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Comparative Studies of Flexible and Rigid Pavement Design Methods

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الآية

قال تعالى:

إِنَّا عَرَضۡنَا ٱلۡأَمَانَةَ عَلَى ٱلسَّمَٰوَٰتِ وَٱلۡأَرۡضِ وَٱلۡجِبَالِ فَأَبَيۡنَ أَن يَحۡمِلۡنَهَا وَأَشۡفَقۡنَ مِنۡهَا وَحَمَلَهَا ٱلۡإِنسَٰنُۖ إِنَّهُۥ كَانَ ظَلُومٗا جَهُولٗا ٧٢

صدق الله العظيم

الأحزاب الاية 72

الإهداء

عندما يعتلي الحرف السكون ...

ويكون معني الصمت ابلغ ما يقال ...

حينها نبحث في خيالنا عن ناس ...

كانوا مثل الشمع ... يفنوا ... كي يضاء الدرب ... حبا واحتراما ...

نهدي هذا البحث الي ...

أمهاتنا الغاليات وآبائنا الكرام

ولو كان معني الحب بيت من الشعر ...

ومعني القول حبر لا يجف ...

فأنتم من صاغ الخواطر ...

وأنتم في ثنايا العمر فخرا واعتزازا ...

Acknowledgement

First of all we would like to thank ALLAH the most merciful and most grateful for giving us the power and the strength to accomplish this project and bring it to successful completion.

We would like also to thank our supervisor **Professor. Galal A. Ali** for his effort, encouragement, patience and helpful comments throughout the period of the study

Abstract

In this project, the analysis was carried out flexible and rigid pavements, these analysis play a great role in the decision making process in selection of pavements types, the two most crucial parameters that govern the design of asphalt and plain-jointed concrete pavement are soil sub-grade strength, generally California bearing ratio (CBR), resilient modulus (M_R) and modulus of sub-grade reaction (K), and the design traffic (million ESAL).

The common design method for flexible pavement are the AASHTO method, Asphalt Institute and Two layer system. The present study applied the AASHTO and PCA method for design of rigid pavements, for both pavement types using 20 year design life and 5% annual growth rate.

Relevant design data where obtained from DAR consult and technique cone group to design Omdurman Eldabaseen Road, a comparison has been done between different design results to find the best design alternative into material availability.

التجريد

في هذا المشروع تمت مقارنة التحليل بين الرصف المرن والرصف الصلب، هذا التحليل يلعب دوراً مهماً في إتخاذ قرار لاختيار نوع الرصف ، أهم عاملين متغيرين لتجربة يحكمان تصميم الأسفلت هما: مقاومة قوة تحمل الأرض الطبيعية ، نسبة تحميل كاليفورينا (CBR) ، وحدة قياس المرونة MR، وحدة قياس مقاومة التربة الطبيعية (K) والتصميم المروري (Million ESAl).

الطرق الشائعة لتصميم الرصف المرن هي طريقة آشتو ومعهد الأسفلت ونظام الطبقات، أما بالنسبة للرصف الصلب استخدمت طريقتي آشتو واتحاد الأسفلت البورتلندي مع استخدام عمر تصميمي (20 سنة) ونسبة نمو (5%) للتصميمين الصلب والمرن.

البيانات والمعلومات تم تجميعها من مجموعة دار الاستشارية والتقنية لتصميم طريق أمدرمان الدباسين، تمت المقارنة بين نتائج التصميم المختلفة لإيجاد أفضل بديل للتصميم.

SYMBOLS & ABBREVEATION

AASHTO American Association Of State Highway and Transportation Official.

PCA Portland Cement Association.

CBR California Bearing Ratio.

AI Asphalt Institute.

HMA Hot Mix Asphalt.

EAB Emulsified Asphalt Base.

Mr Resilient Modulus.

ESG Elastic Modulus of Sub-grade.

Esb Elastic Modulus of Sub-base.

Ebs Elastic Modulus of Base.

R Reliability.

SN Structure Number.

PCC Portland Cement Concrete.

HMAC Hot Mix Asphalt Concrete.

JPCP Jointed Plain Concrete Pavement.

JRCP Jointed Reinforced Concrete Pavement.

CRCP Continuously Reinforced Concrete Pavement.

fc Compressive Strength of Concrete.

Ec Elastic Modulus of Concrete.

CD Drainage Coefficient.

J Load Transfer Coefficient.

D Cumulative Damage.

ESAL Equivalent Single Axle Load.

ELAF Equivalent Load Axle Factor.

ADT Average Daily Traffic.

Nt Number of Truck.

Pt Percent of Trucks in ADT.

N Growth Rate.

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CHAPTER ONE

INTRODUCTION

CHAPTER ONE

1 INTRODUCTION

1.1 Introduction:

Pavement Design Definition ,types :

The structural pavement design means found thickness for pavement layer to resist traffic loading during the design period .

Different types of pavement are commonly used in the construction of roadways .
The two important factors that govern pavement design are soil sub-grade strength and the traffic loading , Both the sub-grade soil strength and the design traffic affect the layer thicknesses of flexible as well as rigid pavements . In the design of flexible pavements , traffic load is expressed in terms of million equivalent single axle load (ESALs) ; where as it is expressed as axle load distribution (ALD) designing for rigid pavements .

The fact that the sub-grade CBR or MR can be convert to K and EASLs into ALD makes it possible to design the two types of pavements . Flexible and Rigid pavement are designed for similar soil and traffic conditions using appropriately related , different methods and their costs are compared .

1.2 Problem Statement:

1. Sudan tropical climate.
2. Sudan is a developing country.

1.3 Significance:

Currently only asphalt pavement are used in Sudan mostly apply empirical method there sum daunts the economical justified under different method with premature failure in most cases .
On the other hand of viability material of concrete pavement justified under taken this study , however for flexible pavement there is problem of finding suitable aggregates .

1.4 Objectives :

In this project we want to compare between the Flexible and Rigid pavement design methods :

Layers system

AASHTO design method

Asphalt Institute (AI)

Portland Cement Association (PCA)

Studding international flexible and rigid pavement design methods ; and knowing disadvantages of each design methods and knowing the differences in thickness and find the best alternative .

The common objectives :

1- Determination of parameter for main design factor , namely layer material strength , design traffic and other required .

2- Design typical section for flexible and rigid pavement .

CHAPTER TWO

BACKGROUUND and LITERATURE REVIW

CHAPTER TWO

2 BACKGROUND and LITERATURE REVIW

2.1 Pavement Definition:

Pavement is the actual travel surface especially made durable and serviceable to withstand the traffic load commuting upon it. Pavement grants friction for the vehicles thus providing comfort to the driver and transfers the traffic load from the upper surface to the natural soil. In earlier times before the vehicular traffic became most regular, cobblestone paths were much familiar for animal carts and on foot traffic load.

Pavements are primarily to be used by vehicles and pedestrians. Storm water drainage and environmental conditions are a major concern in the designing of a pavement. The first of the constructed roads date back to 4000 BC and consisted of stone paved streets or timber roads. The roads of the earlier times depended solely on stone, gravel and sand for construction and water was used as a binding agent to level and give a finished look to the surface. All hard road pavements usually fall into two broad categories namely

2.2 Pavement Types:

There are two major types of pavements:

2.2.1 Flexible pavements:

Flexible pavement is composed of a bituminous material surface course and under lying base and sub-base courses, the bituminous material is more of the asphalt whose viscous nature allows significant plastic deformation. Most asphalt surface are built on gravel base although some full depth asphalt surface are built directly on the sub-grade. Depending on the temperature at which it is applied asphalt is categorized as hot mix asphalt HMA warm mix asphalt or cold mix asphalt. Flexible pavement is so named as the pavement surface reflects the total deflection of all subsequent layers due to the traffic load acting upon it.

2.2.1.1 Flexible pavements types:

a) Conventional Flexible Pavements:

Conventional flexible pavements are layered systems with better materials on top where the intensity of stress is high and inferior materials at the bottom where the intensity is low . Adherence to this design principle makes possible the use of local materials and usually results in a most economical design.

This is particularly true in regions where high-quality materials are expensive but local materials of inferior quality are readily available.

Surface Course:

The surface course is the top course of an asphalt pavement, sometimes called the wearing course. It is usually constructed of dense graded HMA. It must be tough to resist distortion under traffic and provide a smooth and skid-resistant riding surface . It must be waterproof to protect the entire pavement and sub-grade from the weakening effect of water. If the above requirements cannot be met, the use of a seal coat is recommended.

Base Course and Sub-base Course:

The base course is the layer of material immediately beneath the surface or binder course . It can be composed of crushed stone ,crushed slag, or other untreated or stabilized materials. The sub-base course is the layer of material beneath the base course . The reason that two different granular materials are used is for economy. Instead of using the more expensive base course material for the entire layer, local and cheaper materials can be used as a sub-base course on top of the sub-grade . If the base course is open graded, the sub-base course with more fines can serve as a filter between the sub-grade and the base course .

Sub-grade:-

The top 6 in. (152 mm) of sub-grade should be scarified and compacted to the desirable density near the optimum moisture content. This compacted sub-grade may be the in-situ soil or a layer of selected material.

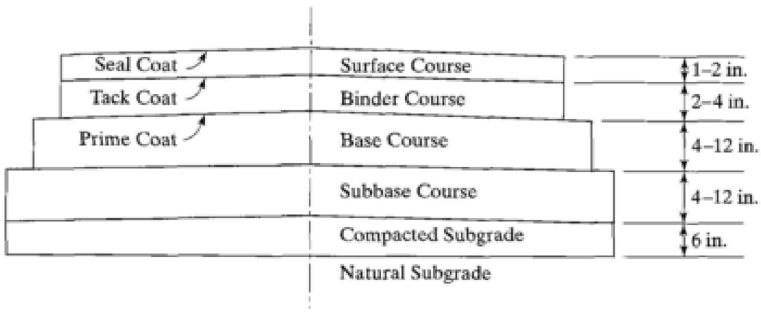


Figure 2-1Typical Cross-section of a Conventional Flexible Pavement

b) Full-Depth Asphalt Pavements:

Full-depth asphalt pavements are constructed by placing one or more layers of HMA directly on the sub-grade or improved sub-grade. This type of construction is quite popular in areas where local materials are not available.

It is more convenient to purchase only one material, i .e. HMA, rather than several materials from different sources, thus minimizing the administration and equipment costs.

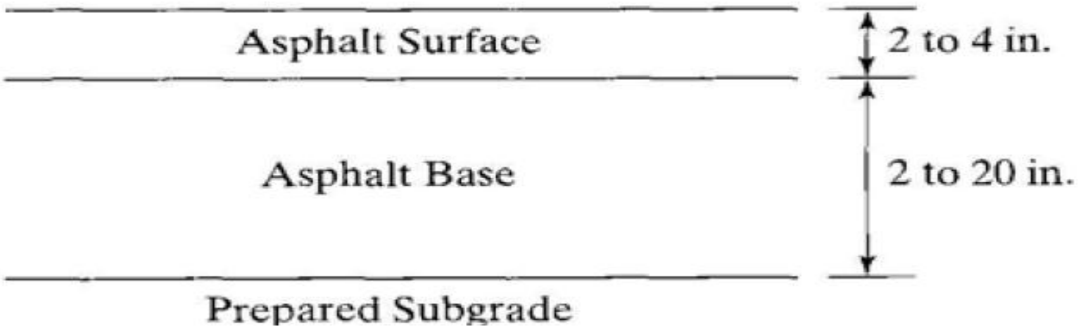


Figure 2-2Typical Cross-section of a Full Depth Asphalt Pavement

2.2.2 Rigid Pavements:

Rigid pavements are constructed of port-land cement concrete and should be analyzed by the plate theory, instead of the layered theory. Plate theory is a simplified version of the layered theory that assumes the concrete slab to be a medium thick plate with a plane before bending which remains a plane after bending. Rigid pavements are placed either directly on the prepared sub-grade or on a single layer of granular or stabilized material. Because there is only one layer of material under the concrete and above the sub-grade, some call it a base course, others a sub-base.

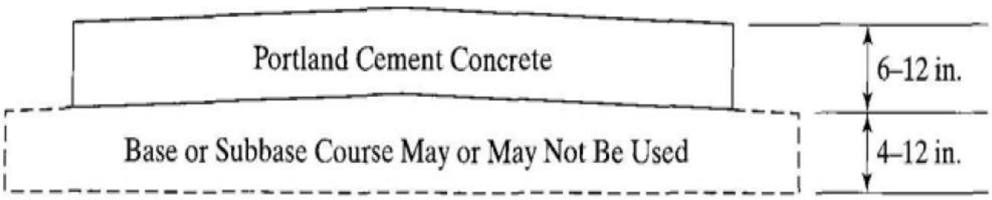


Figure 2-3Typical Cross-section of a Rigid Pavement

2.2.2.1 Rigid Pavements Types:

Rigid pavements can be classified into four types :

Jointed Plain Concrete Pavement (JPCP), Jointed Reinforced Concrete Pavement(JRCP), Continuous Reinforced Concrete Pavement (CRCP), and Pre-stressed Concrete Pavement (PCP). Except for PCP with lateral pre-stressing, a longitudinal joint should be installed between two traffic lanes to prevent longitudinal cracking.

a) Jointed Plain Concrete Pavements:

All plain concrete pavements should be constructed with closely spaced contraction joints. Dowels or aggregate interlocks may be used for load transfer across the joints. The practice of using or not using dowels varies among the states. Dowels are used most frequently in the southeastern states ,aggregate interlocks in the western and southwestern states, and both are used in other areas. Depending on the type of aggregate, climate, and prior experience, joint spacing between 15 and 30 ft (4.6 and 9.1 m) have been used. However, as the joint spacing increases, the aggregate interlock decreases, and there is also an increased risk of cracking .Based on the results of a performance survey.

