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PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

وزارة التــــــــــــــــعـليـم العـــــالي و البــــــــحث العــــلـمـــي

Ministry of Higher Education and Scientific Research

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University Aboubakr Belkaïd – Tlemcen –

Faculty of TECHNOLOGY

THESIS

Presented for graduating with **MASTER'S DEGREE**

In : Public Works

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By :

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Topic

Conception and Design of Flexible Pavements

Defended on 07 /07/2021, before the following jury :

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  Without her i could have not done it.

- May all the members of the Jury find here the expression of my deepest respect for having taken time to examine my thesis.

- My thanks also go to those who though being near or far have helped and encouraged me. May you find here, the expression of my deepest gratitude.

DEDICATIONS

To my father

To my mother

To my brothers

To my sisters

To my friends

For their patience, their encouragement and
Their effective support without which this work
Would not have been done

To all the students in VOA M2 (2020-2021).

Dube

ABSTRACT

The objective of this end of study project is to design and to dimension a flexible pavement structure according to the known methods of dimensioning principally used in Algeria.

Firstly, we are going to present the different types of pavements (flexible, semi rigid and rigid) as well as expose the different methods used to calculate the pavement structures and make a comparison amongst them.

Afterwards, the dimensioning of the structure will be established using software called Alizé-LCPC developed by the LCPC and the Sétra (France). This uses the rational method of dimensioning flexible pavement structures regularly adopted in a number of countries.

This is a first theme in the civil engineering department of the Faculty of Technology where future students will have this project as a reference. It will allow them to master the calculation of flexible pavements so as to help them in their professional life in the field of public works.

Key words: Flexible Pavement, Alizé-LCPC, Bitumen, Gravel, Traffic, Empirical Methods, CBR, CTTP.

RESUME

L’objectif de ce projet de fin d’étude est de concevoir et de dimensionner une structure de chaussée flexible selon les méthodes de dimensionnement connues principalement utilisées en Algérie.

Tout d’abord, nous allons présenter les différents types de chaussées (flexibles, semi-rigides et rigides) et exposer les différentes méthodes utilisées pour calculer les structures de chaussées et faire une comparaison entre elles.

Par la suite, le dimensionnement de la structure sera établi à l’aide du logiciel Alizé-LCPC développé par le LCPC et le Sétra (France). Ceci utilise la méthode rationnelle de dimensionnement des structures de chaussées flexibles régulièrement adoptée dans un certain nombre de pays.

C’est un premier thème dans le département de génie civil de la faculté de technologie où les futurs étudiants auront ce projet comme référence. Il leur permettra de maîtriser le calcul des chaussées flexibles ainsi les aidera dans leur vie professionnelle dans le domaine des travaux publics.

Mots clés: Structure de Chaussée souple, Alizé-LCPC, Bitume, Gravier, Trafic, méthodes empiriques, CBR, CTTP.

ملخص

الهدف الأساسي من هدا المشروع هو تصميم وحجم هيكل مرن للرصيف باستخدام الأساليب المعروفة والمستخدمة أساسا في الجزائر.

أولاً، سوف نقدم مختلف أنواع الطرقات (المرنة وشبه الجامدة والجامدة) ونشرح مختلف الأساليب المستخدمة في حساب هياكل الأرصفة وإجراء مقارنة بينها.

وبعدها، سوف يتم تحديد أبعاد البنية باستخدام برمجيات أ Alizé-LCPC و التي طورتها LCPC وSétra (فرنسا) .والذي يستخدم الطريقة الرشيدة لإضفاء المرونة على هياكل الرصيف. هذه الطريقة التي تستعمل بانتظام في عدة بلدان.

يعتبر هذا الموضوع الأول من نوعه في قسم الهندسة المدنية بكلية التكنولوجيا، حيث سيكون للطلاب المستقبليين مرجعا أساسيا. وبالتالي سوف يساعدهم على التمكن من حساب الأرصفة المرنة بإتقان ويكون لهم خير سند في حياتهم المهنية في مجال الأشغال العمومية.

<u>الكلمات المفتاحية :</u>

بنية الطرقات المرنة، Alizé-LCPC، الزفت، الحصى، حركة المرور، الأساليب التجريبية، CBR, CTTP.

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LIST OF SYMBOLS AND ABBREVIATIONS

BB	Asphaltic concrete
ES	Surface coating
EF	Cold mix
GB	Bitumen gravel
GL	Slag
BCg	Dowelled cement concrete
GNT	Untreated gravel
TUFF	Limestone tuff
SG	Gypsum sand
AG	Decomposed granite (arene)
SB	Bitumen sand
RP1	Main level 1 network
PTAC	Total weight allowed in charge
PL/HV	Heavy Vehicle (vehicle over 3.5 tonnes)
TPLi	Traffic class in number of heavy goods vehicles per day and per lane
TCEi	Cumulative traffic in equivalent axles of 13 tonnes
A	Aggression coefficient
τ	Geometric traffic growth rate
C	Cumulative factor
n	Design Lifetime
CL, ML, SC, GC,C	Soil classes (USCS Classification)
Si	Support soil load-bearing class
EV2	Plate modulus
Dc	Characteristic deflection in 1/100 mm
E	Young's modulus (mpa)
v	Poisson coefficient
σ_6	Bending stress limit at 10^6 cycles
ε_6	Limit strain corresponding to 10^6 cycles
ε_z	Vertical strain
b	Slope of the fatigue line of the treated material

kc	Adjustment coefficient
kr	Risk factor
kθ	Factor related to temperature
kne	Factor related to the cumulative number of equivalent 13-tonne axles Supported by the roadway
SN	Dispersion on the fatigue law
Sh	Dispersion on thicknesses
t	Fractile of the normal law
kd	Factor related to the effects of discontinuities (concrete slab)
r	Risk in percentage %
$\varepsilon_{t,ad}$	Permissible tensile strain by bending at the base of bituminous layers
$\sigma_{t,ad}$	Admissible tensile stress at the base of the hydraulic layers
CBR	California bearing ratio
Ip	Plasticity index
K	Module of the Reaction of the Soil
LCPC	Central Laboratory of Bridges and Pavements
LNTPB	Laboratoire National des Travaux Publics et du Bâtiment
n	Design life of the Road
P	Load of the Wheels
q	Pressure or Load of the Tires
TMJA/AADT	Annual Average Daily trafic
RN	National road
Δ	Laplacien operator
PK	Kilometre point

LIST OF APPENDIX

GENERAL INTRODUCTION

Like many road networks in the world, the Algerian network is mainly made up of flexible pavement structures comprising foundation layers of gravel of various qualities resting on supporting soils of different bearing capacities often presenting significant variations in rigidity in depth.

In addition, an adequate dimensioning of a flexible pavement structure or, in other words, the optimal determination of the thicknesses of the constituent layers of the pavement body inevitably requires a good knowledge of the real characteristics of the supporting soil platforms and in particular the non-linear mechanical behavior of the materials used in the foundations

The pavements are presented as multilayer structures implemented on an assembly called the pavement support platform consisting of the terraced ground (called the support ground) generally surmounted by a subgrade.

One of the main functions of the pavement is to distribute the load induced by traffic. The engineer must therefore be able to verify that the stresses and strains generated inside the pavement and transmitted to the infrastructure are below the values tolerable by the materials.

Like the materials it is made of, pavements undergo deformations which are mainly elastic, but also plastic and viscous.

For the sake of simplicity, most of the methods for calculating the mechanical response of the pavement are based on simplifying assumptions.

Additionally, there are over 96,000 kilometers of paved roads including 1394 kilometers of expressways and 29,000 kilometers of unpaved roads for a total road system of about 127,000 kilometers in Algeria.

Algeria has two routes in the Trans-African Highway network, including the Trans-Sahara Highway, a paved road running from north to south through the country. The country also has an East-West highway.

The Importance of Roads

Roads play a vital role in the economic development of any country. Without roads no nation can ever advance or development as the movement of goods and services would be limited.

- Urban roads have a capital importance:
- They reduce living costs and transportation costs
- They reduce the number of accidents that happen on roads
- Facilitate fluidity of economic activities
- They permit reliable and timely deliveries
- Reduce the time of traveling

Rural road networks permit open up areas of production improving the flow of merchandise towards cities as well as reducing transport costs. They also improve accessibility to basic services such as health, education and access to the markets for agricultural products.
A transport network that is reliable in a country consists of a determining element in the social and economic development of a country, because it facilitates mobility, commercial exchanges, tourism, and access to employment and development resources.

The road network is a key point to the development of a country. In fact, it affects all sectors of development such as: security, production, commerce and tourism.

Security

Security is an essential element for the development of any given country.
The poor quality of the transport infrastructure, that is to say, the road network promotes insecurity in a region because it delays or even prevents the intervention of the police or the army in case of need.
Road insecurity can also become a big problem for a country. Several factors favor this situation, but the closest factor is the poor quality of a countries road infrastructure.

Production

The existence of a good road infrastructure influences the productivity of a region in terms of agriculture, craftsmanship and animal husbandry because it can motivate people to get into production and facilitate the transport of tools and elements necessary for production as well as transportation of products to markets.

Commerce

This is the sector most affected by the quality of road infrastructure because all the failure mentioned above affects all on the price. The cost of transportation remains a big factor that determines the price of products. And it is the road network that is the basis of transport: it affects the price and duration of transport of products from places of production to places of consumption.

Tourism

The tourism sector is a sector that contributes a lot to the development of a country because it is one of the sources of foreign exchange for the state. A good quality of transport infrastructure allows the development of this sector.

Structure of This document

This document consists of 4 chapters, general introduction and conclusions.

Chapter 1 Generalities of the pavement structure.

This part begins with the definition of a pavement and its layers these are support soil also known as the subgrade, the subbase , base course and the surface layer.This is followed by a brief description of the principal constituents of a pavement, its categories which are paved or unpaved roads. Lastly at the end of the chapter we discuss what makes a pavement flexible, semi rigid and rigid

Chapter 2 Pavement calculation methods

Here we focus on explaining on the methods used for pavement calculations. These are grouped into empirical and analytical methods. Empirical methods are the CBR method, new pavement catalogue which was developed by CTTP Algeria, AASHTO and the LCPC french method. This is followed by analytical methods which are Boussinesq, Westergaard, Hogg, Burmister and finite element models.

Chapter 3 Design of a pavement case study.

In this chapter we show how to use the 2 methods that are common for pavement design in Algeria. These methods are the CBR and new pavement catalogue CTTP. The pavement of a road project situated in Tlemcen will be designed using these methods.

Chapter 4 Pavement simulation using ALIZE software.

In this part we give the theoretical principle, description of the problem to be solved by the pavement software ALIZE. We then give the inputs and outputs of the softwares.This is followed by application of the sofware in our project for calculating stresses and strains. We use the software to find the optimal structure. Lastly we are going to compare the pavement structures designed to propose the best solution for our project.

CHAPTER 1 : PAVEMENT GENERALITIES

I.1 Introduction

Before a road can be constructed it goes through phases of study: a feasibility test, a study of the trace, longitudinal, cross section and plan layout.

In this chapter we will focus on the dimensioning and designing of the different layers of the pavement structure.

The pavement sizing catalog is in the form of sizing sheets in which the structures are already pre-calculated.

These pre-calculated structures require knowledge of a number of accompanying documents (standards, technical guides, recommendations, etc.)

The dimensioning of a pavement structure consists in satisfying, at a lower cost and in good conditions of comfort and safety, objectives (desired service life of the structure) under a certain number of parameters (traffic, climate, local materials and maintenance policies).

