662 MPa is uniformly distributed over the cross-section of the structure. The calculation is done in two

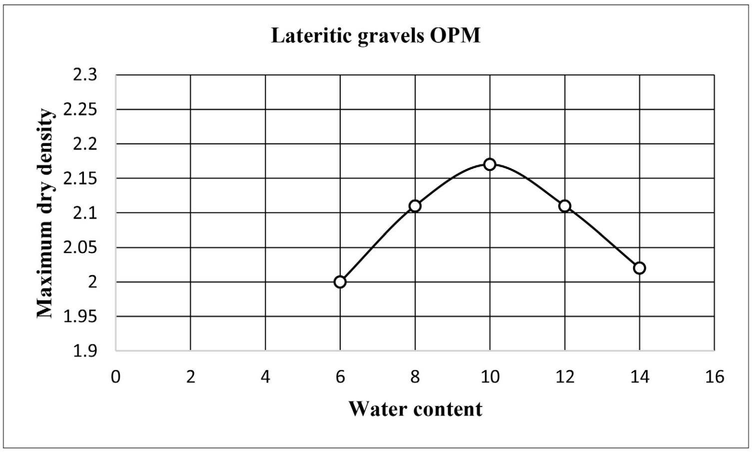

Figure 8. Modified proctor optimum curve for lateritic gravel.

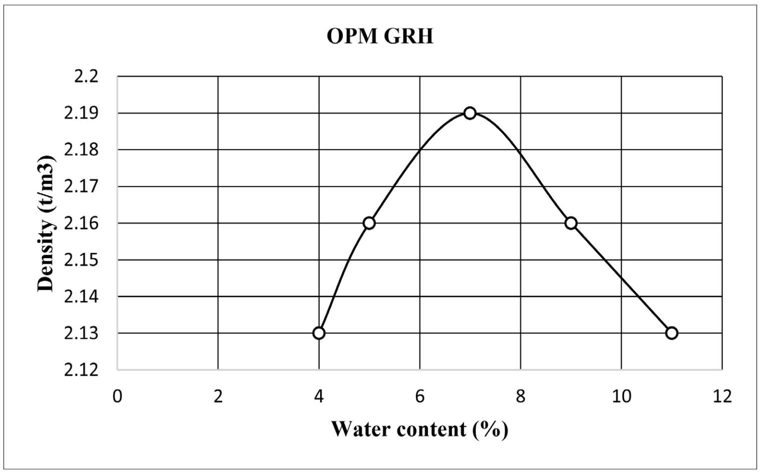

Figure 9. Modified proctor optimum curve for GRH.

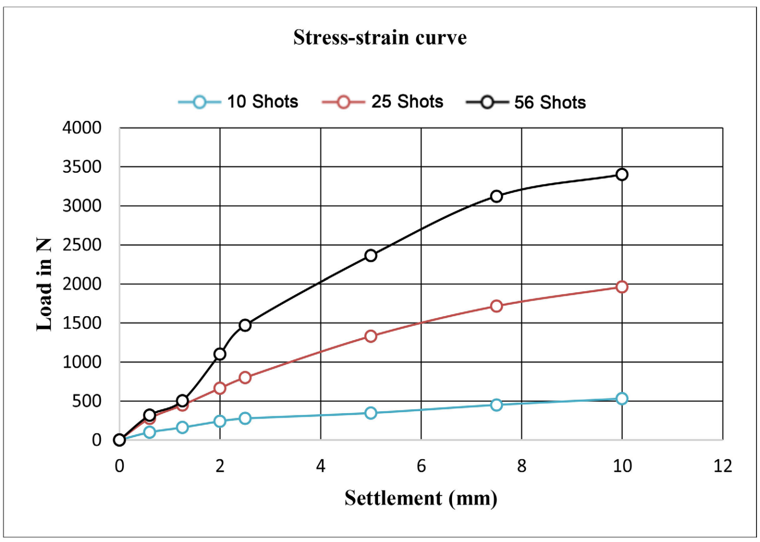

Figure 10. Stress-strain curve CBR lateritic gravel.