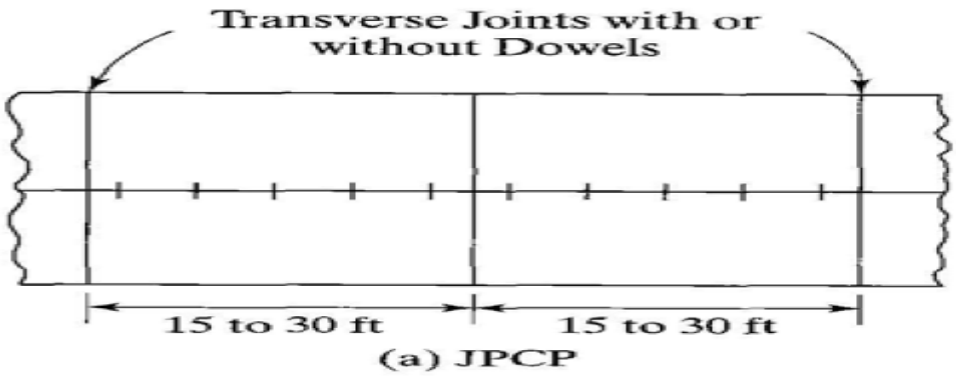


Figure 2-4Jointed Plain Concrete Pavement

b) Jointed Reinforced Concrete Pavements:

Steel reinforcements in the form o f wire mesh or deformed bars do not increase the structural capacity of pavements but allow the use of longer joint spacing. This type of pavement is used most frequently in the northeastern and north central part of the United States. Joint spacing vary from 30 to 100 ft (9 .1 to 30 m). Because of the longer panel length, dowels are required for load transfer across the joints. The amount of distributed steel in JRCP increases with the increase in joint spacing and is designed to holdthe slab together after cracking. However, the number o f joints and dowel costs decrease with the increase in joint spacing. Based on the unit costs of sawing, mesh, dowels, and joint sealants.

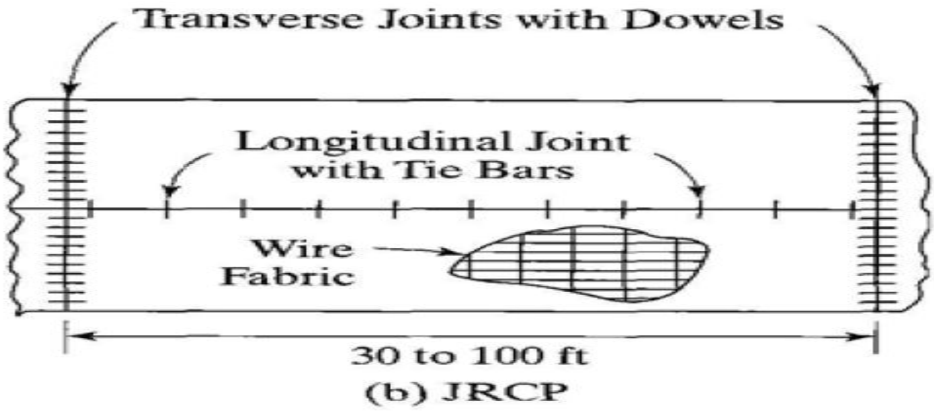


Figure 2-5Jointed Reinforced Concrete Pavement

c) **Continuous Reinforced Concrete Pavement:**

It was originally reasoned that joints were the weak spots in rigid pavements and that the elimination of joints would decrease the thickness of pavement required . As a result, the thickness of CRCP has been empirically reduced by 1 to 2 in. (25 to 50 mm) or arbitrarily taken as 70 to 80% of the conventional pavement.

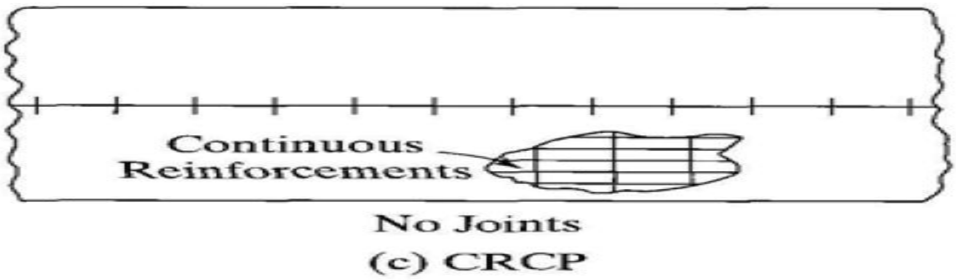


Figure 2-6Continuous Reinforced Concrete Pavement

d) Pre-stressed Concrete Pavements:

Concrete is weak in tension but strong in compression. The thickness of concrete pavement required is governed by its modulus of rupture, which varies with the tensile strength of the concrete. The pre-application of a compressive stress to the concrete greatly reduces the tensile stress caused by the traffic loads and thus decreases the thickness of concrete required . The pre-stressed concrete pavements have less probability of cracking and fewer transverse joints and therefore result in less maintenance and longer pavement life.

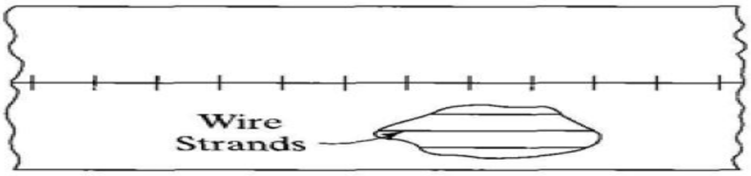


Figure 2-7Pre-stressed Concrete Pavements

2.2.3 Composite Pavement:

Composite pavement are combination of HMA and PCC pavement, Occasionally, they are initially constructed as composite pavement rehabilitation.

2.3 Pavement Design Methods:

2.3.1 Flexible Pavement:

2.3.1.1 Empirical Methods:

An empirical approach is one which is based on the results of experiments or experience. Generally, it requires a number of observations to be made in order to ascertain the relationships between input variables and outcomes. It is not necessary to firmly establish the scientific basis for the relationships between variables and outcomes as long as the limitations with such an approach are recognized. Specifically, it is not prudent to use empirically derived relationships to describe phenomena that occur outside the range of the original data used to develop the relationship. In some cases, it is much more expedient to rely on experience than to quantify the exact cause and effect of certain phenomena. Many pavement design procedures use an empirical approach. This means that the relationship between design inputs (e.g., loads, materials, layer configurations and environment) and pavement failure were arrived at through experience, experimentation or a combination of both. Empirical design methods can range from extremely simple to quite complex. The simplest approaches specify pavement structural designs based on what has worked in the past. For example, local governments often specify city streets to be designed using a given cross section (e.g., 100 mm (4 inches) of HMA over 150 mm (6 inches) of crushed stone) because they have found that this cross section has produced adequate pavements in the past. More complex approaches are usually based on empirical equations derived from experimentation. Some of this experimentation can be quite elaborate.

a) TRL Method:

For designing a new road pavement estimating the amount of traffic and the cumulative of equivalent standard axle load , assessing the strength of sub-grade soil and selecting the most economical combination of pavement materials and layer thickness.

b) Asphalt Institute Method:

The Asphalt Institute's component analysis design approach (termed "effective thickness" by the Asphalt Institute) uses relationships between sub-grade strength, pavement structure, and traffic (Asphalt Institute, 1983). The existing structural integrity of the pavement is converted to an equivalent thickness of HMA, which is then compared to that required for a new design. The structural evaluation procedure developed by the Asphalt Institute allows for either determining the required thickness of asphalt concrete overlay or estimating the length of time until an overlay is required. The essential parts of this overlay design procedure will be briefly described:

1.Sub-grade analysis.

2.Pavement structure thickness analysis.

3.Traffic analysis.

c) AASHTO Method:

The design procedure recommended by the American Association of State Highway and Transportation Officials (AASHTO) is based on the results of the extensive AASHO Road Test conducted in Ottawa, Illinois, in the late 1950s and early 1960s. The AASHO Committee on Design first published an interim design guide in
1961.

2.3.1.2 Mechanistic Method:

Mechanics is the science of motion and the action of forces on bodies. Thus, a mechanistic approach seeks to explain phenomena only by reference to physical causes. In pavement design, the phenomena are the stresses, strains and deflections within a pavement structure, and the physical causes are the loads and material properties of the pavement structure. The relationship between these phenomena and their physical causes is typically described using a mathematical model. Various mathematical models can be and are used the most common is a layered elastic model.

a) **Layered system method:**

- The effect of layers above sub-grade is to reduce the stress and deflections in the sub-grade.
- Burmister (1958) obtained solutions for two-layer problem by using strain continuity equations.
- Vertical stress depends on the modular ratio (i.e., E_1/E)
- Vertical stress decreases considerably with increase in modular ratio.

b) **Shell pavement design method :**

The Shell pavement design method is used in many countries for the design of new asphalt roads. In structural road design, the main considerations consist of soil parameters, parameters (thickness and stiffness) for the other road foundation materials, and the expected number of times a standard load will pass over. The output of the calculation is the thickness of the asphalt layer.

2.3.2 Rigid Pavement:

2.3.2.1 Mechanistic Method:

a) **Portland cement Association:**

This bulletin deals with methods of determining slab thicknesses adequate to carry traffic loads on concrete streets, roads, and highways, The design purpose is the same as for other engineered structures—to find the minimum thickness that will result in the lowest annual cost as shown by both first cost and maintenance costs. If the thickness is greater than needed, the pavement will give good service with low maintenance costs, but first cost will be high. If the thickness is not adequate, premature and costly maintenance P and interruptions in traffic will more than offset the lower first cost. Sound engineering requires thickness designs that properly balance first cost and maintenance costs. While this bulletin is confined to the topic of thickness design, other design aspects are equally important to ensure the performance and long life of concrete pavements. These include—

● Provision for reasonably uniform support. (See Sub-grades and Sub-bases for Concrete Pavements.

● Prevention of mud-pumping with a relatively thin untreated or cement-treated sub-base on projects where the expected truck traffic will be great enough to cause pumping. (The need for and requirements of sub-base are also given in the booklet cited above).

● Use of a joint design that will afford adequate load transfer enable joint sealants, if required, to be effective; and prevent joint distress due to infiltration. (See Joint Design for Concrete Highway and Street Pavements)

.● Use of a concrete mix design and aggregates that will provide quality concrete with the strength and durability needed for long fife under the actual exposure conditions.

b) AASHTO Method:

Traditionally, rigid pavement design has been accomplished through empirically based procedures. Probably the most well-known procedure for highway pavements, the AASHTO Method, was based on the AASHO Road Test held near Ottowa, Illinois between 1958 and 1960. The design procedure utilized empirical relationships developed from the AASHO Road Test and is therefore limited to the conditions of that test. All empirically-based methods share this same common disadvantage in that they are limited to the conditions and observations of the particular road sections.

CHAPTER THREE

DESIGN of FLEXIBLE HIGH-WAY PAVEMENT

CHAPTER THREE

3 DESIGN OF FLEXIBLE PAVEMENT

3.1 Flexible Pavement Components:

The flexible pavement design is made in such a way that the structure basically deflects under load. The structure is designed in such a way that each layer comprising of materials receives load from the upper layer and passes on the load to the next layer. This way the load in different layers is reduced to a great extent. The design is made in such a way that the maximum load bearing layer (i.e. the top layer) will comprise of the most expensive materials and the lowest load bearing layer (i.e. the lower/bottom layers) would be made up of the least expensive materials. While making a design for the flexible pavement two major factors that needs to be considered i.e. determination of the approximate thickness of the layer and the composition of the materials that is required for each layer. The composition has a significant impact on the structure of the flexible pavement because of the impact of traffic loads and variations in the temperature.

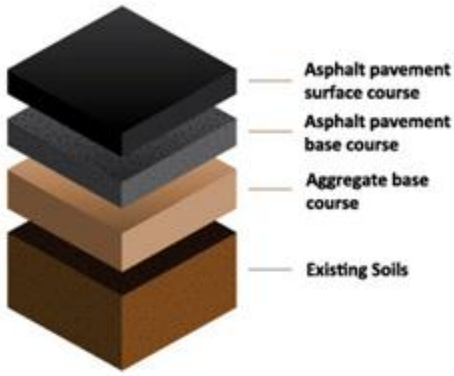


Figure 3-1 Pavement Layers

3.1.1 Base And Sub-base Materials:

Stabilized base or sub-base layers are pavement layers composed of a compacted mixture of aggregate and cementitious material. The binder material is usually lime or cement, though additional pozzolanic materials may also be added. For new construction, the base or sub-base materials are mixed with the binder and water if needed, either in place or at a plant, and are then graded and compacted. Stabilized base layers can also be formed through full depth reclamation when binder is added to the reclaimed pavement material. Stabilized layers provide a strong foundation for both rigid and flexible pavements, though stabilized pavement layers are usually used in flexible pavements. It should be noted that calcium chloride is also used for stabilization in the Southern states, and asphalt cement and asphalt emulsions have also been used as well. However, the focus of this document will be on lime and cement based stabilization.