For this, the quality of the construction of the pavements, first of all requires a good recognition of the support soil and a judicious choice of the materials to be used, allowing it to resist the attacks of external agents (the environment of the road and the climate essentially.), and overloads of operations (traffic).

I.2 Definition of a Pavement

- In the geometric sense: it is the developed surface of the road on which vehicles circulate.
- In the structural sense: it is all the layers of material superimposed to allow the load to be taken up.

I.3 Constitution of Pavement Structures

Pavements appear as multi-layered structures implemented on a set called a pavement platform, made up of terraced ground, most often topped with a subgrade.

Figure V-1 :General pavement structure

I.4 The Road Support Platform

It consists of the terraced ground or support ground generally surmounted by a subgrade.

I.5 The Support Soil

This is the soil whose placement constitutes the Earthworks. It is either the ground in place, when the road is in cut, or the ground brought up when the road is in backfill.
In general, we consider the layer of the top 30 cm; it is improved when it is compressible or weakly wearing. This thickness may vary depending on the sizing method.
Soils of very variable characteristics can be found in the same project. In order to improve and standardize the bearing capacity of the soil, it is necessary to interpose between the support soil and the pavement layers a transition element which can be made either of rolled or crushed grainy materials, or of materials treated with hydraulic binders. It is called a top layer.
It protects the subsoil against the destructive action of large machinery and facilitates the compaction of the upper layers by providing them with a firm and non-deformable support.

I.6 **Subgrade**

The subgrade is a more or less complex structure that serves to adapt the random and dispersed characteristics of backfill or natural terrain materials to the mechanical and geometric characteristics required to optimize the pavement layers.
It is only used there to make geometric corrections and improve the bearing capacity of the underlying soil in the long term.

I.7 **Subbase Course**

Completely made of untreated materials, it partly replaces the role of the support soil, allowing the homogenization of the stresses transmitted by traffic. To ensure a good level and good bearing capacity of the finished pavement, and also, It has the same role as that of the base layer.
Its main role is to reduce the loads which are transmitted to the platform. It only supports vertical constraints. It must be not very deformable and more resistant than the underlying layers.
A common practice is to make its lower part low permeability in order to evacuate water that may have seeped through the base layer.
This zone also prevents the capillary rise of water from the platform.

I.8 **Base Course**

The base layer is generally formed of crushed gravel or gravel bitumen, tuff, sand-gypsum. It plays an essential role, it exists in all pavements, it resists permanent deformation under the effect of traffic and loose soil, it takes up the vertical forces and distributes the normal stresses which result there from on the sub-layers underlying. The thickness of the base layer varies between 10 and 25 cm.
At its level, the efforts due to trafficking are still important. Likewise, the effects of environmental conditions are not fully cushioned. Thus, the materials used must be of good geotechnical qualities, that is to say

- Have a suitable particle size to avoid segregation during the various manipulations;

• Have good resistance to internal friction forces, for this; it must be formed of aggregates that are so much harder and more resistant than the loads are important;

• Have fewer fines if they are not dangerous.

The main role of this layer should be to increase the load-bearing capacity of the structure. Due to the importance of its thickness and the sometimes improved quality of the materials, it contributes to bending stiffness and overall resistance to fatigue. It also helps to drain water and resist erosion of all kinds.

I.9 The Surface Layer

The surface layer is in direct contact with vehicle tires and external loads. It's essential role is to withstand the shear forces caused by traffic. It is generally made up of :

I.9.1 Bonding Layer

The structural contribution of this layer is secondary (except for pavements with a granular base where the surface layer is the only bonded layer), it is dependent on the durability of the pavement.

I.9.2 Wearing Layer

It is the upper layer of the pavement structure on which the combined aggressions of traffic and climate are directly exerted. It is required to have specific qualities of use, namely: strong adhesion, good drainability and a reduction in vehicle rolling noise.

The thickness of the wearing course (surface) generally between 6 and 8 cm.

It consists of the wearing course or coating layer and possibly a tie layer between the wearing course and the base layers.

It is a mixture of good quality aggregate and hydrocarbon binder. Strongly associated, these elements constitute a homogeneous, stable and fairly monolithic whole.

The coating must have good puncture resistance and wear resistance because it is in direct contact with the atmosphere and stress. It must have a good "plain" feel, not be very slippery and waterproof.

There are two types of coatings : Surface plasters: single or multi-layer and Asphalt.

The main roles of the surface layer are :

- Provide comfort to users;

- Resist the horizontal forces of the tires, in fact, the tires exert horizontal forces on the roadway resulting from:
    - Transmission of engine effort (acceleration)
    - The rotation of the non-driving wheels
    - The transmission of braking force.
- Prevent water penetration: it is important to prevent water from seeping into the layers of the pavement. The consequences are
    - It loosens the aggregates
    - It softens fine soils causing their bearing capacity to drop.

I.10 **Principal Constitution of a Pavement Structure**

The roadway is essentially a work for distributing rolling loads on the foundation ground. In order for rolling to take place quickly, safely and without excessive wear and tear on the equipment, the running surface must not deform under the effect

• The load of vehicles

• Shocks

• Bad weather

• Tangential forces due to acceleration, braking and skidding

I.11 **The Categories of Pavement Structures**

We can distinguish two categories of pavement structures, when it comes to pavement road structures.

I.12 **Unpaved Pavements**

These are pavement structures which have not received a hydrocarbon coating. We distinguish:

1. Pavements made of stonework.
2. Pavements of gravel or selected materials.

I.13 **Paved Pavements**

These are pavements structures which have been coated with a hydrocarbon.

I.13.1 Different Types of Pavement Structures

Depending on the mechanical functioning of the road, there are generally three different types of structures:

1- Flexible pavements ;
2- Semi-rigid pavements ;
3- Rigid pavements.

I.13.2 Flexible Pavement Structure

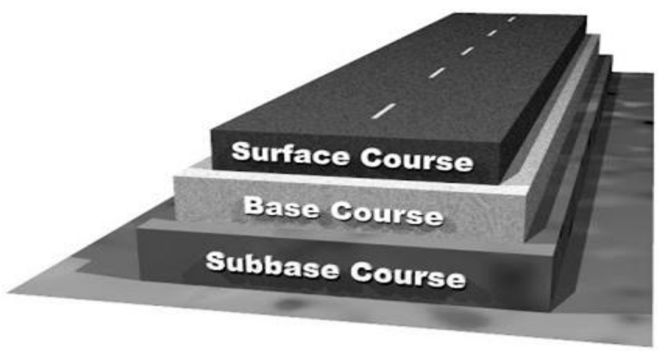


Figure V-2 :Flexible pavement structure

Flexible pavements take their name from the fact that they reversibly deform under stress. They consist of a bituminous layer on the surface and a base of granular materials.
The bituminous layer is relatively thin, the base layer and the foundation layer are usually made of untreated materials.
The thicker the pavement, the less stress applied to the base of the platform. The sizing of flexible structures is based on limiting the vertical deformation of the support soil.

I.13.3 Semi Rigid Pavement

Flexible pavements take their name from the fact that they reversibly deform under stress. They consist of a bituminous layer on the surface and a base of granular materials

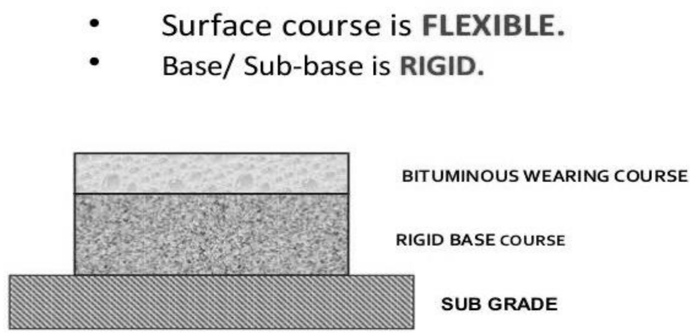


Figure V-3 :Semi-rigid pavement structure

A semi-rigid pavement consists of a relatively thin asphalt pavement, a treated base course and a treated or untreated base course. Its sizing relates to the fatigue failure at the base of the bonded layer and the rutting of the support soil. It must be ensured that the tensile stress at the base of the treated layer is less than the allowable tensile stress of the material and that the vertical deformation at the surface of the unbound layers and supporting soil is less than an allowable value.

I.13.4 Rigid Pavement

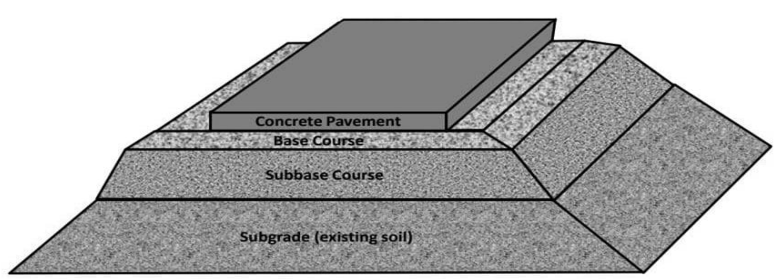


Figure V-4 :Rigid pavement structure

These structures have a layer of cement concrete 15 to 40 cm thick, possibly covered with a thin wearing course of bituminous materials. It is not very deformable, it absorbs the load and finally to avoid deformation, on the foundation or the infrastructure, which could cause failure. Rigid structures mobilize significant tensile forces by bending very high compared to those undergone by semi-rigid structures and are deformed mainly by cracking.

The sizing of rigid structures is based on limiting the tensile forces by bending the concrete under the effect of loads. For high traffic, these types of pavement have very interesting mechanical performance, compared to other types of structures.

I.14 **Difference between flexible, semi rigid and rigid pavement**

Table V-1 Common pavement materials used in Algeria

	Flexible	Semi rigid	Rigid
Surface	Bituminous concrete	Bituminous concrete	Concrete
Base	Bituminous gravel	Bituminous gravel	Treated gravel
Subbase	GNT	Treated gravel	GNT

I.15 **Choice of the Type of Structure**

The choice of the type of structure to adopt for a pavement depends on the following factors:

• The importance of the traffic;

• The quality of the soil of the platform;

• The available finances.

I.16 **Conclusion**

The roadway is a flat and impermeable structure, designed and sized to perform its role over a minimum service period set at the road development stage.

The main role of the pavement is to protect the supporting ground from traffic and climate aggressions.

The pavement design is done using various experimental and theoretical models, these will be described briefly in the following chapter

CHAPTER 2 : PAVEMENT CALCULATION METHODS

II.1 Introduction

The dimensioning of a roadway consists in calculating the different thicknesses of the layers of the body of the roadway, taking into account the characteristics of the subgrade, the traffic and its composition and the projected lifespan.

When it comes to pavement sizing, there are no universal calculation methods that can be applied rigorously to all countries. Thus, each country has its own rules which are refined according to the progress made in the knowledge of the parameters of the road environment and the theoretical results on the mechanical models.

Also, there are a number of practical methods more or less adapted to each context. These methods can be grouped into two types methods :

1. Empirical ;
2. Analytical (theoretical) ;

II.2 Empirical methods

The empirical method is based on tests and observations made on experimental roads. The technique is based on the identification, the conforming and standard reproduction of pavement structures identical to those which have been proven to perform. The materials, traffic and the same environmental conditions are used each time until damage deemed severe, for a reference type of pavement, can be inventoried. The most widely used empirical models are

1. The CBR method (California -Bearing - Ratio);
2. The new pavement design catalog “CTTP”;
3. AASHTO method (American Association of State Highway and transportation Officials);
4. The LCPC method (Laboratoire Central des Ponts et Chaussées).

