Theoretical Study of the Thermal Behavior of a Supple Road Structure in Frequency Dynamic Modulation Under Illumination and Shade: Determination of the Temperatures and the Flow Densities in the Interfaces

Youssou Traore[#1,2], MamadouLamine Lo[*2], CheikhThiam[*2], M. S. Ould Brahim[#1] ,Moussa Dieng[#1] , Ould Mohamed Bah[#1], Issa Diagne[#1], Gregoire Sissoko[#1]

[#1]*Laboratoire des Semi-conducteurs et d'Energie Solaire, Faculté des Sciences et Techniques, Université Cheikh AntaDiop, Dakar, Sénégal*

[#2]*Ecole Polytechnique de Thiès, Sénégal*

***Abstract**:*

The determination of the mechanical parameters for the sizing of a road allows, according to the traffic to choose the minimal thickness for various layers. These parameters vary according to the climatic measurement in strong thermal stress zone (illumination) or in of low thermal stress zone (shade)

In this work, a theatrical study on the temperature variation and the flow density determination method for every interface of the road structure is proposed in frequency dynamic modulation.

This method highlights the influence of the climatic parameters such as the thermal exchange coefficient by radiation and the thermal exchange coefficient by convection.

Keywords: *roadway - temperature-density of flow dynamic frequency modulation –shade-illumination*

I. INTRODUCTION

The road structure is a major element in the development of a country. After their implementation, it is in permanent contact with loads due to the traffic [1] and thermal stress [2-5]. The techniques of sizing neglect the thermal stress compared with those of traffic by fixing the named equivalent temperature for road structure. While this makes vary the constraints and the deformations [6-8].

So, the variation of the temperature through the structure of the road puts real problems. That's why many authors' studied from a model of rigid road the influence of the thermal constraints in transitory regime [9]. And others highlighted the influence of the thermal extrinsic parameters in dynamic frequency modulation for a model of supple road [10].

Our work presents a theoretical study of the heat transfer through the road. A temperature and quantity of heat by unit area determination method on the various interfaces is proposed under the influence of shade or illumination

II. PRESENTATION OF THE ROAD STRUCTURE

A structure of road is a set of several piled layers. In this work, we consider a supple road structure which body's consists of bituminous materials, of grave crushed and the raw laterite. These materials are supported by the ground as indicated in the figure 1.

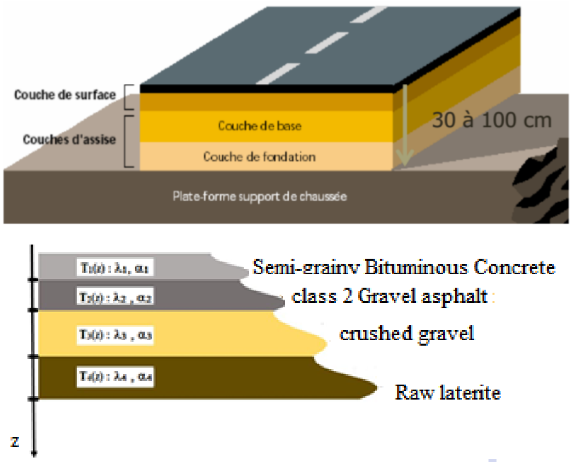

Figure 1: View of the Structure of Road

The thicknesses of layers are the following:

- Semi-grainy Bituminous Concrete : 0.05m
- class 2 Gravelasphalt : 0.08m
- crushedgravel : 0.2m
- Rawlaterite : 0.2m

When the most external layer of the road subjected(submitted)) is submitted to thermal constraint (figure 2), we observe then a heat transfer phenomenon from high towards low temperatures.

