Contribution to the design of road pavements in Cape Verde

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Abstract: Over the past five years, Cape Verde has spent about 147 million dollars a year, almost 8 percent of gross domestic product (GDP) on infrastructures, one of the highest levels of investment in this sector found in the African continent. Expenses are mainly directed to capital expenditures with the resources dedicated to the support of the transports activity being especially high.

This thesis aims to evaluate new paving technologies to be implemented in Cape Verde, analyzing first of all, the solutions implemented to date, studying aspects such as traffic and its temporal prediction and the materials currently used in its design, comparing in terms of direct current cost these solutions and the new solutions deemed adequate to be used in the country.. Some of Cape Verde road projects were analysed, aiming to assess the current state of the country, addressing the paving technology employed, in particular the flexible structure pavements with asphalt concrete wearing course and basalt stone pavements (paving solution most used in Cape Verde). In the second part of this thesis it is analysed, based on traffic studies, foundation analysis and on the catalogue of SATTC, possible flexible pavements structures to implement in Cape Verde. The AUSTROADS and Shell methods are used to validate the pavement structures. Finally it is made a comparison in terms of construction costs between the most used pavement solution that is the traditional flexible pavement and new pavement solutions proposed in this dissertation, namely pavements with soil stabilized with cement.

Keywords: Pavements, Paving Technologies, Granular materials, Materials stabilized with cement, Performance

1. Introduction

Since the second half of the twentieth century there has been a growing evolution in the study of the peculiarities of tropical soils as road construction materials. Due to its extension worldwide, it is important to assess the existing soil as road paving material, which can provide significant economic and technical advantages when compared to other materials traditionally used in pavements.

Thus, it is important to evaluate the possibility of using local materials in the construction of road pavements in order to contribute to more effective solutions that respond to particular aspects as the climate, the traffic intensity, the available resources and the needs of each country.

It is in this context that the need to implement other materials in roads infrastructures such as asphalt, soil stabilizers, namely cement, instead of other materials commonly used in Cape Verde, such as the basalt pavement .

This thesis is a contribution to increasing the knowledge about technologies for road paving in Cape Verde, aiming to present to the country solutions and alternative ways to solve problems and evaluating if these alternatives are sustainable in terms of cost and of existing technologies in the country.

2. Characterization and pavement construction technologies used in Cape Verde

2.1 Initial consideration

Cape Verde, as a small developing archipelago, suffers from a natural vulnerability due to its small size, geographic dispersion and isolation. This is a disadvantage of the islands regarding the spatial planning and development.. The natural beauty of the islands as well as the hot and dry climate led this nation to invest in the tourism sector as a base for the development of the country. Thus, tourism contributes to the overall socio-economic development and enhances the creation of numerous infrastructures, including the road network. However, in the current context of global economic crisis, the economic dependence on foreign countries, aggravated by limited natural resources, put the economy in a fragile position, compromising the progress and, consequently, the development potential that the country has demonstrated in recent years.

The improvement of accessibility and mobility has been key factors in the development of the country. This has been possible with the increasing development of construction technologies and constant research of materials, methods and studies of how to optimize the road pavements taking into account the particularities of the country, the as the road traffic, the weather and the availability of materials.
In the figure 2.1 is possible to see the extension of existing national roads in each of Cape Verde islands.

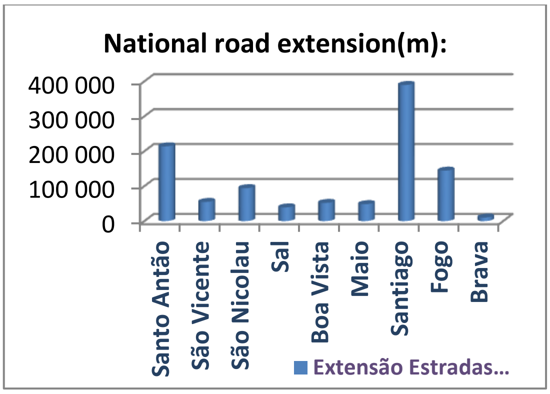

Figure 2. 1: National road extension

As it is possible to see in the chart the bigger islands (Santiago, Santo Antao and Fogo) have greater extensions of roads, which was already expected.

