CONSTRUCTION ON EXPANSIVE SOILS: CASE OF ROAD SECTION SÉHOUÈ-MASSI

Dr. ALLOBA I. Ezéchiel[1], Dr. ZEVOUNOU Crépin[2], Ing. YABI Crespin P.[3]
EcolePolytechniqued'Abomey-Calavi, EPAC,University of Abomey-CalaviBP : 2009 Cotonou (Republic of Benin).1.allobide@yahoo.fr; 2.zevounoucrepin@gmail.com; 3.yabicrespin@yahoo.fr

The expansive soils are some soils able to move after loading or water movement; thus, precocious degradations are observed on the structures that are built on them. The present study based on the Sèhouè-Massi section of the Akassato-Bohicon road that is a part of the RNIE N°2 in Benin. The previous work done on the soil of this road section showed that it is on aexpansive clay formation. After had analyzed the auscultation and the geotechnical study results, a road inverse structure appropriate to the traffic was proposed.
KEYWORDS:soil, expansive, degradation, traffic, road, Benin.

Nomenclature

BB : Bitumen-concrete (bétonbitumineux)
CBR : Californian Bearing Ratio
CEBTP : Centre Expérimental de Recherche et d'Etude du Bâtiment et des Travaux Publics
CNERTP : Centre National d'Essais et de Recherches des Travaux Publics
EPAC: EcolePolytechniqued'Abomey-Calavi
GB: Gravel-Bitumen
GNT: Not Treated Gravel
P_2: Percentage of clay
P_{74}: Percentage of particle with size inferior to 74mm
PI: Plasticity Index
ISTED : Institut des Sciences et des Techniques de l'Equipement et de l'Environnement pour le Développement
LCPC: Laboratoire Central des Ponts et Chaussées
OPM: Modified Proctor Optimum
PF: (Subgrade) Platform
KP: KilometricPoint
SC : Sand-Cement

Introduction

Some clay soils are subject to large variations in volume when their moisture grade varies: when such soils are moistened from a dry and dense initial state, their volume increases and we talk about inflation. When the same soil dries from an initial state looser and saturated, their volume decreases and we talk about *retirement*. These two mechanisms (*swelling/retirement*) characterize the called expansive soils.

The soils of this type are present everywhere in the world [1]. Specifically, the Costal Bassin of Benin is crossed from West to East by a large depression highly concentrated in expansive clay (Figure 1).

Expansive soils are not only at low lift, but cause damage to structures especially in countries characterized by alternating between dry and rainy seasons: it is the case of Sèhouè-Massi road section.

By this studywe find a sustainable road structure, appropriate to the traffic, on a swelling soil from a method of building technically and economically suitable.

Figure 1:Median depression in Benin and study environment

1. Methodology

After visual inspection of the section and the statement of damages, we then made three withdrawals on the section Sèhouè-Massi, as detailed in Table 1. The geotechnical tests on intact and remoldedsamples were realized at the National Testing and Research of Public Works Center (CNERTP) in Benin.

Table1: Details of the sample collected

N°	Position of wells	Depth	Sample Type	Nature
1	KP 66+903 CG	0,80m	Reshuffled	Grayish clay
2	KP 67+963 CD	0,70m	Reshuffled	Clay mixed with gravel laterite, blackish red
3	KP 68+800 CG	0,80m	Reshuffled and intact	Blackish Clay

2. Results and analysis

2.1 Auscultation of the pavement and measure of degradation:

Visual inspection of the pavement made of penetrating southern Séhouè (KP 78 456) to the north exit of Massi (KP 86+720).