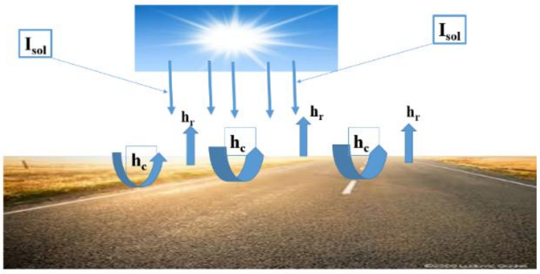

Figure 2: Contraints and Thermal Exchanges on the Asphalt

This phenomenon creates thermal exchanges governed by the equation of the heat (1)

$$\frac{\partial^2 T(z,hc,hr,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha}\frac{\partial T(z,hc,hr,\omega,t,Cn)}{\partial t} = Pp (1)$$

The heat equations relative to every layer are proposed by considering that there is no internal source of heat:

In the of Semi-grainy Bituminous concrete layer

$$\frac{\partial^2 T_1(z,hc,hr,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_1}\frac{\partial T_1(z,hc,hr,\omega,t,Cn)}{\partial t} = 0 (2)$$

In the connection layer of class 2 Gravel Asphalt of

$$\frac{\partial^2 T_2(z,hc,hr,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_2}\frac{\partial T_2(z,hc,hr,\omega,t,Cn)}{\partial t} = 0 (3)$$

In the basic layer crushed crushed gravel

$$\frac{\partial^2 T_3(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_3}\frac{\partial T_3(z,h1,h2,\omega,t,Cn)}{\partial t} = 0 (4)$$

In the layer of foundation in Raw Laterite

$$\frac{\partial^2 T_4(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_4}\frac{\partial T_4(z,h1,h2,\omega,t,Cn)}{\partial t} = 0 (5)$$

With $\alpha_1 = \frac{\lambda_1}{\rho_1 C_1}$; $\alpha_2 = \frac{\lambda_2}{\rho_2 C_2}$; $\alpha_3 = \frac{\lambda_3}{\rho_3 C_3}$ et $\alpha_4 = \frac{\lambda_4}{\rho_4 C_4}$

- ✓ $T_1(z,hc,hr,\omega,t,Cn)$: temperature in a considered point in the Grainy Semi Bituminous Concrete
- ✓ $T_2(z,hc,hr,\omega,t,Cn)$: temperature in a considered point in class 2 Gravel Asphalt
- ✓ $T_3(z,hc,hr,\omega,t,Cn)$: temperature in a considered point in the Crushed Gravel
- ✓ $T_4(z,hc,hr,\omega,t,Cn)$: the temperature in a point considered in the Raw Laterite

However, we meet three types of boundary conditions:

- ➢ The boundary conditions told condition imposed flow (problem of Neumann)
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- ➢ The boudary conditions) said condition of Fourier or Newton (problem of Fourier)

The heat transfers in this domain are conductive and monodimensional.
In the interface outer environment and the layer of bituminous concrete, a condition of continuity of flows is held:

- ❖ Interface outer environment and the layer of Grainy Semi Bituminous Concrete:

$$-\lambda_1 \frac{\partial T_1(z)}{\partial z}\Big|_{z=0} = hc\big(Ta1 - T(0)\big) + hr\big(T_s - T(0)\big) + I_{sol} \quad (6)$$

- ✓ hc:Coefficient of thermal exchange by convection
- ✓ hr :coefficient of thermal exchange by radiation
- ✓ Ta1 : ambient temperature of the environment
- ✓ Ts : temperature supplied by the sun in the ambient environment.
- ✓ Isol : solar flow arriving on the surface of the first layer

The expression of the solar flow is proposed by the following [11,12] :

$$I_{sol} = (0.828.\mathrm{I} + \mathrm{b}).(1 - \mathrm{Cn}/100) \quad (7)$$

So the cloud layer allows estimate the quantity of light which reaches the surface of the ground.