For representing the bigger islands, they require greater lengths of roads to meet their needs and reach all the villages, towns and populations. Furthermore there is a large discrepancy in the use of funding between the various islands. Santiago, being the island where the country's capital, has benefited more than the other islands, and therefore one whose development is greater, especially in terms of transport infrastructure.

In the figure 2.2 it is presented the road extension by type of pavement.

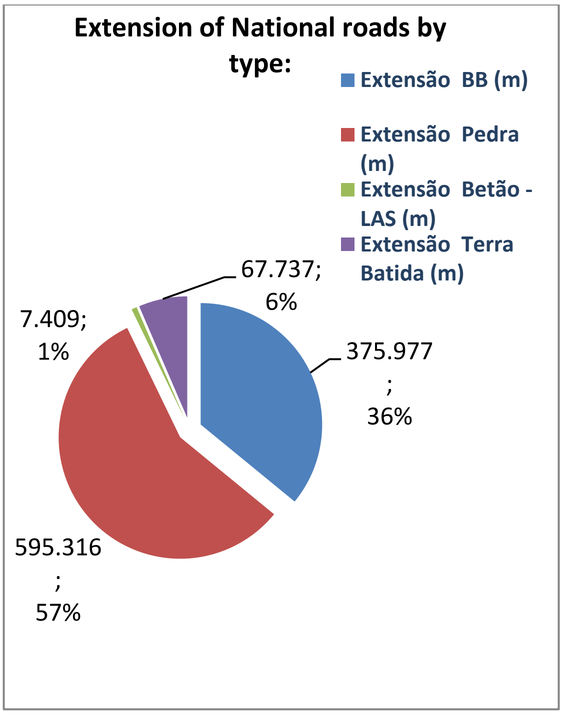

Figure 2. 2: Extension of National roads by type

2.2 Flexible pavements and materials used in its design

The flexible pavements have been, in recent years, the main option as paving solution of most of the roads of the national road network in Cape Verde.
The introduction of the asphalt concrete in Cape Verde began on Sal Island in the nineteenth century. The road that extends from the only international airport at the time, Amilcar Cabral Airport and the main village, village of Asparagus consisted simply on 1 carriageway with 2, one in each direction. This was important for the economic development of the country.
Only many years later, it was possible to observe the growth on the development of roads in Cape Verde based on asphalt concrete.

2.2.1. Structure of a flexible pavement

In the figure 2.3 below, it is possible to see the typical structure of a flexible pavement and its composition.

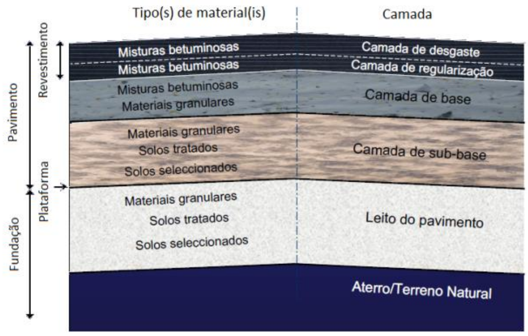

Figure 2. 3: Schematic section of a flexible pavement (Antunes et al, 2006)

Two recent road projects with greather impact in terms of economic growth were analyzed to examine the technologies and materials used in the pavements(flexible pavements), namely:

• Rehabilitation of the road between Lém Ferreira and the port of Praia - Santiago Island

• Design of the road between the city of Praiaand Cidade Velha.

2.2.1.1 Design and rehabilitation of the road between Lém Ferreira and Port of Praia-Santiago Island

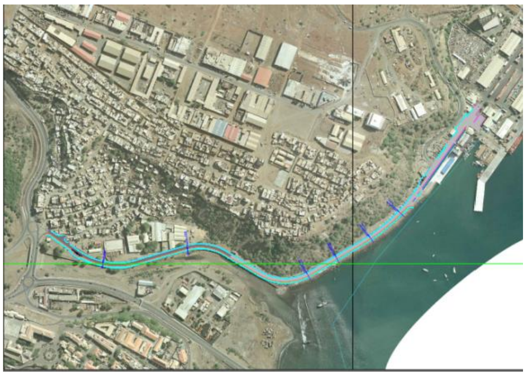

Figure 2.4: Extension of the road between Lém Ferreira and Port of Praia

This road existed already, and it was a basalt stone pavement.
On this rehabilitation, two solutions were used. On the first solution, the existing pavement was totally removed and replaced with a new flexible pavement. On the second solution the existing pavement was reused as a base for new asphalt concrete wearing course..
For the first solution, the existing ground was excavated, regraded and compacted. For the sub-base and base layers a 20 cm layer crushed aggregate (coarse aggregate) were used. On top of the base layer a prime layer was used to provide adherence to the wearing course. For wearing course a 5 cm thick asphalt concrete was used.

