OPITIZATION OF FLEXIBLE PAVEMENT USING MECHANISTIC APPROACH

FINAL YEAR PROJECT UG 2015

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CERTIFICATION

This is to certify that thesis entitled

Optimization of Flexible Pavement using Mechanistic Approach

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Has been accepted towards fulfillment

Of the requirements

For Bachelors in Civil Engineering

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DEDICATION

This thesis is dedicated to our parents and to all the people who supported us unconditionally and to the people who are working hard for the development and prosperity of Pakistan

DECLARATION

We hereby declare that the thesis entitled “Optimization of flexible pavement using mechanistic approach”, submitted by us is based on the study and work by us. Any references to work done by any other person, institutions or sources have been duly cited. We further clarify that this thesis has not been published or submitted for publication anywhere else.

ACKNOWLEDGEMENT

We are thankful to Almighty Allah, who gave us the courage and strength to complete this work. We would like to pay a debt of gratitude to our advisor, Lec Malik Kamran Shakir for his profound encouragement, support, motivation and valuable time he provided for this research. We would also like to thanks our co-advisor Dr. Arshad Hussain for his valuable support. We would also like to pay our solemn and honest gratitude to our parents for their absolute support, encouragement, prayers and patience.

Abstract

Infrastructure is the backbone of a country's development and it has a very high budget requirement. Pakistan is a third world country with limited resources and budget. Economic condition of Pakistan is very serious, and it needs proper attention. In this scenario budget allocation is very important. Pakistan spends billions of moneys on roads, highways and bridges construction. Roads are very important in economic development of Pakistan as they provide access to people and freight to reach their work places and target areas. In addition, roads also contribute in the growth and development of economy and provide the important social benefits. Roads are also necessary for the growth and development of a nation. Roads also helps us to fight the poverty by providing us the access to health, education, employment and social services. A good infrastructure is the insurance for tourism industry. In this project the aim is to come up with an optimized design of roads in Pakistan to counter the economic crises without compromising the quality and durability of roads.

In addition, the existing patterns of Pakistani roadway designs will be analyzed. This will help in determining the loopholes of the design and to provide them with recommendations for future design considerations. Moreover, the construction practices will also be reviewed, and adequate feedback will be provided to respective construction departments for improvements.

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KEY TO ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
HMA	Hot Mix Asphalt
MEPDG	Mechanistic Empirical Pavement Design Guide
CBR	California Bearing Ratio
ESAL	Equivalent Single Axle Load
Lips	Linear Integer Program Solver
OD	Optimized Design
AD	AASHTO Design

CHAPTER 1

INTRODUCTION

1.1 Study Background

Road construction industry acts as a backbone in country development but it also has very high budget requirements. In developing countries like Pakistan with all budget constraints it is very important to minimize the overall budget requirements for road construction. The major cost factor in a road project is Asphalt layer thickness. This research work emphasizes on cost effective design of flexible pavements by reducing the thickness of asphalt concrete layer without compromising the durability and longevity/service life of pavement. The existing design practices in road construction in Pakistan will be reviewed and suitable recommendations will be provided to concerned departments. Base and sub base layer thickness will be increased to reduce the asphalt concrete layer thickness; therefore, the strength requirements will be adequate. This technique seems to be considerable in a developing country like Pakistan where very high-quality granular material is abundantly available. The study will also be a good viable solution for conservation of local material and provide a plate form for any pursuit at local and national level to make pavement thickness design economical.

1.2 Problem Statement

- Pakistan is a developing country with many budget constraints and road construction required enormous amount of budget.
- Most of the cost is incurred in asphalt layer construction as asphalt is an expensive item.
- Highways and road cover a huge portion of land thus their construction cost is far more than any other civil engineering projects.

- By keeping in view, the discrepancies in design this research study is based on logical reduction in thickness by optimizing the pavement structural design.
- The main reason for selection of this topic is to determine the cost-effective pavement design techniques in order to economize the pavement construction in Pakistan.

1.3 Aims & Objectives

- The aim of the project is to analyze the current design practices in Pakistan. The design of highways, motorways and local roads in Pakistan are to be analyzed.
- Secondly to come up with an optimized design for these roadways. The purpose of the project is to determine an optimal cost-effective flexible pavement design based on asphalt layer thickness without affecting the qualities of pavement like durability, flexibility, stability and serviceability.

1.4 Scope of Project

As Pakistan is facing economic crises and it is dire need of foreign financial aids and helps. Pakistan has a serious financial problem. The foreign reserves of Pakistan are very less that resulted in devaluating the PKR. The construction of roads requires a huge amount of capital. It is the asphalt layer which takes a lot of money as it is an expensive material. This project will help in minimizing the asphalt layer thickness to a reasonable level without quality compromise. Hence the cost of the road construction will be reduced.

In addition, the existing patterns of Pakistani roadway designs will be analyzed. This will help in determining the loopholes of the design and to provide them with recommendations for future design considerations. Moreover, the construction practices will also be reviewed, and adequate feedback will be provided to respective construction departments for improvements.

1.5 Relevance to National need

The project is relevant to our national need. The highways in Pakistan have over designs. These overly designed roads cost a lot of national capital. This project will help in making the design adequate according to our national requirements.

CHAPTER 2

LITERATURE REVIEW

2.1 Flexible Pavement

Flexile pavements are those pavements which have an asphalt or bituminous top most layer followed by Base, Sub Base and Sub grade. The traffic load bend or deflect this pavement which make it flexible. Flexible pavements can have different quality of materials which can increase the flexing ability of the pavement. Flexible pavements cover more than 90% of our roads.