3.1.2 Hot Mix Asphalt Concrete:

Hot mix asphalt concrete (commonly abbreviated as HMAC or HMA) is produced by heating the asphalt binder to decrease its viscosity, and drying the aggregate to remove moisture from it prior to mixing. Mixing is generally performed with the aggregate at about 300 °F (roughly 150 °C) for virgin asphalt and 330 °F (166 °C) for polymer modified asphalt, and the asphalt cement at 200 °F (95 °C). Paving and compaction must be performed while the asphalt is sufficiently hot. In many countries paving is restricted to summer months because in winter the compacted base will cool the asphalt too much before it is able to be packed to the required density. HMAC is the form of asphalt concrete most commonly used on high traffic pavements such as those on major highways ,racetracks and airfields. It is also used as an environmental liner for landfills, reservoirs, and fish hatchery ponds.

3.2 Design Factor:

Design factors can be divided into four broad categories:

1. Traffic and Loading

- Axle Loads.
- Number of Repetitions.
- Contact Area.
- Vehicle Speed.

2. Environment

- Temperature.
- Effect on Asphalt Layer.
- Effect on Concrete Slab.
- Frost Penetration.

- Precipitation.

3. Material

- General Properties.

4. Failure Criteria

Flexible Pavements:

- Fatigue Cracking.
- Rutting.
- Thermal Cracking.

Rigid Pavement:

- Fatigue Cracking.
- Pumping or Erosion.
- Other Criteria.

3.2.1 Traffic Loading and Volume:

Traffic is the most important factor in pavement design. The consideration of traffic should include both the loading magnitude and configuration and the number of load repetitions.

a) Equivalent Axle Load Factor:

An equivalent axle load factor (EALF) defines the damage per pass to a pavement by the axle in question relative to the damage per pass of a standard axle load, usually the18-kip (80-kN) single-axle load. The design is based on the total number of passes ofthe standard axle load during the design period, defined as the equivalent single-axle load (ESAL) and computed by

$$\mathbf{ESAL}=\sum \boldsymbol{fi} * \boldsymbol{ni}$$

in which *m* is the number of axle load groups, f_i is the EALF for the *i*th-axle load group, and $n_i$is the number of passes of the *i*th-axle load group during the design period. The EALF depends on the type of pavements, thickness or structural capacity ,and the terminal conditions at which the pavement is considered failed. Most of the EALFs in use today are based on experience. One of the most widely used methods is based on the empirical equations developed from the AASHO Road Test (AASHTO ,1972). The EALF can also be determined theoretically based on the critical stresses and strains in the pavement and the failure criteria. In this section, the equivalent factors for flexible and rigid pavements are discussed separately.

b) Traffic Analysis:

To design a highway pavement, it is necessary to predict the number of repetitions of each axle load group during the design period. Information on initial traffic can be obtained from field measurements or from the W-4 form of a load meter station that has traffic characteristics similar to those of the project in question. The initial daily traffic is in two directions over all traffic lanes and must be multiplied by the directional and lane distribution factors to obtain the initial traffic on the design lane. The traffic to be

used for design is the average traffic during the design period, so the initial traffic must be multiplied by a growth factor . If *n*, is the total number of load repetitions to be used in design for the *i*th load group.

$$\text{Daily ESAL} = \sum (NA * EALF)/((NT * ADT) * \left(\frac{D}{100}\right) * \left(\frac{PT}{100}\right))$$

Where:

NA=number of axle in each axle group.

EALF=equivalent axle load factor.

ADT=average daily traffic.

NT=number of trucks surveyed by day.

D=directional split of traffic.

PT=% trucks in ADT.

Design ESAL=daily ESAL*365*growth factor.

Where:

Growth factor = $((1 + r)^n$-1/ r

n=the design period.

r=the growth rate.

3.3 Design Methods:

3.3.1 AASHTO Method:

The design procedure recommended by the American Association of State Highway and Transportation Officials (AASHTO) is based on the results of the extensive AASHO Road Test The empirical performance equations obtained from the AASHO Road Test are still being used as the basic models in the current guide, but were modified and extended to make them applicable to other regions in the nation. It should be kept in mind that the original equations were developed under a given climatic setting with a specific set of pavement materials and sub-grade soils. The climate at the test site is temperate with an average annual precipitation of about 34 in. (864 mm). The average depth of frost penetration is about 28 in . (711 mm) . The sub-grade soils consists of A-6 and A-7-6 that are poorly drained, with CBR values ranging from 2 to 4.

Design Variables:

a) Time Constraints:

To achieve the best use of available funds, the AASHTO design

guide encourages the use of a longer analysis period for high volume facilities, including at least one rehabilitation period. Thus, the analysis period should be equal to or greater than the performance period, as described below.

b) Performance Period :

The performance period refers to the time that an initial pavement structure will last before it needs rehabilitation or the performance time between rehabilitation operations . It is equivalent to the time elapsed as a new, reconstructed, or rehabilitated structure deteriorates from its initial serviceability to it terminal serviceability. The designer must select the performance period within the minimum and maximum allowable bounds that are established by agency experience and policy. The selection of performance period can be affected by such factors as the functional classification of the pavement, the type and level of maintenance applied the funds available for initial construction, life cycle costs, and other engineering considerations.

c) Analysis Period:

The analysis period is the period of time that any design strategy must cover. It may be identical to the selected performance period. However, realistic performance limitations may necessitate the consideration of staged construction or planned rehabilitation for the desired analysis period.

Table 3-1 Length of analysis period

Highway conditions (years)	analysis period
High-volume urban	30-50
High-volume rural	20-50
Low-volume paved	15-25
Low-volume aggregate surface	10-20

d) Traffic:

The design procedures are based on cumulative expected 18-kip (80-kN)equivalent single-axle load (ESAL).

e) Reliability:

Means of incorporating some degree of certainty into the design process to ensure that the various design alternatives will last the analysis period. The level of reliability to be used for design should increase as the volume of traffic difficulty of diverting traffic, and public expectation of availability increase.

Table 3-2Levels of Reliability for various functional classification

Recommended level of reliability		
Functional Classification	Rural	Urban
Interstate and other freeways	85-99.9	80-99.9
Principal arterials	80-99	75-95
Collectors	80-95	75-95
Local	50-8	50-80

f) Environmental Effects:

The AASHO design equations were based on the results of traffic tests over a two-year period. The long-term effects of temperature and moisture on the reduction of serviceability were not included. If problems of swell clay and frost heave are significant in a given region and have not been properly corrected, the loss of serviceability over the analysis period should be estimated and added to that due to cumulative traffic loads.

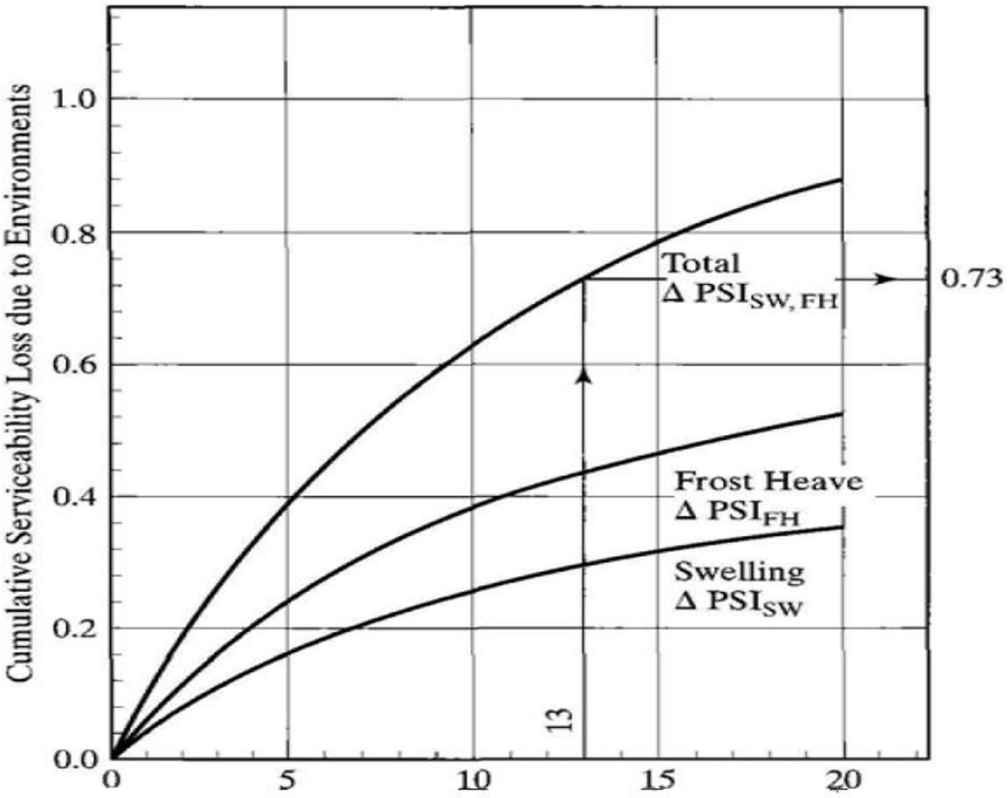


Figure 3-2 Environmental serviceability loss versus time

g) Serviceability:

Initial and terminal serviceability indexes must be established to compute the change in serviceability, APSI, to be used in the design equations. The initial serviceability index is a function of pavement type and construction quality. Typical values from the AASHO Road Test were 4 .2 for flexible pavements and 4.5 for rigid pavements. The terminal serviceability index is the lowest index that will be tolerated before rehabilitation, resurfacing, and reconstruction become necessary. An index of 2.5 or higher is suggested for design of major highways and 2 .0 for highways with lower traffic. For relatively minor highways where economics dictate a minimum initial capital outlay, it is suggested that this be accomplished by reducing the design period or total traffic volume, rather than by designing a terminal serviceability index less than 2.

h) Design Equations:

The original equations were based purely on the results of the AASHO Road Test but were modified later by theory and experience to take care of sub-grade and climatic conditions other than those encountered in the road test.

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

Where:

a_1, a_2, a_3 :layer coefficient for the surface, base ,sub-base respectively

a_2=0.249(logE_2)-0.2977

a_3=0.277(logE_3)-0.839

D_1,D_2,D_3=thickness of surface, base, sub-base respectively

m_2,m_3=drainage coefficient for base, sub-base respectively

3.3.2 Asphalt Institute Method:

Design alternatives:

a) Full-Depth HMA:

Full-depth asphalt driveways are built entirely of asphalt paving mixture from the soil sub-grade up. Full-depth driveways keep water out of the pavement. So water never enters the pavement to swell when it freezes. Full-depth asphalt provides a better balance of strength and flexibility plus durability than any other material. For improved soil stability, it is recommended that topsoil containing clay be removed or modified. A solid sub-grade requires thorough compaction. Paving with asphalt follows. A 4-inch thickness may be adequate, but 5 or even 6 inches of full-depth asphalt will assure you of a stronger, stable driveway under a wider range of climate and loads. As an option, some contractors use 6 to 8 inches of compacted aggregate, or gravel, as a base under 3 inches of asphalt pavement.

b) HMA over Emulsified Asphalt Base:

There are three types of mixes specified:

1.Type I

2.Type II

3.Type III

The minimum thickness for HMA over the emulsified asphalt are shown in this table .

Table 3-3 Minimum thickness or HMA over emulsified

Traffic level ESAL	HMA Thickness for type I	HMA thickness for type II,III
10000	1	2
100000	1.5	2
1000000	2	3
10000000	2	4
>10000000	2	5

c) HMA over Untreated Aggregate Base :

The designer must first determine the thickness of aggregate base to be used and select the design chart to find HMA thickness

d) HMA and Emulsified Asphalt Mix Over Untreated Aggregate Base :

Design chars for pavements consisting of a HMA surface, an emulsified asphalt base, and an untreated base are currently not available. The best alternative is to use the charts for full-depth

HMA and emulsified asphalt mix to determine a substitution ratio, which indicates the thickness of emulsified asphalt mix required to substitute for a unit thickness of HMA . Then the chart for HMA over untreated aggregate base is applied to determine the thickness of HMA, part of which can be replaced by the emulsified asphalt

mix according to the substitution ratio. The following method has been recommended by the Asphalt Institute :

1. Design a full-depth HMA pavement for the appropriate traffic and sub-grade conditions . Assume a 2-in . (51-mm) surface course, and calculate the corresponding base thickness .

2. Design a pavement for the same traffic and sub-grade conditions, using the selected emulsified mix type . Assume a 2-in. (51-mm) surface course, and calculate the corresponding base thickness.

3. Divide the thickness of the emulsified asphalt base in step 2 by the thickness of the HMA base in step 1 to obtain a substitution ratio .

4. Design a pavement for the same traffic and sub-grade conditions, using HMA and untreated base.

5. Select a portion of the HMA thickness to be replaced by the emulsified asphalt mix, based on the minimum HMA thickness.

6. Multiply the above thickness by the substitution ratio determined in step 3 to obtain the thickness of emulsified asphalt mix required.