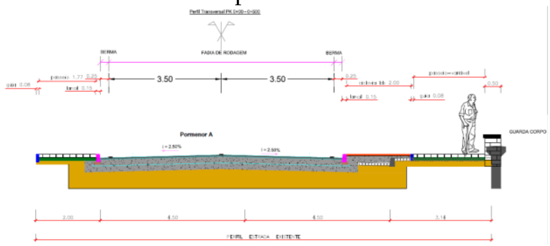

Figure 2. 5: Cross section of the new solution adopted

The second solution, shown in Figure 2.6 below, differs from the previous because the existing was not removed. It was reused as base for the wearing course. This solution does not consider the sub-base and base layers..

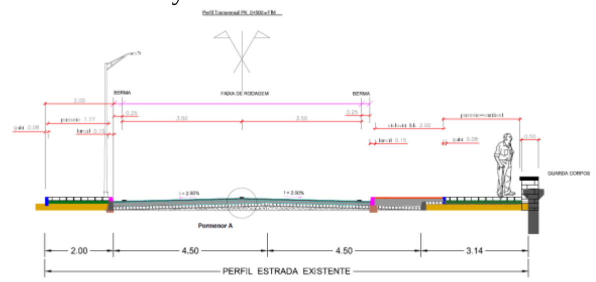

Figure 2. 6: Cross section of the second situation of rehabilitation of the road section Lem Ferreira- Port of Praia

2.2.2. Design of the link road of between the city of Praia City link and Cidade Velha

This is a road project with 10 km of extension, starting at Km 0 + 000 (at São Martinho junction) and ending at Km 10 + 300 right at
Caniço (Cidade Velha). The road works started in March 2012 and and the road open to traffic in July 2013.

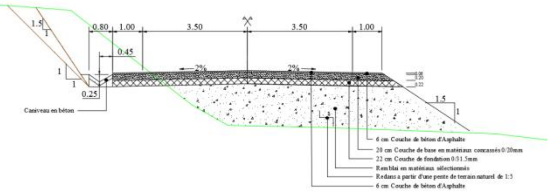

Figure 2. 7: Profile Cross Type – Cidade Velha road section

After the completion of the ground investigation the design software Ecoroute was used to determine the pavement structure. The following structure was adopted:

- Base layer of asphalt concrete 0/10 (6 cm)
- Base layer of crushed gravel 0/20 (20 cm)
- Layer Foundation in gravel crushed 0 / 31.5 (22 cm)

2.3 Basalt stone pavement and the materials used in its design

2.3.1. Structure of a stone pavement

For the structure, the pavement can be rigid or flexible, depending on the foundation layer (Figure 2.8).

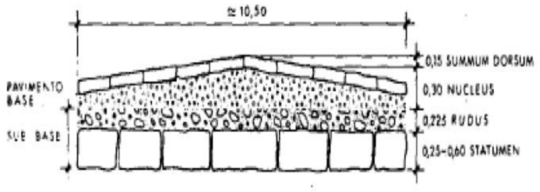

Figure 2. 8: pavement old structure with basaltic stone

Basalt stone pavement are very common in Cape Verde. One of the road projects were this type of pavement structure was used was the Rehabilitation of National Highway - EN3-SN02 RIBEIRA BRAVA / Juncalinho – São Nicolau Island

2.3.1.1. Rehabilitation of National Highway-EN3-SN02 Ribeira Brava/Juncalinho

The heavy rains that occurred on October and November 2009, caused considerable damages to the road network on São Nicolau island. One of the roads affected and that was rehabilitated was the road that connects Ribeira Brava to Juncalinho. In Figure 2.9 it is possible to see the road that was submited of rehabilitation works:

Figure 2. 9: Map of the Island of São Nicolau and its intervention villages (Instituto de Estradas de Cabo Verde, 2010)

The pavement solution consist of:
• Base layer with 0.20m thickness of crusher run;
• gravel layer with a thickness of 0.10 m;
• Basalt stone pavement.