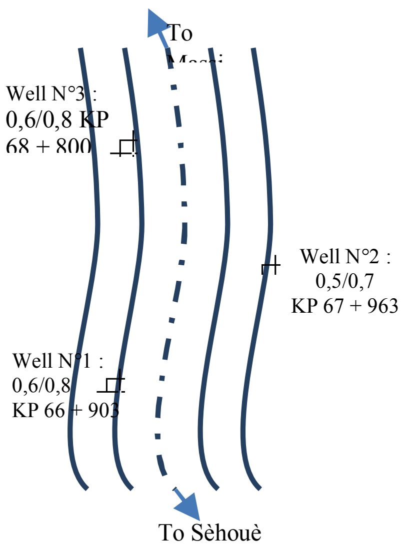


Figure 2 : Scheme of borrowing itinerary

From these observations, it is noticed that the structure is affected by very advanced pathologies; the most important are the crockery, joint cracks, subsidence and rut, potholes. These degradations are remarkable on almost all of the section, despite the repairs that are made recently.

To better characterize the state of degradation of the road we used the VIZIR method. Which led us to a fissuring index $\boldsymbol{I_s = 4}$ and a deformation index $\boldsymbol{I_d = 4}$. These values correspond to an area dex$\boldsymbol{I_s = 7}$, This Indicates a very bad state of surface degradation.

Furthermore, analysis of these degradations and their causes has shown that these pathologies and especially their precocity are mainly due to the nature of the support soil [2].

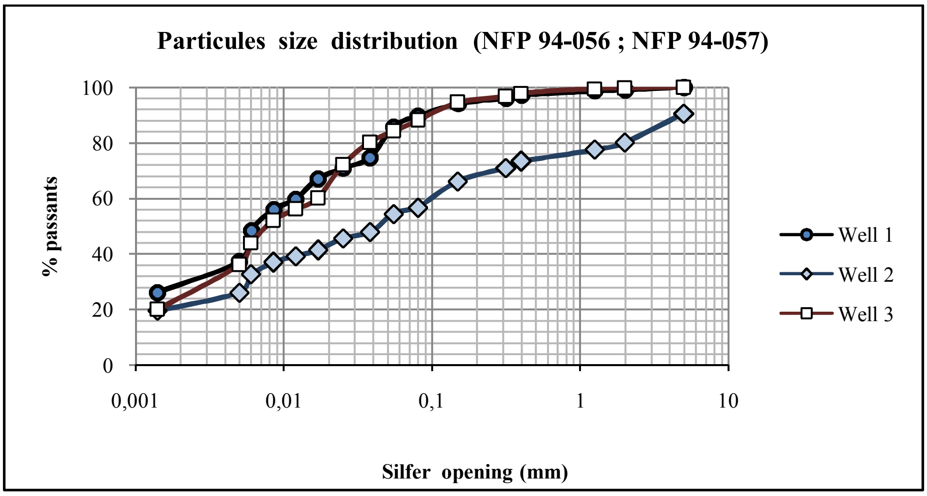
2.2. Physical characteristics and classification

The tests for determining the densities of solid grains and organic matter content have made given the results presented in Table 2.

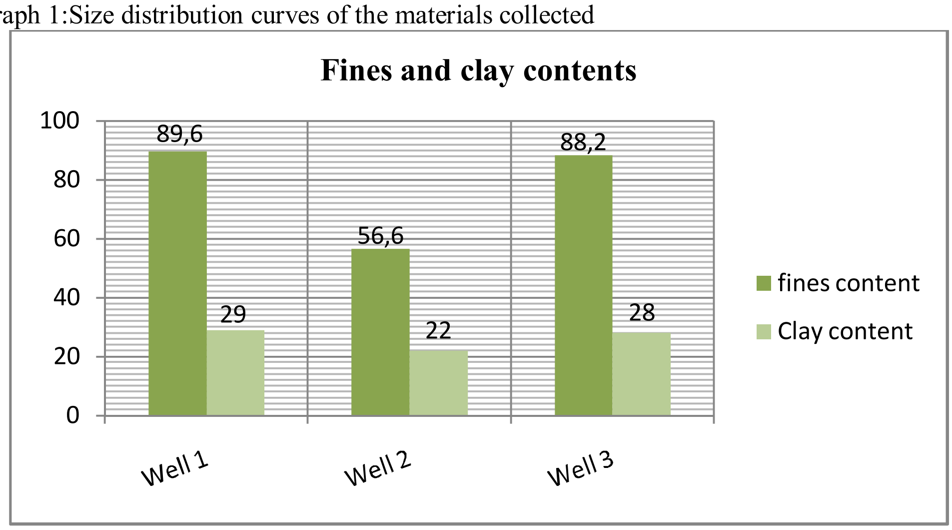
Table2: Results of tests to determine the organic content and density of solid grains