II.3 The CBR (California-Bearing -Ratio) method

It is a semi-empirical method which is based on a punching test on a sample of the support soil by compacting the test tubes (90 to 100%) of the modified optimum Proctor. The determination of the thickness of the pavement body to be implemented is obtained by applying the following formula

$$e = \frac{100 + \sqrt{P}(75+50\,log\left(\frac{N}{10}\right))}{I_{CBR}+5} \quad \text{(V-1)}$$

- e: thickness in centimeters ;
- ICBR: CBR index (support soil) in percentage ;
- N: designates the daily number of unladen heavy goods vehicles in projected year ;
- P: reference load per wheel P = 6.5 t (13 t axle) ;
- Log: decimal logarithm.

II.3.1 The equivalent thickness

The equivalent thickness is introduced to take account of the different mechanical qualities of the layers and it is equal to the sum of the equivalent thicknesses of the layers.
The equivalent thickness is given by the following relation

$$e = \sum_{i=1}^{n} a_i e_i \quad \text{(V-2)}$$

e = a1 × e1 + a2 × e2 + a3 × e3
with:

- e1: actual thickness of the surface layer.
- e2: actual thickness of the base layer.
- e3: actual thickness of the layer.
- a1, a2, a3: coefficients of equivalence respectively of the materials of the layers e1, e2, e3.

II.3.2 Equivalence coefficients values

The table below indicates the equivalence coefficients for each material

Table V-2 : Equivalence coefficients for each material

Used materials	**Equivalence coefficient**
Bituminous concrete or dense coating BB	2.00
Grave cement - gravel slag	1.50
Cement sand	1.00 to 1.20
Crushed gravel or gravel GNT	1.00
Grave rolled - gravel sand and TVO	0.75
Sand	0.50
Severe bitumen GB	1.50

Note

The thicknesses e1, e2 and e3 are all arbitrary. A third thickness (among e1, e2 and e3) is obtained by having fixed the other two.

II.4 The new pavement design catalog method "CTTP"

The use of the sizing catalog makes use of the same parameters used in the other pavement sizing methods:

- Traffic ;
- Materials ;
- Ground support ;
- Environment.

These parameters often constitute input data for designing, depending on this the choice of a given pavement structure is made.

The new pavement design catalog method is a rational method based on two approaches

1. Theoretical approach ;
2. Empirical approach.

II.4.1 The catalog approach

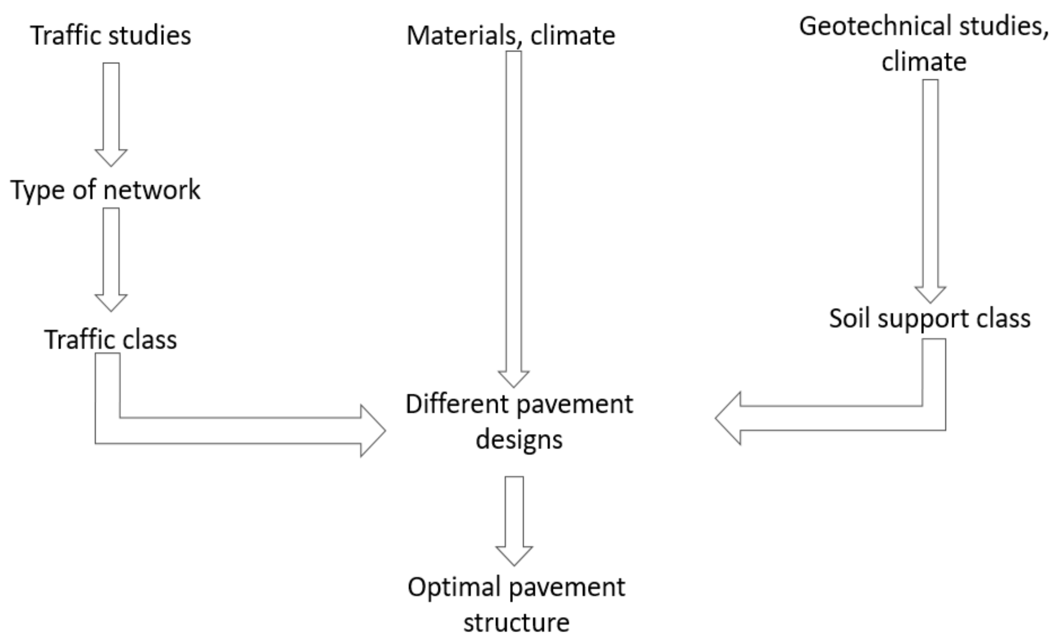


Figure V-5 :Catalog Approach

II.4.2 Determination of the type of network

The studies initiated by the services of the Ministry of Public Works led in 1996 to the breakdown of the national road network as a result

II.4.2.1 The main network rated RP

It consists of the roads connecting

- The Heads of the wilaya;
- Ports, aerodromes and border posts ;

- The main towns and important industrial zones.

This main network is broken down into two levels

-The main level 1 network (RPl) ;

-The main level 2 network (RP2).

II.4.2.2 The secondary network noted RS

It consists of the rest of the roads which are not classified in RP.

NB: Only the main network (RP) is taken into consideration in this catalog

II.4.3 Choice of main network level

The main network level category is determined from the given criteria below

II.4.3.1 Main Level 1 Network (RP1)

It includes:

- links supporting traffic greater than 1,500 vehicles / day ;
- links connecting two chief towns of the wilaya ;
- links of economic and / or strategic interest;

It is essentially a network made up of national roads (RN)

II.4.3.2 Main Level 2 Network (RP2)

It is made up of links supporting traffic of less than 1,500 vehicles / day. This network is made up of national roads (RN), wilaya paths (CW) and links linking Algeria to the riparian countries.

II.4.4 Determination of traffic class

The traffic class (TPLi) is given in number of heavy goods vehicles per day and per direction on the busiest lane in the year into service. For the calculation of the dimensioning itself, it will be necessary to calculate the cumulative traffic in equivalent axles of 13 tonnes (TCEi), which brings into play the notion of aggressiveness of heavy goods vehicles.

II.4.5 Definition of Heavy Vehicle

A heavy vehicle (HV) is a vehicle weighing more than 35kN (3.5tonnes) of total authorized laden weight. These vehicles are easily identifiable visually on the road, as they include all vehicles with two axles or more, and whose rear axle is a twin.

II.4.6 Cross-sectional distribution of Traffic

In the absence of precise information on the distribution of heavy vehicles on the various traffic lanes, the following values will be adopted

- 2-lane unidirectional carriageways: 90% of HV traffic on the slow right lane,
- 3-lane unidirectional carriageways: 80% of HV traffic on the slow right lane,
- 2-lane two-way carriageways: 50% of HV traffic,
- 3-lane two-way carriageways: 50% of HV traffic.

II.4.7 Determination of the traffic class (TPLi)

The traffic classes (TPLi) adopted in the design structure sheets are given, for each level of the main network (RP 1 and RP2), in number of heavy vehicle (PL's) per day and per direction in the year of commissioning.

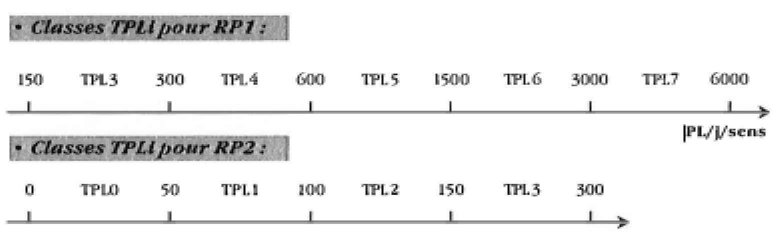


Figure V-6 : Adopted TPLI traffic classes

II.4.8 Determination of the load-bearing capacity of the ground support

II.4.8.1 Soil bearing capacity class

The soil bearing capacity classes are in ascending order from S4 to S0. This classification will also be used for pavement substrates according to the maximum modified Proctor density CBR value.

Table V-3 : Soil bearing capacity classes

Bearing capacity (Si)	CBR
S4	<5
S3	5-10
S2	10-25
S1	25-40
S0	> 40

II.4.8.2 Determination of the load-bearing class of subgrade

The pavement structures are built on the subgrade generally made up of terraced ground, or if necessary (poor bearing capacity) capped with a top layer. The subgrade bearing capacity is a function of that of the terraced ground (cut or fill), and possibly of the contribution of the layer of form. It is considered under two aspects :

a) In the short term (during the construction works)

The subsoil must meet one of the two constructability criteria (compaction, site traffic)

1- deflection under axle at 13 tonnes < 2 mm.

2- EV2 plate module > 50 MPa.

b) *In the long term (pavement in service)*

This bearing capacity will be taken into account in the dimensioning of the pavement structures.

II.4.8.3 Bearing capacity of terraced soils

a) *Case of soils sensitive to water*

The geotechnical study is obligatory, because it makes it possible to identify the soils and to study the variation of the bearing capacity thanks to the CBR shear punching test.

The CBR test to be taken into account will depend on the climatic zone considered, namely

1. 4-day soaked CBR for climatic zones I and II

The value of the 4-day soaked CBR index to be retained corresponds to 100% of the density at the immediate CBR OPT for climatic zones III and IV

2. The value of the immediate CBR index will be determined at 95% of the OPT.

b) *Case of soils insensitive to water*

In the case of soils insensitive to water, soils where the CBR test is not feasible, the bearing capacity will be determined from plate loading tests, or deflection measurements provided that the water state at the time of the test is representative (W ≥ WOPM)

The ground modulus EV2 and the characteristic deflection (dc) of are related by the following relation:

$$\text{EV2} = \frac{10340}{dc} \qquad \text{(V-3)}$$

With : E is in Mpa and dc in mm / 100

II.4.8.4 Classes of load-bearing capacity of soils for pavement design

For the design of pavement structures, there are 4 classes of bearing capacity of supporting soils, namely S3, S2, S1 and S0. The values of young modulus indicated in the table below have been calculated at from the following empirical relation :

$$E(MPa) = 5.CBR \quad \text{(V-4)}$$

Table V-4 : Classes of load-bearing capacity of support soils

Classes of Support soil	S3	S2	S1	S0
Module (Mpa)	25-50	50-125	125-200	> 200

NB: Relation obtained from laboratory tests carried out on a family of soils predominant in Algeria.

II.4.8.5 Classification of pavement subgrade

When cases of low bearing soils (<S4 in RP2, <S4 and S3 in RP 1) are encountered, capping of subgrade becomes necessary to allow the construction of the paved layers under acceptable conditions. The use of a subgrade in selected or treated natural materials allows an over classification of the bearing capacity of the terrace floor.

Depending on the construction site (traffic, type of soil, climatic zones), the top layer will be of different types. It can be in one or more layers depending on the bearing capacity of the terraced soil and the target soil-support class (Sj).

Table V-5 : Classification of pavement support soils

Bearing capacity of terraced ground (Si)	Nature of materials	Sub-layer material thickness	Targeted soil-support class (Sj)
< S4	Untreated materials	50cm (in 2 layers)	S3
S4	Untreated materials	35cm	S3
S4	Untreated materials	60cm (in 2 layers)	S2
S3	Untreated materials	40cm (in 2 layers)	S2
S3	Untreated materials	70cm (in 2 layers)	S1

II.4.9 Choice of surface course

The choice of surface course is made according to the level of the main network

1. RP1: Asphalt concrete surface course (BB), the thicknesses are modulated according to the traffic (TPLi).
   - 6BB to 8BB for structures treated with bitumen (GB / GB, GB / GNT,…)
   - 6BB to 10BB for GL / GL structure.