The typical cross-section of the track, shown in Figure 2.10, consists of a carriageway with two lanes of 3.00m, a side drain of 0.50m and a road shoulder of 0.5m on both lanes, for a total width of 8,00m.

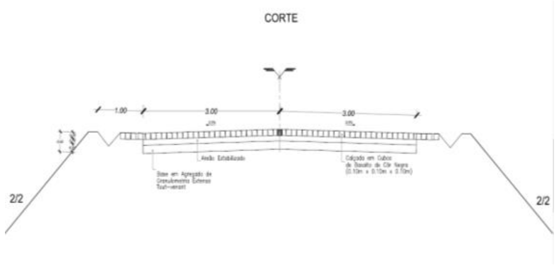

Figure 2. 10: Profile cross-sectional – São Nicolau Island (Cape Verde Roads Institute, 2015)

3. Analysis of proposed paving technologies and their feasibility in Cape Verde

New alternatives were compared to the methods commonly used to asses if they can be used in Cape Verde for the design of road pavements. For this propose, the SATCC manual (Southern Africa Transport and Communications Commission, SATCC, 1988- Code of Practice for the Design of Road Pavements) was used.

3.2. SATCC

The manual SATCC - Draft Code of Practice for the design of Road Pavements (1998) includes a catalogue of pavement structures with alternative pavement solutions. The pavement structures are designed depending on the traffic, the class of foundationand climatic conditions. The SATCC design catalogue is used for roads with less traffic than 30 million ESA (standard axles equivalent) of 80 kN.

3.3. Structural design methodology

The design process in this manual is divided in five stages:

- Estimated cumulative traffic expected during the design working life of the pavement.

The pavement design process requires the estimation of the average daily number of ESAs on one lane at the opening of the new road to traffic, which is then projected and cumulated over the design period to give the design traffic loading.The pavement structures suggested in this guide are classified in various traffic categories by cumulative ESAs expected. It is assumed that traffic growth will be in a range between 1% and 3% per year. Considering for a pessimistic forecast a growth rate of 1% per year with small growth of traffic, and a design working life of 15 years, the T1 class is adopted, with 0.12 million standard axles for prediction of traffic (light vehicles). For a more realistic and optimistic forecast, with growth rate of 3% per year and a high traffic growth, also with design working life of 15 years it is adopted the T5 class with 3.1 million standard axles.

- Definition of the foundation strength (soil) on which the pavement will be built

This section focuses on the classification of the sections in terms of the California Bearing Ratio (CBR) to represent realistic conditions for design. In practice this means determining the CBR strength for the wettest moisture condition likely to occur during the design life, at the density expected to be achieved in the field

The results of geotechnical investigations for the road in Cidade Velha show the predominance of CBR between 5 and 7%, represented by class S3.

- Definition of climate conditions

The SATCC manual distinguishes specific pavement structures for wet and dry regions, which are defined according to the average annual precipitation-Cape Verde was considered to be included in a dry region (average annual temperature of 25ºC and average annual precipitation of 230mm/year).

- Pavement design life selection

The design life is the period during which the road is expected to carry traffic at a satisfactory level of service, without requiring major rehabilitation or repair work. It is implicit, however, that certain maintenance work will be carried out throughout this period in order to meet the expected design life.

- Selection of possible pavement structures that will be addressed in the next subchapter

3.3.1. Characterization of the models for Bisar 3.0 software use

The Bisar software loading models adopt only allows a uniform contact pressure, applied to a circular area with uniform time distribution, that is, does not account for the dynamic character of the load. In Figure 40 one can observe an outline of treating floor structure with reference to the quantities which have to be made for calculating the stress-strain state: h layer thickness in m; [and so on].

The main stresses usually analysed in the design of a flexible pavement are:
• Horizontal tensile strain at the bottom of asphalt layers - Fatigue criterion of bituminous mixtures
• Vertical compressive strain on top of the foundation layer - criterion of permanent deformation.
• If applicable, in case of materials stabilized with cement, horizontal tensile strain at the bottom of the layers with these materials - Fatigue criterion for mixtures stabilized with cement.

