Modern Civil Engineering (ISSN 2470-4180)
March 2025, Volume 5, No. 1-3, pp. 48-56
Doi:10.15341/mce(2470-4180)/01-03.05.2025/006
Academic Star Publishing Company, 2025
www.academicstar.us

Importance of Considering the Influence of Temperature in the Structural Design of Flexible Pavements

Josefa Rombe A., and José Diogo B.

Polytechnic University, Paulo Samuel Kakomba, 913, Mozambique

Abstract: Flexible pavements are the most verified type of structures in Mozambique. These, which have too many pathologies, which makes their good performance questionable. The presence of these negatively affects the road mobility of people and goods, a fact that contributes to large losses in the general economic scope of the country. With the repeated passage of the wheelsets combined with the viscoelastic characteristic of the flexible pavement, it is verified that after the removal of the load on it, the pavement does not fully recover its initial position. This phenomenon is called creep, defined as a slow and progressive deformation of the material when subjected to constant stress, in which the deformations grow over time even under a non-variable load. The objective of this research is to eliminate the pathologies that occur in flexible pavements in Mozambique, demonstrating that the effect of temperature should be considered in the calculation of pavement sizing. In the present work, the scope of the problem is directed through the hypothesis that the lack of consideration of the viscoelasticity phenomenon in the analysis of flexible pavements, underestimates the stresses and strains actions required in the structural calculation. In this study, two analysis models are adopted for the simulations, in which the first is the elastic A-linear model, which assumes all layers as elastic linear and the second, as the B-viscoelastic model, which admits the first layer as viscoelastic and the remaining linear elastic. For this purpose, in the study a methodology was adopted based on the results of the deformations of the simulations carried out for each model, in the case of the study of the road construction project in section 1 - Maputo By Pass, Maputo ring road, whose results demonstrated the existence of a strong correlation between the temperature effect and the excessive deformations during the analysis of model pavements. Each model was made up of 6-layer structures, and each structure was considered to have a double circular wheel-loaded area, the sensitivity parameters of the pavement materials, such as load, tire contact pressure, Poisson coefficients and modulus of elasticity, were also considered. From the simulation made with the help of the KENLAYER program for the two pavement models, it was revealed that: Model A — Elastic linear pavement admits low surface stresses in relation to Model B — viscoelastic pavement, both models showed that both the stresses as well as the deformations, decrease as the depth increases and being higher in the positions of load location.

Key words: floors, viscoelasticity, temperature variation

1. Introduction

The theory of the effect of the influence of temperature on the design of flexible road pavements is presented with the combination of two types of actions, temperature and traffic, which results in the accumulation of damage on a road pavement. The purpose of considering the temperature in the bituminous layers and the heavy traffic in the design of flexible road pavements is to simulate the real behavior of the pavement, in order to better define the demands to be considered for the design of this pavement, in order to mitigate the early appearance of pathologies in them.

The viscoelastic model, lately, is more accepted in relation to the theory of the elastic linear model in the analysis of deformations and stresses in pavements, because, although it also considers that the material deforms immediately with the application of loading, this theory considers that the pavement does not return

Corresponding author: Josefa Rombe A., Ph.D. Candidate; research areas: pathologies in road pavements. E-mail: vanguir90@gmail.com.

to its original state when this loading is removed. This theory allows a better approximation to the actual performance behavior of road pavement during the service period.

2. Material and methods

2.1 Type of Flooring Under Study

The use of bitumen as a material for bituminous pavement mixtures began in the United States in 1896. The use of bitumen for the preparation of the surface coating layer occurred after the decision to use it as an alternative solution for repairing a rigid pavement that showed early deterioration. The structural strength of flexible pavements is given by the different layers that constitute it, as well as the materials used, in which strength and rigidity are fundamental [1]. The pavement is composed of a coating or sealing layer, base, sub-base, reinforcement of the subgrade, regularization of the subgrade and subgrade as shown in Fig. 1.