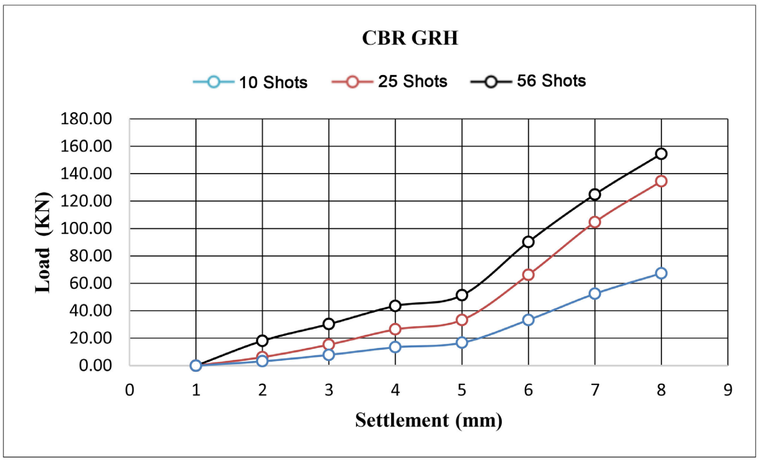

Figure 11. CBR stress-strain curve for GRH.

Table 5. ALIZE verification.

	ε_t	ε_z	Permissible values
BB	36.4	-	142
GB	76.9	-	117.6
GHR-A	-	201.5	360
GL	-	337.8	360
Plateform	-	359.6	360

phases. A first phase of initialization of the stresses by deactivating the loading and a second phase of activation of the loading. The duration of the calculation is 7300 days, *i.e.* 20 years, in order to appreciate the evolution of the displacements in time.

The following **Figure 12** shows the displacement curve over time at the platform interface.

The maximum displacement is 1.113 m.

The following **Figure 13** shows the vertical deformations in the structure.

The maximum vertical rutting deformation at the head of the platform is identified at node 4645 of the global mesh and is 585×10^{-6}.

3.4. Discussion

A comparison of the results of the numerical calculation with previous works shows that the calculated deformation is lower than the deformations found by Djellali in 2018 in his modelling study of pavement on expansive soil in the region of Tébessa in Algeria [9]. Its deformations, which are estimated at 2154×10^{-6}, are calculated on a soil which is however 2 times less swelling than the soil studied in this study ($\lambda = 0.086$ compared to $\lambda = 0.140$ in our case). This surge in deformation is therefore probably due to the absence of an embankment between the structure and the supporting soil, which is on the surface in their case.