Flexible pavement has different types of layers' combinations, aggregate sizes and thicknesses. The widely and commonly used type of layer in pavement is Hot Mix asphalt (HMA). Most of the agencies consider bituminous Surface Treatment (BSTs) for maintenance and rehabilitation purposes. The difference among HMA types is mainly based on aggregate gradation, aggregate size, and asphalt binder. The most commonly used type of HMA is dense graded HMA. In flexible pavement failures are caused by the surface fatigue of bitumen layer, settlements, consolidation, cracking and shear development in layers due to poor pavement thickness.

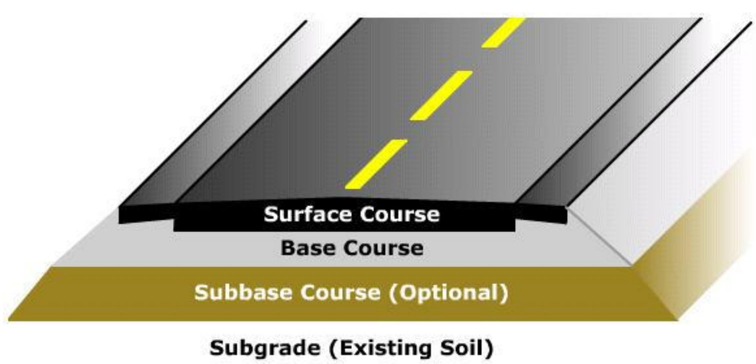


Figure 2.1 Typical Road Structure Cross Section

2.2 AASHTO 1993 Flexible Pavement Structural Design

The empirical equations are used to compare pavement characteristics with pavement performance. Here the pavement characteristics are measurable phenomena and the pavement performances are the outcomes. The widely used AASHTO equation is in the following form.

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

where:	W_{18}	Equals	Allowed number of 18 kips ESALs
	Zr	Equals	It is the standard normal deviation
	S_o	Equals	Standard error of both ESALs and performance prediction.
	SN	Equals	Structural number
		Equals	$a_1D_1 + a_2D_2m_2 + a_3D_3m_3 = SN_3$
	ΔPSI	Equals	Serviceability difference between initial and final serviceability index
	M_R	Equals	Resilient modulus of subgrade

From the nomogram the value of structure number is determined against the provided values of reliability, standard deviation, ESAls, resilient modulus and design serviceability loss.

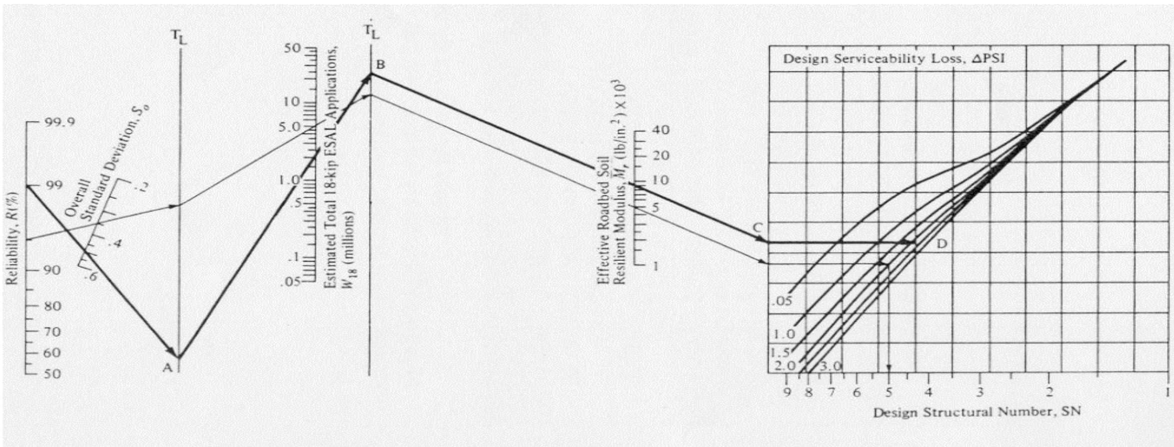


Figure 2.2 1993 AASHTO Flexible Design Nomograph

2.3 Structural number

To sustain the design's traffic loadings structural number tells us about the overall structural requirement we need. Strength of structure for pavement required for given combinations of different soil resilient modulus, number of ESALs, serviceability and the environment is showed by a structural number.

Its equation is given as:

$$SN = a_1D_1m_1 + a_2D_2m_2 + a_3D_3m_3$$

Where:

- The structural-layer coefficients are represented by a_1, a_2, a_3 for the pavement's surface course, base course and subbase layers, respectively,
- Thickness of the surface course, base course, and subbase layers are represented by D_1, D_2, D_3 in inches, respectively, and

- m_2 and m_3 shows coefficients of drainage for the base and subbase, respectively.
- The layer coefficient a show the material strength and it also helps in converting the structural number into layer thickness of pavements.
- m represents reduction in pavements strength due to drainage characteristics. The value of m is usually taken as 1 but for the layers that are drained quickly can have m value as higher as 1.4, but for slow draining layers the its value is taken as low as 0.40.
- Drainage coefficients makes a layer thick, but it does not make a layer denser. If any drainage problem is detected it is better to ponder on actual drainage problem by making the layer denser or by developing a better drainage system.