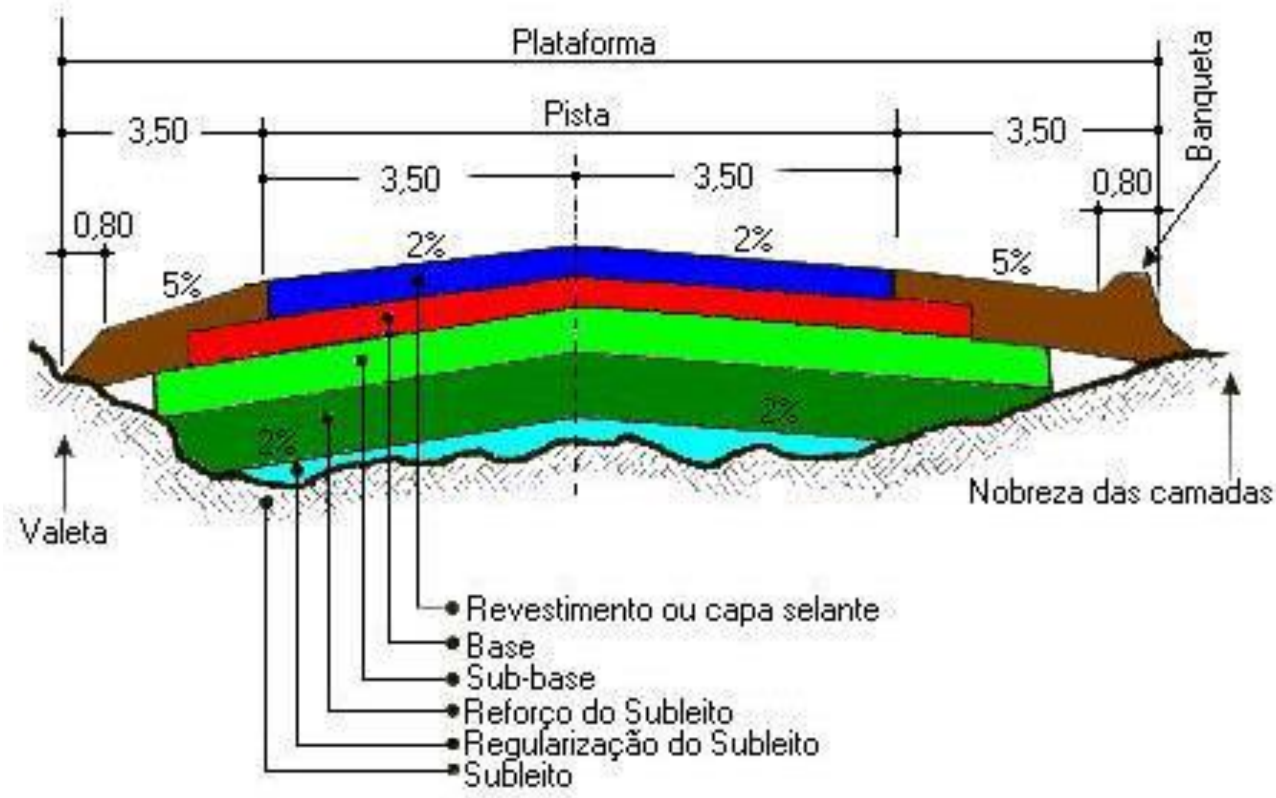

Fig. 1 Flexible pavement structure – Source: Merighi (2004).

2.2 Poisson Coefficient

The mechanistic approach to pavement design requires information on the Poisson coefficient. During the modulus of resilience test, the lateral and axial strains in the specimen can be measured and consequently the Poisson coefficient indicated in Eq. (1) can be determined. The ratio between lateral deformation and axial deformation for a load applied in the axial direction defines this coefficient, i.e.:

$$\mu = -\frac{\varepsilon_l}{\varepsilon_a} \tag{1}$$

2.3 Modulus of Elasticity

The modulus of elasticity of a material is a mechanical characterization of the material, obtained in the triaxial test of repeated loads, which defines the relationship between the applied deviation stress and the recoverable or resilient deformation. This test seeks to reproduce the field conditions, where the specimen is subjected to a compressive stress (σ_1) and a confinement stress (σ_3). When the sample is subjected to successive loading and unloading, it deforms, thus obtaining recoverable deformations (ε_r). With this value and the deviation voltage (σ_d), the resilience modulus (*MR*) is obtained, which translates the capacity of the soil to return to its initial situation after being subjected to a load. By definition, the modulus of resilience (*RM*) is defined by the following Eq. (2) below:

$$MR = \frac{\sigma_d}{\varepsilon_r} \tag{2}$$

Where:

σ_d = repeated voltage deviation;

ε_r = recoverable or resilient deformation corresponding to a certain number of applications of σ_d

2.4 Temperature in Floors

According to Santos (1995) [2], in flexible road pavements, there is a combination of two types of actions, temperature and traffic, which results in the accumulation of damage to a pavement. Road. The purpose of considering the temperature of bituminous layers and heavy traffic in the design of flexible road pavements is to allow a better approximation of the actual performance of the road pavement during the service period.

According to Lakes (1999), the effect of temperature is considered in the resistance to permanent deformation of bituminous mixtures. A basic characteristic of viscoelastic materials is called creep, which is a slow and progressive deformation of the material when subjected to constant stress, that is, the deformations that grow over time even under a non-variable load. There is a validated method for calculating pavement temperature distribution, which is based on the relationship between air temperatures and pavement temperatures. According to Diogo (2007) [3] & Citing Huang (2004) [4], the calculation of pavement temperature can be done by Eq. (3).

$$Mp = Ma \times (1 + \frac{1}{Z+4}) - \frac{34}{Z+4} + 6 \tag{3}$$

2.5 Theory of the Elastic Linear Model

According to Portela (2011), this model is still one of the most used to deal with the stress-strain relationship in asphalt coatings. This is basically due to its simplicity and easy application. This model is based on the idea that the material deforms immediately with the application of loading and returns to its original state when this loading is removed. The model is governed, in one-dimensional form, by Hooke's Law given by Fig. 2 and can be well used for small deformations of materials:

$$\sigma = E\varepsilon \tag{4}$$

Where:

σ = represents elastic tension;

E = the modulus of elasticity;

E = elastic deformation.

2.6 Theory of the Viscoelastic Model

The linear viscoelastic model has been widely used in the characterization of asphalt mixtures [4] due to the good correlation obtained between the theory and the laboratory tests (Soares & Souza, 2002). Asphalt mixtures, when subjected to not very low temperatures, can have their behavior satisfactorily

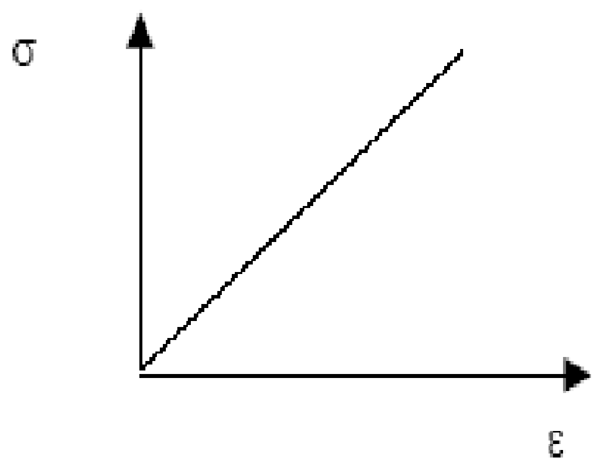

Fig. 2 Elastic linear behavior (Rocha, 2010).

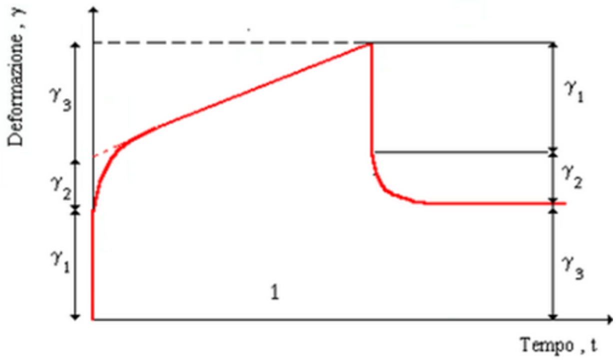

Fig. 3 Viscoelastic behavior (Rocha, 2010).

represented by the theory of viscoelasticity [5]. When these mixtures are present in the linear viscoelastic phase, the Time-Temperature Superposition Principle (Shames & Cozzarelli, 1997; Lakes, 1998; Roylance, 2001) is applicable and the material can be considered thermo-rheologically simple.