3.3.3 Layered Systems :

Flexible pavements are layered systems with better materials on top and cannot be represented by a homogeneous mass, so the use of Burmister's layered theory is more appropriate .Burmister first developed solutions for a two-layer system and then extended them to a three-layer system. With the advent of computers, the theory can be applied to a multilayer system with any number of layers.

The basic assumptions to be satisfied are :

1. Each layer is homogeneous, isotropic, and linearly elastic with an elastic modulus E and a Poisson ratio v.

2. The material is weightless and infinite in a real extent .

3. Each layer has a finite thickness h, except that the lowest layer is infinite in thickness.

4. A uniform pressure q is applied on the surface over a circular area of radius a.

5. Continuity conditions are satisfied at the layer interfaces, as indicated by the same vertical stress, shear stress, vertical displacement.

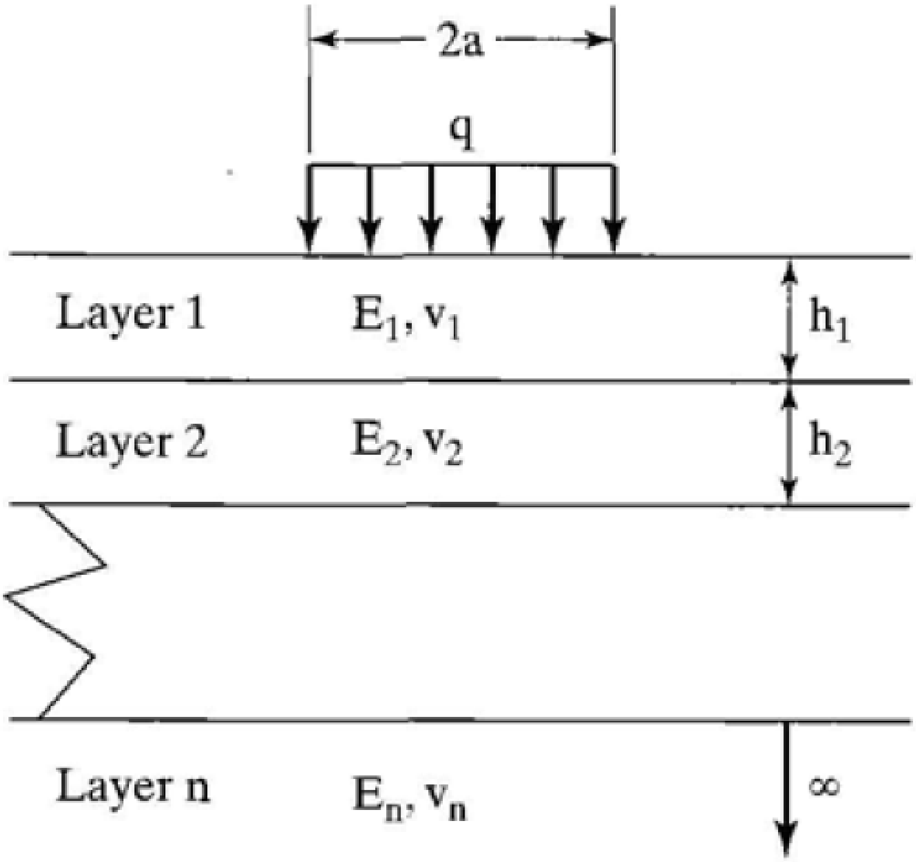


Figure 3-3 Multi-layer subjected to a circular load

1. Two-Layer Systems:

The exact case of a two-layer system is the full-depth construction in which a thick layer of HMA is placed directly on the sub-grade. If a pavement is composed of three layers (e.g. an asphalt surface course, a granular base course, and a sub-grade), it is necessary to combine the base course and the sub-grade into a single layer for computing the stresses and strains in the asphalt layer or to combine the asphalt surface course and base course for computing the stresses and strains in the sub-grade.

CHAPTER FOUR

Design of Rigid Pavement

CHAPTER FOUR

4 DESIGN of RIGID PAVEMENT

4.1 Rigid Pavement Components :

4.1.1 Sub-grade Soil :

The sub-grade is the compacted soil layer that forms the foundation of the pavement system. Sub-grade soils are subjected to lower stresses than the surface and sub-base courses. These stresses decrease with depth, and the controlling sub-grade stress is usually at the top of the sub-grade unless unusual conditions exist. Unusual conditions, such as a layered sub-grade or sharply varying water content or densities, may change the locations of the controlling stress. The soils investigation should check for these conditions. The pavement above the sub-grade must be capable of reducing stresses imposed on the sub-grade to values that are low enough to prevent excessive distortion or displacement of the sub-grade soil layer

4.1.2 Base Course :

The purpose of a base course is to distribute the induced stresses from the wheel load so that it will not exceed the strength of the underlying soil layers. Figure shows the distribution of stress through two base courses. When the sub-grade strength is low, the stress must be reduced to a low value and a thick base is needed.

When the sub-grade strength is higher, a thinner base course will provide adequate stress distribution. Because the stresses in the base course are always higher than in the sub-grade (Figure 5-5), the base course must have higher strength .The base course is normally the highest-quality structural material used in a flexible-pavement structure, having CBR values near the CBR standard material (crushed limestone). Base courses are always cohesion less materials and are normally processed to obtain the proper gradation.

4.1.3 Surface Course

Concrete surfaces (specifically, Portland cement concrete) are created using a concrete mix of Portland cement, coarse aggregate, sand and water. In virtually all modern mixes there will also be various admixtures added to increase workability, reduce the required amount of water, mitigate harmful chemical reactions and for other beneficial purposes. In many cases there will also be Portland cement substitutes added, such as fly ash. This can reduce the cost of the concrete and improve its physical properties. The material is applied in a freshly mixed slurry, and worked mechanically to compact the interior and force some of the cement slurry to the surface to produce a smoother, denser surface free from honeycombing. The water allows the mix to combine molecularly in a chemical reaction called hydration. Concrete surfaces have been refined into three common types: jointed plain (JPCP), jointed reinforced (JRCP) and continuously reinforced (CRCP).

4.1.3.1 Joints

Expansion Joints :

Expansion joints consist of a preformed joint filler, generally 1 in. thick, that compresses and allows the pavement to expand. The joints are placed at the locations noted on the plans. The joint filler is required to be shaped to the sub-grade, parallel to the surface, and the full width of the pavement. The edges of the expansion joint are to be finished.

Contraction Joint :

Typically, a contraction joint is a sawed transverse joint normally placed every 18 ft to control cracking due to pavement contraction caused by shrinkage and temperature fluctuations. The plans for the particular contract are required to be checked to verify the proper joint placement. The minimum/maximum joint spacing is reviewed with the Area Engineer or District Construction Engineer so that joints may be established in the initial pours that will complement adjacent pavements.

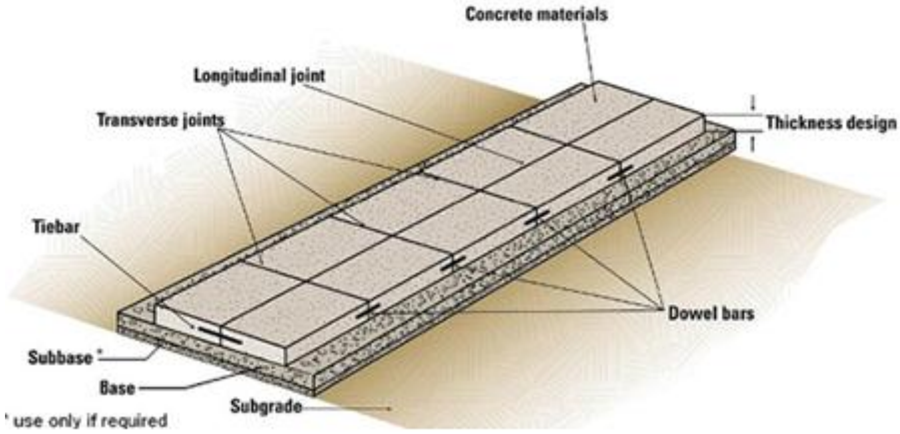


Figure 4-1 Joints

4.2 Design Factor :

4.2.1 Traffic Loading :

Traffic is the most important factor in pavement design. The consideration of traffic should include both the loading magnitude and configuration and the number of load repetitions.

ESAL Equation :

1- Daily ESAL = ∑ ((NA*EALF)/(NT*ADT)*(D/100)*(PT/100))

2-∑ESAL=ESAL*365*((1+i)*n)-1)/i

Where:

NA ≡ number of axle in each axle group
EALF ≡ equivalent axle load factor
ADT ≡ average daily traffic
NT ≡ number of trucks surveyed by day
D ≡ directional split of traffic
PT ≡ % trucks in ADT

4.2.2 Sub-grade and Sub-base Support :

Sub-grade and sub-base support is defined by the modulus of sub-grade reaction, *k*. Methods for determining the modulus of sub-grade reaction are described in Section 7 .5 .1. Figure 7 .36 can be used to correlate *k* values with other soil properties. The PCA method does not consider the variation of k values over the year. The contention is that the reduced sub-grade support during thaw periods has very little or no effect on the required thickness of concrete pavements, as evidenced by the results of AASHO Road Test.

4.2.3 Concrete Modulus of Rupture :

The flexural strength of concrete is defined by the modulus of rupture, which is determined at 28 days by the method specified by AST M in "C78-84 Standard Test Method for Flexural Strength of Concrete Using Simple Beam with Third Point Loading." The 28 day flexural strength is used as the design strength. The variability of strength and the gain in strength with age should be considered in the fatigue analysis.

4.2.4 Elastic Modulus of Concrete :

The elastic modulus of concrete can be determined according to the procedure described in ASTM C469 or correlated with the compressive strength. The following is a correlation recommended by the American Concrete Institute :

$$E_c = 57000 {f_c}^{0.5}$$

in which E_c is the concrete elastic modulus in psi and f_c is the concrete compressive strength in psi.

4.2.5 Design Period :

The term "design period" should not be confused with the term "pavement life," which is not subject to precise definition. "Design period" is more nearly synonymous with the term "traffic analysis period." Because traffic probably cannot be predicted with much accuracy for a longer period, a design period of 20 years has commonly been used in pavement design. However, there are cases where the use of a shorter or longer design period is economically justified.

4.2.6 Temperature :

Temperature differential between the top and bottom of the slab causes curling (warping) stress in the pavement, if the temperature of the upper surface of the slab is higher than the bottom surface then top surface tends to expand and the bottom surface tends to contract resulting in compressive stress at the top, tensile stress at bottom and vice versa.

4.3 Rigid Pavement Methods:

4.3.1 AASHTO Method :

The design guide for rigid pavements was developed at the same time as that for flexible pavements and was published in the same manual . The design is based on the empirical equations obtained from the AASHO Road Test, with further modifications based on theory and experience.

4.3.1.1 Design factors:

a) Reliability:

AASHTO uses the reliability concept to account for design uncertainties. Basically, a pavement structure is designed using the most accurate input data available; data are not manipulated or inflated (nor are conservative values used) to compensate for their estimated variability but rather the best value is used. All variability the pavement structural design process is then accounted for in the “reliability” factor.

Table 4-1 Recommended Level of reliability

Functional Classification	**Recommended Level of Reliability**	
	Urban	**Rural**
Interstate and Other Freeways	85 – 99.9	80 – 99.9
Principal Arterials	80 – 99	75 – 95
Collectors	80 – 95	75 – 95
Local	50 – 80	50 – 80

b) Load Transfer Coefficient :

The load transfer coefficient J is a factor used in rigid pavement design to account for the ability of a concrete pavement structure to transfer a load across joints and cracks. The use of load transfer devices and tied concrete shoulders increases the amount of load transfer and decreases the load-transfer coefficient.

Table 4-2 Recommended load transfer coefficient for various pavement types and design conditions

Type of shoulder	Asphalt		Tied PCC	
Load transfer devices	Yes	No	Yes	No
JPCP and JRCP	3.2	3.8–4.4	2.5–3.1	3.6–4.2
CRCP	2.9–3.2	N/A	2.3–2.9	N/A

c) Drainage Coefficient :

The drainage coefficient C d has the same effect as the load transfer coefficient J ,an increase in C d is equivalent to a decrease in J, both causing an increase in W18, As with flexible pavements, the percentage of time is dependent on the average yearly rainfall and the prevailing drainage conditions.

Table 4-3 Recommended values of range coefficient Cd for rigid pavements

Quality of drainage		Percentage of time pavement structure is exposed to moisture levels approaching saturation			
Rating	Water removed within	Less than 1%	1–5%	5–25%	Greater than 25%
Excellent	2 hours	1.25–1.20	1.20–1.15	1.15–1.10	1.10
Good	1 day	1.20–1.15	1.15–1.10	1.10–1.00	1.00
Fair	1 week	1.15–1.10	1.10–1.00	1.00–0.90	0.90
Poor	1 month	1.10–1.00	1.00–0.90	0.90–0.80	0.80
Very poor	Never drain	1.00–0.90	0.90–0.80	0.80–0.70	0.70

4.3.2 PCA Method :

The Portland Cement Association's (PCA) thickness-design procedure for concrete highways and streets was published in 1984, superseding that published in 1966. The procedure can be applied to JPCP, JRCP, and CRCP. The design criteria are based on general pavement design performance, and research experience, including relationships to performance of pavements in the AASHO Road Test.