2. RP2: surface coating course (ES) or cold coating (EF) depending on the material chosen and the corresponding climatic zone.

II.4.10 Input data for design

The basic data for the dimensioning of pavement structures are :

1. Lifetime ;
2. The calculation risk considered ;
3. Climate data ;
4. Traffic ;
5. The ground support of the road;
6. Material characteristics.

II.4.10.1 Lifetime

The lifespan is related to the investment strategy adopted by the client. It corresponds to an average to high initial investment and lifespans ranging from 15 to 25 years depending on the level of the main network considered.

II.4.10.2 Calculation risk

Taking into account the probabilistic nature relating to the dimensioning of the pavements due to the importance of the dispersion and the random nature of the fatigue tests, the objective which is retained is that the probability of appearance of deterioration before a given period of x years is less than a fixed value. This probability of failure is called the "design risk" and the period of X years the "service life" or design time.

a. Definition of risk

A risk r% over a period of x years taken for the dimensioning of the pavement, is the probability that structural degradation will appear during these X years which would imply reinforcement of the pavement. The risk levels chosen are in fact closely related to the options chosen by the project owner in terms of service level and investment and maintenance strategy. The calculation risks (r%) adopted in the dimensioning of the structures, which are a function of the traffic and the level of the main network, are given in the Tables below.

Table V-6 : Risks adopted for the RP1 network

	Traffic class (TPLi) (HV/Day/ direction)	TPL3	TPL4	TPL5	TPL6	TPL
Risk (%)	GB / GB GB / GNT	20	15	10	5	2
	GL / GL	15	10	5	2	2
	BCg / GC	12	10	5	2	2

Table V-7 : Risks adopted for the RP2 network

	Traffic class (TPLi) (HV / Day / direction)	TPL0	TPL1	TPL2	TPL3
Risk%	GNT / GNT; TUF / TUF SG / SG; SB / SG	25		20	

II.4.10.3 Climatic data

The data directly used in the pavement design calculation relate to :

- In the hydric state of the subgrade,
- Seasonal temperature cycles.

a. Water state of the subgrade

The water state of the soil is taken into account through the bearing capacity of the support soil. This capacity is estimated from a CBR punching test in which the imbibition conditions (immediate or at 4 days) are linked to the climatic zone considered.

Table V-8 : Algeria climatic zones (see appendix)

Climatic zone	Rainfall (mm / year)	Weather	Region
I	> 600	Very humid	North
II	350-600	Humid	North, Highlands
III	100-350	Semi-arid	Highlands
IV	<100	Arid	South

b. Seasonal temperature cycles

The seasonal temperature cycles which influence the mechanical characteristics of bituminous materials (GB, BB, SB) are taken into account through the concept of equivalent temperature.

c. Definition of equivalent temperature

The designing calculation is made for a constant temperature called equivalent temperature θeq. This is such that the sum of the damage suffered by the roadway during a year, for a given temperature distribution, is equal to the damage that the roadway subjected to the same traffic would undergo but for a constant temperature θeq. The latter is determined by application of the cumulative damage of Miner's law.

Table V-9 : Equivalent temperature values (θeq)

Climatic zone	I and II	III	IV
Equivalent temperature ($\boldsymbol{\theta eq}$)℃	20	25	30

II.4.10.4 Traffic

The calculation of the dimensioning itself, it is the traffic accumulated over the chosen lifetime that is to be taken into consideration. This involves the notions of aggressiveness of heavy vehicles and equivalent cumulative traffic (TCEi).

a. Calculation of cumulative HV traffic (TCi)

TCi is the cumulative HV traffic over the period considered for dimensioning (lifetime). It is given by the following formula

$$TCi = TPLi \times 365 \times \frac{(1+i)^{n}-1}{i} \qquad \text{(V-5)}$$

- i = geometric growth rate, (taken equal to 0,04 in the design calculation), this rate of 4% results from a national traffic survey carried out as part of the study of the national road master plan.
- n = considered lifespan.

- TPLi = traffic class

b. Calculation of Equivalent Cumulative Traffic (TCEi)

The TCEi is the traffic to be taken into account in the design calculation, it corresponds to the cumulative number of equivalent axles of 13 tonnes over the considered service life.

NB: The standard reference axle in Algeria is the isolated axle with twin wheels of 130 kN (13 tonnes). This is the legal maximum axle.

The calculation of TCEi which involves the aggressiveness (A) of the HV is given by the formula

$$TCEi = TPLi.C.A.10^3 \qquad \text{(V-6)}$$

with

- C: cumulative factor

$$C = 365 \times \frac{(1+i)^n}{i} \times 10^3 \qquad \text{(V-7)}$$

- A: HV aggressiveness coefficient compared to the 13 tonnes reference axle.

Table V-10 : Values of the aggressiveness coefficient A

Network level main	Types of materials and structures	Values of A
RP1	Pavements for materials treated with bitumen: GB / GB; GB / TUF; GB / SG	0,6
	Materials treated with hydraulic binders GL / GL, BCg / GC	1
RP2	Untreated materials: GNT / GNT; TUF / TUF; SG / SG; AG / AG	0,6
	Pavements for materials treated with bitumen SB / SG	0,4
RP1 and RP2	Support soil (calculation of Ez, ad)	0,6

II.4.10.5 Soil-support

a. Support soil classes retained

The pavement support soil is assimilated to an elastic, homogeneous and isotropic semi-infinite mass. The mechanical characteristics necessary for the modeling are the Young's modulus (E) and the Poisson's ratio (υ).

1. The Poisson's ratio (υ) for soils is generally taken equal to 0.35.
2. The modulus of the support soil (E) also called Young's modulus is given below

Table V-11 : long-term load bearing classes of the subsoil

Bearing capacity class (Si)	S4	S3	S2	S1	S0
Modules (Mpa)	15	25	50	125	200

b. Soil support classes by main network level (RPi)

There is a relationship between the quality of the pavement support soil and the good behavior of pavements. For this reason, and for each main network level (RP1 and RP2), the supporting soil classes considered are as follows

1. For the main network RP1: S0, S1, S2

2. For the main network RP2: S0, S1, S2, S3

If these bearing capacity levels are not reached, then a subgrade will have to be provided in order to improve the modulus of the pavement support and this in accordance with the tables for upgrading the support soils given in part I

c. Calculation of admissible strain on the support soil $\varepsilon_{z,ad}$

The vertical compressive strain εz calculated by the model (finite element ALIZE III), must be limited to an admissible value $\varepsilon_{z,ad}$ which is given by an empirical relation deduced from a statistical study of the behavior of Algerian pavements. This formula is of the following form

$$\varepsilon_{z,ad} = 22 \times 10^{-3} (TCEi)^{0,235} \quad \text{(V-8)}$$

For each traffic class (TCEi), there corresponds a value of $\varepsilon_{z,ad}$

Note: The check εz $< \varepsilon_{z,ad}$ will be especially to be done in the case of pavements with untreated materials, because it is the predominant criterion in the design calculation.

In the case of pavements treated with bitumen and hydraulic binders, the pressure on the support soil will be so low that the criterion εz $< \varepsilon_{z,ad}$ will practically always be verified.

II.4.10.6 Materials

d. Mechanical performance

The mechanical performances relating to the different types of materials are given in the tables below.

- Bitumen treated materials (MTB)

Table V-12 : Mechanical performance bituminous materials

Material (MTB)	E $(30°, 10Hz)$ (Mpa)	E $(20°, 10Hz)$ (Mpa)	E $(20°, 10Hz)$ (Mpa)	E $(10°, 10Hz)$ (Mpa)	ε_6 $(10°, 25Hz)$ (10^6)	-1 / b	SN	Sh cm	υ	Kc
BB	2500	3500	4000	.	.	.	.	.	0,35	.
GB	3500	5500	7000	12500	100	6,84	0,45	0,3	0,35	1,3
SB	1500	.	.	3000	245	7,63	0,68	2,5	0,45	1,3

- Materials treated with hydraulic binders (MTLH)

Table V-13 : Mechanical performance of materials treated with hydraulic binders

Material MTLH	E (MPa)	$\sigma6$ (Mpa)	-1 / b	SN	Sh (cm)	V	kd	Kc
GL	20,000	0,50	18,4	1,24	3	0,25	1	1,5
GC	20,000	0,70	12	1	3	0,25	1	1,5
BCg	35000	2,15	16	1	3	0,25	1 / 1,47	1,5

- Untreated materials (MNT)

Table V-14 : Mechanical performance of untreated materials

Layers level	Young Modulus (Mpa)	K values	$\boldsymbol{\upsilon}$
Base (15 ≤ h ≤ 20cm)	GNT = 500 TUF1 = 500 TUF2 = 300 SG1 = 700 SG2 = 300 GA = 300	2,5 2 2 2 2 2	0,25 0,25 0,25 0,25 0,25 0,25
Foundations (in under layers of 25cm)	E (sublayer i) = kE (sublayer i-1)		
MNT Foundation Under GB and SB (GB / MNT)	E (sublayer i) = kE (sublayer i-1)		

e. Interface conditions

The conditions at the interfaces intervene in the modelling of the structure for the computations of stresses and strains carried out using the model retained in the computations. The various assumptions adopted are summarized in the table below :

Table V-15 : Synthesis of the hypotheses on the bonding conditions

Typical structures	Hypothesis on the type of interface
MTB: 1BB / GB / GB / support floor	All interfaces are glued
2 BB / GB / GNT or TUF or SG / ground	All interfaces are glued
3 SB / SG / support floor	All interfaces are glued
MTLH: 1 BB / GL / support floor	All interfaces are glued
2 BCg / GC / support soil	BCg / GC interface removed GC / ground glue interface
MNT: GNT / GNT / ground support 1. TUF / TUF / support floor 2. SG / SG / support floor 3. AG / AG / subsoil	All interfaces are glued

f. Calculation of admissible stresses and strains

The admissible stresses for each type of material are calculated from the following relations:

i Bitumen treated materials

The calculation of the admissible tensile strain ($\varepsilon_{t,ad}$) at the base of the bituminous layers is given by the following relation

$$\varepsilon_{t,ad} = \varepsilon_6(10°\mathrm{C}, 25Hz).kne.k\theta.kc \quad \text{(V-9)}$$

with

- ε_6 (10 ° C, 25Hz): limited deformation held after 10^6 cycles with a probability of failure of 50% at 10 ° C and 25Hz (fatigue test).
- Kne: factor linked to the cumulative number of equivalent axles supported by the roadway
- K: factor related to temperature
- Kr: factor linked to risk and dispersions
- Kc: factor linked to the calibration of the results of the calculation model with the behavior observed on pavements.

