

Impact of climate change on pavements

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ABSTRACT - Climate change is reflected in changes in average weather conditions and the more frequent occurrence of extreme conditions. It also affects the field of road transport and shows impacts both on traffic and road users as well as on the road infrastructure itself.

The main objective of this work is therefore to evaluate the impact of climate change on the performance of road infrastructure (pavements) and to educe recommendations through proposals for adaptation measures.

The impacts of climate change on road infrastructure result in changes in some road design parameters (average temperatures, radiation index, etc.).

The different cases of cracking (fatigue or other) are assessed separately using degradation indices for each layer composing a pavement (surface layer, base layer, stabilized layer, etc.)

Keywords: climate change, weather conditions, pavements,

INTRODUCTION

Morocco provides the transition between the temperate Mediterranean climate of southern Europe and the arid Saharan climate of the desert areas of the Sahara. Indeed, Morocco's climate varies from sub-humid in the north, semi-arid to arid in the centre, to Saharan in the south.

Bituminous asphalt mixes are materials containing a viscous binder that gives the material a viscoelastic behaviour. Thus, they are influenced by temperature and stress rate. Thus, the variation of their mechanical properties follows approximately the sinusoidal evolution of temperatures. Bituminous mixes are also susceptible to cracking in winter due to the thermal stresses that develop in the material at low temperatures.

Flexible pavement structures and their materials are influenced by temperature and humidity levels. Temperature has a significant influence on the behaviour of soils and granular materials only if their temperature changes from a positive to a negative value. This is mainly because the water contained in the pores of unbound materials strongly binds the particles together as they pass from the liquid phase to the solid phase. Contrariwise, freezing water in the pores of a soil as well as the formation of an ice lens tend to degrade surface conditions in winter, create cracking, decompact pavement materials, and affect thawing behaviour.
(Golden 2004; Golden and Zubeck 2009).

The desired implications and contributions for practice are numerous and make it possible to integrate the phenomenon of climate change into the long-term objectives of the life of a road pavement.

1. Methodology

The assessment of the effect of pavement climate change on the service life, is based on the study of the base layer behaviour and the coating.

In this evaluation we can proceed with the following methodological approach:

- Analysis of the interaction between the road domain and climate change.
- Analysis of the impact of climate change on the performance of the bituminous layer

2. Case study

The road section, subject of our study, is located in the Province of Chefchaouen, in the northwest of Morocco on the Rifaine chain, is bordered to the north by the Mediterranean over a length of 120 km, to the south by the Provinces of Taounate and Sidi Kacem, to the east by the Province of Al Hoceima and to the west by the Provinces of Tetouan and Larache.

In addition, this province is part of the Tangiers-Tetouan Region.

Road traffic is type 2 in a humid and hot climate zone, with an average temperature of 35°C for a lifespan of 10 years.

The following table illustrates the results of the mechanical tests performed on the pavement:

Table 1. Pavement's tests

| Legend | Nature | Place of sampling | IP (%) | ES | LA(%) | MDE (%) | crushing % |
|-----------|-----------|-------------------|--------|----|-------|---------|------------|
| ● - - - ● | GNF2 0/40 | PK 8+000 | NP | 64 | 25 | 19 | 73 |

Therefore this impact must also be evaluated using a model of coating behaviour, which will have a positive impact on costs and the duration of the construction work.

Based on the results of these tests in terms of soil capacity, degree of fragmentability, wear resistance and based on the climate of the area, we can propose the following structure:

Table 2. Proposed structure

| Pavement structure | Shoulder structure |
|--------------------|--------------------|
| 10AC+20GNF2 | 10AC+20GNF2 |
| +20GNB+RS | +20GNB+20MS type I |

This proposed structure is based on laboratory tests, and on traffic classification based on meteorological factors.

2.1 Analysis of the interaction between the road domain and climate change

2.1.1. The temperature effect

Temperatures and atmospheric conditions have multiple impacts on road infrastructure in Morocco. These impacts, such as the degradation and cracks of the roadway under study (Fig. 1), are mainly related to temperature changes and factors constitute the weather conditions, affecting the pavement layers.



Fig 1. Pavement degradation

The following table (tab3.), summarizes the temperature status, of the area during the follow-up months:

Table 3. Area temperature

| Months | Jan | Feb | Mar | Jul | Aug | Sep |
|----------|-----|-----|-----|-----|-----|-----|
| Temp(°C) | 20 | 21 | 29 | 38 | 45 | 37 |

This table shows a temperature rise in the summer months that have critical impacts on the pavement and its structural and functional performance.