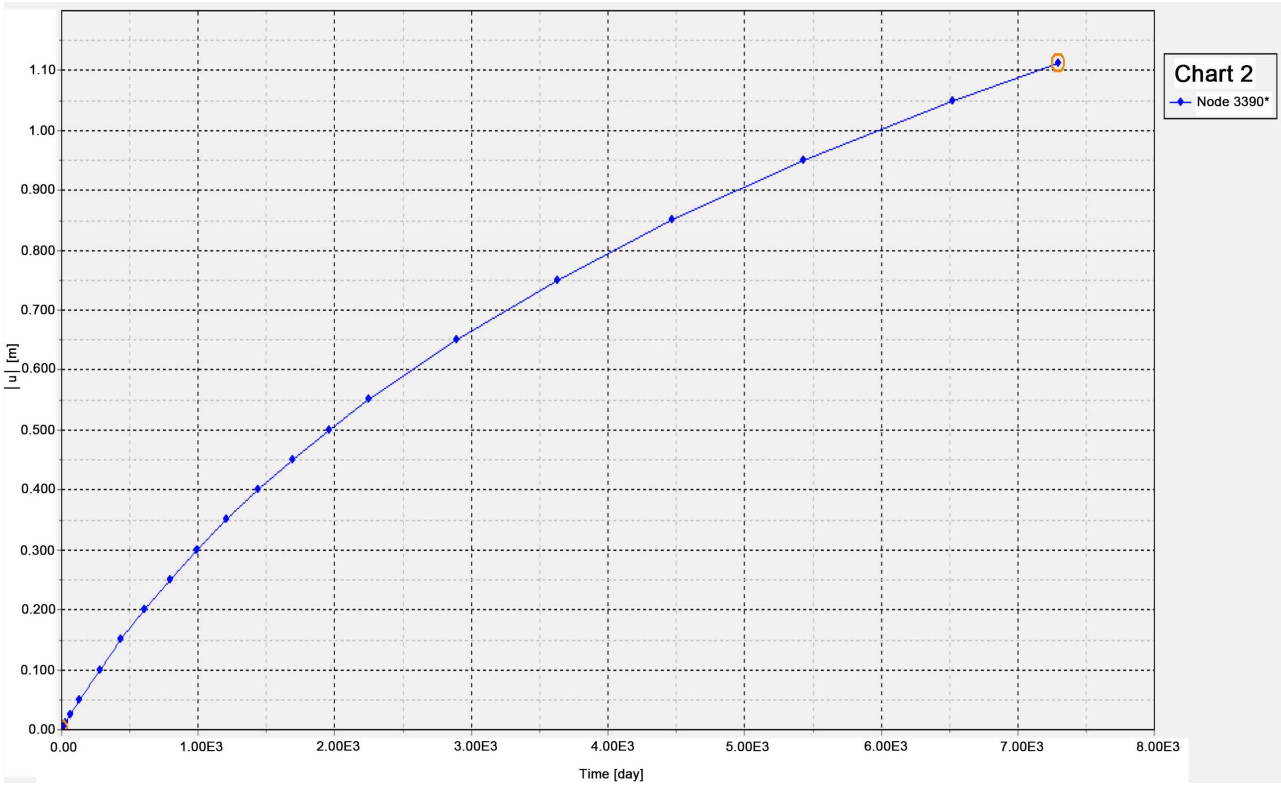

Figure 12. Numerically calculated displacements.

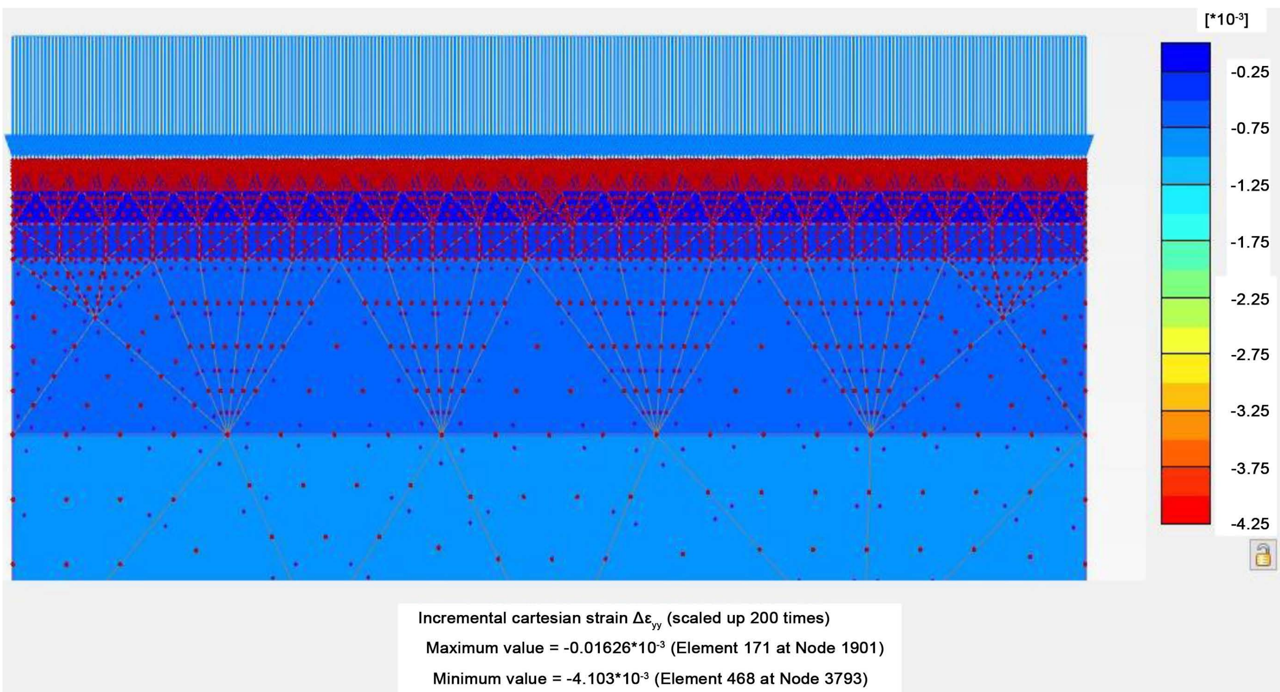

Figure 13. Numerically calculated deformations.

Another probable reason would be the absence of drainage of the compressible soil in their study.

The calculated settlement is of the same order as the settlement found by AKOU in his study on the numerical modelling of a reduced model of an embankment on soft clay [19]. Its interpolated displacement at 1.06 m over a period of 20 years is calculated on a soft clay that is more compressible than that of this study (λ = 0.217 compared to λ = 0.140 in our case). The calculation tool used, which is CESAR LCPC, could justify this displacement value despite the compressibility of the clay soil.