	well 1	well 2	well 3
Density of solid grains*(en g/cm³)*	2.58	2.51	2.57
Organic matter content*(%)*	2.89	1.52	2.24

The results of sieve analysis effect at CNERTP on all three wells are presented on a graph. The curve of the material of two wells containing coarse lateritic is more spread out compared to other materials. We usually have a very fine soil with a percentage of thinly matter (<80µm) very high up to more than 88% for materials of samples 1 and 3 and 56.6% for the wells 2 even though it is consisting of a mixture of clay and lateritic. The percentage of clay particles is large enough for three wells about nearly 30% for wells 1 and 3. Graph 2 summarizes these percentages. The maximum diameter of the grains is less than 5mm for wells 1 and 3 and 8mm for the wells 2.



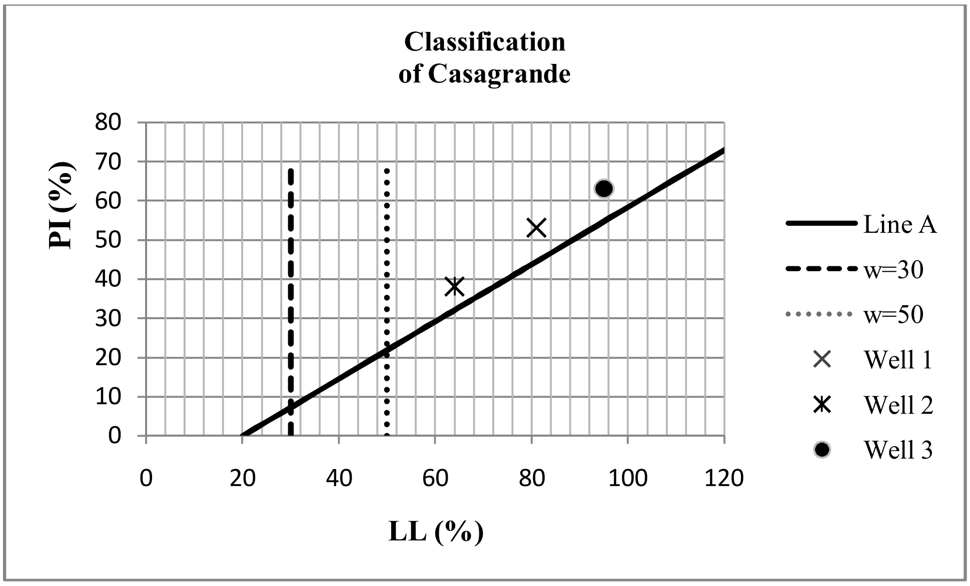
Graph 1:Size distribution curves of the materials collected



Graph 2 : Content of clay and fine particles

Atterberg limits were determined and they showed a soil with a high liquid limit and plasticity index.

Combining the results of particle size distribution test and Atterberg limits and, among other things, that of the organic matter content, we were able with standard NFP 11-300 and classification LPC to classify soils of different wells as recorded in Table 3.