4.3.2.1 Design Factors :

a) Traffic Loading :

Each axle load is further multiplied by a load safety factor (LSF) according to the following recommendation:

- LSF=1.0 for roads, residential streets and other streets with small volume of truck traffic.
- LSF=1.1 for highway and arterial streets with moderate volume of truck traffic.
- LSF=1.2 for interstate highway and other multilane project with high volume of truck traffic.

4.3.2.2 Fatigue Design :

Fatigue design for slab thickness is performed with the aim to control fatigue cracking. The design is based on the most critical edge stress, with the applied load positioned at the mid-length of the outer, as shown in figure 4.2:

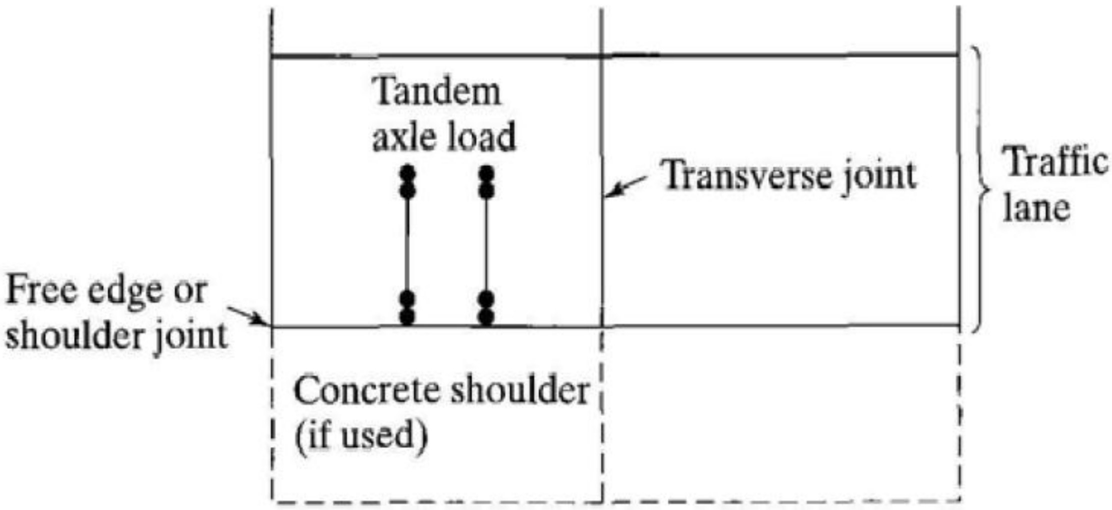


Figure 4-2Critical position for fatigue analysis

The steps in the fatigue design procedure are:

1- Multiply the load of each design axle load group by the appropriate LSF.

2- Assume a trial slab thickness.

3- Knowing the modulus of sub-grade reaction K, obtain from table A the equivalent stress for the projected slab thickness, and calculate the stress ratio factor as:

Stress ratio factor = Equivalent Stress ÷ MR

4- For each axle load i, obtain from figure A the allowable load repetition Ni.

4.3.2.3 Erosion Design:

The PCA erosion design for pavement thickness design is to guard against foundation and shoulders erosion, pumping and faulting.

The critical deflection considered is at the corner.

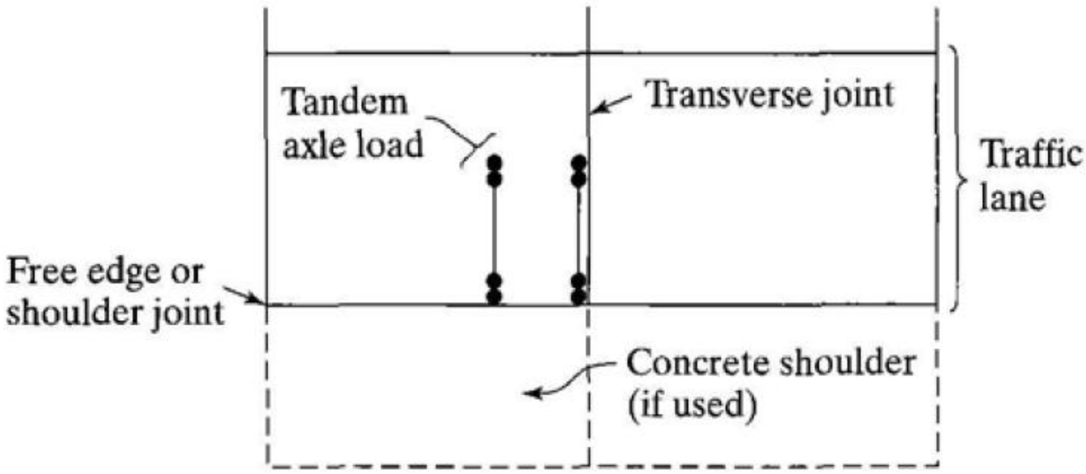


Figure 4-3 Critical loading position for a erosion analysis

The steps of procedure are :

1- Multiply the load of each design axle load group by LSF.

2- Assume a trail slab thickness.

3- Obtain from Table A the erosion factor for the projected slab thickness and the modulus of sub-grade reaction K.

4- For each axle load i: obtain from Figure A the allowable load repetition Ni for two criteria calculate damage ratio:

% D_r=(Expected Reps ÷ Allowable Reps) < 1

CHAPTER FIVE

CASE STUDY of HIGH-WAY PAVEMENT DESIGN

Chapter FIVE

5 Case Study of Highway Pavement Design

5.1 Umdurman Eldabaseen Road:

5.1.1 Site Description:

The Road is section of Omdurman Eldabaseen Road apart of network road across the southern countryside (SALHA) to near Omdurman University length 6 Km with material properties.

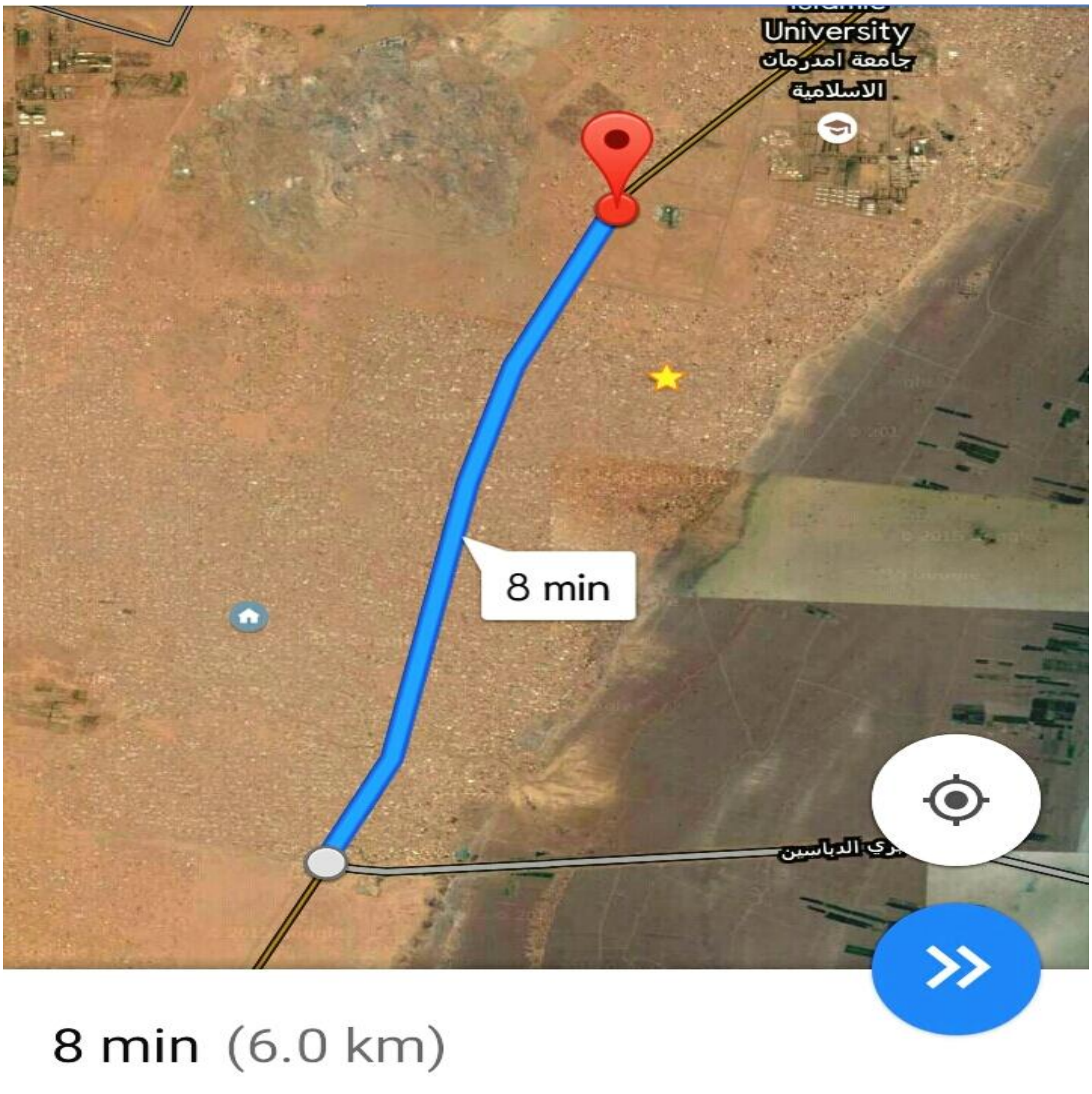


Figure 5-1 Survey location

5.1.2 Site Information:

Length of road: 6000 m

Width of driving lanes: 7 m

Location: Khartoum State

Soil Characteristics:

Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CBR	15	6.2	10	8	5.1	2.5	4.5	5.1	10	7	6.8	3.5	3	6.1	17

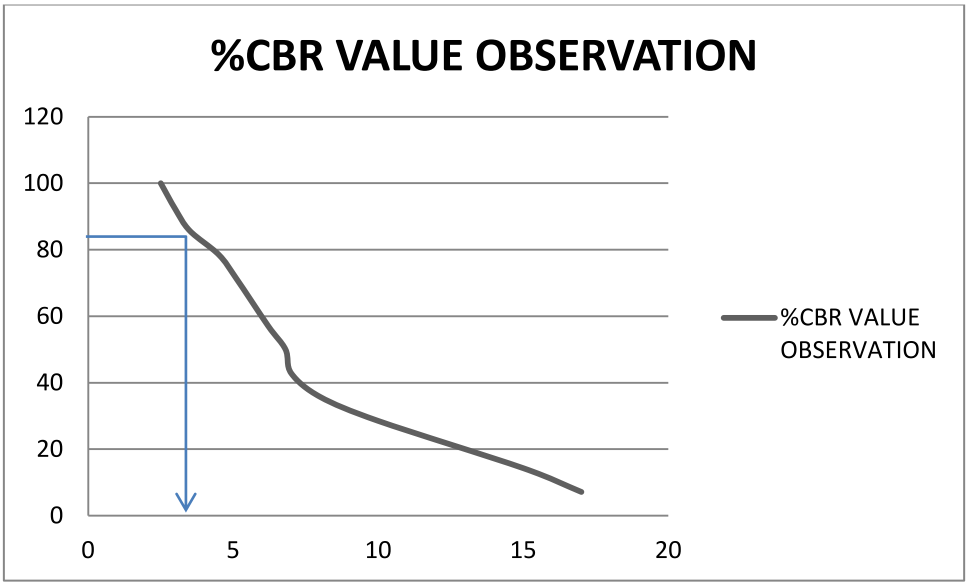
Design CBR :

Asphalt Institute Criteria Method :

∑EAL	Low	Medium(10^4–10^6)	High (>10^6)
Design Percentile	60	75	87.5

Design Percentile = 87.5

CBR value	2.5	3	3.5	4.5	5.1	6.2	6.8	7	8	10	15	17
Observation	1	1	1	1	2	1	1	1	1	2	1	1
CBR value ≥ observation	14	13	12	11	10	8	7	6	5	4	2	1
% CBR value ≥ observation	100	92.2	85.7	78.5	71.4	57.1	50	42.8	35.7	28.5	14.28	7.14



Design CBR = 4.2%

Use design CBR = 20 (see Table B-1)

Design Traffic :

Table 5.1 Traffic Data for Omdurman Dabaseen Road

Analysis Period	20 years
AADT (0)	4918
Percentage of heavy trucks (above class 4)	43.7
Percentage of heavy trucks in design direction	50
Percentage of heavy trucks in design lane	100
Truck Equivalency factor	1
Annual truck volume growth rate	3
Annual truck weight growth rate	0.6

Traffic Analysis :

Truck growth factor =1.12

Traffic Volume growth factor = 1.6

Design year AADT = 7869

Average AADT = 6393

Design year truck factor = 1.12

Average truck factor =1.06

Truck ADDT in one direction = 1398

Daily ESAL =1482

Design ESAL = 1.08*10^7

Sub-grade Evaluation :

M_r (SG) =17.6*$(cbr)^{0.64}$

= 17.6*$(20)^{0.64}$ = 119.72 M_{pa}

= 17359.6 psi

E_{sb} = 22502.8 psi

E_{bs}= 42155.8 psi

5.1.3 Design Method :

5.1.3.1 Flexible Pavement :

a) AASHTO Method :

Design Input :

1-Reliability R = 80%.
2-Standard Deviation So = 0.35.
3-Serviceability ΔPSI = 1.7.
4-Base Coarse Ebs =42155.8 psi.
5-Sub-base Coarse Esb =22505.8psi.
6-Improved Sub-grade Resilient Modulus M^R =17359.6psi.
7- W18=1.08*10^7.