The maximum peak of this temperature is increased by the following graph (fig2):

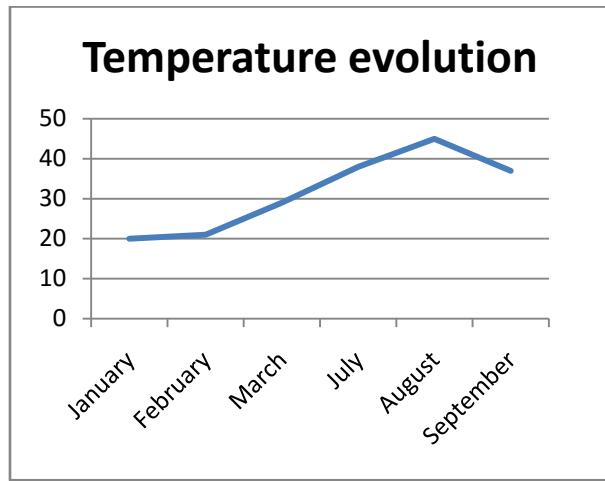


Fig 2. Temperature evolution

We note that the maximum temperature reaches a value of 45°C in the summer period, which negatively impacts the pavement layers and causes degradation, makes it easy to drop materials and then submerges the road with scour downstream (fig 3).



Fig 3.Fall of blocks from the pavement

Road infrastructure is directly affected by weather conditions, whether average or extreme conditions. These conditions have an impact on materials, on the choice of road layout, etc....

Air temperatures directly influence pavement temperatures, while other atmospheric conditions (solar radiation, UV radiation, clouds, etc.) can accentuate these phenomena.

2.1.2. Meteorological factors of the study area

The study area is recognized by a wind speed varies from 2.4 to 3.2 m/s, which causes damage to the infrastructure (falling objects, cracks... etc.). The average rainfall of 65 mm / month, also corresponds to one of the factors having a direct impact on the road infrastructure, with a significant presence of snow and 65% humidity affecting pavement performance.

Air temperature and radiation are two factors often related.

Most of the time, there is a slight delay between the radiation cycles and the temperature cycles.

This air temperature is on average 6.5°C, which leads to thermal ageing of the bitumen with thermal expansion/contraction of the joints in the upper layer.

In winter, high radiation and low air temperatures can occur.

These solar radiations are from 5.3 to 5.5 kWh/m², which generates an increase in Warming /cooling of the pavement temperature.

Indeed, this temperature-radiation pair generates the following impacts:

- The appearance of rutting, thermal ageing, adhesion, differential settlement of dry foundations, etc.
- The presence of thermal cracking, fatigue, due to low temperatures and temperature changes around 0°C.
- Thermal cracking and fatigue phenomena caused by daily and seasonal temperature changes
- Radiation can accentuate phenomena related to the high temperatures and can cause UV ageing problems in materials (oxidation of bitumen and contained polymers).

A change in precipitation results in a change in the water content of the foundations, which directly influences the load-bearing capacity of the soil.

Wind can cause faster changes in pavement surface temperature due to air mixing over the road, and shoulder falls can be observed on the pavement.

The problem of road sizing against winter conditions is also an important point where weather conditions are present.

2.1.3. Properties of the pavement ground

The soil properties of the pavement foundation may depend on climatic conditions. Mainly, the impact of water parameters on these soils should be considered (groundwater level, soil moisture, presence and flow of groundwater, etc.).

In situ and geotechnical tests are carried out in the study area:

- Piezometric measurements
- PROCTOR, CBR test

Table 4. In situ and geotechnical tests

| Ground water level (m) | Proctor | | CBR | |
|------------------------|--------------------------------|-------|-------------------|----------------|
| | δ_s (t/m ³) | W (%) | Without immersion | with immersion |
| 2.5 | 2.15 | 7.4 | 7 | 2 |

With this CBR and PROCTORlift test, the water parameters do not affect the foundation soil, and the pavement is not influenced by climatic conditions,

Table 5. Results of the plate test

| | Test N°1 | Test N°2 | Test N°3 |
|-------------------------|----------|----------|----------|
| | P1 | P2 | P3 |
| Deformation modulus EV1 | 83 | 81 | 88 |
| Deformation modulus EV2 | 47 | 46 | 48 |
| K = EV2/EV1 | 0.57 | 0.57 | 0.55 |

The test is carried out on 3 different points distributed between the upstream and Laval of the pavement.

This test is validated as long as the report K = EV2/EV1 does not exceed the value 2 so that the pavement foundation ground is permanently secured.

The safety test on the pavement foundation ground are essential to assess the climatic impact and its effects on the layers structuring the pavement.

2.2 Analysis of the impact of climate change on the performance of the bituminous layer

The temperature of the bituminous layer is directly dependent on several factors during its lifetime, but other factors can have a significant influence such as wind or the relative humidity of the bituminous layer.