With:

$$\begin{cases} kne = \left(\frac{10^6}{TCEi}\right)^b \\ k\theta = \sqrt{\frac{E(10°C)}{E(\theta eq)}} \\ kr = 10^{-tb\delta} \end{cases} \tag{V-10}$$

$$\varepsilon_{t,ad} = \varepsilon_6(10°C, 25Hz).\left(\frac{10^6}{TCEi}\right)^b.\sqrt{\frac{E(10°C)}{E(\theta eq)}}\;.10^{-tb\delta} \tag{V-11}$$

With:

- TCEi: traffic in cumulative number of equivalent axles of 13 tonnes over the service life considered.
- b: slope of the fatigue line (b <0).
- E (10 ° C): Complex modulus of bituminous material at 10 ° C.
- Eeq : Complex modulus of bituminous materials at the equivalent temperature which is depending on the climatic zone considered.
- δ: f (dispersion)

$$\delta = \sqrt{SN^2 + \left(\frac{c}{b}Sh\right)^2} \tag{V-12}$$

With :

- SN: Dispersion on the fatigue law;
- Sh: Dispersion on the thicknesses ;
- c: Coefficient equal to 0,02 ;
- t : Fractile of the normal distribution, which is a function of the adopted risk (r%). (See table below)

Table V-16 : value of t = f (r%)

r%	2	3	5	7	10	12	15
t	-2,054	-1,881	-1,645	-1,520	-1,282	-1,175	1,036
r%	20	23	25	30	35	40	50
t	-0,842	-0,739	-0,674	-0,524	-0,385	-0,253	0

ii Materials treated with hydraulic binders:

The calculation of the admissible tensile stress (σt, ad) at the base of the layers treated with hydraulic binders is given by the following relation

$$\sigma_{t,ad} = \sigma_6 . kne . kr . kc \quad \text{(V-13)}$$

with

- σ_6: bending stress limit at 106 cycles given by the fatigue test;
- Kne, Kr, Kc: same as bitumen treated materials;
- Kd: factor linked to the effects of discontinuities (cracks) and thermal gradient (concrete slabs).

$\sigma_{t,ad}$ can be written as follows:

$$\sigma_{t,ad}(bars) = \sigma_6 . \left(\frac{TCEi}{10^6}\right)^b . 10^{-tb\delta} . kd . kc \quad \text{(V-14)}$$

iii Untreated materials (MNT)

There is no calculation of admissible stresses for this type of material. It is necessary to ensure the correct choice of the characteristics of the material in order to establish a good resistance to rutting. It is also necessary to ensure that the support soil is not too deformable.

g. Fatigue verification of structures and deformation of the subgrade

i Bitumen treated materials (MTB)

It will be necessary to check that εt and εz calculated (by ALIZE), are lower than the calculated admissible values, that is to say respectively to $\varepsilon_{t,ad}$ and $\varepsilon_{z,ad}$

$$\varepsilon_t < \varepsilon_{t,ad} \ and \ \varepsilon_Z < \varepsilon_{z,ad}$$

ii Materials treated with hydraulic binders (MTLH)

Also in this case, it will be necessary to check that the stresses and strain calculated by (ALIZE) are lower than the calculated admissible stresses and strain.

$$\sigma_t < \sigma_{t,ad} \ and \ \varepsilon_Z < \varepsilon_{z,ad}$$

iii Untreated materials (MNT)

In the case of MNT, the only verification is to be done on the support soil:

$$\varepsilon_Z < \varepsilon_{z,ad}$$

II.5 The AASHTO (American Association of State Highway and TransportationOfficials) method

It is a method based on an empirical analysis of the results of the AASHO Road test tests carried out in the late 1950s on more than 500 road test sections. Its role is to establish a relationship between the structural characteristics of the pavement and the evolution over time of the level of pavement quality (expressed as a viability index).

II.5.1 Equation of the AASHTO method

The equation based on a statistical correlation derived from observations for bituminous pavements is:

$$\log W_{18} = Z_R.S_0 + \log(SN+1) - 0{,}20 + \frac{log\left[\frac{\Delta PSI}{4{,}2-1{,}5}\right]}{0{,}40+\frac{1094}{(SN+1)^{5{,}19}}} + 2{,}32.\log(145{,}04Mr) - 8{,}07 \qquad \text{(V-15)}$$

with

- W18: total allowable number of axle passages equivalent to a single axle with dual wheels of 8,165 kg (18,000 lb)
- S0: standard error of the estimate, including the dispersion of all the data (materials, traffic, site, drainage, model, etc.). The recommended value is 0,45.
- ZR: normal deviation associated with the risk of calculus (1-R). A standard statistical table is used to directly determine the ZR to use according to the level of confidence (R) targeted.
- R: level of confidence or reliability. It represents the probability that the pavement has a quality level greater than or equal to that targeted at the end of the design period. (1-R) represents the design risk.

- PSI: present serviceability indice. It is an overall pavement quality index that varies between 0 and 5.
- The ΔPSI is the difference between a new pavement and a deteriorated pavement. The accepted deviation for the two initial states is presented with the values 4,2 and 1,5.
- Mr: effective modulus of resilience of the infrastructure soil. It is used to quantify the stiffness of a material. The Mr of each layer is also used to determine the structural number.
- SN: structural number. It expresses the effective thickness of the pavement structure whose lift is evaluated.

II.5.2 Principle of application of the AASHTO equation

The equation expresses a link between the service life in number of admissible heavy axles (W18) and the deterioration in the level of service (ΔPSI). The structural design of the pavement is considered adequate when its service life, expressed as the number of passages of axles equivalent to an axle of 8,2 tonnes, is greater than or equal to the number of passages envisaged for the reference axle. After solving this equation, the unknown of which is SN, the thickness of the different layers constituting the pavement structure must be determined from equation (V-1) which expresses the structural number.

$$SN_n = (a_1 D_1 + \cdots a_i m_i D_i + a_n m_n D_n)/25{,}4 \qquad \text{(V-16)}$$

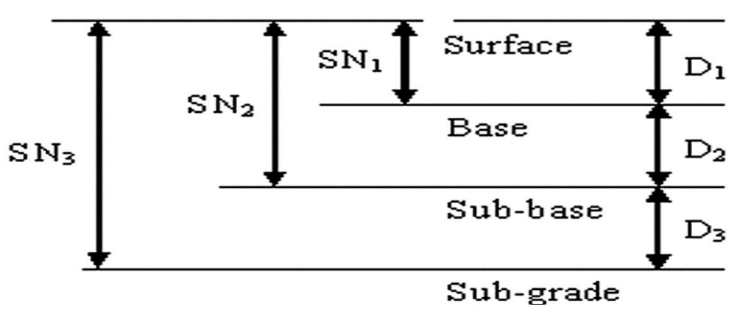


Figure V-7 :Distribution of layer thicknesses according to AASHTO (AASHTO, 1986)

With :

- SNn: composite structural number for n layers
- Di: thickness of layer i
- mi: drainage coefficient of layer i
- ai: structural coefficient of layer i.

The weight coefficient of each layer depends on the nature of the materials ai and the drainage conditions of the layer mi.

II.6 The LCPC method (Laboratoire Central des Ponts et Chaussées)

This method is derived from the AASHO tests, it is based on the determination of traffic equivalent given by the expression

$$T_{eq} = \frac{TJMA \times a[(1+\tau)^n - 1] \times 0.75P \times 365}{[(1+\tau) - 1]} \quad \text{(V-17)}$$

- Teq: equivalent traffic per axle of 13 tonnes
- TJMA: traffic in the year of commissioning of the road (v/d)
- a: coefficient which depends on the number of lanes (see the calculation of the traffic capacity)
- τ : Geometric annual growth rate (taken equal to 0,04 in the calculation of sizing. This rate of 4% is the result of a national traffic survey carried out as part of the study of the national road master plan.
- n: considers life of the road (in years between 15 to 25).
- P: percentage of heavy goods vehicles.

The LCPC chart is divided into a number of areas for which it is recommended depending on the nature and quality of the base layer. Once the value of the equivalent traffic is determined, we look for the value of the equivalent thickness e (according to Teq, ICBR) from the LCPC chart.

II.7 Analytical methods (theoretical)

The method is called so because it partially uses an analytical approach which is supplemented by empirical data. It is based on the mechanics of continuous medium and the resistance of materials. It is based on the analysis of the results of tests on materials carried out in the laboratory or on an experimental site (test board) to which the data checked in the field are associated to validate the selected structures. The process is done in two steps

1. Calculation of the admissible stresses and strains in the pavement as a function of the expected traffic (fatigue and strain model),
2. Calculation of the thicknesses required to meet the criteria of admissible stresses or strains.

II.7.1 Boussinesq's model (1885)

If the body of the road is not too different from the natural ground, it can be considered that the pressure is distributed in the same way as in a ground. This leads to consider the pavement structure as a semi-infinite mass and to propose a simple sizing method. With the assumption of isotropy and linear elasticity, this problem was solved by Boussinesq.

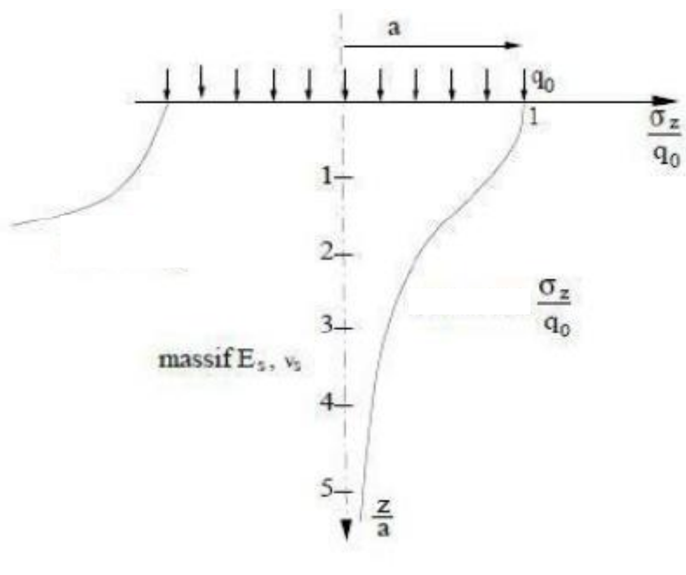


Figure V-8 :Stress distribution in a Boussinesq massif

A load of intensity q0 applied to a circle of radius a, the displacement, the vertical and radial stress at a point on the axis of the load located at a depth z are determined by the formula below:

$$\sigma_z = q_o \left[1 - \frac{(\frac{z}{a})^3}{(1+(\frac{z}{a})^2)^{\frac{2}{3}}}\right] \qquad \text{(V-18)}$$

- q_0: pressure applied by the tire;
- a: radius of action of the load;
- z: depth.

Thanks to Boussinesq's results, we can find the thickness H of the roadway where the vertical pressure does not exceed the admissible value of the soil. This template is simple and easy to use. However, its application to the dimensioning of the road has the following disadvantages

- The field of application of this model is limited (in the event that the body of the road is not too different from the subgrade).

- It does not characterize the behavior of multilayer structures.

- The stress σz does not depend on the modulus E2 of the support soil. It leads to uneconomical structures as soon as the allowable stress of the soil becomes relatively weak.

II.7.2 The Westergaard Model (1925)

He created the first real model dedicated to pavements. The simplicity of the model retained (bilayer model in today's terms) associated with Westergaard's mathematical genius enabled him to express the constraints in the form of simple, explicit equations accessible to all.
This Westergaard hypothesis is written

$$P = K \times W \qquad \text{(V-19)}$$

With:
P: Vertical stress on the ground;
W: Vertical displacement of the plate;

K: Coefficient of proportionality is called reaction modulus.

This model gives the stresses and strains of a system made up of a plate resting on a ground assimilated to a set of vertical springs without horizontal connections commonly called a Winkler foundation, whose vertical displacement at a point is proportional to the vertical pressure in this point.