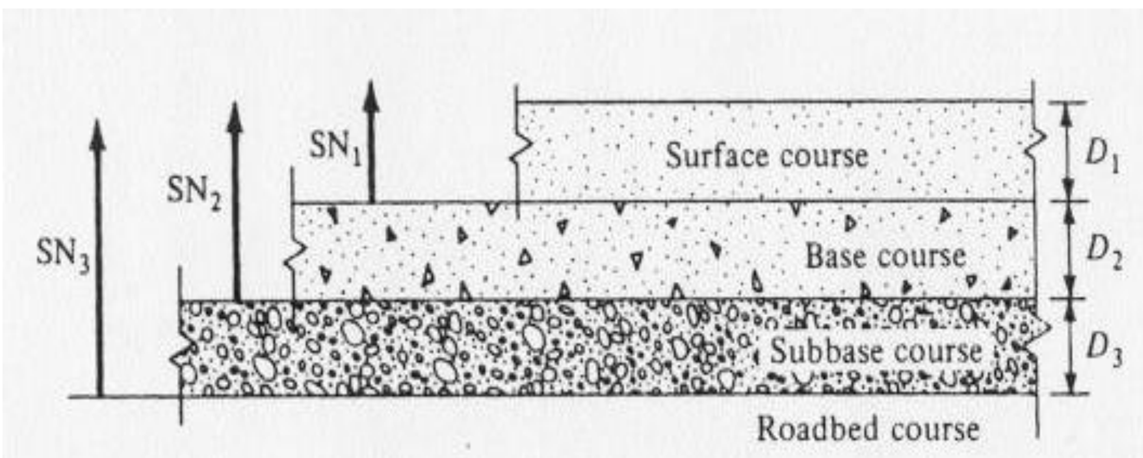


Figure 2.3 Typical Cross Section of Pavement

Table 20.18
AASHTO-Recommended Minimum Thicknesses of Highway Layers

	Minimum Thickness (in.)	
Traffic, ESALs	Asphalt Concrete	Aggregate Base
Less than 50,000	1.0 (or surface treatment)	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Table 2.1 AASHTO- Recommended Minimum Thicknesses of Highway layers

The 1993 AASHTO equation requires a number of inputs related to loads, pavement structure and subgrade support. These inputs are:

The 1993 AASHTO design equation requires the following inputs which have been briefly described in the following paragraphs.

2.4 The predicted loading.

It is the predicted number of ESALs that the pavement will experience during its design life. it is usually taken as 18KN of ESALs that will use the facility.

2.5 Reliability

It is the pavement design performance during its design lifetime. It is the probability of a pavement structure that will perform satisfactory over different conditions like traffic and environmental conditions during the life period of the pavement structure. In other way, it is the assurance of the better performance of the pavement during the designed period. Reliability depends on standard normal deviation and serviceability predicted for the design.

2.6 Pavement structure

Pavement structure is represented by the structure number. the abstracted structure number is converted into pavement layer thicknesses using a layer coefficient (a) that represents the construction material relative strength. All the layers accept HMA layer are given a drainage coefficient represented by “m” which represents the loss of relative strength of the pavement due to drainage characteristics and total time of its exposure to the saturation moisture conditions of the provided layer. Although, drainage coefficient is taken as 1 but for quick draining layers that do not become saturated can have coefficients as high as 1.4 while the layers which drain slowly and often gets the saturation conditions may have m value as low as 0.40. drainage coefficient makes a layer thick, but it does not make a layer denser. If any drainage problem is detected it is better to ponder on actual drainage problem by making the layer denser or by developing a better drainage system.

2.7 Serviceable life.

It is the difference between the serviceability index of pavement during construction and end of life of the pavement. The equation provided is used to compare these values with default values which are 4.2 immediately after construction and 1.5 after the end of design life of the structure.

The typical values used are 4-5 depending on the construction conditions for post-construction. And for end of life values used are 1.5 to 3. It depends on the type of highway and it’s uses.

2.8 Subgrade support

Sub-grade support is represented by the resilient modulus of the soil beneath the pavement structure. The resilient modulus depends on the value of CBR values of the soil. Typical value of CBR values used can be 5%, 7%, 9% and 10%. It is tested in the laboratory and calculated accordingly

2.9 Mechanistic-Empirical Pavement Design

The action of forces and the motion of bodies is mechanics. Hence, the mechanistic approach is used to explain the processes only referring to physical causes. And strains, stresses and deflections in pavement structure are caused due to the physical causes i.e. loads and material properties of the given pavement. The physical phenomena and physical causes and their relationship can be explained with the help of a mathematical model.

In addition, besides mechanistic approach, empirical elements help in determining those values of calculated stress and strain that can cause the pavement failure. The relationship between the parameters i.e. pavement phenomena and pavement failure are well explained by deriving equations that calculated total number of load cycles to failure.

The primary benefits of this method have the following advantages.

- It can analyze and design of both newly constructed pavement and rehabilitation of old pavements
- It can incorporate different load types.
- It can better utilize and characterize different materials by
    - Quality use of available material.
    - New material utilization
    - Revised and updated definitions of existing layer properties.
- More reliable prediction of performance.
- It defines the important role of construction precisely.
- It also incorporates the environment and aging conditions and effects of the materials.

2.10 Mechanistic-empirical approach for pavement design

We can divide the design input into four categories in MEPDG i.e.

I. Structure

II. Materials

III. Traffic

IV. Climate

MEPD use these input parameters for studying the models and finds the levels of pavement's stresses and strains in the horizontal direction as well as vertical and with help of those stresses and strains finds out the distress levels.

Fatigue and rutting are the main failures in flexible pavement. With the number of cumulative standard axles (denoted by N_F herein), we can determine the failure criterion for fatigue. And also, we can use the cumulative standard axles (denoted by N_R herein) to determine the failure criterion.

$$N_F = 0.0796 \times \left(\frac{1}{\varepsilon_t}\right)^{3.291} \times \left(\frac{1}{E_1}\right)^{0.854} \quad (1)$$

Here, ε_t represents the horizontal tensile strain formed beneath the asphalt layer because of traffic loads and E_1 represents the modulus of elasticity of the asphalt concrete.

To calculate the total number of load repetitions which cause the rutting failure (N_R), Asphalt institute has given the following empirical model.

$$N_R = (1.365 \times 10^{-9}) \times \left(\frac{1}{\varepsilon_v}\right)^{4.477} \quad (2)$$

Here, ε_v represents the vertical compressive strain and is evaluated at the top of subgrade layer. During its deterministic analysis, for a certain pavement if the value of both N_F and N_R exceeds the design traffic I.e. total allowable load repetitions estimated N_{lim}, no failure will occur; and if the value of any of N_F or N_R is less than N_{lim}, the pavement will be failed. Here, the factor of safety can be defined as the ratio of estimated load repetitions (the smaller of N_F and N_R) to total allowable load repetitions N_{lim}. The minimum required value say 1.0 shows the realization of deterministic design.