- ❖ Grave Asphalt of class 2 Interface between the Grainy Semi Bituminous Concrete and crushed gravel:

$$\lambda 1 \frac{\partial T1(z)}{\partial z}\Big|_{z=L1} = \lambda 2 \frac{\partial T2(z)}{\partial z}\Big|_{z=L1} (8)$$

$$T1(L1) = T2(L1) (9)$$

- ❖ Interface between class 2 Gravel Asphalt and the Crushed Gravel:

$$-\lambda_2 \frac{\partial T2(z)}{\partial z}\Big|_{z=L2} = -\lambda_3 \frac{\partial T3(z)}{\partial z}\Big|_{z=L2} (10)$$

$$T2(L2) = T3(L2) (11)$$

- ❖ Interface between the Crushed Gravel and the Raw Laterite: :

$$-\lambda_3 \frac{\partial T3(z)}{\partial z}\Big|_{z=L3} = -\lambda_4 \frac{\partial T4(z)}{\partial z}\Big|_{z=L3} (12) \quad T3(L3) = T4(L3) \quad (13)$$

- ❖ Interface between the Raw Laterite and the platform: :

$$-\lambda_4 \frac{\partial T4(z)}{\partial z}\Big|_{z=L4} = 0 (14)$$

$$T4(L4) = Tp (15)$$

At the initial moment, the temperature in a layer is isothermal. But This initial temperature is not constant for the set of layers. Indeed we supposed a one degree variation between layers: of the bearing layer to the layer of platform. So, by taking into account this temperature, we proceed to a change of variables .

In the layer of Semi-grainy Bituminous concrete rotation

$\bar{T}_1(z, h1, h2, \omega, t, Cn) = T_1(z, h1, h2, \omega, t, Cn) - T_{i1}$

In the connection layer of class 2 Gravel Asphalt

$\bar{T}_2(z, h1, h2, \omega, t, Cn) = T_2(z, h1, h2, \omega, t, Cn) - T_{i2}$

In the basic layer of crushed gravel

$\bar{T}_3(z, h1, h2, \omega, t, Cn) = T_3(z, h1, h2, \omega, t, Cn) - T_{i3}$

In the foundation layer of Raw Laterite

$\bar{T}_4(z, h1, h2, \omega, t, Cn) = T_4(z, h1, h2, \omega, t, Cn) - T_{i4}$ (19)

The heat equation becomes:

In the layer of Semi-grainy Bituminous concrete

$$\frac{\partial^2 \bar{T}_1(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_1}\frac{\partial \bar{T}_1(z,h1,h2,\omega,t,Cn)}{\partial t} = 0$$ (20)

In the class 2 connection layer of Gravel Asphalt

$$\frac{\partial^2 \bar{T}_2(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_2}\frac{\partial \bar{T}_2(z,h1,h2,\omega,t,Cn)}{\partial t} = 0$$ (21)

In the basic layer crushed gravel

$$\frac{\partial^2 \bar{T}_3(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_3}\frac{\partial \bar{T}_3(z,h1,h2,\omega,t,Cn)}{\partial t} = 0$$ (22)

In the foundation layer in Raw Laterite

$$\frac{\partial^2 \bar{T}_4(z,h1,h2,\omega,t,Cn)}{\partial z^2} - \frac{1}{\alpha_4}\frac{\partial \bar{T}_4(z,h1,h2,\omega,t,Cn)}{\partial t} = 0$$ (23)

The resolution of these equations from the method of separation of variables gives the expression of the additional temperature under the following shape: (16)

$$\bar{T}_i(z, hc, hr, \omega, t, Cn) = (A_i(hc, hr, \omega, t, Cn)\sinh(\beta_1.z) + B_i(hc, hr, \omega, t, Cn)\cosh(\beta_1.z)) * e^{j.\omega.t}$$ (24) (17)

The indications i=1,2,3,4 are respectively attributed from the first to the last layer. To determine the coefficients $A_i(h1, h2, \omega, t, Cn)$et $B_i(h1, h2, \omega, t, Cn)$, we are going to define the conditions on the borders. (18)

III. RESULTS AND DISCUSSIONS

A. Studied Frequency Band in Shade and Illumination Zone

When a system is submitted to thermal excitements, its thermal response depends on the solicitation time . Indeed, for short periods of excitements (high frequencies), the system does reach frequency for a reaction. The same remarks are made for long periods excitements, but here the system does not have time to attenuate the thermal shock.