2.2.1. The influence of temperature on the behaviour of asphalt mixes

The Equivalent Temperature depends on the pavement structure, pavement temperatures, E modulus of elasticity, fatigue strength values of the materials, and their variation with temperature.

During an evaluation study on the pavement, we observe the presence of cracking (fig 4), corner breaks and sometimes a total subsidence of the trench under the influence of temperature.



Fig4. Material recovery from the bituminous layer

To remedy this problem, a temperature monitoring was carried out during the months of the works.

| | February | May | August |
|----|----------|------|--------|
| EB | 19°C | 29°C | 42°C |

Table 6. Layer temperature

The table shows the increase in the temperature of the bituminous layer during the months of the year. This indicates a remarkable thermal variation causing the dilation. This impacts the viability of

the pavement and over time contributes to pavement deformations.

Then, we calculate the modulus of elasticity to see its evolution with temperature,

The registration of this module is given by the following table:

Table 7. Evolution of the modulus of elasticity of asphalt

| Temp (°C) | 20°C | 30°C | 40°C |
|-----------|-------|------|------|
| E(Mpa) | 11000 | 5000 | 1200 |

mixes

The modulus of elasticity decreases significantly with increasing temperature (fig 5), which makes the bituminous layer of the pavement very weak.

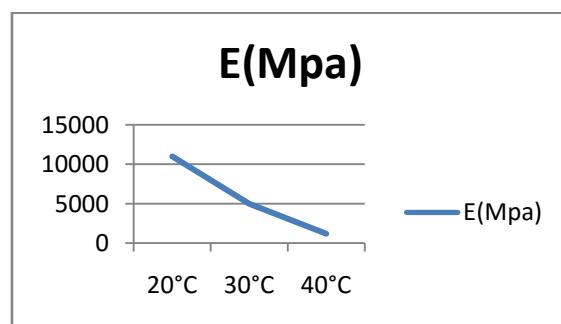


Fig 5. The modulus as a function of temperature

2.2.2. Assessment of fatigue damage

The fatigue model developed by ASPHALTINSTITUTE was used and is illustrated by the equations:

$$\begin{aligned} - \quad NF &= 0.001135 * KF1 * |\varepsilon| - 3.291 * E^{-0.854} \\ - \quad KF1 &= 104^{.84} * \left(\frac{V_{be}}{V_v + V_{be}} - 0,9 \right) \end{aligned}$$

With

N_f = number of permissible load applications
 K_{F1} = Functional parameter of the content of vacuum and bitumen

ε = extension at the base of the pavement (m/m),
 E = elastic modulus of the asphalt mix (MPa)

V_{be} = Bitumen content (%)

V_v = Empty content (%)

Direct compression-traction tests were performed on asphalt cores, collected from the study section.

These tests determined the bitumen content and void content for the calculation of parameter $KF1$. The following table, shows the values of bitumen content and void content of asphalt mixes.

Table 8. Determination of parameter $KF1$

| Parameters | (EB 10) |
|--------------|---------|
| V_{be} (%) | 5,3 |
| V_v (%) | 3,3 |
| K_{F1} | 0,440 |

The Determination of deformations at the base of the asphalt pavement ε , is done by installing gauges at the base of the asphalt pavements measuring horizontal deformation in the study area.

Any calculation made after an estimate of the deformation in the bituminous layer is given in the following table:

Table 9. Damage assessment

| Temp (°C) | 20°C | 30°C | 40°C |
|-----------|--------|--------|--------|
| E(Mpa) | 11000 | 5000 | 1200 |
| NF | 0,0345 | 0,0876 | 0,1234 |

We can deduce that with:

The rise in temperature, and the repeated passage millions of times, by vehicles and more particularly by heavy vehicles.

- Polish surface aggregates (decrease in pavement adhesion),
- Remove out microparticles from the pavement,

In addition, in rainy weather, water can slip through gaps between aggregates and asphalt and act under tire pressure.

As a result, the bitumen becomes more brittle, the appearance of cracks and leading consequently to a shorter pavement life.

Temperature has a marked influence on the pavement, which has very different mechanical effects, depending on the temperature range encountered.

The two main mechanisms are:

- Change in pavement stiffness: A bituminous asphalt pavement changes its stiffness as a function of temperature (heat-sensitive material).

Indeed, asphalt at high temperature is softer than at low temperature.

- Stresses and deformations are formed within the coatings due to thermal dilation and contraction during temperature changes.

On very cloudy or rainy days the temperature of the coating remains almost constant during the day.

These mechanisms are responsible for the typical degradation of coatings (cracking, rutting, etc.).

2.2.3. Solicitations

In the absence of official measures, the Average Annual Daily Road Traffic is estimated at AADT = 250 car/day.