Drainage Coefficient
m_1=m_2 =1

Layer coefficient

a_1=0.44

a_2=0.14

a_3=0.11

from figure

SN_1=3.2

SN_2=3.5

SN_3=4.2

Design Of Thickness :

Option one :

$\boldsymbol{D_1} = \boldsymbol{SN_1/a_1}$

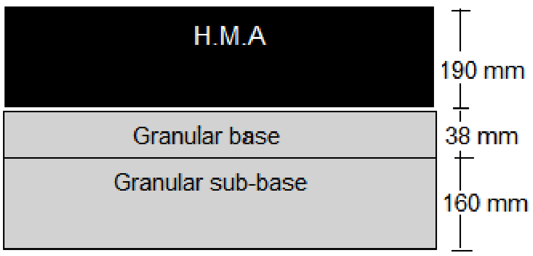
= 3.2/0.44 = 7.5 in (190mm**)**

$\boldsymbol{D_2}$ = (SN_2 - $\boldsymbol{a_1}$ *D_1) /a_2 *m_2

= (3.5-0.44*7.5) /0.14*1 =1.5 in (38mm**)**

$\boldsymbol{D_3= (SN_3- a_1*D_1*m_1-a_2*D_2*m_2)/a_3*m_3}$

=(4.2-0.44*7.5*1-0.14*1.5*1) /0.11*1 = 6.3 in(160mm**)**



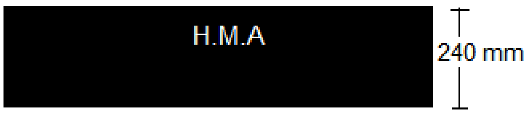
Option two :

Full Depth :

from figure

$\boldsymbol{SN_1}$**= 4.2**

$\boldsymbol{D_1}$**= 4.2 /0.44 = 9.5 in**

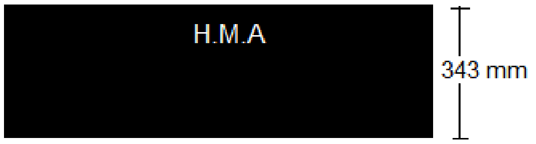


b) Asphalt Institute Method:

- Full depth A.C :

From figure A-1 :

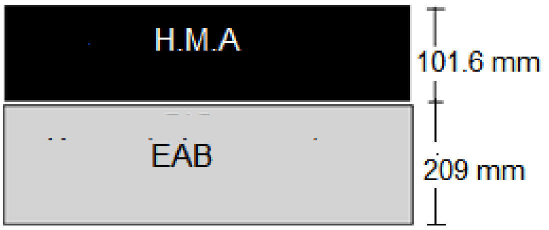
Full depth = 13.7 in (348 mm)



Emulsified Asphalt Base:

From Figure A-2:

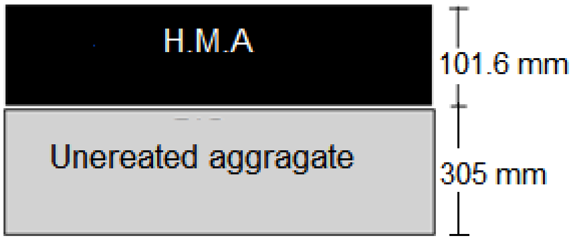
EAB = 412-101.6 = 209 mm



Untreated Aggregate base 6 in granular sub-base (152 mm):

From figure A-3:

Total thickness = 12 in (304.8 mm)

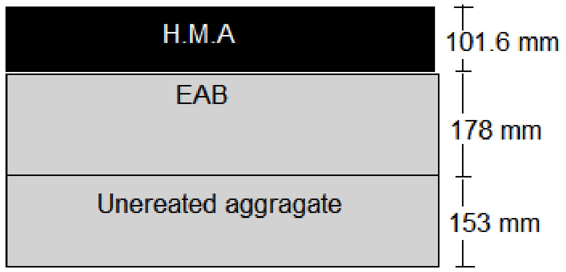


use this option with emulsified asphalt type 2

The ratio between H.M.A and emulsified asphalt (substitution ratio) = 209/241 = 0.87

minimum H.M.A = 101.6 mm

Emulsified asphalt base = (305-101.6)*0.87 = 178 mm.



c) Elastic Layered Method:

Design input:

Load applied on the surface Pd = 9000 Ib

Uniform pressure q= 80 psi

Sub-grade elastic modulus E_2=17359.6 psi

Surface elastic modulus E_1= 30000 psi

a = $\sqrt{p \div (\pi q)}$

=$\sqrt{(9000 \div 13.4 * 80})$ = 6 in

For one layer:

Δ = (1.18*q*a*F_1)÷E_2

Δ=(1.18*80*6)÷17359.6=0.033 in

For Flexible pavement:

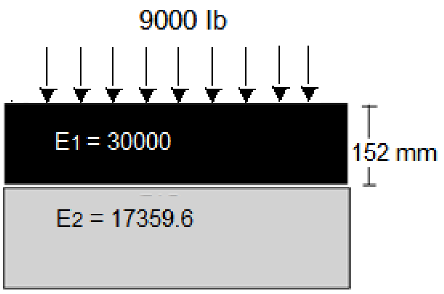
Δ(1.5*q*a*F_2)÷E_2

F_2=(0.033*17359.6)÷(1.5*80*6)=0.795

From Figure A-7:

By use (F2=0.795 , E_1/E_2 =1.73≈2) h/a =1

H = 6*1 = 6 in (152 mm)



5.1.3.2 Rigid Pavement :

a) AASHTO Method :

Design Input :

R = 80%

W18 = $1.08*10^7$

So = 0.35

M_r = 17359.6psi

ΔPSI = 2.5

Design K = 700pci E_c = 25907.27psi J = 2.5 CD = 1.0

form AASHTO design chart

D = 9in

b) PCA Method:

B_1 Design Traffic:

ADTT design = 4918*1.6=7868.8 vpd

ADTT = 7868.8*0.437= 3438.66 Trucks

ADTT one way = 3438.66/2 = 1719 trucks

Total number of trucks on design lane on design period =1719*1*365*20 = 12548700 trucks.

Single

Axle load kips	Axles per 1000 trucks	Axle load in design period
30	0.45	5646.9
28	0.85	10666.3
26	1.78	22336.68
24	5.21	65378.7
22	7.85	98507.2
20	16.33	204920.2
18	25.15	315599.8
16	31.82	399299.6
14	47.73	598949.4
12	182.02	2284114.3

Tandem

Axle load kips	Axles per 1000 trucks	Axle load in design period
52	0.09	1129.3
48	2.21	27732.6
44	8.01	100515.1
40	21.31	267412.7
36	56.25	705864.3
32	103.63	1300421.7
28	121.22	1521153.4

24	72.54	910282.6
20	85.94	1078435.2
16	99.34	1246587.8

B-2 Design

Design Factors:

Trial thickness 8.5 design K = 153.33 pci

M_r= 650 LSF = 1.1

Design period 20 years

Single:

Equivalent stress = 233.2 Stress ratio factor = 0.358

Erosion factor = 2.72

Axle load Kips	**Multiplied by LSF**	**Expected Repetition**	**Fatigue Analysis**		**Erosion Analysis**	
			Allowable Reps	**Fatigue percent**	**Allowable Reps**	**Erosion percent**
30	33	5646.9	15000	37.6	Unlimited	
28	30.8	10666.3	41000	26.01	Unlimited	
26	28.6	22336.68	120000	18.6	Unlimited	
24	26.4	65378.7	410000	15.9	Unlimited	
22	24.2	98507.2	3000000	3.28	Unlimited	
20	22	204920.2	Unlimited		Unlimited	
18	19.8	315599.8	Unlimited		Unlimited	
16	17.6	399299.6	Unlimited		Unlimited	
14	15.4	598949.4	Unlimited		Unlimited	
12	13.2	2284114.3	Unlimited		Unlimited	

Tandem

Equivalent stress= 207 Stress ratio factor=0.318 Erosion factor=2.89

Axle load Kips	Multiplied by LSF	Expected Repetition	Fatigue Analysis		Erosion Analysis	
			Allowable Reps	**Fatigue percent**	**Allowable Reps**	**Erosion percent**
52	57.2	1129.3	1000000	0.112	1000000	0.112
48	52.8	27732.6	Unlimited		1900000	1.45
44	48.4	100515.1	Unlimited		2900000	3.46
40	44	267412.7	Unlimited		4300000	6.21
36	39.6	705864.3	Unlimited		9000000	7.84
32	35.2	1300421.7	Unlimited		20000000	6.50
28	30.8	1521153.4	Unlimited		100000000	1.52
24	26.4	910282.6	Unlimited			
20	22	1078435.2	Unlimited			
16	17.6	1246587.8	Unlimited			
			Total	101.502	Total	27.092

Single:

Equivalent stress= 233.2 Stress ratio factor=0.35 Erosion factor=2.73

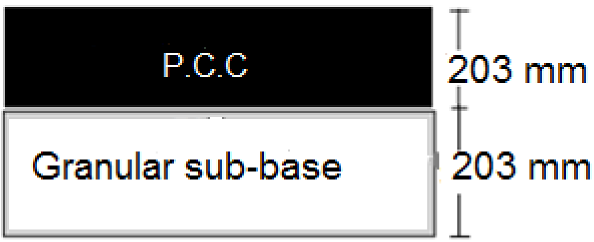
Axle load Kips	Multiplied by LSF	Expected Repetition	Fatigue Analysis		Erosion Analysis	
			Allowable Reps	**Fatigue percent**	**Allowable Reps**	**Erosion percent**
30	33	5646.9	18000	31.37	Unlimited	
28	30.8	10666.3	60000	17.77	Unlimited	
26	28.6	22336.68	190000	11.7	Unlimited	
24	26.4	65378.7	800000	8.17	Unlimited	
22	24.2	98507.2	4000000	2.46	Unlimited	
20	22	204920.2	Unlimited		Unlimited	
18	19.8	315599.8	Unlimited		Unlimited	
16	17.6	399299.6	Unlimited		Unlimited	
14	15.4	598949.4	Unlimited		Unlimited	
12	13.2	2284114.3	Unlimited		Unlimited	

Tandem

Equivalent stress= 207 Stress ratio factor=0.318 Erosion factor=2.89

Axle load Kips	Multiplied by LSF	Expected Repetition	Fatigue Analysis		Erosion Analysis	
			Allowable Reps	Fatigue percent	Allowable Reps	Erosion percent
52	57.2	1129.3	2000000	0.056	1000000	0.112
48	52.8	27732.6	Unlimited		1800000	1.45
44	48.4	100515.1	Unlimited		3000000	3.35
40	44	267412.7	Unlimited		5000000	5.34
36	39.6	705864.3	Unlimited		8000000	8.82
32	35.2	1300421.7	Unlimited		20000000	6.5
28	30.8	1521153.4	Unlimited		780000000	1.95
24	26.4	910282.6	Unlimited			
20	22	1078435.2	Unlimited			
16	17.6	1246587.8	Unlimited			
			Total	71.526	Total	27.612

The PCA design thickness:



CHAPTER SIX

RESULTS and DISCUSSION

CHAPTER SIX

6 RESULT and DISCUSSION

6.1 Introduction:

In this chapter the analysis has been done on both flexible and rigid pavement,according to AASHTO 93 design guide to Omdurman Eldabaseen Road.

6.2 Comparison Between Flexible and Rigid pavement :

The pavement thickness are calculated with the parameters above and the results obtain from different method for both pavements.

6.2.1 Comparison Between Flexible Pavement Design :

The difference in design variables makes it difficult to compare two different design methods. The AASHTO design method applies the reliability concept by using average values for all variables, including the effective roadbed soil resilient modulus. The Asphalt Institute method does not consider reliability and uses a normal sub-grade resilient modulus.

The design method from the Asphalt Institute is based on the equivalent 18-kipsingle-axle load. Two failure criteria are employed:

(a) fatigue cracking based on the horizontal tensile strain at the bottom of the asphalt layer and

(b) rutting based on the vertical compressive strain on top of the sub-grade.

The Asphalt Institute devoted extensive effort to comparing the predicted thickness obtained from the charts with the actual thickness on pavements of known performance.

The AASHTO design method is based on the empirical regression equation obtained from the AASHO Road Test, The design is based on the equivalent 18-kip single-axle load.

The design thickness calculated from the average obtain from AI, AASHTO, Elastic layer method for Omdurman Eldabseen Road.

1. Omdurman Eldabaseen Road :

Table 6-1 Comparison between Flexible Pavement Design Method (Omdurman Eldabaseen Road)

Layer	surface(mm)	base(mm)	subbase(mm)
AI Method			
-Full depth	101.6	241.4	
-EBA	101.6	209	
-Untrated base 6in	101.6	305	
-HMA and EBA over untreated base 6in	101.6	178	153
AASHTO Method			
-Granular base and sub base	203	33	191
-Full depth	50	210	
EL. Method	152	203	

Design Thickness :

Table 6-2 Flexible Pavement Design (Omdurman Eldabaseen Road)

Layer	Flexible pavement average design
Surface(mm)	126
Base(mm)	197
Subbase(mm)	172

6.2.2 Comparison Between Rigid Pavement Design :

To compare results between the AASHTO and the PCA methods the AASHTO method is based on reliability, using mean values for all variables, where as the PCA method does not consider reliability, but incorporates load safety factors and more conservative material properties. The AASHTO method is based on the equivalent18-kip (80-kN) single-axle load applications and does not distinguish the type of distress; the PCA method considers both fatigue cracking and foundation erosion, using actual single- and tandem-axle loads.