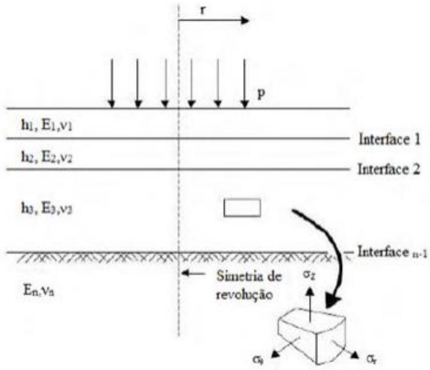

Figure 3. 1: Pavement structure treatment Scheme (FUNDEC-IST, 2014)

The study of the fatigue behaviour, relates the maximum tensile strain induced in the number of load applications leading to ruin the material by this failure criterion.
Fatigue law proposed by the method of AUSTROADS is applied to layers bonded with cement. This model can be expressed by equation 3.1 as follows:

$$N = r(\frac{k}{\mu\varepsilon})^{12} \qquad [3.1]$$

in which:
N is the number of repetitions of allowable load;
K, reliability anáçise fatigue;
με, tensile strain in the base layer;

The law of fatigue proposed by Shell, is one of the most known and used. The design working life of a bituminous layer to fatigue is function of the strain level, of the bitumen content and of the elastic modulus. This model can be expressed by equation 3.2 as follows:

$$\varepsilon_z = (0{,}856 \times V_b + 1{,}08 \times E^{-0{,}36} \times N^{-0{,}2} \quad [3.2]$$

In which,

N is the number of standard axle loads until the occurrence of failure by fatigue;
Vb, bitumen content by percentage voulme;
εz, horizonta/radial microstrain;
E- Elastic modulus of bituminous mixture [Pa].

The criterion for failure by permanent deformation (Shell Method) is expressed by the relationship between the vertical compressive strain, measured on top of the foundation layer, with the number of standard axles (N) according to the following expression 3.3:

$$\varepsilon_z = K_s \times N_{80}^{-0,25} \quad [3.3]$$

at where,
ε(z) is the vertical compressive strain on top of the foundation soil;
N80, the number of standard axles;
Ks, the parameter that depends on the probability of survival, and its value is given by:

$$\text{Ks} = 1,8 \times 10^{-2}$$

3.3.2. Materials characterization at structural evaluation of pavements

For the characterization and study of the solution to be implemented by the software Bisar 3.0, it is necessary to define the materials that will be part of the surface.

It was admitted for the city of Praia, capital of the country, an optimistic forecast, considering the growth rate of 3% per year for the traffic. It is presented in Table 3.1 below the other values used to start the design of the new pavement structure:

Table 3. 1: Foundation soil characteristics and foundation class for optimistic solution

Class of Foundation soil	S3	CBR=6% ν=0,35 E= 55 Mpa
Traffic class (SATCC, 2011)	T5	eixo de 80KN (15 anos) N80: $3,06 \times 10^6$

For the foundation soil it is used an empirical formula for estimating the elastic modulus given by equation 3.4:

$$E = 17,6 \times CBR^{0,64} \ [3.4]$$

Where CBR is the California bearing ratio (percent value)

For layers of granular soils recourse to the forward formulas given by equation for deformability module:

$$E_{granular} = K \times E_{subj}$$
$$K = 0,2 \times h^{0,45}$$

For the layers stabilized with cement it is used the recommendation of AUSTROADS [Design and Consevação of Pavements, Picados Luis Santos] for the elastic modulus for bases and sub-bases treated with cement. It was assumed for the base layers and sub-base 3% - 4% binder material (cement) so that it can be seen from Table 11.3 that the value of the deformability modulus is 2000 MPa adopted.

. For the wearing course layer, considering the use of bituminous mixtures, it is determined by the Shell method the value of the elastic modulus. Below, the expression used:

$$E = 10^A$$

Considering for the case study, the deformability modulus of 2413 MPa for the entire thickness of bituminous mix because it is believed to be necessary to use a kind of AC20 (for basic) and thus simplifies the calculation (instead of considering the analysis two layers, base longer, it is considered one).