Graph3: Plasticity diagram ofCasagrande

Table3: Classification

	standard NFP11-300	LPC/USCS
Well 1	Very plastic clay or marly	Highly plastic inorganic clay
Well 2	Very plastic silt or Clay	Highly plastic inorganic clay
Well 3	Very plastic clay or marly	Highly plastic inorganic clay

Analysis of various tables, it brings out that all these wells materials are highly plastic (high PI). However, there is a relatively low liquid limit for the two wells while those of the other wells are very high (> 80%). This is explained by the fact that this well constitutes of a mixture of clay and laterite small grains eroded to the existing embankment.

2.2 Evaluation of swelling potential

There are several classifications to evaluate the swelling potential of a soil, we have based on Sanglerat, Holtz and Gibbs, Chen, Williams and Donaldson classifications.

Table 4: Swelling potential according to Holtz et Gibbs [3]

Table 5: Swelling potential according to Sanglerat[3]

I_P	Swelling Potential
>55	Very high
25 - 55	High
10 – 25	Middle
<15	Low

I_P	%□2µm	W_L	Swelling potential
>35	>28	>63	Very high
25 – 41	20 - 30	50 - 63	High
15 – 28	13 – 23	39 – 50	Middle

The parameters of the test of Atterberg limits gave:

- **Well N°1** : This material has**PI = 53% ; P_2 = 29% et P_{74} = 89,6%**
- **Well N°2** : This material has**PI = 38% ; P_2 = 22% et P_{74} = 56,6%**
- **Well N°3** : This material has**PI = 63% ; P_2 = 28% et P_{74} = 88,2%**

Table6: Swelling potential according to Chen (KIKI S. Y., 2004)

I_P	P_{74} (%)	Swelling Potential
>35	>95	Very high
22 - 35	60 - 95	High
18 – 22	30 – 60	Middle
<18	<30	Low

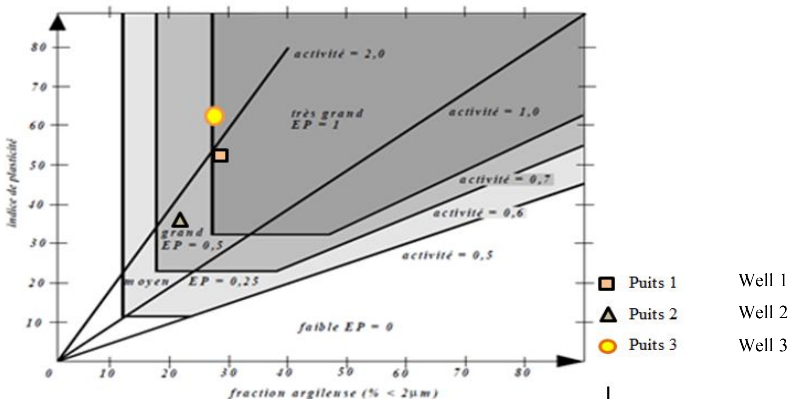
When we inserted these values obtained in the tables, we deduced according to-Sanglerat and Gibbs and Holtz we are in the presence of a soil with a very high swelling potential for wells 1 and 3 and high Potential for the well 2. According to Chen on the other hand, we had a high swelling potential for wells 1 and 3 and the average for well 2. However, the soil is at least for average potential swelling.

Before checking these conclusions by other tests we used the clays activity notion of to characterize these soils

- Clays activity $\mathbf{A_C}$

The activity A_C, is the quantity defined as the ratio of plasticity index PI and in clay particles: $\boldsymbol{A_C} = \frac{\boldsymbol{PI}}{\boldsymbol{P_2}}$.

For the material of the well 3, we have: **PI = 63% and P = 28%** this led us to$\boldsymbol{A_{C3}} = \mathbf{2,25.}$ The activity of wells 1 and 2 give respectively 1.83 and 1.72.These results show the presence of montmorillonite very active in the soil according to [3]. Values were checked with the abacus that Williams and Donaldson developed from the work of Van der Merwe on South African soil (Williams A. & G. Donaldson, 1980) cited in [3] (Graph 4).