The theory of the effect of the influence of temperature on the design of flexible road pavements, is presented with the combination of two types of actions, temperature and traffic, which results in the accumulation of damage on a road pavement. The purpose of considering the temperature in the bituminous layers and the heavy traffic in the design of flexible road pavements is to simulate the real behavior of the pavement, in order to better define the demands to be considered for the design of this pavement, in order to mitigate the early appearance of pathologies in them.

The theory of viscoelasticity in flexible pavements, lately, is the most accepted in relation to the elastic linear theory in the analysis of deformations and stresses in pavements, because, although it also considers that the material deforms immediately with the application of loading, this theory considers that the pavement does not return to its original state when this loading is removed. This theory allows a better approximation to the actual performance behavior of road pavement during the service period.

2.7 Case Study

2.7.1 Presentation of the Case Study

The Maputo By Pass — Maputo Circular project is located in Maputo, in the south of Mozambique, whose total length is about 79 km. Section 1 of the Maputo By Pass project, about 6.125 km long, is located on Avenida da Marginal, characterized as flexible pavement. Fig. 4 shows the section corresponding to the object of study. Section 1 starts from the Radisson hotel and ends at the Costa Do Sol Bridge, as shown in Fig. 4.

Fig. 4 Satellite image showing the longitudinal profile of the area located in section 1 of the Maputo by Pass Project.

This project consists of the construction of a ring road in order to make the areas covered by the project more accessible, in order to decongest vehicle traffic in the city of Maputo. The state of conservation of the indicated road, in 2012, before the intervention, was in an advanced state of degradation, and to improve its condition, the Mozambican government decided to requalify this section and launched a project that in the same year culminated in its construction in order to connect Maputo with the National Road that ends in the north of the country.

2.7.2 Pavement Structure Models and Sensitivity Parameters

To analyze the pavement response, two pavement models were proposed, each model consisting of a 5-layer structure as shown in Fig. 5. For the first model, the asphalt layer is simulated as linear elastic and in the second model as viscoelastic. The entire structure was considered to be an area carried by double circular wheels. The sensitivity parameters of the flooring materials are shown in the figures themselves. The load on each wheel is 20 KN and the contact pressure of the tyres is 520 KPa (Theyz et al., 1996). The moduli of elasticity or moduli of resilience are calculated by the form (Yoder & Wiczack, 1975), indicated in Eq. (5).

$$E(MR) = 10.3 \times CBR \qquad (5)$$

Where:

E(M)→ Modulus of elasticity or resilience Mpa;

CBR → California bearing ratio, from CBR tests.

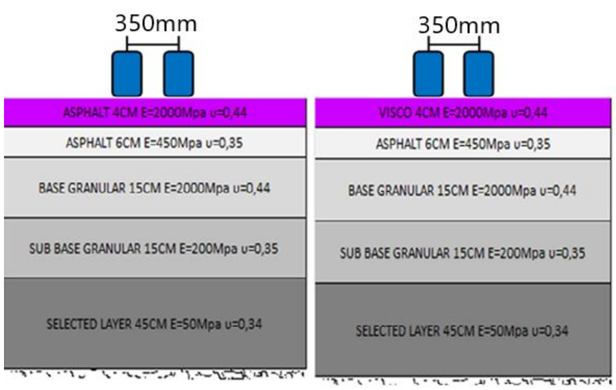

Fig. 5 Linear and viscoelastic pavement structure.

The following simulation is done using the KENLAYER program [4] in order to determine the deformations of the pavement foreseen in this study. The pavement under study consists of 5 layers, the first being asphalt and the rest granular.

2.7.3 Determination of Permanent Deformation in Pavement

According to Diogo (2007) (citing Lytton, Uzan, Fernando, Hiltunen, Roque & Stoffels 1993), to date, most research on the estimation of permanent deformation in asphalt pavements has been based on a layer displacement approach, and in a way dependent on the viscoelastic property of the asphalt material. The total deformation in the asphalt pavement can be calculated by the equation below and is defined as the sum of deformations of individual layers along the entire depth.

$$RD_{total} = RD_{AC} + RD_{B} + ... + RD_{SG} \qquad (6)$$

Where:

RD → permanent deformation of the pavement;

RDAC, RDB, RDSG → are permanent deformations for the asphalt, base and subgrade layers, respectively.