3.3.3. Solutions for structure of Pavement evaluated

3.3.3.1. Case 1 (Flexible Structure/semi-rigid)

This case corresponds to the solution proposed by SATCC catalogue shown in Figure 3.2. It is used stabilized soil cement (SC) in the base and sub-base with a double surface treatment (SD double seal) as wearing surface and all over a selected layer of soil (SS), as shown in Figure 3.2, where it is also indicated the elastic modulus and thickness for each layer.

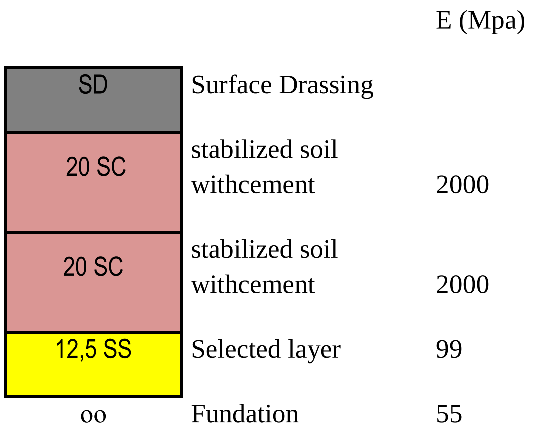

Figure 3. 2: 1st attempt to case 1

3.3.3.2. Case 2 (Flexible Structure/semi-rigid reverse)

This case corresponds to the solution proposed by SATCC catalogue shown in Figure 3.3. It is used crusher runin the base layer and stabilized soil cement (SC) in the sub-base with a double surface treatment (SD) as wearing surface and all over a selected layer of soil (SS), as shown in Figure 3.3.

SD	Surface dressing	
15 ABGE	ABGE	500
25 SC	stabilized soil withcement	2000
15 SS	Selected layer	105
oo	Fundation	55

Figure 3. 3: 1st attempt to case 2

3.3.3.3. 3 (Flexible Structure)

The third and last structural solution is considered the most common and usual with regard to flexible pavements. The proposal made by SATCC catalogue consists of a pavement with an asphalt concrete wearing course and two granular layers (crusher run) as subbase and base layers, as can be seen in Figure 3.4. In order to obtain an optimized solution, like on the previous solutions, several attempts have been tested / iterations through the Encore program, changing some variants to the method of Shell.

5 BB	Hot mix asphalt	2413
20 ABGE	ABGE	311
30 ABGE	ABGE	143
oo	Foundation	55

Figure 3. 4: 1st attempt to case 3

For the three cases several iteration were performed on the software, changing thicknesses of the layers, mechanical characteristics of the materials or removing some layers in order to find an optimal solution for each case.

3.3.4. Conclusion on structural solutions

The solution 1 for the first attempt with 95% confidence, the pavement structure was over-designed as the values for damage due to fatigue reached only 4% and 3% damage due to permanent deformation.

For the 2nd, 3rd and 4th iterations it was observed that that the proposed solutions exceed the acceptable limits. Thus, it was possible to conclude that the proposed structures do not support the considered loads for the time spanconsidered, not being therefore viable structures.

On the fifth and last iteration the elastic modulus of layers of soil cement was increased to 2500 MPa, as it is assumed a material of less quality, thereby increasing the proportion of cement in the soil (up to 4.5%) and consequently increasing the elastic modulus.

Note that the increase in cement soil characteristics of the 2nd attempt led to a solution that, a priori, it would be good practice due to poor fatigue behavior of the cross layer to be an acceptable solution, with a rate of 100% fatigue damage to the useful life of the road. Although this solution is not an optimum solution, since this range of values is not between 60 to 80% damage, or reaches the end of life of the floor with a damage 60 to 80% of the structure, this constitutes a good approximation of what is intended to analyze, considering so this as the best solution found. Proceeds to the analysis of the case 2, consisting of soil-cement layer, granular layer ABGE, selected soil and surface coating.

For the case 2 it was possible to observe that for the first attempt, and for a reliability of 95%, these values are much greater than the desired percentage, which leads us to conclude that solution is infeasible, giving damages about 2000%, or is the structure does not support the loads to which it is subject.

The second attempt is the solution best adapted to the characteristics required by this solution. With damage to the fatigue of 67% and damage to permanent deformation of 23%, this presents, not a great solution, but considered rather interesting technological point of view.

The third attempt is to add another layer SC at the second attempt. This has lower damage as would be espectável.