Graph 4 : Abacus of Williams and Donaldson, with EP swelling potential (Williams A. & G. Donaldson, 1980)

It brings out from there according to Williams and Donaldson that the clays of wells 1 and 3 are very active with a large swelling potential of order unity while the clay of Well 2 is active with less important swelling potential.The centralization of all these results leads us to the following table:

Table 7: Classification summary

Classification	Sanglerat	Holtz et Gibbs	Chen	Williams et Donaldson
Well 1	Very high	Very high	High	Very high
Well 2	High	High	Average	High
Well 3	Very high	Very high	High	Very high

From all these tests identifications made, it is understandable that the support soil of the road section under study is a high potential of swelling. But all this is due to low clay content for a high plasticity. To verify this result, we had therefore use tests to determine mechanical properties.

2.3 Mechanical properties and swelling potential

Out of classical identification tests, tests to determine mechanical properties of soil were conducted on materials from wells 1 and 3 because they are the ones who interested more, the well 2 which is constituted of mixing, and consequently less moving.

From CBR test results, it was deduced very low CBR (CBR = 4 and 5) and a high linear swelling (Average GL = 6.57% □ 3%, accepted value to describe a swelling soil). This supports the hypothesis of a swelling clay soil with a very low bearing CBR.

The odometer test realized on the intact sample well 3 on other hand gave us not too unfavorable parameters presented in the summary table below.

Tableau 8: Paramètres oedométriques

Parameters	Values
Initial moisture contentW %	**43,91**
Void ratioeo	1,175
Compression coefficient Cc	0,372
Swelling coefficient Cg	0,03
Consolidationpressure σ ‘c (daN/cm^2)	1,12
coefficient of permeability kmoy (daN/cm^2)	7,03x10^{-9}
Swelling pressure (kPa)	**22,5**

This table provides 22.5 kPa as swelling pressure. But the previous studies results conducted by the CNERTP on this section of road and presented in [2], give a general trend towards **50 kPa** for an initial moisture content of 17%. The oedometric-tests revealed a swelling coefficient of **Cg = 0.030**. It shows that the clays of the road section are effectively swelling with a large construction risk on them (**Cg ≥ 0.03**). Here, the presence of lateritic gravel in the sample from well 2 has considerably varied results. Thus the presence of these unwanted particles inhibited the swelling of the material. However, these tests could be complemented by X-ray diffraction does in no Beninese laboratory.

The low values of the parameters associated with the oedometer swelling would certainly be due to the initial moisture content depending on the season in which the test was performed.

3. Construction method chosen:

3.1. Site conditions

The road section under study is on aexpansive clay formation.

From **KP81+000 au KP86+000**, it was setting up a dam in lateritic material. The pavement with is 7 m for 1.5 × 2 m of verge [5].

3.2. Study on «Karal»in Cameroon

A joint study by ISTED and CEBTP in Cameroon has elucidated the process of ground degradation in the area. The pathologies noted on road infrastructure built on swelling soil are only the consequences of such degradation processes arising at the lower layers of swelling soil and appearing by changes in the surface layers. [6]

Technically appropriate methods

From the synthesis of road construction methods on expansive soil, it appears that:

↳ The method of ***draining*** is only effective for a full drain, but the swelling soil is very big here (4). So full drain is technically impossible, also a partial purge is little effective.

↳ The method of ***soil treatment with lime*** is relatively effective for fine soils, only the latter is realized only on a small thickness (60 cm). And when the soil is highly plastic as it is the case its use becomes problematic. Also, the existence of a road on this section poses accessibility problems of bad soil under the embankment at the dam area.

↳ ***Treatment or stabilization to a noble ground*** together reduce the swelling of the soil and improves some characteristics of the latter as well as ***hydrophobic agents*** that are not controlled.

↳ The consolidation methods by ***grouting***, by ***stone columns*** and ***lime columns*** are rarely used for clay materials. In addition they are applied more locally than on a linear because they extremely expensive.