3. Results and Discussion

From the simulation carried out with the aid of the KENLAYER program we can verify the following results:

3.1 Stress Analysis

For both linear pavement models (Fig. 6), which assumes the first elastic linear layer and the viscoelastic model (Fig. 7), which assumes the surface layer of asphalt as viscoelastic and the remaining linear elastic; Stresses decrease as the depth increases and is higher at the surface.

a) Stress analysis:

For both linear pavement models (Fig. 8), which assumes the first elastic linear layer and the viscoelastic model (Fig. 9), which assumes the surface asphalt layer as viscoelastic and the remaining linear elastic;

Stresses decrease as the depth increases and is higher at the surface.

b) Deformation Analysis:

For all linear pavement models (Fig. 6 and Fig. 8), which assumes the first layer of elastic linear and the viscoelastic model (Fig. 7 and Fig. 9), which assumes the surface layer of asphalt as viscoelastic and the remaining linear elastic, the same phenomenon is repeated for deformations that decrease as the depth increases and is higher on the surface.

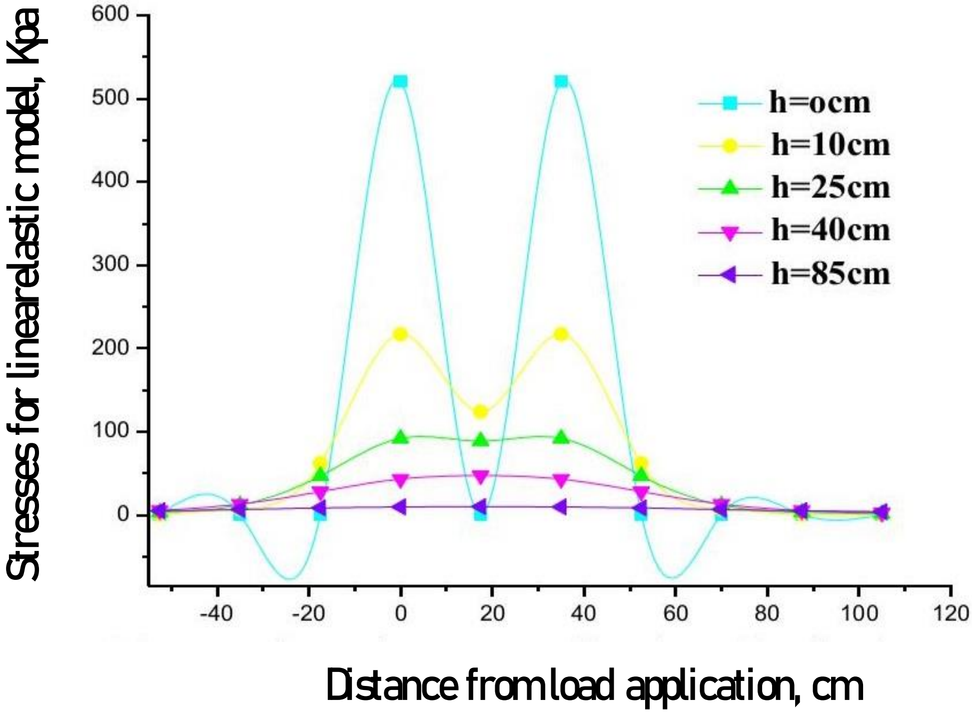

Fig. 6 Tensions - linear model.