CHAPTER 3

METHODODLY

3.1 Introduction

Our project's research methodology was divided into four main stages.

1. AASHTO Flexible pavement structural design.

2. Mechanistic empirical pavement design

3.. Analysis

3.2 AASHTO Flexible pavement structural design

Based on 1993 AASHTO basic design equation for flexible pavements and equation to calculate layer thicknesses from the structure numbers of all the layers we developed a MATLAB program to calculate structural number of different layers followed by the calculation of thicknesses of different layers of flexible pavement. Following is the equation for flexible pavements under 1993 AASHTO basic design.

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

Here the design Parameters i.e. Z_R, S_o, P_i, P_t and M_R used were average of all Design Reports of Islamabad, Pakistan Studied and were kept constant according to each reliability.

Design was carried out at three different values of reliability that are 75, 85 and 90.

And for each reliability the range of ESALs used was 100000 - 70 Million with difference of 5 Million.

Structural number equation to calculate different thicknesses of different layers has the form:

$SN = a_1D_1 + a_2D_2M_2 + a_3D_3M_3$

Here the drainage coefficients (M_2 and M_3) are assumed as 1.

structural-layer coefficients of the wearing surface, base, and sub base layers are taken as

Layer	ai	mi	E	SN	di	Revised di
Asphaltic Course, a1	0.41		E= 400,000 Psi	3.0	7.32	7.5
Granular Base Course, a2	0.12	1.0	E= 25,000 Psi	3.9	6.875	7
Granular Sub-Base, a3	0.098	1.0	E= 13,000 Psi	5.0	11.07	11.5
Sub Grade Resilient Modulus	5000 Psi					

Table 3.2 Structure-layer coefficients of different pavement layers

3.3 MATLAB Program

- Can calculate thickness of up to 4 layers.
- Based on 1993 AASHTO Guide basic design equation for flexible pavements
- Gives output data in the form of easily workable Excel Sheet.

3.3.1 Inputs

- ESALs (In Millions)
- Sub grade Resilient Modulus Mr (psi)
- Standard Normal Deviation Zr

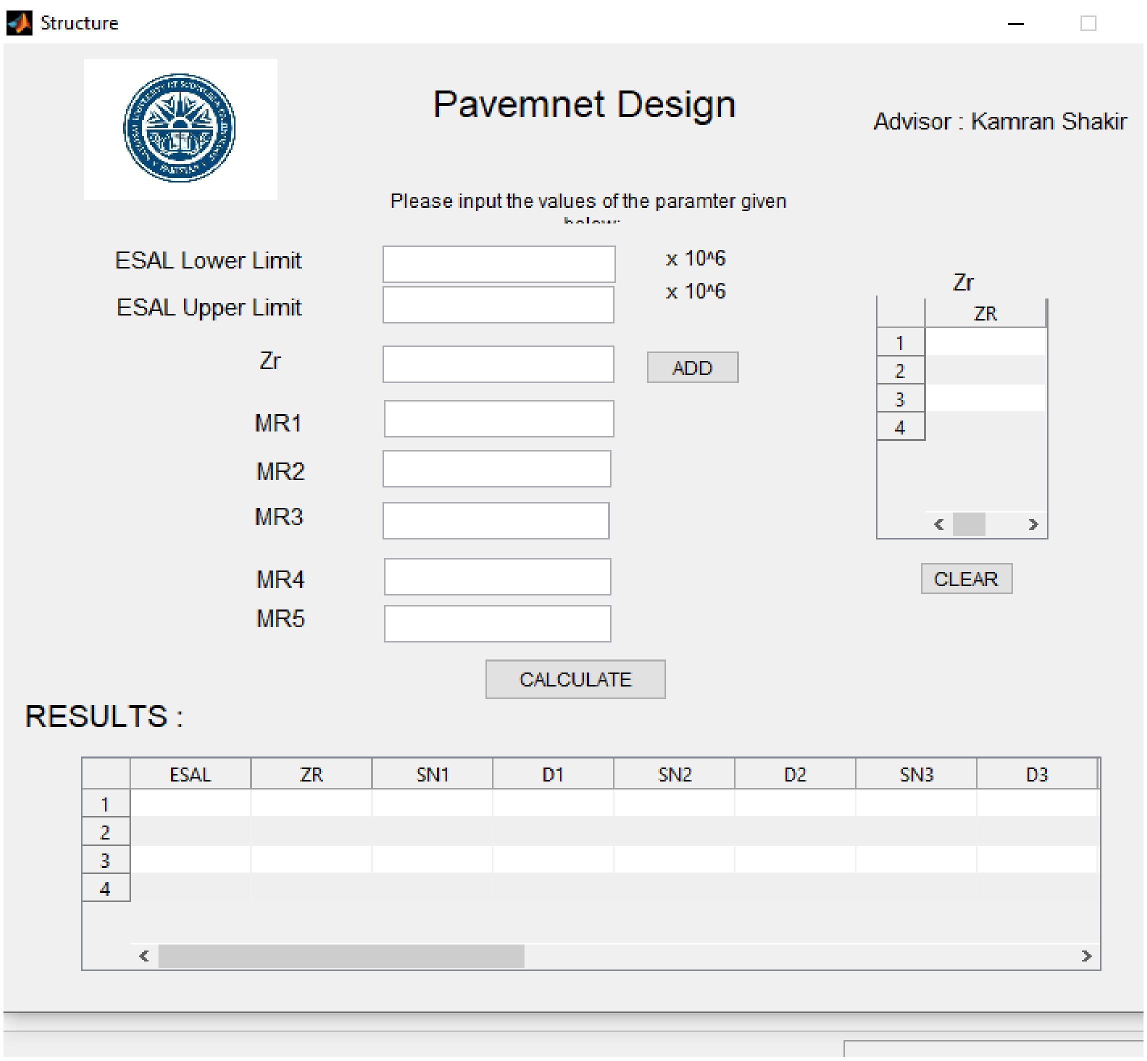


Figure 3.1 User Interface of MATLAB program

3.3.2 OUTPUTS

- Structural Number
- Layer thicknesses (In)
- EXCEL Sheet

3.4 Mechanistic empirical pavement design

Mechanistic empirical pavement design was carried out by Optimization of pavement structure thicknesses.