Given the presence of soil stabilized with cement, similar to the first structural solution, the fourth attempt is to alter the proportion of cement in relation to its incorporation third attempt, causing the deformability modulus increases to 2500MPa.

Although the damage associated with this new attempt have decreased considerably to about 300% to fatigue, this solution is not feasible.

The third and final case, it is possible to observe that the sixth attempt is the only solution that respects the ruin of criteria to fatigue and permanent deformation, with 74% and 37% respectively, while the remaining go beyond the acceptable values. Recall that this structure is the most common in Cape Verde, not necessarily the cheapest nor the most efficient. Although ruin criteria are closer to the range of values that you want, consider a bituminous concrete layer 13cm thick is not the most common in Cape Verde. In general, wear layers 5 to 8 cm are most frequently used, but it is also observed that, although not verify the destruction of the flooring, pavements reaching the end of its useful life without the need for intervention because its inability to withstand the loads they are subjected to the effect of rain and not least the high temperatures to which they are subject.

3.4. Cost analysis of paving proposals

A cost analysis was performed for all the proposed solutions. The analysis was based on established costs for the Portuguese realityw which is a fairly good approximation to the Cape Verdean reality, although for Cape Verde it should be considered additional costs for the import of the materials, especially the bitumen.

The following prices, shown in Table 3.3, were considered for the analysis :

Table 3.3: materials price list for paving employed in Portugal

Materials	Measuring unit	Cost
Selected soil	€/m²/15cm	1,80€/m²/15cm
Granular layer (ABGE)	€/m²/20cm	4,00€/m²/20cm
Granular (ABGE) layes stabilized with cement	€/m²/20cm	4,80€/m²/20cm
Surface dressing	€/m²	2,5€/m²
BB (hot mix asphalt)	€/m²/cm	1€/m²/cm de espessura

For the 1st solution proposed, composed by 15m layer of selected soil, a 30cm layer of soil cement, divided in two layers of 15cm and by a wearing course with double surface tretment, the associated costs are 14,0 €/m², equivalent to 1540 ECV (Cape Verdean currency)

For Case 2, this is constituted, by double surface coating, granular layers, soil-cement layers and selected soil. the second proposed solution has a total cost per square meter of 14.8 €, equivalent to 1628ECV.. As can be seen, there was an increase in the cost of the solution from the previous solution.

In case 3, it can be observed that the cost associated with this structural solution is 19 € / m², corresponding to 2090 ECV.

By comparing with previous proposals it can be verified a considerable increase on the costs associated with this solution, which was expected, considering the thickness of the asphalt concrete layer of this solution. It is possible to concludethat the granular layers are less expensive when compared to asphalt concrete layer.

4. Conclusions

Figures 3.5, 3.6 and 3.7 below indicates the percentage of material used in terms of costs associated to the proposed solution. It can be seen , for the case 1, that 33% of the total value of this proposal is due to the surface dressing and 47% due to layers bonded with cement.

For the case 2 and observing the figure 3.6 it can conclude that in terms of costs, layers stabilized with cement and the surface dressing layer have the highest percentage of the total cost of the solution.

Finally, it is also possible to observe by the figure 3.7 that for the case 3, 68% of the cost of this solution is due to the hot mix asphalt layer.

The results and comparative analysis of pavement structures considered, showed that the stabilized soil solutions have the potential to replace the more traditional pavement, "BB" type, providing better results when we compare of cost, simplicity of execution and ability to withstand the loads imposed .