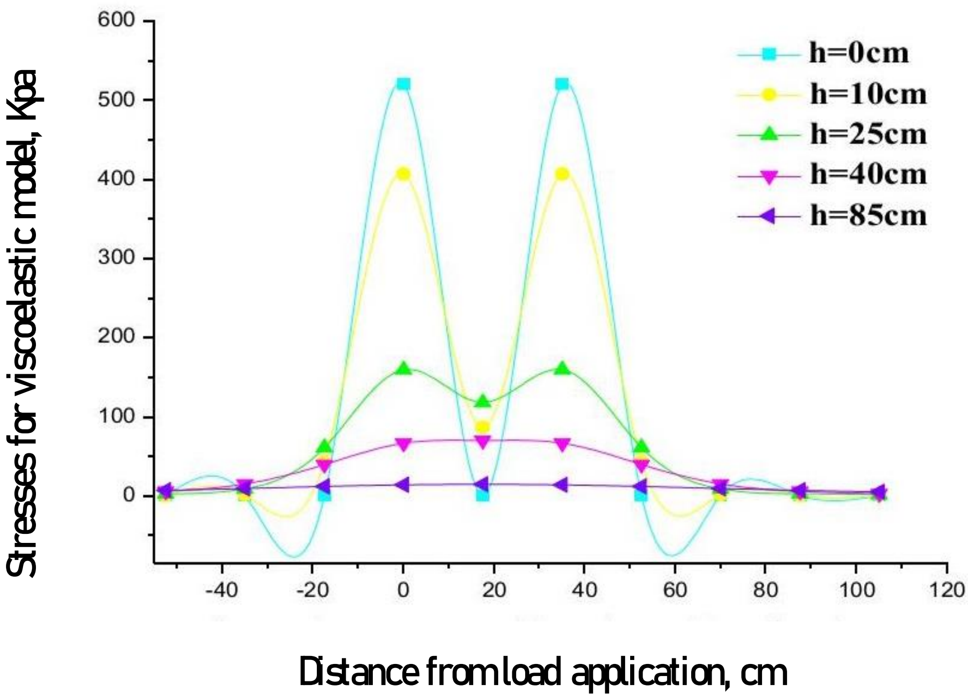

Fig. 7 Tensions - viscoelastic model.

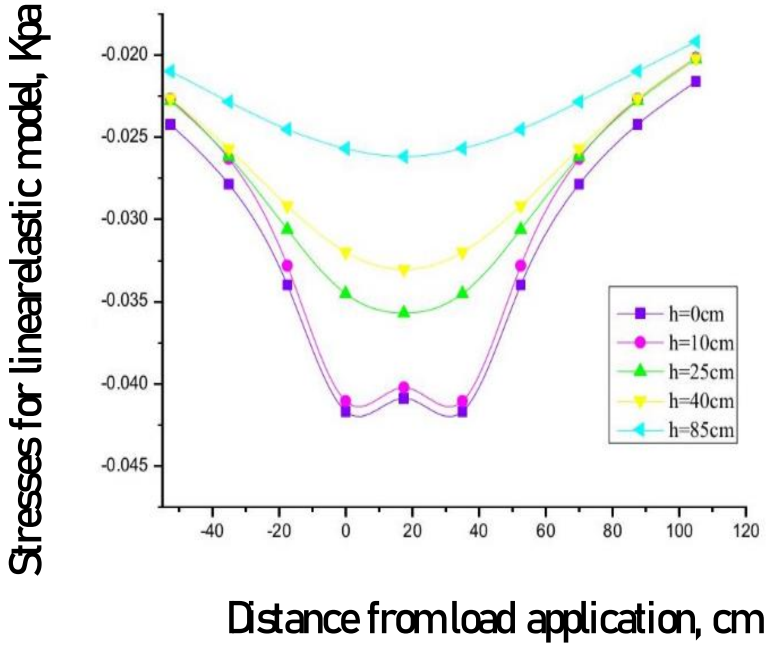

Fig. 8 Deformations - linear model.