3.4.1 Optimization of pavement structure thicknesses

Optimization of pavement structure thicknesses was done by using a software named as Linear integer programming solver (LIPS).

3.4.2 LIPS

Linear Program Solver (LIPS) is a software used to solve linear and integer etc. type problems.

Following are its main features:

- To solve large scale problems, it implements the modified simplex method It implements efficiently the modified simplex method.
- It gives us the detailed solution in the form of tables other than just showing the answer.
- To study the behavior of any model on changing its parameters, it can also perform the sensitivity analysis.

For optimization firstly, we developed an optimization model which included an objective function which gives us the minimum cost of pavement design

$$\frac{C_{AC}.\ d_{AC}}{100} + \frac{C_{AB}.\ d_{AB}}{100} + \frac{C_{GB}.\ d_{GB}}{100} + \frac{C_{GSB}.\ d_{GSB}}{100}$$

Different constraints Based on AASHTO 1993 Procedure included

$$a_{AC}.\, d_{AC} + a_{AB}.\, d_{AB} \geq SN_1$$

$$a_{AC}.\, d_{AC} + a_{AB}.\, d_{AB} + a_{GB}.\, m_{GB}.\, d_{GB} \geq SN_2$$

$$a_{AC}.\, d_{AC} + a_{AB}.\, d_{AB} + a_{GB}.\, m_{GB}.\, d_{GB} + a_{GSB}.\, m_{GSB}.\, d_{GSB} \geq SN_3$$

$$d_{AWC} \geq \text{Min } d_{AWC}$$

$$d_{AB} \geq \text{Min } d_{AB}$$

$$d_{GB} \geq \text{Min } d_{GB}$$

$$d_{GSB} \geq \text{Min } d_{GSB}$$

Decision Variables

$$d_{AWC}, d_{AB}, d_{GB}, d_{GSB} = \text{integer}$$

Where

C= Cost as per NHA CSR 2014

d = Respective Pavement Layer Thickness

AC/AWC= Asphalt wearing course

AB= Asphalt Base course

GB= Granular base

GSB= Granular sub-base

All these constraints and objective function were introduced in LIPS and the optimized pavement structure thicknesses and the cost of flexible pavement came as a result.

Figure 3.2 includes the optimization model and results

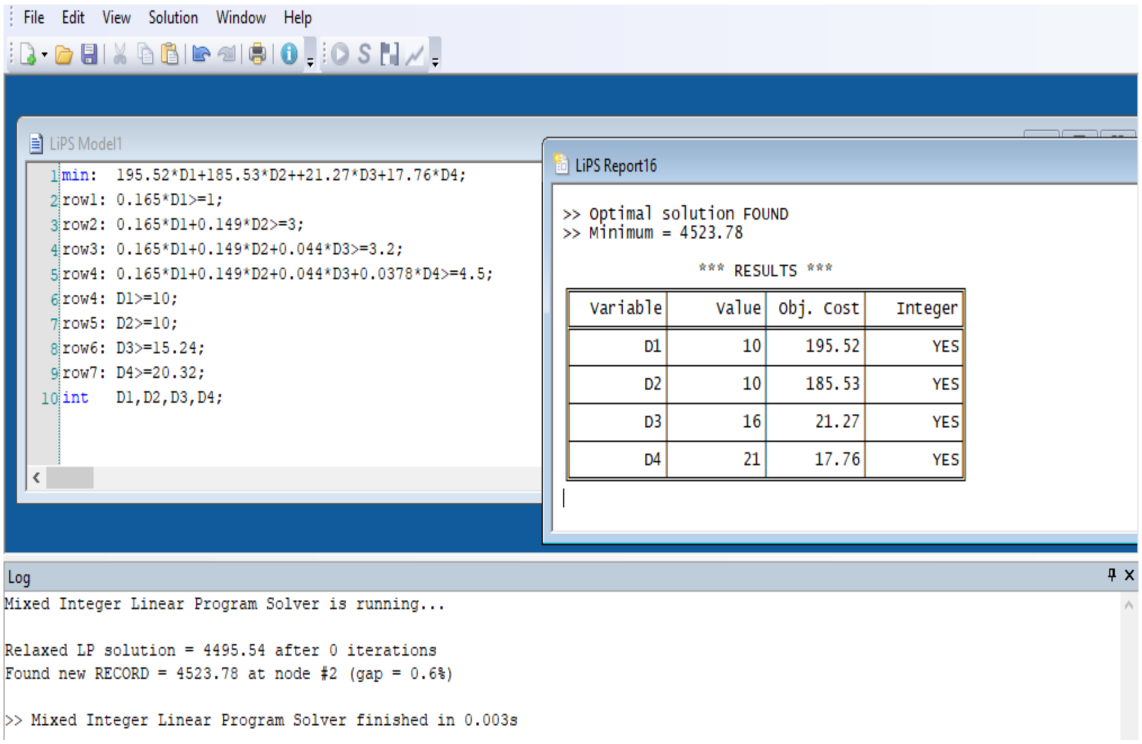


Figure 3.2 linear integer program solver

3.5 Software Analysis

3.5.1 Introduction

The data obtained in designing was analyzed to obtain the pavement responses i.e., horizontal tensile strain under surface course and vertical compressive strain above sub grade layer.