Between these two situations, we distinguish frequencies allowing to obtain answers translating the variable frequency modulation. Figures 3 and 4 show that, the frequency band corresponding to the regime does not practically vary as we are in zone of shade or illumination. But the quantity of energy by unit area is more significant in illumination than in shade (figures 5 and 6).

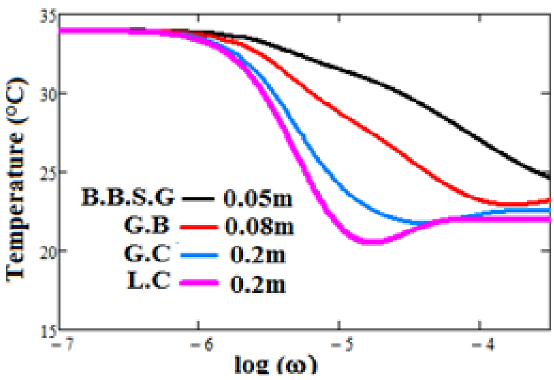

Figure 3: Road Temperature Under Shade According to the Pulse Decimal Logarithm of the Pulsation. Hc=100W.M^{-2}.K^{-1}, Hr=0.01W.M^{-2}.K^{-1}

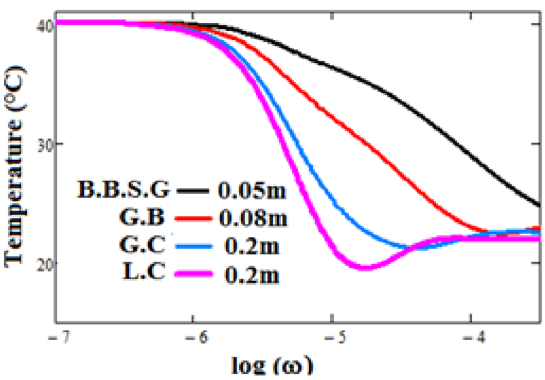

Figure 4: Road Temperature Under Illumination According to the Pulse Decimal Logarithm Hc=0.01W.M^{-2}.K^{-1},Hr=100W.M^{-2}.K^{-1}

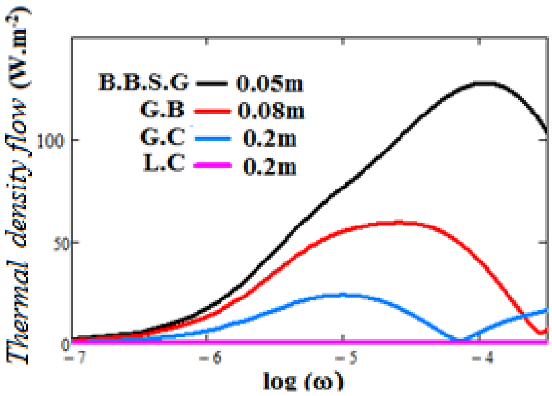

Figure 5: Road Temperatureunder Illumination According to the Decimal Logarithm of the Pulsation. Hc=100W.M^{-2}.K^{-1}, Hr=0,01W.M^{-2}.K^{-1}

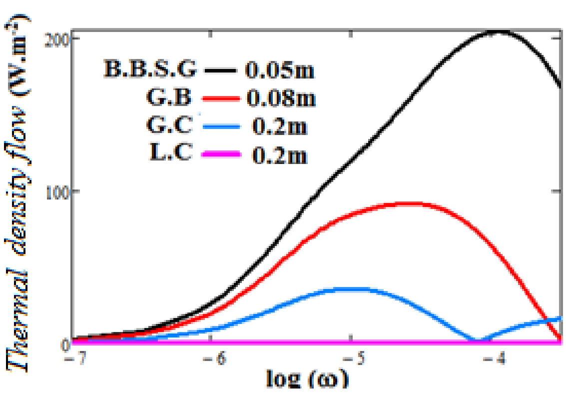

Figure 6: Road Density Flow The Under Illumination According to the Decimal Logarithm of the Pulsation. Hr=100W.M^{-2}.K^{-1}, Hc=0,01W.M^{-2}.K^{-1}