↳ ***Widening*** is a proposal arising from a relevant observation but it alone cannot solve the problem because water can infiltrate through the cracks of pavement or edge of pavement. Thus over time the equilibrium zone of water ratio would be reduced.

↳ A ***waterproofing with geo-membrane*** keeps the water content of soil varies very little. However care must be taken in contact with aggregates of layers which will be laid on him.

↳ Geogrids have a very important role in limiting cracks and increasing the performance of the road for its resistance to possible swelling. The results of experimental boards on the same road in 1997 showed that the geogrid has reduced by 40% deflection of the road after four years of experimentation. (5)

↳ The ***rigid inclusions*** are widely used on compressible soils (settling), on expansive soil (settling/swelling) as is the case here; they can give the same assurance when ensures saturation of the soil before application. Accommodated to the large depths of bad soil, they can transmit the loads leading to a basement or by side rubbing to the bad soil (floating piles).This technique suffers of a complete misunderstanding of the phenomena of transmission charges by vault or membrane effects to the heads of inclusions [2]. So he will carefully study the stability of the piles on the ground (swelling).

Most, if not all these methods are inadequate, more or less important but offsetting weaknesses of one by the other forces could result in a combination of techniques, making a highly efficient and effective method.

From this analysis it is clear that the method of rigid inclusions proves to be possible to solve problems on the road segment under study. Notwithstanding, an assembling of technology and expansion of the geo-synthetics use (geogrid and geo-membrane) could be very

3.3. Efficient method

- **Presentation of methods preselects:**

  - ***Method type 1 : Rigid inclusions***

The reinforcement by rigid inclusions principle is shown in Fig. 3.

  - ***Method type 2:Widening with use of geo-synthetics***

From the technical study and CEBTP recommendations, for road construction on expansive soils we can do any combination of these methods technically inefficient to form a relatively suitable and efficient.

The variation of the water ratio of expansive soils being the basic cause that leads to destruction of roads built on these soils; the following dispositions may be considered to limit the change in water content of clay immediately below the ground:

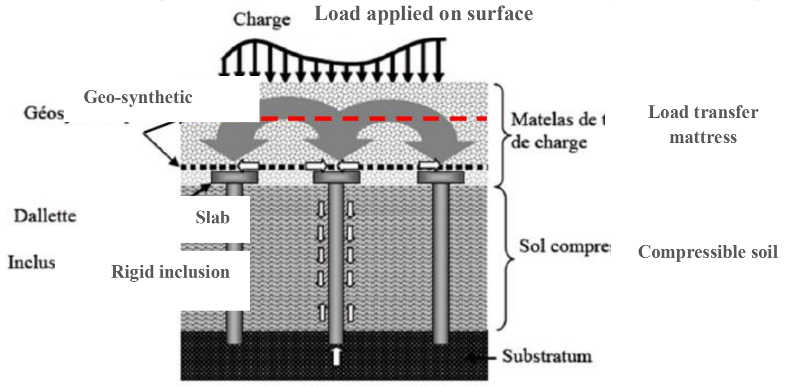


Figure 3:Principle of rigid inclusion method:

- The widening at the embankment of subgrade on a width of 3 ml of both sides of the pavement. This widening is not intended to be circulated. Its main objective is to maintain the equilibrium zone of moisture around the band of 10ml off the pavement (the equilibrium zone is the area where the water content of natural soil does not vary during different seasons of the year). Before embankment, the subgrade will be compacted with rollers for pads to stabilize the clay soil.
- The earth-work on the area of widening and establishment of an impermeable geo-membrane on 3 ml of widening either side of the road and the extending it to cover the embankment of the existing pavement. Its purpose is to minimize infiltration and evaporation of water at any natural ground level.
- The recycling of 20cm thick of the old road; the compacting of the recycled tranche should be done so that the geo-membrane above mentioned is posed there without problem.
- The establishment of a geogrid on the width of 10ml (pavement + verge) before execution of the other layers of the proposed pavement structure. The purpose of the geogrid is to strengthen the proposed structure to attenuate horizontal and vertical traction effort transmitted to the latter in the case of any swelling or retirement of the clay in place and limit the cracking of the pavement responsible for water infiltration.
- The extensions will be constructed with a covering of concrete pavers with a maximum thickness of 5cm or stone facing.
- Covered ditches will be executed on both sides of widening to collect and drain off the pavement waters which arrive there.