The design thickness calculated from the average thickness obtain from AASHTO and PCA methods for Omdurman Eldabaseen Road.

Table 6-3 Comparison between Rigid pavement design (Omdurman Eldabaseen Road)

Layer	Surface (mm)	Base (mm)
AASHTO method	203	203
PCA method	228.6	203

Design Thickness:

Table 6-4 Rigid pavement design (Omdurman Eldabaseen Road)

Layer	Rigid pavement average design
Surface (mm)	215.8
Baes(mm)	203

CHAPTER SEVEN

SUMMRY, CONCLUSION and RECOMMENDATION

CHAPTER SEVEN

7 SUMMARY, CONCLUSION AND RECOMMENDATION

7.1 SUMMARY :

The study provides Asphalt Institute, AASHTO and two layered system methods for design of flexible pavement for one road study cases, while the AASHTO and PCA was adopted for rigid pavement.The comparison had been made for construction cost via AASHTO design method for flexible and concrete pavement of Umduman Dabseen street.The comparing study include the design parameter,design method. By using the average design thickness for both pavements

7.2 CONCLUSION:

In this project the following design method were presented and applied is Asphalt institute, AASHTO and two layered system for flexible and PCA and AASHTO in rigid pavement.This will be considered in an extension of this project which is already underway.Having developed the structural design of both pavement types under similar traffic and subgrade strength condition.The design of a rigid pavement is highly influenced by the occurrence of small number of heavy axle loads. The fatigue life of a rigid prone to small changes in the in the stress ratio which can happen with a small increase of the loading along the axle load axis. The AASTHO method for rigid pavement it is the appropriate method in Sudan where PCA depended on axle load which there is no devices to measure axle load.

7.3 RECOMMENDATION :

The following recommendation for using rigid pavement

1. Using rigid pavement because of the existence of the intial material from naturalness concrete ,sand and poweder.

2. The surface must be totaly plaine witout transience lean,which fits highways.

3. Dragging resistance immensely few.

4. Using rigid pavemens does not cause sliding of vehicles when surfaces are wet. for example when RAIN happens.

5. Using rigid pavements makes the concrete to be less effected with heat than flexible roads.

6. Designing age is immensely big,more than 25 yeasr.

7. Maintenance cost is insignificant.

8. Light colour of the surface gives better vision for the driver at night.

9. Erosion of the surface is insignificant without undulation and twist.

Appendix

8 Appendix: Design chart and Tables

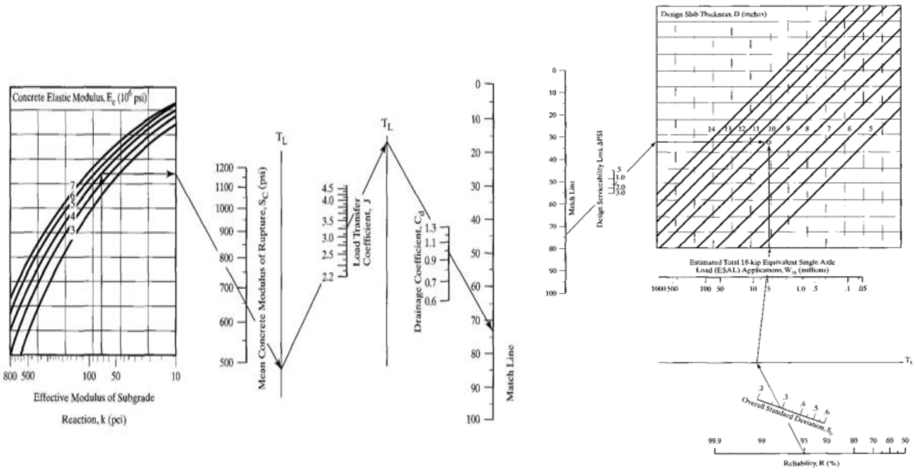


Figure 8-1 Design chart for Rigid pavements from AASHTO guide

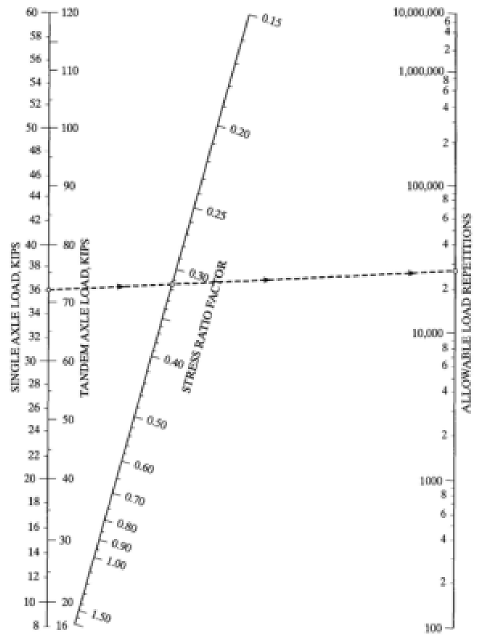


Figure 8-2 Stress ratio factors versus allowable load repetitions without concrete shoulders

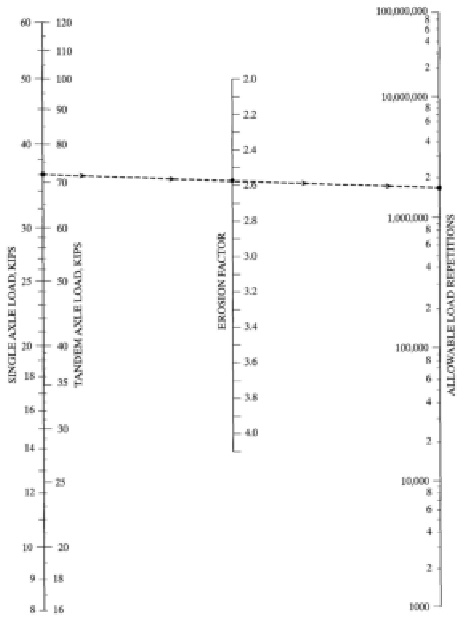


Figure 8-3 Erosion factors versus allowable load repetitions without concrete shoulders

Table 8-1Erosion Factors for Slabs with Aggregate Interlock Joints and no Concrete Shoulders

Slab thickness (in.)	k of Subgrade–subbase (pci)					
	50	100	200	300	500	700
4	3.94/4.03	3.91/3.95	3.88/3.89	3.86/3.86	3.82/3.83	3.77/3.80
4.5	3.79/3.91	3.76/3.82	3.78/3.75	3.71/3.72	3.68/3.68	3.64/3.65
5	3.66/3.81	3.63/3.72	3.60/3.64	3.58/3.60	3.55/3.55	3.52/3.52
5.5	3.54/3.72	3.51/3.62	3.48/3.53	3.46/3.49	3.43/3.44	3.41/3.40
6	3.44/3.64	3.40/3.53	3.37/3.44	3.35/3.40	3.32/3.34	3.30/3.30
6.5	3.34/3.56	3.30/3.46	3.26/3.36	3.25/3.31	3.22/3.25	3.20/3.21
7	3.26/3.49	3.21/3.39	3.17/3.29	3.15/3.24	3.13/3.17	3.11/3.13
7.5	3.18/3.43	3.13/3.32	3.09/3.22	3.07/3.17	3.04/3.10	3.02/3.06
8	3.11/3.37	3.05/3.26	3.01/3.16	2.99/3.10	2.96/3.03	2.94/2.99
8.5	3.04/3.32	2.98/3.21	2.93/3.10	2.91/3.04	2.88/2.97	2.87/2.93
9	2.98/3.27	2.91/3.16	2.86/3.05	2.84/2.99	2.81/2.92	2.79/2.87
9.5	2.92/3.22	2.85/3.11	2.80/3.00	2.77/2.94	2.75/2.86	2.73/2.81
10	2.86/3.18	2.79/3.06	2.74/2.95	2.71/2.89	2.68/2.81	2.66/2.76
10.5	2.81/3.14	2.74/3.02	2.68/2.91	2.65/2.84	2.62/2.76	2.60/2.72
11	2.77/3.10	2.69/2.98	2.63/2.86	2.60/2.80	2.57/2.72	2.54/2.67
11.5	2.72/3.06	2.64/2.94	2.58/2.82	2.55/2.76	2.51/2.68	2.49/2.63
12	2.68/3.03	2.60/2.90	2.53/2.78	2.50/2.72	2.46/2.64	2.44/2.59
12.5	2.64/2.99	2.55/2.87	2.48/2.75	2.45/2.68	2.41/2.60	2.39/2.55
13	2.60/2.96	2.51/2.83	2.44/2.71	2.40/2.65	2.36/2.56	2.34/2.51
13.5	2.56/2.93	2.47/2.80	2.40/2.68	2.36/2.61	2.32/2.53	2.30/2.48
14	2.53/2.90	2.44/2.77	2.36/2.65	2.32/2.58	2.28/2.50	2.25/2.44