B. *Thermal Transfer Through the Road Structure*

1) *In Shade Zone*

The temperature and the density of flow of heat decrease according to the depth when we are in shadowed zone (influence of the convection thermal exchange coefficient). Indeed, the bearing layer receives the solar at sunshine period and warms up. Then, we notice a decrease of it from the high towards the low temperatures from the flayer layer up to the last one. The rising convection thermal exchange coefficient translates a temperature increase. However, more the temperature difference between the outside environment and the bearing layer is more is high, more the thermal exchange is important

The heat flow stored by the bearing layer is important. But it is necessary to note that by crossing the various thicknesses from the top to downward, we notice a heat loss due to the thermo physical parameters consisting the road.

Tables 1 and 2 give respectively, in each interface the values of the temperature and the flow density under the influence of the convection thermal exchange coefficient of.

Figure 5 : road density flow under shade according to the pulse decimal logarithm hc=100W.m^{-2}.K^{-1}, hr=0,01W.m^{-2}.K^{-1}

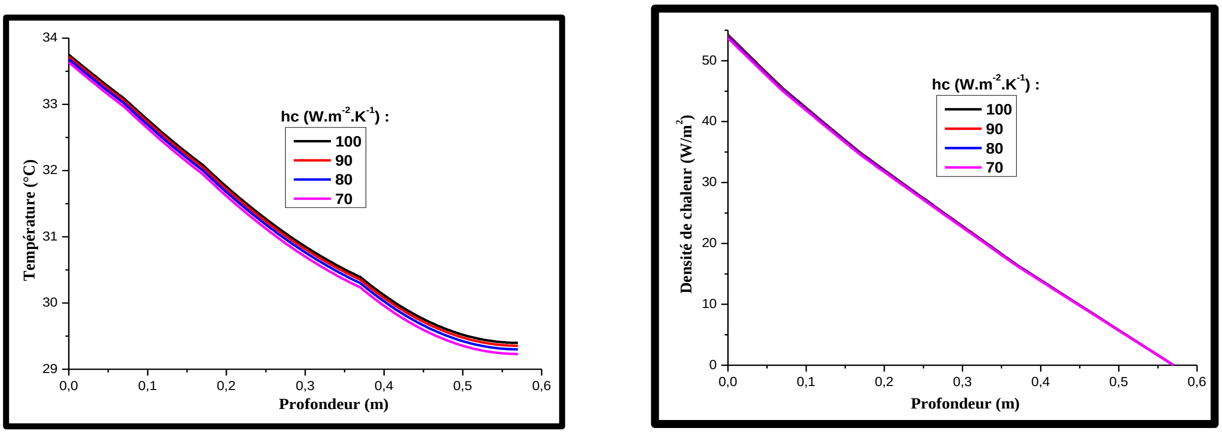

Figure II- 1 : Temperature (Figure II-8.A) and Heat Flow Density (Figure II-8.B) According to the Road Depth Under the Influence of the convection thermal Exchange Coefficient in Shadowed Zone. Hr=0.01W.M^{-2}.K^{-1}, □=10$^{-5.5}$rad/S

Table 1: Temperature Values on the Road Structure Borders Under Shade for□ □=10$^{-5.5}$rads/S

	Thermal exchange coefficient by convection (W.m^{-2} .K^{-1})			
Temperature (°C) à	100	90	80	70
Z=0	33.78	33.75	33.72	33.67
Z=0.05m	33.36	33.33	33.30	33.25

Z=0.13m	32.62	32.59	32.55	32.50
Z=0.33m	31.02	30.99	30.94	30.88
Z=0.53m	30.08	30.04	29.99	29.93

Table 2: Density Flow Values on the Road Structure Borders Under Shade for□ □=$10^{-5.5}$rads/S

	Coefficient d'échange thermique par convection ($W.m^{-2}.K^{-1}$)			
Heat flow density ($W.m^{-2}$)	100	90	80	70
Z=0	51.40	51.28	51.14	50.96
Z=0.05m	44.98	44.88	44.75	44.59
Z=0.13m	36.15	36.07	35.97	35.84
Z=0.33m	17.08	17.04	17.00	16.93
Z=0.53m	$7.38*10^{-15}$	$2.46*10^{-15}$	$2.46*10^{-15}$	$1.01*10^{-14}$

*2) **In Illumination Zone:***

A decrease of the temperature and the flow density is observed at period of illumination (influence of the radiation thermal exchange coefficient).