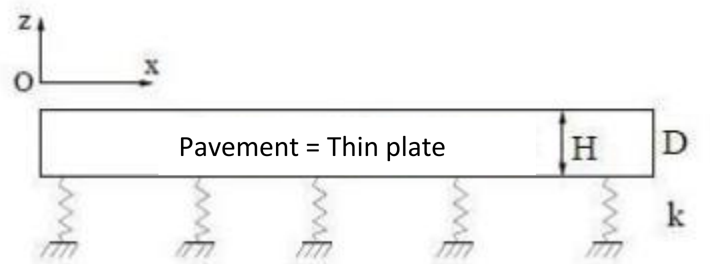


Figure V-9 :Diagram of the westergaard model

This implies that the soil reacts elastically and only vertically. Or, the ground does not behave like an elastic mass:

- It shows permanent deformations ;
- The reaction of the soil is therefore not strictly vertical;
- The stresses are dispersed in depth and shear stresses cannot be excluded;
- All specialists today recognize that the Westergaard model overestimates the constraints.

II.7.3 Hogg's bilayer model (1938)

When the vertical stress on the support soil is limited to a very low value (1/10 or 11/20 of the pressure exerted on the surface, for example), the distribution of the pressures by a granular body can be expensive, the thickness H is huge, to reduce this thickness, it suffices to increase the modulus ratio between the layer El of the roadway and E2 of the support soil. it using a hydraulic binder (cement, slag).

With a base treated with hydraulic binders, it is possible to obtain a low pressure on the supporting soil, without the pavement thickness being important. The pavement layer flexes under the applied load, this sag is accompanied by bending tensile stresses at the base of the pavement.
The dimensioning of the pavement then consists in verifying two criteria which condition its behavior over time.

- The vertical stress on the support soil must be less than a limited value, depending on (nature of the support soil and the number of loads envisaged).
- The flexural tensile stress at the base of the pavement layer must also be less than a limited value depending on the nature of the pavement material and the number of cycles.

With foundations treated with hydraulic binders, the first dimensioning criterion is generally satisfied when the second is, it is therefore sufficient to check both criteria. This is where the sizing of a pavement layer differs from a foundation. Since in soil mechanics, it is the first criterion, that is to say the pressure on the soil, which is preponderant.
The study of such a problem cannot be done using a Boussinesq model. The use of a bilayer model is necessary. In short it will take.

$\boldsymbol{\delta_z \le \delta_{zad}}$ and $\delta_t \le \delta_{tad}$ which is a necessary and sufficient condition; indeed $\delta_t \le \delta_{tad} \rightarrow \delta_z \le \delta_{zad}$

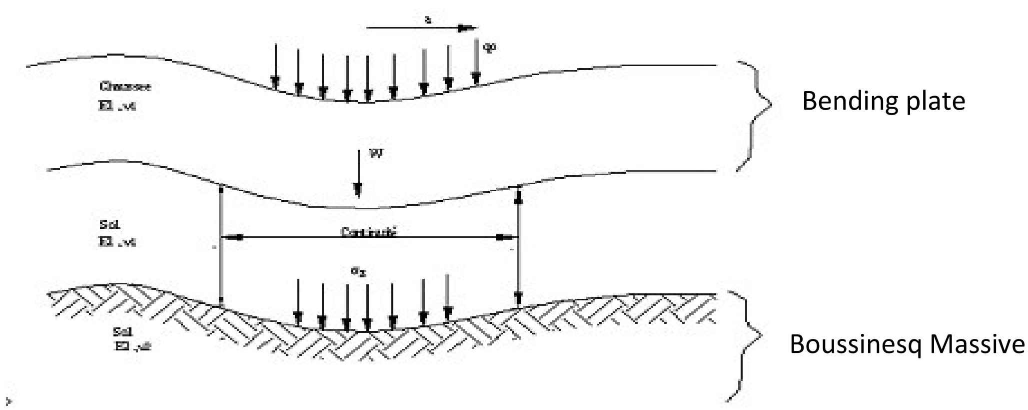


Figure V-10 :HOGG bilayer model (1938)

In the dimensioning of the pavement, apart from the condition of admissible stress at the surface of the subsoil, we must also check the criterion of tensile deformation at the base of the pavement layer. Among the theoretical solutions, we can mention the Westergaard solution.

II.7.4 Burmister's Multilayer Model (1943)

Bilayer models do not reproduce the multilayer nature of the pavement and do not correctly model the mechanical behavior of the pavement layers (plate assumption). Starting from these remarks, Burmister treated the general problem with n infinite layers in the plane and resting on the infinite ground of Boussinesq.

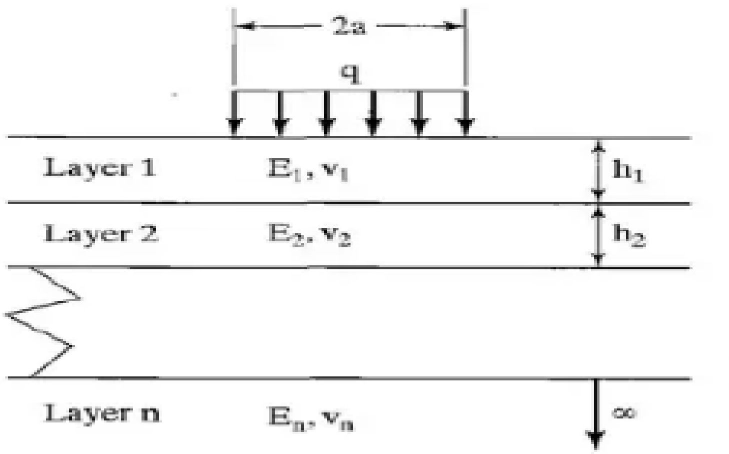


Figure V-11 :Schema of the Burmister model (1947)

Compared to previous models, Burmister dealt with the general problem of n layers, making the following assumptions:

- All layers are assimilated to elastic-linear, homogeneous, isotropic solids, characterized by a modulus of elasticity Ei and a Poisson's ratio µi, of infinite dimensions in plan and of thickness hi
- The interfaces between the layers are either glued or slippery, and the same structure can have interfaces with or without friction;

- Multiple load cases (twinnings, tandem or tridem axles, trailers) can be treated by supplementing the effects of elementary loads.
- The problem is solved by taking into consideration the symmetry of revolution of the system using the cylindrical coordinates.

II.7.5 Finite element model

Finally, (Cesar-LCPC in particular) imposes itself whenever continuous, elastic and linear multilayer models prove to be too simplistic. This approach makes it possible in particular to deal with the following cases:

- Three-dimensional character of the structure due to non-infinite geometries in plan,
- Nonlinearity or evolution of the conditions of contact,
- Viscoelastic behavior of materials under rolling loads, etc.

II.8 Conclusion

There are several methods of designing pavements. Among these are the CBR method, year and the catalogue of new pavements in Algeria. Most of these methods are empirical and lead to very favourible designs. The existence of theoretical models such as Boussinesq for one layer pavement, Westergaard, Hogg for bilayer pavements and Burmister for multilayer pavements has led to development of softwares for calculating stresses and strains in pavement such as Alize LCPC.
The comparison CBR and catalogue method will be done by designing a pavement situated in Tlemcen using CBR and catalogue method, this is done in the following chapter.

CHAPTER 3 : DESIGN OF A PAVEMENT - CASE STUDY

III.1 Introduction

Figure V-12 :Proposed pavement project [Google earth]

Figure V-12presented the layout of the proposed 1 km road pavement section situated in Tlemcen Mansourah. It is a dual carriageway separated by a central reservation. Taking trafic studies that were done in 2017, there was a total of 12675 vehicles per day and 8 percent were heavy vehicles. 20 years lifespan and trafic growth rate of 4 percent were adopted for the pavement design.
In the following section the proposed pavement will be designed using the common methods in Algeria which are following

1. The CBR (California-Bearing -Ratio) method;
2. The new pavement design catalog method.

III.2 **Required project data**

- AADT (2017) = 12765 V / D
- Estimated lifespan: n = 20 years
- Percentage of heavy vehicles: % HV = 8%
- Growth rate: τ = 4%
- Year of construction = 2021
- 2-way bidirectional pavement
- 1km long road located in **Tlemcen zone climatique II**

After geotechnical studies the road section will be divided into two chainages shown below

Table V-17 : CBR test results

Station (PK)	CBR Index
0 + 000 - 0 + 5000	10
0 + 5000 -1 + 000	7

III.3 **CBR method**

It is a simple design method which only takes heavy trafic volume of the projected years and cbr index of the subgrade into consideration. The design is based on the structural verification of punching shear on the subgrade. The materials used for the pavement layers are factored by equivalent coefficients. Proposed materials to be used are BB, GB and GNT.

III.3.1 Calculation of AADT for the year of construction (2021)

AADT 2021 = AADT (2017)$(1+\tau)^n$

= 12765 $((1+0{,}04)^4$

= 14934V/D

III.3.2 Calculation of AADT for the projected year (2041)

AADT 2041 = AADT (2021)$(1+\tau)^n$

= 14934 ($(1+0{,}04)^{20}$

= 32723V/D

III.3.3 Number of heavy vehicles by the year projected (2041)

$\text{N} = \%\, HV \times AADT\ (2041) \times\ Distribution\ coefficient$

= 0.08×32723×0.5

= 1309 HV /D/ lane

III.3.4 Section PK 0 + 000 to PK 0+ 500

See (**The CBR (California-Bearing -Ratio) method** for the values of P, a1 a2 and a3)

Total thickness

$$e = \frac{100+\sqrt{P}(75+50\log(\frac{N}{10}))}{I_{CBR}+5}$$

$$= \frac{100+\sqrt{6.5}(75+50\log(\frac{1309}{10}))}{10+5}$$

= 37,40cm

Total thickness equivalent

$\text{Eeq} = \sum_{i=1}^{n} a_i e_i$

= a1 × e1 + a2 × e2 + a3 × e3

= 2×8 + 1,50×10 + 1×10

= 41cm

e <Eeq pavement is verified for punching shear on the subgrade.

Final structure for section 1 is 8cm surface layer made of BB, 10cm base layer made of GB and 10cm subbase layer made of GNT. **(8BB 10GB 10GNT)**

III.3.5 Section PK 0 + 500 to 1 + 000

See (**The CBR (California-Bearing -Ratio) method** for the values of P, a1 a2 and a3)

Total thickness

$$e = \frac{100 + \sqrt{P}(75+50\log\left(\frac{N}{10}\right))}{I_{CBR}+5}$$

$$= \frac{100 + \sqrt{6.5}(75+50\log\left(\frac{1309}{10}\right))}{7+5}$$

= 46,75cm

Total thickness equivalent

$$Eeq = \sum_{i=1}^{n} a_i e_i$$

= a1 × e1 + a2 × e2 + a3 × e3

= 2×8 + 1,50×10 + 1×20

= 51 cm

e <Eeq pavement is verified for punching shear on the subgrade.

Final structure for section 1 is 8cm surface layer made of BB, 10cm base layer made of GB and 20cm subbase layer made of GNT. **(8BB 10GB 20GNT)**

III.4 **New Algerian Pavement DESIGN Catalog Method (CTTP)**

This method is a combination of both empirical and theoretical methods. It uses the values from the empirical results deducted from the tests done on Algerian soils and pavements. It takes into consideration the climate of the region with effects of varying temperatures.

III.4.1 NETWORK type

TJMA (2020) = 14934V / D is greater than 1200V / D, road is main network level 1 (RP1)

III.4.2 TPLi traffic class

TPLi = 0,08×14934×0,5

= 597HV / D / Direction at the year of commissioning

300 <**598** <600 TPL4 traffic class (Figure V-6)

III.4.3 Soil support class for pavement

$E(MPa) = 5.CBR$ (V-4)

$= 10\times 5$

= 50Mpa **Soil class S2**

III.4.4 Pavement structure Selected

Section Pk 0 + 000 to 0 + 500 : 6BB 15GB 35GNT

Section Pk 0 + 500 a 1 + 000 : 6BB 15GB 35GNT (**see appendix**)

III.4.5 Setting up the subgrade

Section Pk 0 + 000 to 0 + 500: CBR index is 10 the subgrade is not needed.