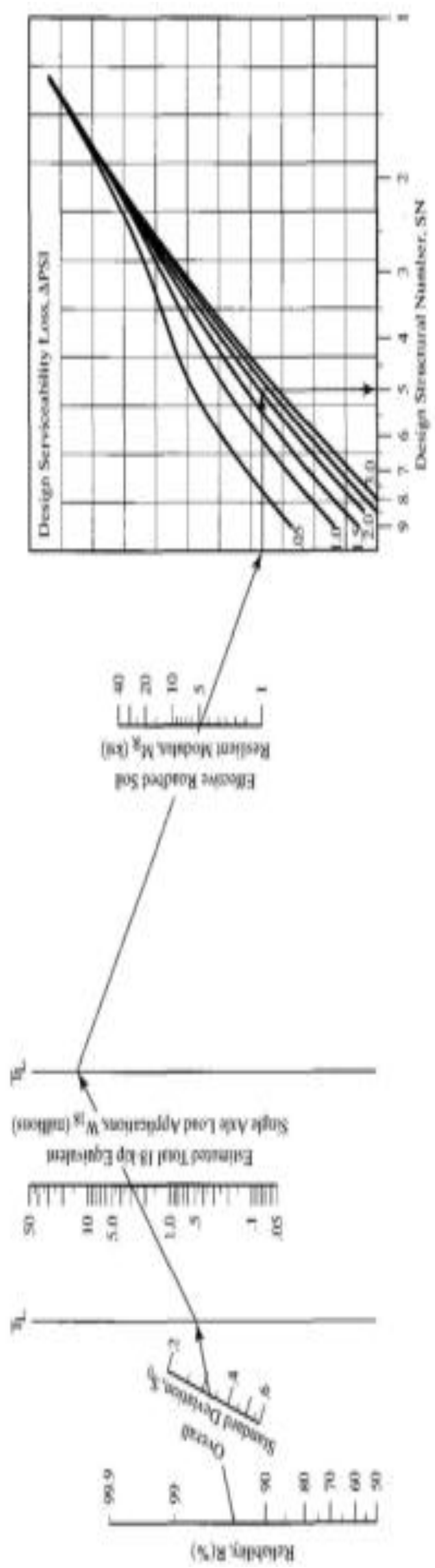


Figure 8-4 Design chart for flexible pavements from AASHTO guide

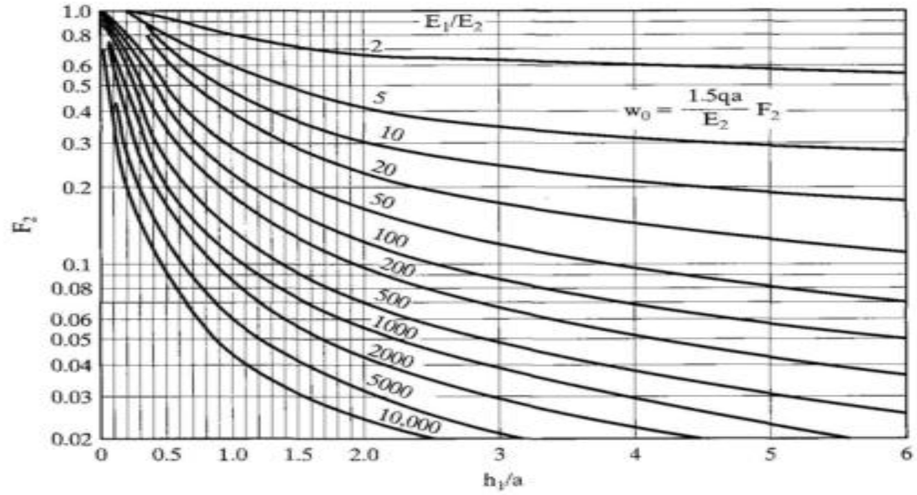


Figure 8-5 Vertical surface deflections for two-layer systems

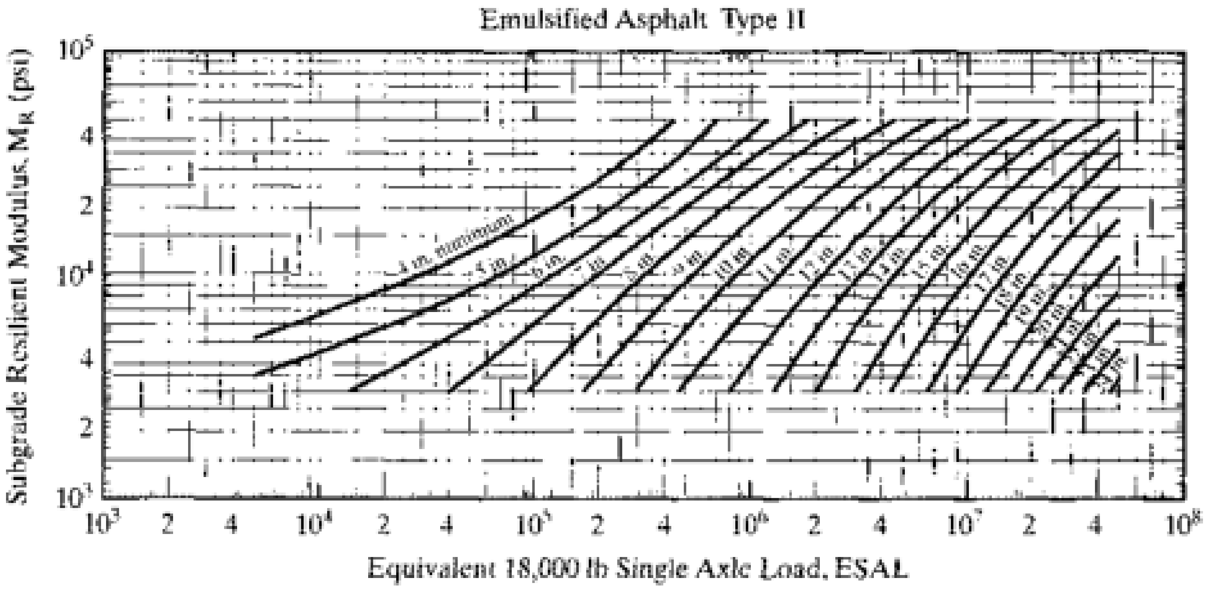


Figure 8-6 Design Chart for Type 2 Emulsified Asphalt Mix

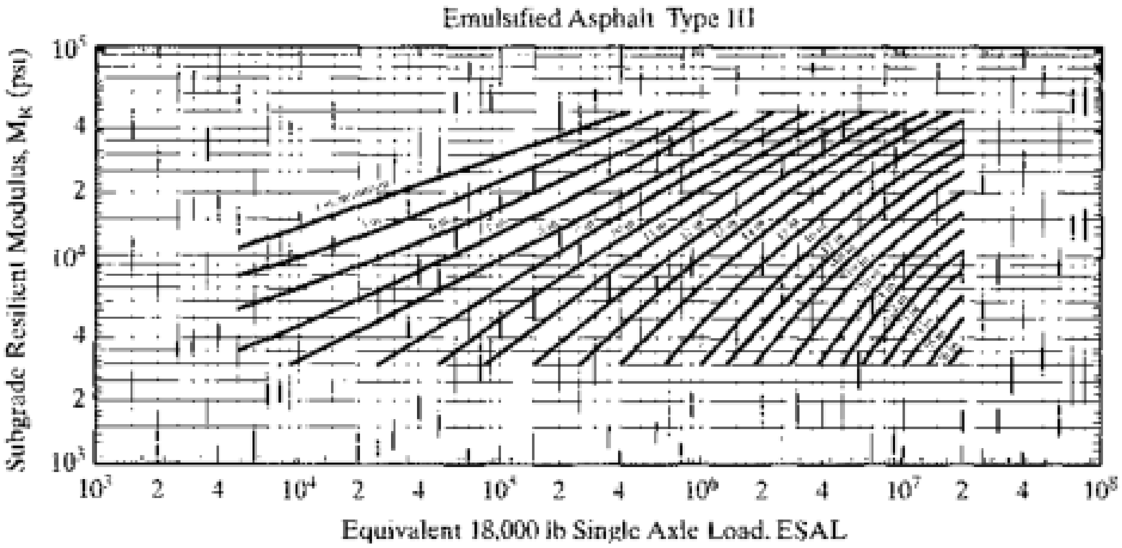


Figure 8-7 Design Chart for Type 3 Emulsified Asphalt Mix

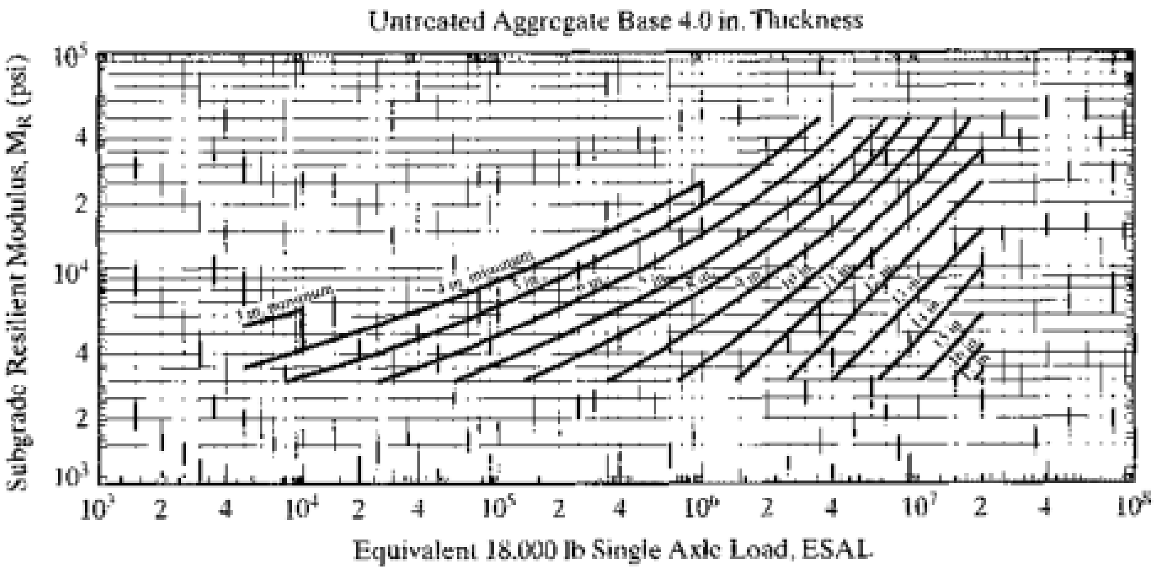


Figure 8-8 Design chart for HMA with 4-in. untreated aggregate base

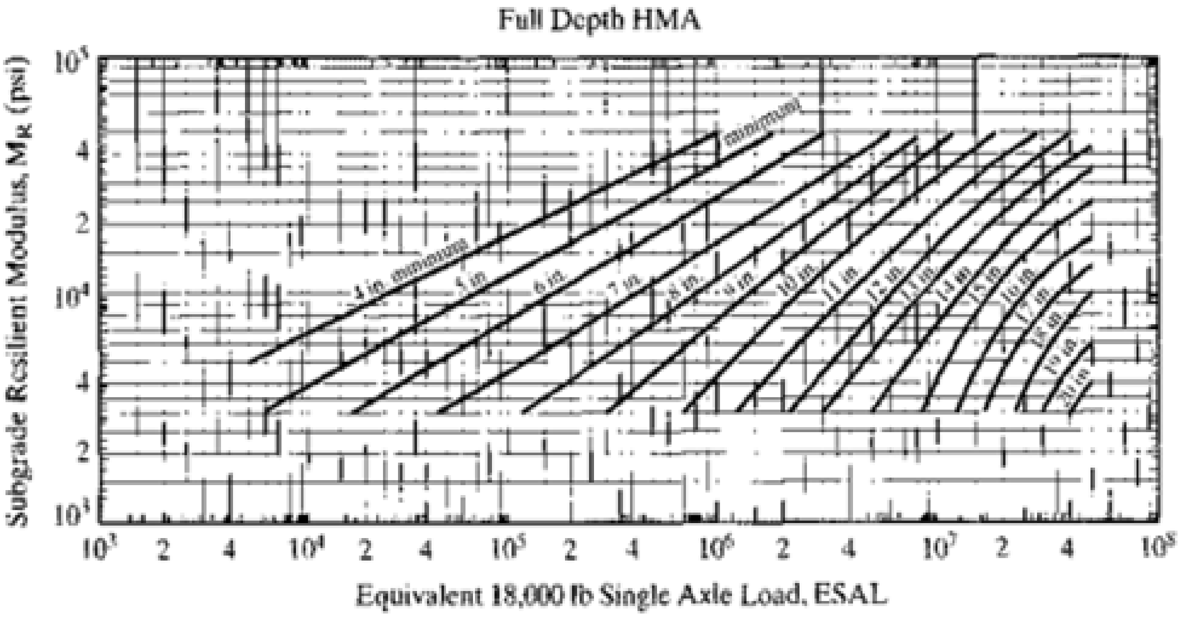


Figure 8-9 Design Chart for Full-depth HMA

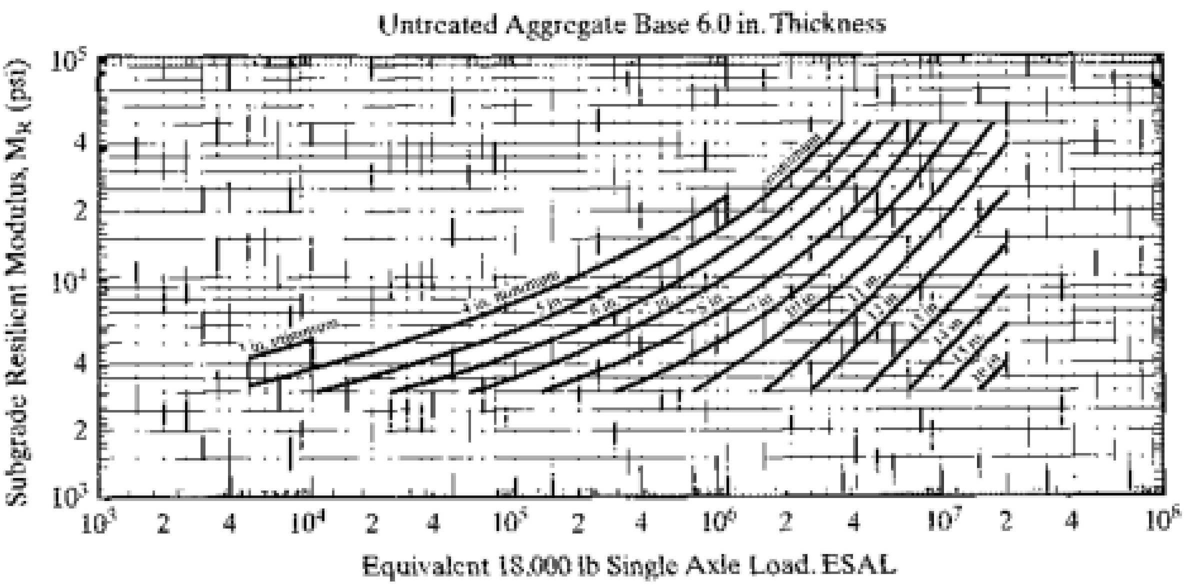


Figure 8-10 Design chart for HMA with 6-in. untreated aggregate base

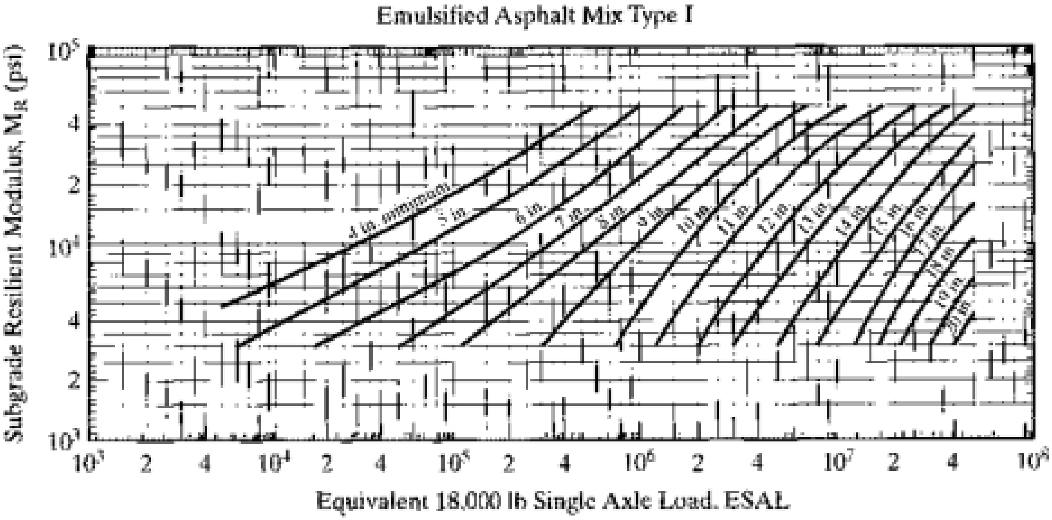


Figure 8-11 Design Chart for Type 1 Emulsified Asphalt Mix

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