In the opposite of shadowed condition, the temperature more is important as the radiation thermal exchange coefficient is low. In depth of the structure, we note a temperature diminution.

The thermal flow characterizes the quantity of heat stored by unit area. This is higher at the peripheral and decreases inside the road.

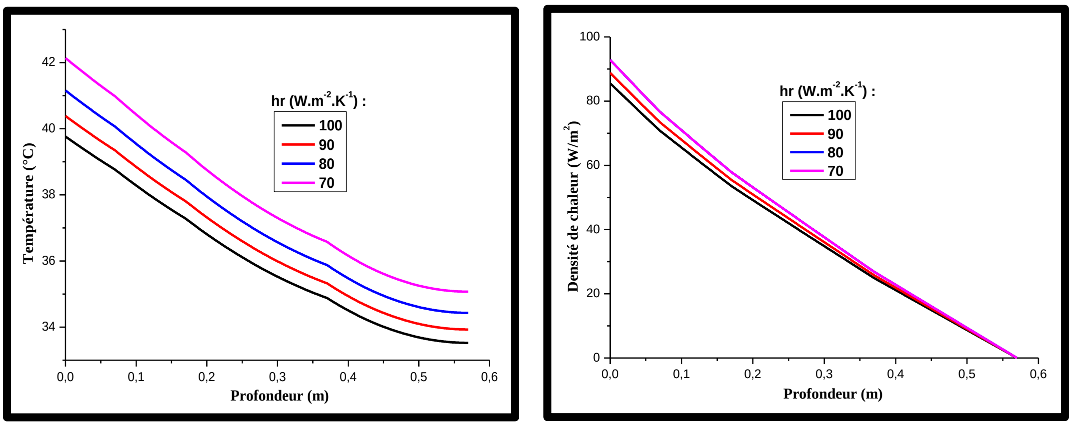

Figure II- 2 : Temperature (Figure II-9.A) and Heat Flow Density (Figure II-9.B) According to the Road Depth Under the Influence of the by Convection Thermal Exchange.Hr=0.01$W.M^{-2}.K^{-1}$, □=$10^{-5.5}$rad/S

Table3: Density Flow Values for Various Interfaces Under Illumination for□ □=$10^{-5.5}$rad/S

	Radiation thermal exchange coefficient ($W.m^{-2}.K^{-1}$)			
Temperature (°C) à	100	90	80	70
Z=0	39.81	40.44	41.22	42.21
Z=0.05m	39.18	39.78	40.53	41.48
Z=0.13m	38.08	38.64	39.34	40.23
Z=0.33m	35.82	36.30	36.90	37.67
Z=0.53m	34.54	34.99	35.54	36.25

Table4 : Density Flow Values in Various Interfaces Under Illumination For □=$10^{-5.5}$rad/S

	Radiation thermal exchange coefficient ($W.m^{-2}.K^{-1}$)			
Heat flow density ($W.m^{-2}$)	100	90	80	70
Z=0	80.68	83.75	87.57	92.43
Z=0.05m	69.84	72.44	75.68	79.81
Z=0.13m	55.57	57.60	60.13	63.35
Z=0.33m	25.85	26.76	27.90	29.35
Z=0.53m	$9.84*10^{-15}$	$1.97*10^{-14}$	$4.92*10^{-15}$	$2.03*10^{-14}$

IV. CONCLUSION

In this work, we proposed a theoretical thermal transfer study within the road in shade and illumination zone in frequency dynamic modulation. In these two zones, we proposed the frequency band determination. We highlighted the influence of the convection thermal exchange coefficient when we are in a shadowed zone and the radiation thermal exchange coefficient in illuminated zone on the temperature and the heat density flow.

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