3.5. Comparative Study

The following **Table 6** shows a comparison of the deformations of the Alize calculation and the numerical calculation at the level of the pavement platform.

The comparative strain values are taken at the platform surface as required by the verification criteria of the French standard. It can be seen that the deformations calculated by the numerical modelling are higher than the deformations calculated with Alize. In addition, the verification of the deformations with respect to the permissible deformations is not respected. Based on this value of deformation, it is not obvious that the structure ensures the expected trafficability and comfort over the design period.

3.6. Sustainability Assessment

By varying the cumulative number of trucks under the same conditions of traffic and aggressiveness, it was possible to determine the cumulative number of trucks that would correspond to the numerical deformation if this were the permissible deformation (verification hypothesis of the numerical structure).

Table 7 shows the method for calculating the cumulative heavy goods vehicle traffic corresponding to the numerical deformation by interpolation.

The cumulative number of heavy goods vehicles is in the following range:

A linear interpolation allows to write:

$$\frac{N_{PL} - 600000}{585 - 595.5} = \frac{750000 - 600000}{566.8 - 595.5}$$

$$N_{PL} = \frac{(585 - 595.5) * (750000 - 600000)}{566.8 - 595.5} + 600?$$

$$N_{PL} \approx 654878$$

It is therefore the accumulated heavy vehicle traffic that would have allowed the structure to be checked on the basis of the deformation resulting from the numerical calculation. Using the ALIZE software, an inverse calculation considering the previously calculated cumulative number of heavy goods vehicles, the geometric progression and the daily traffic allows to find the following number of years:

$$n = 3.2ans$$

$$n \approx 3ans$$

Table 6. Comparison of deformations.

	Deformations (10^{-6})	Permissible values (10^{-6})
ALIZE	359.6	360
PLAXIS	585	360

Table 7. Sustainability assessment.

Deformations (10^{-6})	Cumulative number of heavy goods vehicles
666.8	750,000
585	N_{PL}
595.5	600,000

The following Figure 14 shows the table for calculating the number of years corresponding to the cumulative heavy goods traffic in ALIZE software.

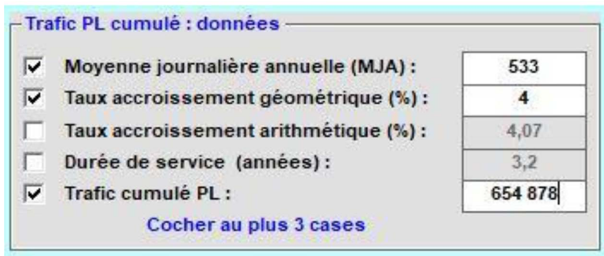

Figure 14. ALIZE sustainability calculation.

The deformation calculated by numerical modelling allows the structure to withstand the least amount of deformation for 3 years of traffic, taking into account the average annual daily traffic and the geometric progression rate. However, this period does not correspond to the ruin of the structure but rather to the appearance of the first rutting deformations which could make the pavement impassable or uncomfortable during the rest of its life. The structure therefore does not take the traffic loads for the 20 years foreseen but rather for 3 years.

4. Conclusion

The objective was firstly to compare the numerical deformations obtained from PLAXIS with the calculated stresses under the assumption of elastic deformation, and then to evaluate the durability of the pavement based on the calculated numerical deformations.

An initial verification of the structure was carried out according to the French dimensioning standard NF P 94-086. At the end of this verification, it was found that the structure was accepted in accordance with the French standard.

Next, numerical modelling was carried out on the same structure using the finite element method implemented under the PLAXIS software. This numerical modelling made it possible to calculate the displacements and deformations in the structure at the interface of the platform. The results of this numerical modelling allowed us to make the following conclusions:

- A structure can be verified following ALIZE design but not necessarily when considering the plastic deformation of soils and granular materials.
- An estimate of the durability of the pavement under study by taking into account the rutting deformation at the platform interface by numerical calculation reveals that the structure in question will only be able to withstand traffic for 3 years before the first fatigue deformations appear. This durability assessment allows the structure to be optimized to meet the life expectancy requirements.

In order to increase the service life of the analyzed structure, it is recommended to carry out an optimization study by varying the subgrade material according to the requirements of the supporting soil and by varying its thickness.