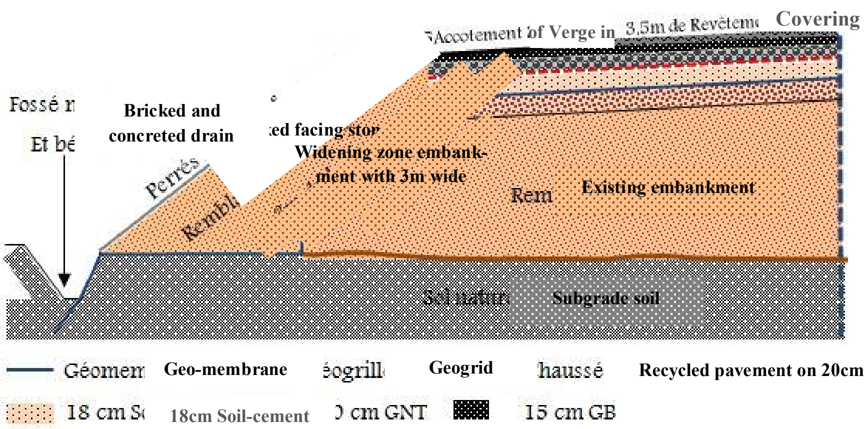


Figure 4 : Across profile type of proposed method

To define the most appropriate method, we used the multi-criterion method AHP. The selection criteria specified in the order of priority are:

1. Effectiveness; 2. Additional cost; 3. Functioning; 4. Environmental impact ;5. Aesthetic.

We evaluated the additional cost of each method. Thus we obtained:

Methods of inclusions: ***SC1 = 3,936,385,780 FCFA / km.***

Widening method with using geo-synthetics: ***SC2 = 598,341,780 FCFA / km.***

This led to a report SC1/SC2 = 6.5. So method 2 is much larger point of view of cost. We subsequently obtained the global matrix of decision, with the global weight of each method. Hence it appeared that the method of widening present the highest weight. It is therefore to be chosen to the detriment of rigid inclusions method:

4. Pavement selected structure:

Once the method chosen, we have gone to a proposed route structure.

From traffic class T4 and from a soil class S4 we obtained in the catalogs of the guide, the bituminous structure as follows: 7BB+20GB+15GNT. Indeed given the conclusions of studies on the boards of tests performed on the section, a structure with high thicknesses of asphalt has been proposed for fsuture rehabilitations.

This structure is adequate but, aggregates may punch the membrane. Thus, we proposed to intercalate between the membrane layer and GNT layer a SC layer by reducing its thickness.

Also, to stiffen the structure against movements possible, we planned a geogrid. This will also cracks and thus, water infiltration.

The structure permanently retained constitutes of: **7BB+15GB+10GNT+geo-membrane+18SC+geogrid**. It was checked with the program ALIZE III.

Conclusion:

In summary, reconstruction of road on expansive soil by this method of widening with the use of geo-synthetics has advantages such as maintaining the equilibrium zone water content in the full width of the roadway provided by extension of embankment and the utilization of geo-membrane waterproofing. Moreover this method protects slope of widening embankment by a coating of concrete pavers with a maximum thickness of 5cm or in stone facing, just as the drainage of the roadway provided by dressed ditches both sides of the widening.

So this method will enable the avoiding of precocious damages, reducing accidents on this road section.

But a study on a model could be made to justify the performance of this method.

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