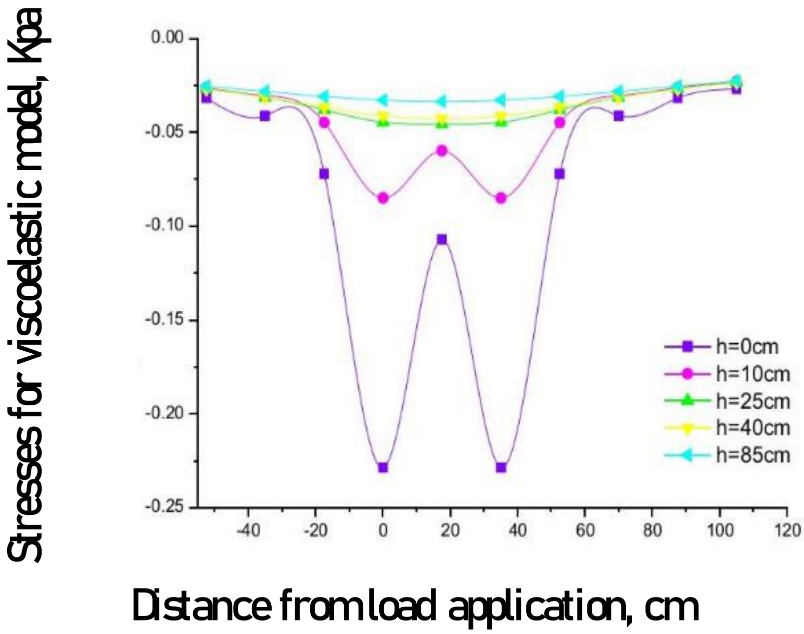

Fig. 9 Deformations - viscoelastic model.

3.2 Comparative Interpretation of Responses in the Linear and Viscoelastic Pavement Model

The comparative evaluation aims to demonstrate the responses of the pavements generated by the simulation carried out by the KENPAVE program, for two models, elastic and viscoelastic model. From the comparison of the deformation results for the linear elastic and viscoelastic models, according to the results of the simulation for the surface layer of asphalt in Fig. 10 and the results presented in Table 1, it is noted that the linear elastic model admits lower deformation values than the viscoelastic model, due to the lack of consideration of the temperature effect that affects the viscous asphalt layer in the design of the pavements. Under these conditions, it is validated that in asphalt pavements the effect of viscoelasticity is always present and should be considered for the present case of projects built in southern Mozambique.

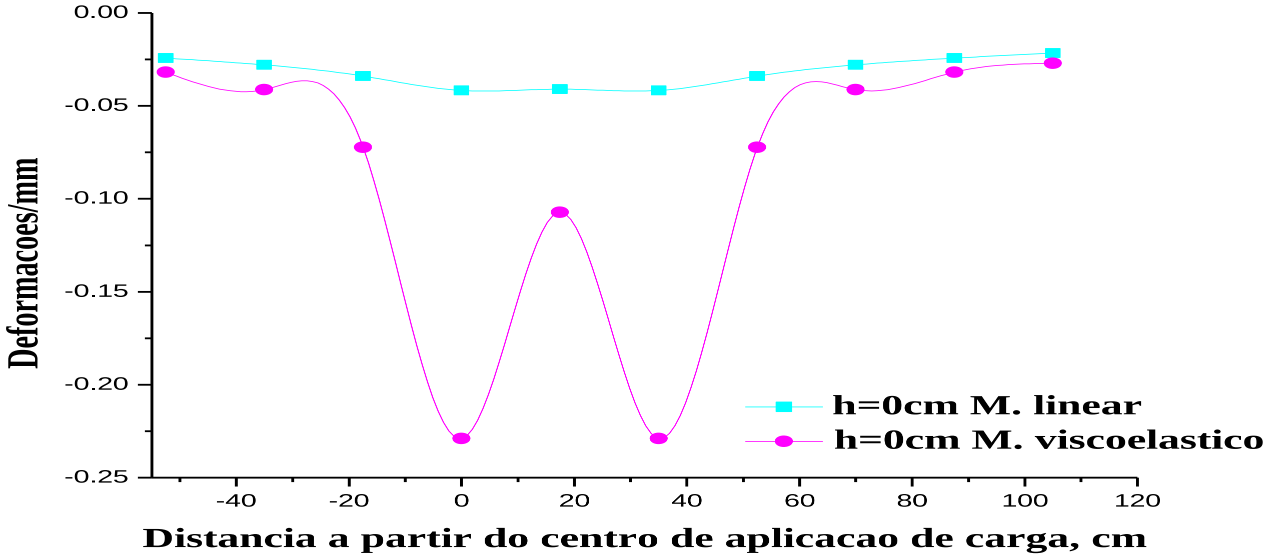

Fig. 10 Comparative graph of deformations for the models, linear and viscoelastic, for h = 0 cm.

Table 1 Results obtained from the simulations made to the pavement through the KENLAYER program, analysis made at the point of the load application center.