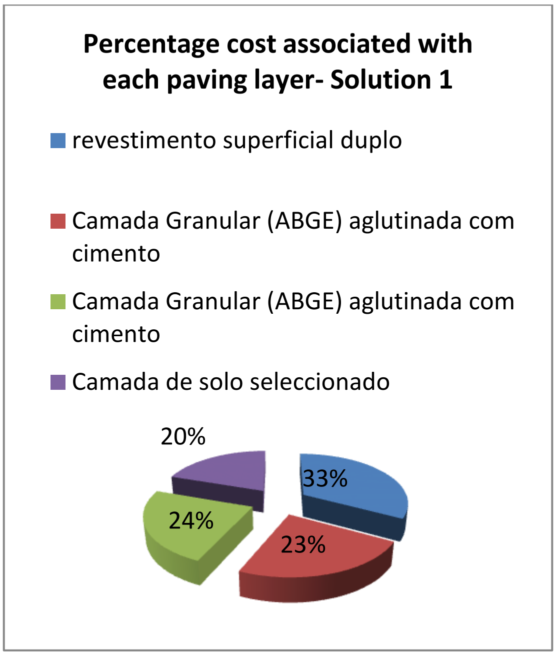

Figure 3. 5: Percentage cost associated for case 1

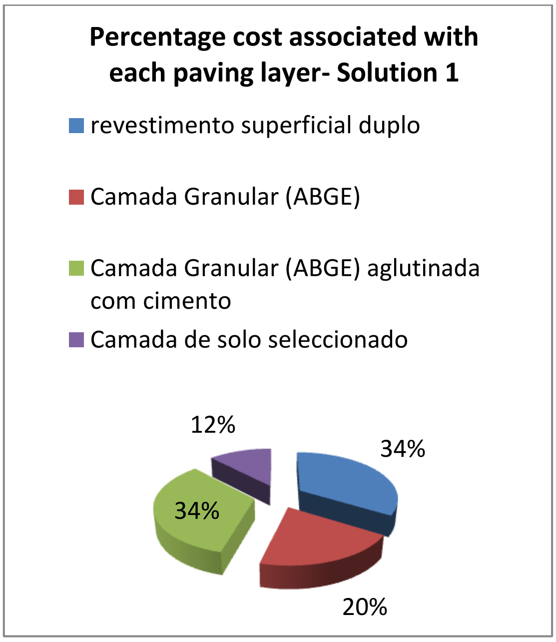

Figure 3. 6: Percentage cost associated for case 2

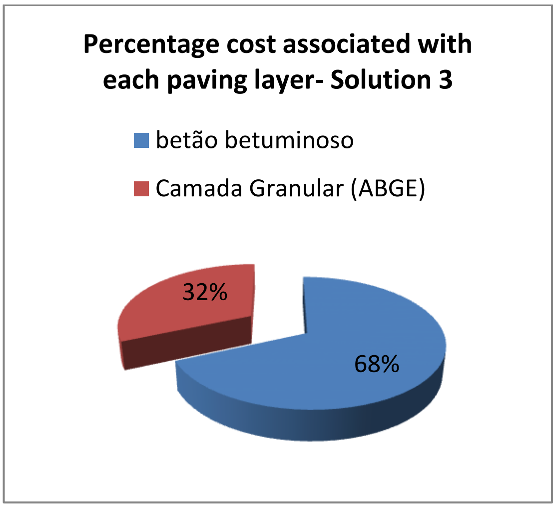

Figure 3. 7: Percentage cost associated for case 3

The results and comparative analysis of pavement structures considered, showed that the stabilized soil solutions have the potential to replace the traditional pavement, "BB" type. It was observed that, besides having solid structural behavior, the soil solutions stabilized with cement to wear layer surface implies lower costs, under specified conditions, to fix the bracket identified as critical traffic.

At figure 3.8 it is possible to observe de total costs of each case studying .

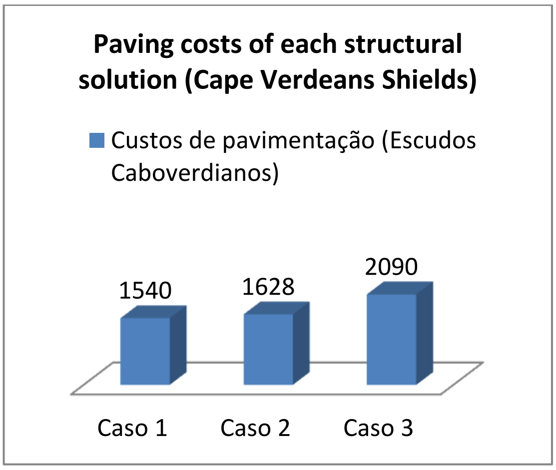

Figure 3. 8: Total costs per square meter of each case

Therefor, it is necessary to reinforce the fact that the technology for the production of stabilized soil depend largely on the type of soil available. So, is required a more consistent validation in particular on the behavior of these with actually available materials and also with regard to the development of pathologies that may not be compatible with the service required by certain routes.

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