The corrected traffic to be taken into account is calculated using the following formula:

$$N_{cp} = N_p \times C_1 \times C_2 \times C_2 \times C_3 \times C_4$$

According to the pavement reinforcement manual, the weightings to determine the final traffic to be considered into account for reinforcement are given in the following table:

Table 10. Correction coefficients

| Coefficient | Value | Observation |
|-------------------------------|-------|--------------------|
| Width of the roadway | C1 | Pavement width: <4 |
| Traffic aggressiveness | C2 | Np=250 ≥200 |
| Percentage of heavy vehicles | C3 | 35% |
| Growth rate of heavy vehicles | C4 | 6% |

The corrected traffic is either:

AADT = 1124 car/day.

And a T2 class according to the manual for the reinforcement of paved pavements.

The dimensioning traffic according to the new pavement structure catalogue expressed as an average daily number of heavy goods vehicles over 8 tonnes loaded on both sides of the road 4 heavy goods vehicles is TPL1.

The design traffic according to the new pavement structure catalogue expressed in EEC of 13T is given by the following formula:

| $N_e = N_p \times 0,5 \times 0,149 \times \%PL \times 365 \times \left[\frac{(1 + tp)^{10} - 1}{tp} \right]$ | | |
|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|--------|
| | years (p) | |
| %PL | Percentage of heavy goods vehicles | 35% |
| tp | Growth rate of heavy goods vehicles | 6% |
| 0,149 | Equivalent coefficient of a Moroccan heavy truck axle of 13T | 0,149 |
| F | =0.5 if traffic balance; x% traffic distribution | 0,5 |
| Do not | Equivalent axle traffic of 13 tonnes | 35 307 |

Table 11. Traffic dimensioning parameters

Either: $N_e \approx 2.2 \times 10^4$ EEC of 13 ton

The traffic to be taken into account for pavement design, is TPL1 class according to the new pavement design catalogue.

2.2.4. Geotechnical environment

Following the visual observation, of the study road, the geotechnical environment is of class EV2 (zone of dominant instability that conditions the condition of the pavement).

3. Results and discussion

The analysis of the impact of climate change on pavement life has led to several findings.

The difference between the lifetime compared to rutting and that compared to fatigue cracking from top to bottom can be significant.

In general, this difference is higher for S2 class foundation soils, and to a lesser extent for class S3 soils, as well as for type 5 superstructures (with hydraulic binder stabilized layer).

However, no clear trend is observed in relation to the traffic class.

The traffic class corresponds to an important factor in determining the service life of the road structures evaluated.

Indeed, for several cases of type 1 (bituminous mix on a grave) and type 5 (with hydraulic binder stabilised layer) superstructures, a difference in service life that can exceed 50% between the different types of traffic.

It should be remembered that the transition from a traffic class to a higher class is associated with an increase in the thickness of the bituminous layers of road structures.

Foundation soil also corresponds to an important factor for the service life of the road structures evaluated, lower lifetimes for the S2 bearing capacity classes of the foundation soil, and higher lifetimes for the S4 class soils are observed.

S3 Class soils fall between these two extremes.

Type 1 superstructures (bituminous mix on a grave) show the highest differences between the different bearing capacity classes of the foundation soil.

The "hot" region clearly has the lowest values, while the "cold" region has the highest values.

The lifetime cycle analysis made it possible to compare expected lifetimes for a multitude of evaluated cases.

However, this notion of lifespan is difficult to use to analyse the impact of climate change on pavements in a comprehensive way and to propose general adaptation measures.

The multitude of factors influencing pavement life and their probabilistic characteristics require the use of risk analysis to better judge the likely impact.

The observed changes in lifespan are too small to be able to detect clear trends in relation to the two climate regions and other evaluated parameters (traffic class, foundation soil class, climate scenario, etc.).

The sections located at the level of a sloped relief must be drained by a concrete ditch, also in the vicinity of all structures.

In the sloped and schist sections, drain with redons to prevent landslides and erosion above the concrete ditch.

4. Conclusion

The results obtained in this study have shown the potential effects of climate change on flexible pavement structures. Tests and analyses focused on the effect of temperature increase on pavement performance and lifetime.

Climate change will have positive effects (decrease in winter air freezing index) and negative effects (increase in the number of winter thaws that can cause foundation rutting performance problems and fatigue cracking of pavement layers);

the relation between water content in pavement soils, to precipitation has been developed in the context of this article, in order to relate the water content in soils with the expected increase in rainfall;

The loss of life of road structures, for the effect of increased precipitation on pavement rutting, permanent deformation due to fatigue cracking, respectively;

The increase in winter temperatures is associated with a decrease in life-span, a decrease in winter upheavals and a decrease in the rate of degradation;

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