We used to follow two software for the analysis of both the AASHTO Flexible pavement structural design and Mechanistic empirical pavement design.

1.Kenpave

2. Michigan Flexible Pavement Design System (MFPDS)

3.5.2 KENPAVE

- Huang, developed the software KENPAVE software was developed in 1993 and it was updated in 2004.
- Here we can perform damage analysis on up to 19 layers.
- By using KENPAVE we can perform damage analysis on different layer systems under different wheel conditions i.e. single, dual, dual-tandem, or dual-tridem. Here each layer behaves differently that could be nonlinear elastic, linear elastic, viscoelastic.
- Here we can divide each year into maximum of 12 periods, with each period hiving its own set of material properties.
- Kenpave can accommodate 12 load groups that could be either single or multiple in each period.
- It Implies Fatigue and Rutting Model for different conditions. (Minen 1945).
- Design life of pavement can be achieved by the summation of damage ratios in each period for the applied load groups.

3.5.3 Michigan Flexible Pavement Design System (MFPDS)

- MFPDS was developed by Hari Chandran, R. S (2000).
- This software is based on finite element analysis.
- It performs analysis using both tools based finite element and multilayer.
- MichPave and Chevronx (enhanced Chevron) are the pavements layers' analysis programs and both are used to perform mechanistic analysis.
- Depth rutting and fatigue life can be evaluated by this software.
- Here it is assumed that each layer in a cross section of pavement infinitely extends in the horizontal direction.
- Analysis is performed under single circular wheel load.

- Here the problem reduces to axisymmetric one because of Due to the assumptions used.

3.5.4 Analysis

3.5.4.1 KENPAVE Analysis

- First, we developed KENPAVE Model
- Parameters were same for Both Designs
- Pavement Structure Change
- Analysis was done for ESALs (100000 to 70 Million) with the difference of 5million.
- The input parameters for linear elastic analysis are Material properties, number of periods, thickness of each layer, Traffic load, number of load groups.