Conflicts of Interest

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

References

[1] Ministère de la transition écologique et de la cohésion des territoires (FRANCE). https://www.statistiques.developpement-durable.gouv.fr/edition-numerique/chiffres-cles-transport-2021/

[2] République du Bénin. https://www.fao.org/faolex/results/details/fr/c/LEX-FAOC210365/

[3] République du Bénin. https://finances.bj/presentation-du-programme-dactions-du-gouvernement-2021-2026/

[4] Ministère de l'Enseignement Supérieur et de la Recherche Scientifique Universite Aboubekr Belkaid—Tlemcen, Algerie. http://dspace.univ-tlemcen.dz/handle/112/11939

[5] Kim, M. and Lee, J.H. (2011) Study on Nonlinear Pavement Responses of Low Volume Roadways Subject to Multiple Wheel Loads. *Journal of Civil Engineering and Management*, **17**, 45-54. https://doi.org/10.3846/13923730.2011.554012

[6] Colin Leek, D.A.C. (2006) Numerical Simulation (Using ABAQUS Software) of Granular Materials Used as Base Layer in Pavement, Considering Shakedown Effects and Soil-Asphalt Interaction. *International Journal of Engineering and Technology*, **7**, 198-203.

[7] Thompson, M.R. and Elliott, R.P. (1985) ILLI-PAVE-Based Response Algorithms for Pavements. *Transportation Research Record*, **1043**, 50-57.

[8] Djellali, A., Ounis, A., Saghafi, B., Gadri, L., Messaoud, L. and Hamdane, A. (2014) Comportement d'une Chaussée Souple sur Sol Support Gonflant. *MATEC Web of Conferences*, **11**, Article No. 03010. https://doi.org/10.1051/matecconf/20141103010

[9] Ministère de l'Enseignement Supérieur et de la Recherche Scientifique Université Larbi Tebessi—Tébessa, ALGERIE. http://dspace.univ-tebessa.dz:8080/xmlui/handle/123456789/156

[10] Dolin, R.F., Ramaroson, M., Rabevala, R., Arnolev, R.Z. and Richard, R.T. (2021) Modelisation Thermo-Mecanique Des Chaussees Souples Les Liants Vegetaux Locaux Modelization Thermo-Mecanical Behavior of Soft Pavement Applied to the Prediction of Orniering of the Base Traeted Wiht Local Vegetable. *American Journal of Innovative Research and Applied Sciences*. https://american-jiras.com/Dolin%E2%80%93Ref3-ajira260421

[11] Laboratoire Central des Ponts et Chaussées, 58 Boulevard Lefebvre, 75732 Paris Cedex 15. https://pastel.archives-ouvertes.fr/pastel-00001846/file/these_coquillay

[12] Etude de stabilisation et renforcement des sols. http://dspace.univ-jijel.dz:8080/xmlui/handle/123456789/3776

[13] Rizi, D., Flavigny, E. and Meksaouine, M. (2019) Détermination des paramètres d' un modèle hyperbolique et simulation numérique du comportement du matériau analogique de Schneebeli [Determination of Parameters for a Hyperbolic Model and Numerical Simulation of Behavior of an Analog Schneebeli Material]. *Synthèse: Revue des Sciences et de la Technologie*, **25**, 82-96.

[14] Khemissa, M. (2020) Comportement des sols fins. https://www.researchgate.net/publication/339553257_COMPORTEMENT_DES_SOLS_FINS_SOUS_SOLLICITATIONS_HOMOGENES

[15] Castonguay, V. (2020) NorSand-aUL: Une loi de comportement améliorée pour la modélisation des sables sous sollicitations statiques et cycliques. Université LAVAL, Québec. https://library-archives.canada.ca/eng/services/services-libraries/theses/Pages/item.aspx?idNumber=1197946676

[16] Centre Expérimental de Recherches et d'Etudes du Bâtiment et des Travaux Publics, Guide Pratique de dimensionnement des pays tropicaux. https://fr.scribd.com/document/467357282/GUIDE-PRATIQUE-DE-DIMENSIONNEMENT-DES-CHAUSSEES-POUR-LES-PAYS-TROPICAUX-CEBTP-version-2014#

[17] Guide des terrassements des remblais et des couches de forme, Cerema. https://www.cerema.fr/fr/centre-ressources/boutique/guide-terrassements-remblais-couches-forme

[18] AFNOR (2018) Nf p11-300: Classification des matériaux.

[19] Akou, Y. and Magnan, J.-P. (1997) Etude numérique d'un modèle réduit de remblai sur argile molle. *Revue Française de Géotechnique*, No. 80, 53-64.