Coord x (cm)	Deflections									
	Z = 0 cm		Z = 10 cm		Z = 25 cm		Z = 40 cm		Z = 85 cm	
	Linear model	Visco model	Linear model	Visco model	Linear model	Visco model	Linear model	Visco model	Linear model	Visco model
-52.5	-0.02426	-0.03181	-0.02273	-0.02635	-0.02282	-0.02691	-0.02269	-0.02707	-0.02102	-0.02554
-35	-0.02789	-0.0413	-0.02635	-0.03064	-0.02621	-0.03151	-0.02574	-0.03147	-0.02288	-0.0284
-17.5	-0.03402	-0.07224	-0.03285	-0.04489	-0.03064	-0.03819	-0.02921	-0.03684	-0.02456	-0.03105
0	-0.04171	-0.22889	-0.04108	-0.08527	-0.03455	-0.04473	-0.03202	-0.04139	-0.02572	-0.03296
17.5	-0.04092	-0.10725	-0.04025	-0.05996	-0.03572	-0.04571	-0.03308	-0.04286	-0.02621	-0.03367
35	-0.04171	-0.22889	-0.04108	-0.08527	-0.03455	-0.04473	-0.03202	-0.04139	-0.02572	-0.03296
52.5	-0.03402	-0.07224	-0.03285	-0.04489	-0.03064	-0.03819	-0.02921	-0.03684	-0.02456	-0.03105
70	-0.02789	-0.0413	-0.02635	-0.03064	-0.02621	-0.03151	-0.02574	-0.03147	-0.02288	-0.0284
87.5	-0.02426	-0.03181	-0.02273	-0.02635	-0.02282	-0.02691	-0.02269	-0.02707	-0.02102	-0.02554
105	-0.02165	-0.02714	-0.02021	-0.02315	-0.02028	-0.02345	-0.02024	-0.0236	-0.01922	-0.02281

Table 2 Permanent deformation of the pavement.

Depth	Strain on x = 0 axis	Total Strain for Linear Model	Strain on x = 0 axis	Total deformation for the viscoelelavic model
0	0.04171		0.22889	
10	0.04108	0.00063	0.08527	0.14362
25	0.03455	0.00653	0.04473	0.04054
40	0.03202	0.00253	0.04139	0.00334
105	0.02572	0.0063	0.03296	0.00843
	∑	**0.01599**	∑	**0.19593**

The phenomenon of viscoelasticity can be considered as the cause of the rapid breakage of asphalt pavements. The assumption of the asphalt layer as elastic linear by our country and countries in the Southern African region that underestimates this effect can be considered as a mistake because the result is demonstrable by the current lack of control in the management of pavement systems.

3.3 Determination of Permanent Deformation in the Pavement

Table 2 presents the results of the calculations of permanent pavement deformations for two models (linear, elastic and viscoelastic) obtained with the help of the KENLAYER program. From the results it can be seen that the permanent deformation in the linear model is 0.01599 cm, i.e., 0.15 mm, and in the viscoelasic model it is 0.19593 cm, i.e. 1.95 mm. Comparing the two models, it is verified that the viscoelastic model admits greater permanent deformations.

4. Conclusion

It was evident that the aspects of viscoelasticity in asphalt pavements, when subjected to temperatures, are always present, so it is recommended to consider them in the design of asphalt pavements in Mozambique, particularly for regions whose temperatures are high in the summer season.

It is also concluded that:

- Temperature influences the increase in deformations related to the coating layer of a flexible floor;
- The phenomenon of viscoelasticity is always present in asphalt pavements and thus the study validated the study;

It is recommended that:

- Consider temperature in the design of asphalt pavements in Mozambique, in particular due to high temperatures in the summer season;
- The use of the KENPAVE program to evaluate the pavements;
- For future studies, to verify the effect of temperature on the deformability of asphalt pavements at airports where loads are too excessive.

References

[1] Reis, Nuno Filipe Dos Santos (2009). *Structural Analysis of Road Pavements, Application to a Steel Mesh Reinforced Pavement*, chapter 2.

[2] SANTOS, Luís Guilherme de Picado (1995). Consideration of temperature in the design of flexible road pavements.

[3] Diogo, J. F. R. (2007), PhD Thesis, Southwest Jiaotong University, Chengdu, China.

[4] Huang, Y. H. (2004). Pavement analysis and design.