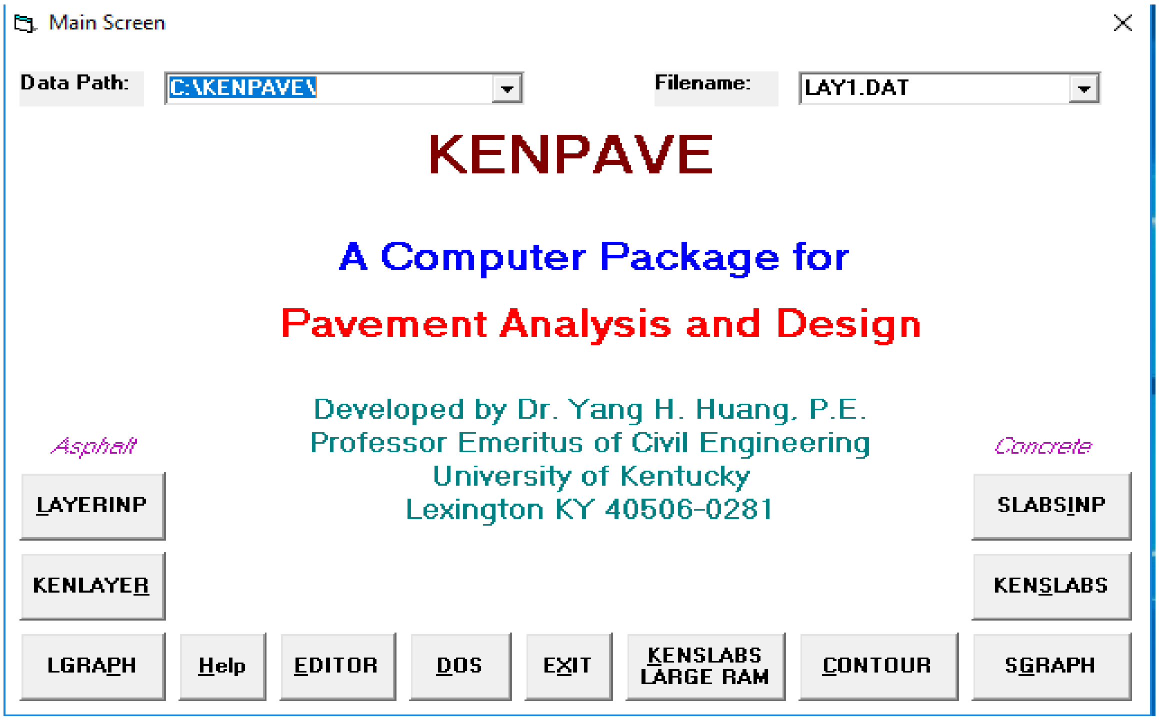


Figure 3.3 User Interface of KENPAVE software

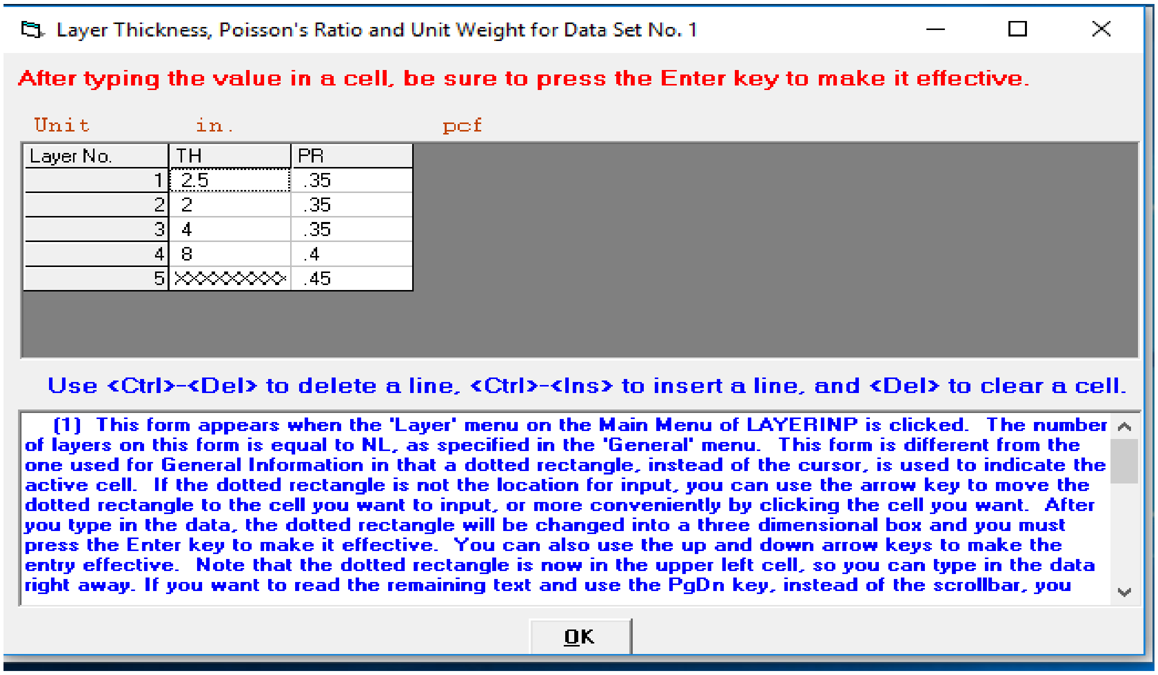


Figure 3.4 thickness input cells in Kenpave

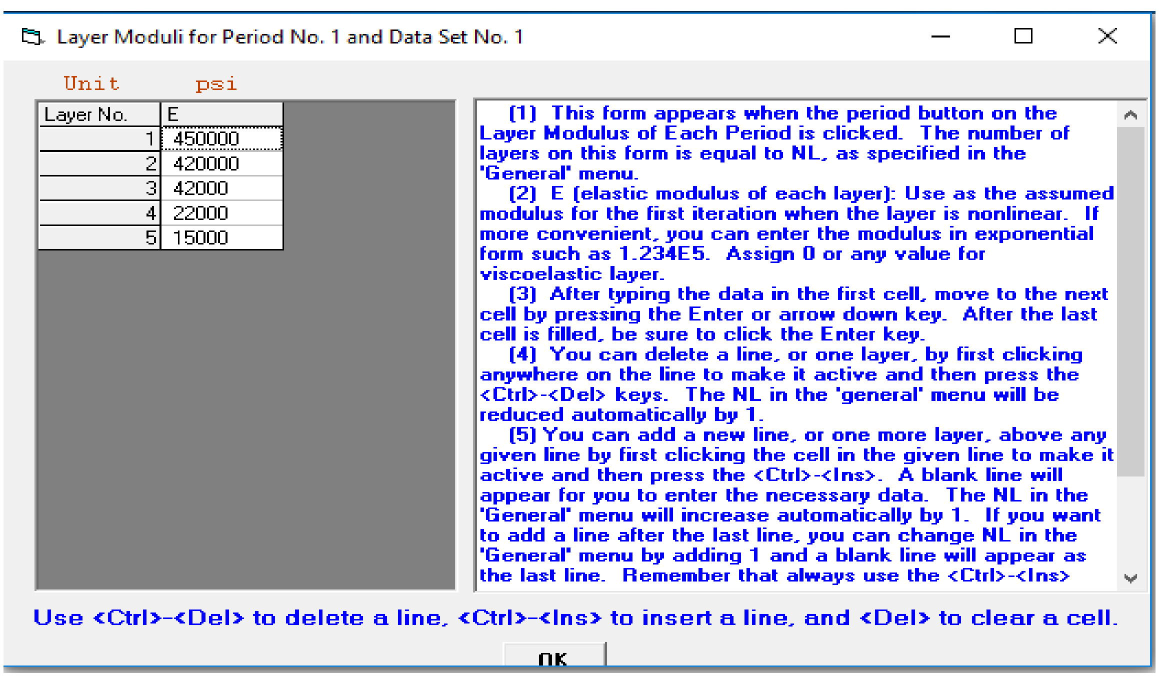


Figure 3.5 resilient modulus input cells in Kenpave

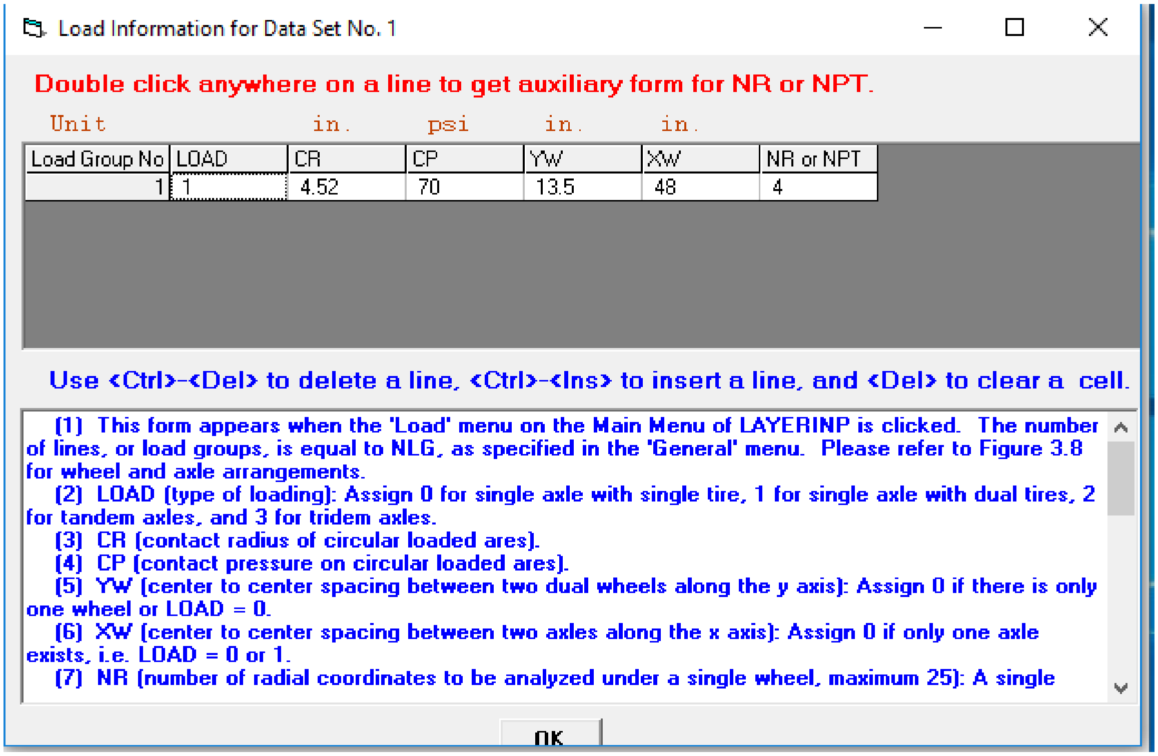


Figure 3.6 ESALs Input Cell in KENPAVE

3.5.4.1.1 KENPAVE OUTPUTS

- Horizontal tensile strains at the bottom of Asphaltic base layer.
- Vertical compressive strains at top of sub grade.