Section Pk 0 + 500 to 1 + 000: CBR index less than 10, the subgrade is necessary. Soil class s3 and targeted soil class s2, the topping layer is 40cm of untreated material implemented in 2 layers of 20cm (**see Table V-5**) **(see page 22)**

III.4.6 Calculation of admissible stress and strain

Aggression : A = 0,6	Table V-10
Calculation risk : r = 15%	Table V-6
Interface conditions :all interfaces are glued	Table V-15
Equivalent temperature : θ℃ = 20 ℃	Table V-9
Calibration data :Kc = 1,3	Table V-12

III.4.7 Cumulative HV traffic (TCEi)

$TCEi = TPLi.C.A.10^3$ (V-6)

$= \text{TPLi} \times 365 \times \frac{(1+i)^n - 1}{i} \times A \times 10^3$

$= 598 \times 365 \times \frac{(1+0,04)^{20} - 1}{0,04} \times 0,6 \times 10^3$

$= 3,899 \times \mathbf{10^6}$ Equivalent 13 tonnes axle

III.4.8 Modeling

Table V-18 layer modeling

	Thickness (cm)	Young Modulus (MPa)	Poisson's ratio (ν)
surface layer	6BB	4000	0.35
base layer	15GB	7000	0.35
Subbase layer 1	15GNT	500	0.25
subbase layer 2	20GNT	500	0.25
Subgrade	Infinity	50	0.35

III.4.9 Calculation of the admissible vertical compressive strain on the support soil $\boldsymbol{\varepsilon_{z,ad}}$

$\varepsilon_{z,ad} = 22 \times 10^{-3} (TCEi)^{0,235}$ (II 8)

$= 22 \times 10^{-3} (3,899 \times 10^6)^{0,235}$

$= 621 \times 10^{-6}$

III.4.10 Calculation of the admissible horizontal tensile strain on the base of GB $\boldsymbol{\varepsilon_{t,ad}}$

-Factor linked to the cumulative number of equivalent axles supported by the pavement

$\text{Kne} = \left(\frac{10^6}{TCEi}\right)^b = \left(\frac{10^6}{3,899 \times 10^6}\right)^{-0,146} = 0,820$ (II-10)

-Factor related to temperature

$$K\theta=\sqrt{\frac{E(10℃)}{E(\theta eq)}}=\sqrt{\frac{12500}{7000}}=1{,}34 \qquad \text{(II-10)}$$

-Factor linked to risk and dispersions

$$\delta=\sqrt{SN^2+\left(\frac{c}{b}Sh\right)^2}=\sqrt{0{,}45^2+\left(\frac{0{,}02}{-0{,}146}3\right)^2}=0{,}609 \qquad \text{(II-12)}$$

$$\text{Kr} = 10^{-tb\delta}=10^{-1{,}036\times0{,}146\times0{,}609}=0{,}809 \qquad \text{(II-10)}$$

$$\varepsilon_{t,ad}=\varepsilon_6(10℃,25Hz).kne.k\theta.kc \qquad \text{(II-9)}$$

$$=100\times10^{-6}\times0{,}82\times1.34\times0{,}81\times1.3$$

$$=115\times10^{-6}$$

III.5 Interpretation of the results

The cbr method has a total pavement thickness of 28 and 38 cm for chainage 1 and 2 respectively, the difference was due to low bearing capacity of the soil for the 2nd section. The catalogue provided the same structure for two chainages because the low bearing capacity of the soil was topped with imported subgrade.

III.6 Conclusion

The CBR method has the most economic structure as compared to the catalogue. It uses projected trafic for the design whereas the catalogue uses the concept of cumulative trafic, it does not take into consideration effect of temperature cycles, hydric state of the soil and the risks involved. The pavement structure obtained from the catalogue will be simulated using the ALIZE software in the following chapter.

CHAPTER 4 : PAVEMENT SIMULATION USING ALIZÉ LCPC SOFTWARE

Figure V-13 :Alizé LCPC software

IV.1 **Theoretical principle**

The ALIZE calculation program used by the central laboratory of bridges and causeways, makes it possible to determine, from an elastic multilayer model based on the Burmister hypothesis, the stresses, deformations and displacements at different levels and distances of loads represented by a general circular imprint.

The principle of use of the program is therefore as follows.

- Modeling of a structure, ie; choice of number of layers, their thickness, their bonding between them, characteristics of the constituent materials (Young modulus and Poisson coefficient)
- Searches for the maximum stress likely to cause degradation of a layer, for the typical load

- comparison of this stress with the admissible limit value deriving from the fatigue strength of the material considered, for the application intensity of the typical load determined from the desired bearable traffic

A pavement calculation carried out from ALIZE therefore calls upon both theoretical data (stress calculation), experimental data (characteristics of the materials) and the knowledge of the engineer (choice of model, bonding, layer thickness, etc ...)

IV.2 **Description of problem**

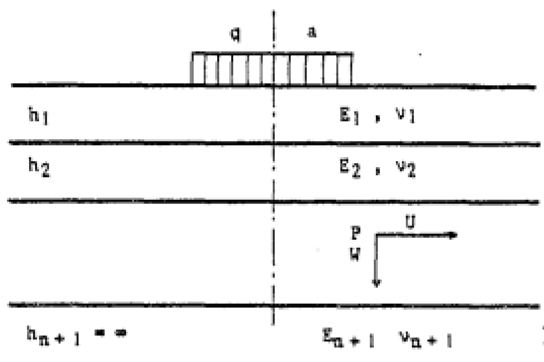


Figure V-14 :Theoretical model

n horizontal layers of thickness hi with elastic deformation modulus Ei and Poisson's ratio vi, surmount a semi-infinite mass. This stratified structure can be subjected to various types of loads of revolution (radius a)

u and w are the displacements in point P

IV.3 **Principle of resolution Burmister method**

$$\text{we are looking for} \quad \begin{cases} \mathrm{u, w\ (r, z)} \\ \sigma_r, \sigma_\theta, \sigma_z et\ \tau_{rz} \end{cases}$$

Calling the function of tension, it will suffice to solve the double Placian $\phi\nabla^2\emptyset(r,z)$ = 0 and deduce from it the expressions of displacements and of the constraints after introduction of the selected boundary conditions.

$$\text{Surface}\begin{cases}\sigma_Z = q(r) = \begin{cases} q_0 \text{ if r} \leq \text{a} \\ 0 \text{ if r} > \text{a}\end{cases} \\ \tau_{rz} = 0\end{cases}$$

$$\text{at interfaces}\begin{cases}-\text{continuation of displacements and stresses if the layers are glued.} \\ -\text{continuation of displacements and stresses if the layers are glued.}\end{cases}$$

The search for bi-harmonic functions $\emptyset$ is greatly facilitated by placing it in the Hankel plane

$$\emptyset(r,z) \Longrightarrow \text{Hn=[} \emptyset\ (r,z)\ ] \int_0^\infty r\ J_n\ (mr)\emptyset(r,z)\ dr$$

The integrations corresponding to the inverse transformation are carried out numerically.

IV.4 **The input parameters**

- Geometric and mechanical characteristics of the different layers composing the structure ;
- Interface conditions at each interface ;
- The reference load ;
- The coordinates of the points to be calculated.

IV.5 **The output parameters**

At each point, we determine

- The two displacements r and z;

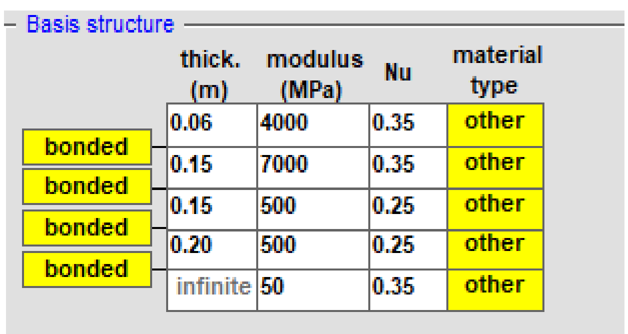
- The four stresses of axisymetry (σ_r , σ_θ , σ_z et τ_{rz});
- The four corresponding deformations ;
- The radius of curvature of the deformation in the planes (r, z);
- The radius of curvature in the plane (y, z) under a twinning symbolized by two charged circles.

IV.6 **Application in the Project**

Pavement structure preliminary designed using the Catalogue of new pavement will be introduced into ALIZE software for calculating stresses and strains. These values will be compared with the allowable values calculated in chapter 3. See Table V-18 for geometric and mechanical characteristics of the pavement layers

The steps for the use of software are shown below;

1. Interface condition assumption: All the layers are bonded.



Basis structure

interface	thick. (m)	modulus (MPa)	Nu	material type
	0.06	4000	0.35	other
bonded	0.15	7000	0.35	other
bonded	0.15	500	0.25	other
bonded	0.20	500	0.25	other
bonded	infinite	50	0.35	other

Figure V-15 : Pavement characteristics

2. Reference load used and calculation points.

   The Algerian pavement design catalogue adopted the 130 kN standard axle, with dual tires of wheel loads, for both flexible, which corresponds to the maximum legal limit. For analysis purpose, the load was applied on two circular loaded areas, each one with a radius of 12,5 cm and a center-to-center distance of 37,5 cm, which corresponds to a gap between the loads of 12,5 cm, adopting the uniform pressure of 0,662 MPa.

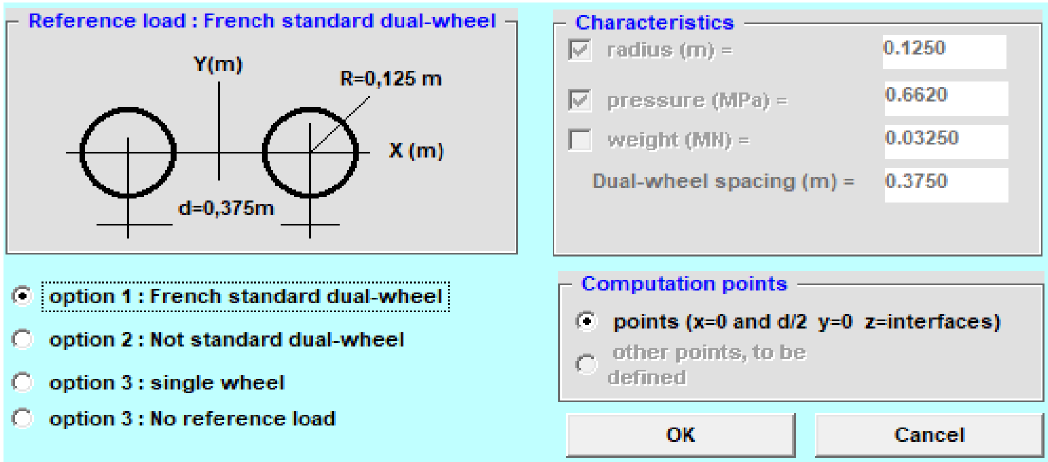
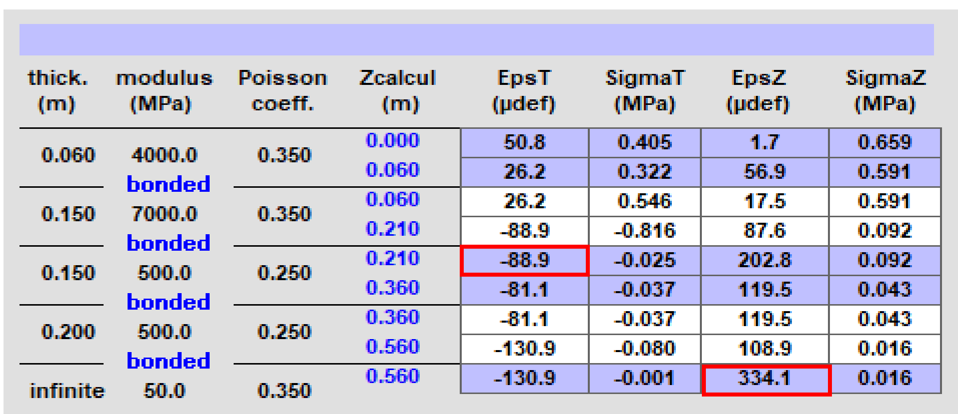


Figure V-16 :Reference load and calculation points

3. Stress and strain results calculated by ALIZE LCPC Software



thick. (m)	modulus (MPa)	Poisson coeff.	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0.060	4000.0	0.350	0.000	50.8	0.405	1.7	0.659
			0.060	26.2	0.322	56.9	0.591
	bonded						
0.150	7000.0	0.350	0.060	26.2	0.546	17.5	0.591
			0.210	-88.9	-0.816	87.6	0.092
	bonded						
0.150	500.0	0.250	0.210	-88.9	-0.025	202.8	0.092
			0.360	-81.1	-0.037	119.5	0.043
	bonded						
0.200	500.0	0.250	0.360	-81.1	-0.037	119.5	0.043
			0.560	-130.9	-0.080	108.9	0.016
	bonded						
infinite	50.0	0.350	0.560	-130.9	-0.001	334.1	0.016

Figure V-17 :Strain and stress values

4. Comparison with admissible strain

	Calculted Strain	Allowable strain
$\varepsilon_{z,ad}$ (above subgrade)	334.1×10^{-6}	621×10^{-6}
$\varepsilon_{t,ad}$(below base GB)	88.9×10^{-6}	115.7×10^{-6}

IV.7 **Determination of the optimal pavement structure**

Optimal pavement is the most economic structure which corresponds to future projected trafic, this is done by using knowledge of the engineer. The pavement materials will be chosen from local available to minimize costs. In our case the optimal structure will be done by removing one layer of GNT, this is done on the sofware as follows;

1. Thickness of the untreated gravel is varied between 15 to 24 cm.

	starting data no1			thickness alternatives								
	thick. (m)	modulus (MPa)	Nu	no2	no3	no4	no5	no6	no7	no8	no9	no10
	0.06	4000	0.35	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060	0.060
bonded												
	0.15	7000	0.35	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150	0.150
bonded												
	0.15	500	0.25	0.160	0.170	0.180	0.190	0.200	0.210	0.220	0.230	0.240
bonded												
	infinite	50	0.35	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite	infinite

Figure V-18 : Thickness variants

2. Stress and strain results calculated by ALIZE LCPC Software .

thick. (m)	modulus (MPa)	Poisson coeff.	Zcalcul (m)	EpsT (µdef)	SigmaT (MPa)	EpsZ (µdef)	SigmaZ (MPa)
0.060	4000.0	0.350	0.000	70.3	0.538	-16.6	0.658
			0.060	33.0	0.374	48.2	0.588
	bonded						
0.150	7000.0	0.350	0.060	33.0	0.639	9.0	0.588
			0.210	-106.4	-0.998	102.8	0.076
	bonded						
0.200	500.0	0.250	0.210	-106.4	-0.042	185.7	0.076
			0.410	-178.7	-0.107	145.9	0.023
	bonded						
infinite	50.0	0.350	0.410	-178.7	-0.001	460.6	0.023

Figure V-19:Stress and strain for optimal structure.

3. Comparison with admissible strain

	Calculated Strain	Allowable strain
$\varepsilon_{z,ad}$(on the subgrade)	460.6×10^{-6}	621×10^{-6}
$\varepsilon_{t,ad}$(below GB)	106.4×10^{-6}	115.7×10^{-6}

New structure **6BB - 15GB - 20GNT**

IV.8 **Comparaisons between structures**

The table below shows materials thickness used for each chainage designed using different methods.

Table V-19 Pavement structure comparison

	PAVEMENT STRUCTURE	
	Pk 0 + 000 to 0 + 500	Pk 0 + 500 to 1 + 000
CBR	8BB 10GB 10GNT	8BB 10GB 20GNT
CATALOGUE	6BB 15GB 35GNT	6BB 15GB 35GNT 40MNT
CATALOGUE-OPTIMAL STRUCTURE	6BB 15GB 20GNT	6BB 15GB 20GNT 40MNT

1st chainage : **Section PK 0 + 000 to PK 0 + 500**

CBR METHOD	CATALOG METHOD	OPTIMAL STRUCTURE
8BB	6BB	6BB
10GB	15GB	15GB
10GNT	15GNT	20GNT
GROUND	20GNT	GROUND
	GROUND	

2nd chainage : Section PK 0 + 500 to PK 1 + 000

CBR METHOD	CATALOG METHOD	OPTIMAL STRUCTURE
8BB	6BB	6BB
10GB	15GB	15GB
20GNT	15GNT	20GNT
GROUND	20GNT	40MNT
	40MNT	GROUND
	GROUND	

IV.9 **Conclusion**

Cbr method gives us the most economical structure as compared to the optimal structure which is refined from the structure provided by the Algerian catalogue. The best solution which is going to be used for the project is the optimal structure for the following reasons it considers the climate, risks associated with the design and the makes use of the technology software for the best designs.

GENERAL CONCLUSIONS AND PERSPECTIVES

Design is an important element in the study of a road project. Many empirical and theoretical methods have been developed for the sizing of pavements. The scope of use of these methods may be limited by conditions and each of these methods has its own assumptions. The choice of the method to be applied for a project must then be analyzed according to the circumstance.

The objective of pavement design is to provide an economic structure, in terms of material types and thicknesses, that can withstand the expected traffic loading over a specified time, without deteriorating below a predetermined level of service.

When analyzing the pavement design method in Algeria, we conclude that the two structural pavement design criteria are fatigue cracking at bottom of the bitumen layers and permanent deformation, at the top of the subgrade.

The CBR method is an outdated method of design which needs to be used for roads with low traffic roads with limited budget, for roads with high traffic volume adopt Algerian pavement catalogue method.

Finally for future pavement design, we need to take into consideration all type vehicle traffic and convert them into equivalent heavy design traffic load. This will be done using 4^{th} power law.

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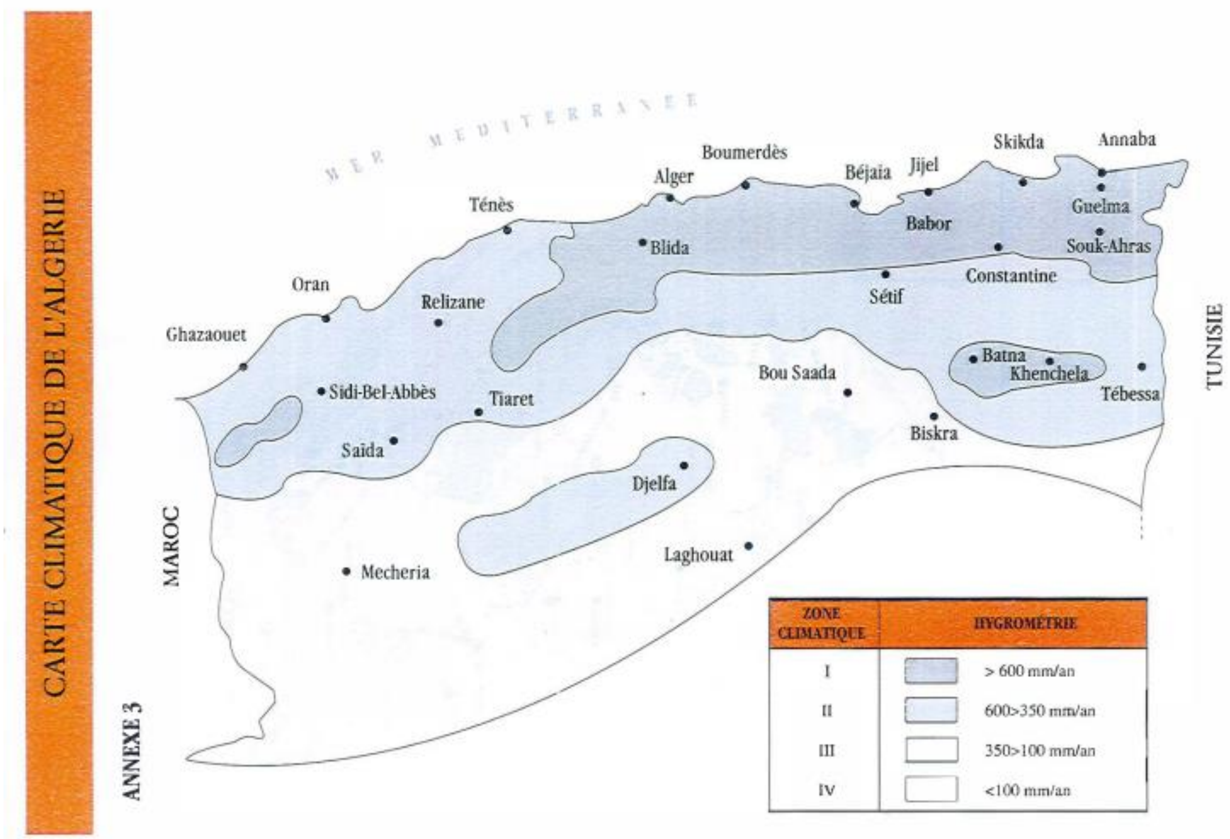
APPENDIX

APPENDIX I : ALGERIAN CLIMATIC ZONES



APPENDIX II : CHARTS USED TO DETERMINE THE THICKNESSES OF PAVEMENTS

RESEAU PRINCIPAL DE NIVEAU 1 (RP1) GB/GNT

FICHE STRUCTURE GRAVE BITUME/GRAVE NON TRAITEE

Type : MTB
Zone climatique : I et II
Durée de vie : 20 ans, taux d'accroissement : 4%

Si / TPLi PL/j/sens	S2 (50 MPa)	S1 (125 MPa)	S0 (200 MPa)
6000 **TPL7** 3000			
3000 **TPL6** 1500			
1500 **TPL5** 600	6 BB 20 GB 30 GNT	6 BB 14 GB 30 GNT	6 BB 12 GB 30 GNT
600 **TPL4** 300	6 BB 15 GB 35 GNT	6 BB 10 GB 35 GNT	6 BB 10 GB 20 GNT
300 **TPL3** 150	6 BB 15 GB 30 GNT	6 BB 10 GB 25 GNT	6 BB 10 GB 15 GNT

Si : Classe de sol support, TPLi : Classe de trafic PL/jour/sens
BB : Béton bitumineux, GB : Grave bitume (0/20), GNT : Grave non traitée
Epaisseurs de mise en œuvre : GB (min = 10, max = 15), GNT : (min = 15, max = 25)

Toutes les épaisseurs sont données en cm

APPENDIX III: CHARTS USED TO DETERMINE THE THICKNESSES OF PAVEMENTS LCPC METHOD