- Fatigue/Service life.
- Damage ratios for both Fatigue and Rutting criteria.

3.5.4.2 MICHIGAN FLEXIBLE PAVEMENT DESIGN SYSTEM(MFPDS) ANALYSIS

- First, we developed MFPDS Model
- Parameters were same for Both Designs
- Analysis was done for ESALs (100000 to 70 Million) with the difference of 5million.
- wheel load, tire pressure, layer characteristics, and cross section details are some of the input parameters.

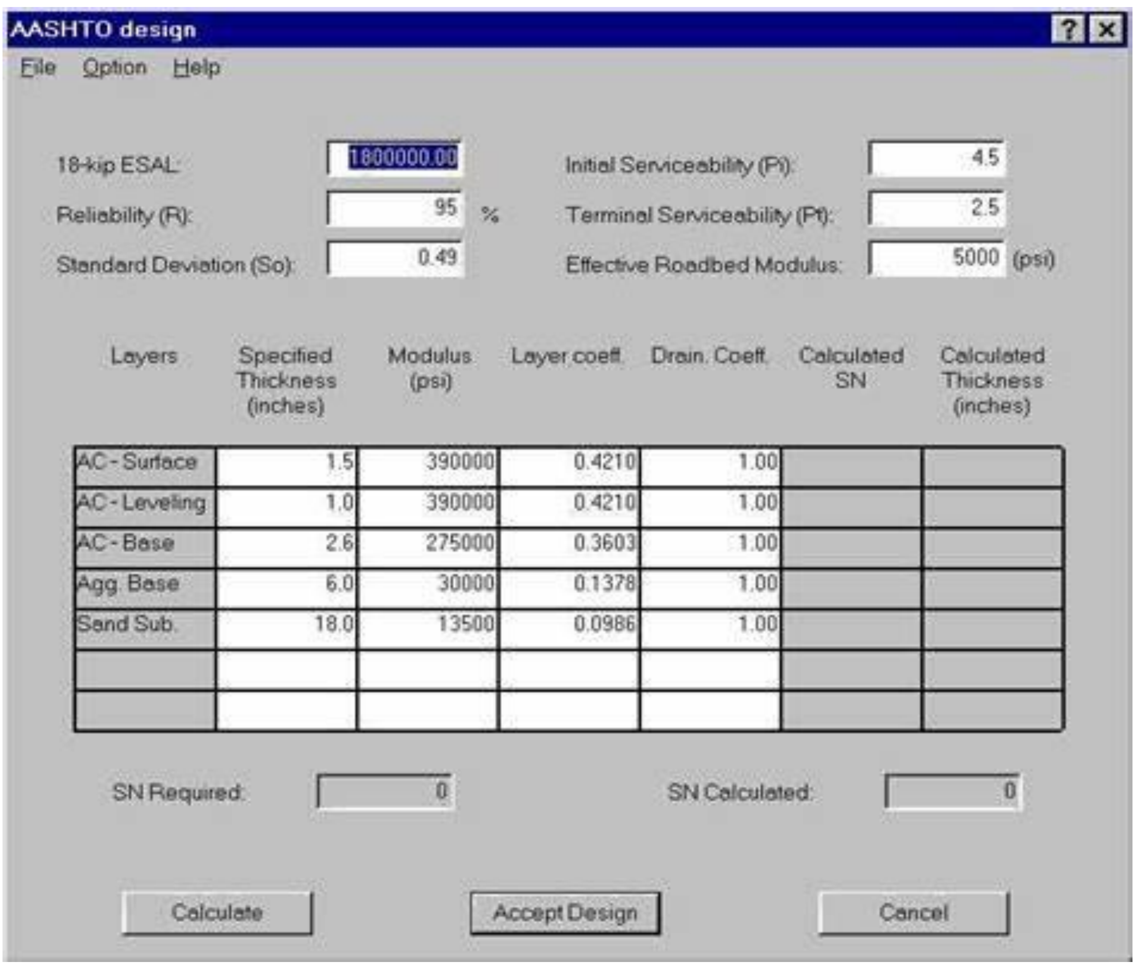
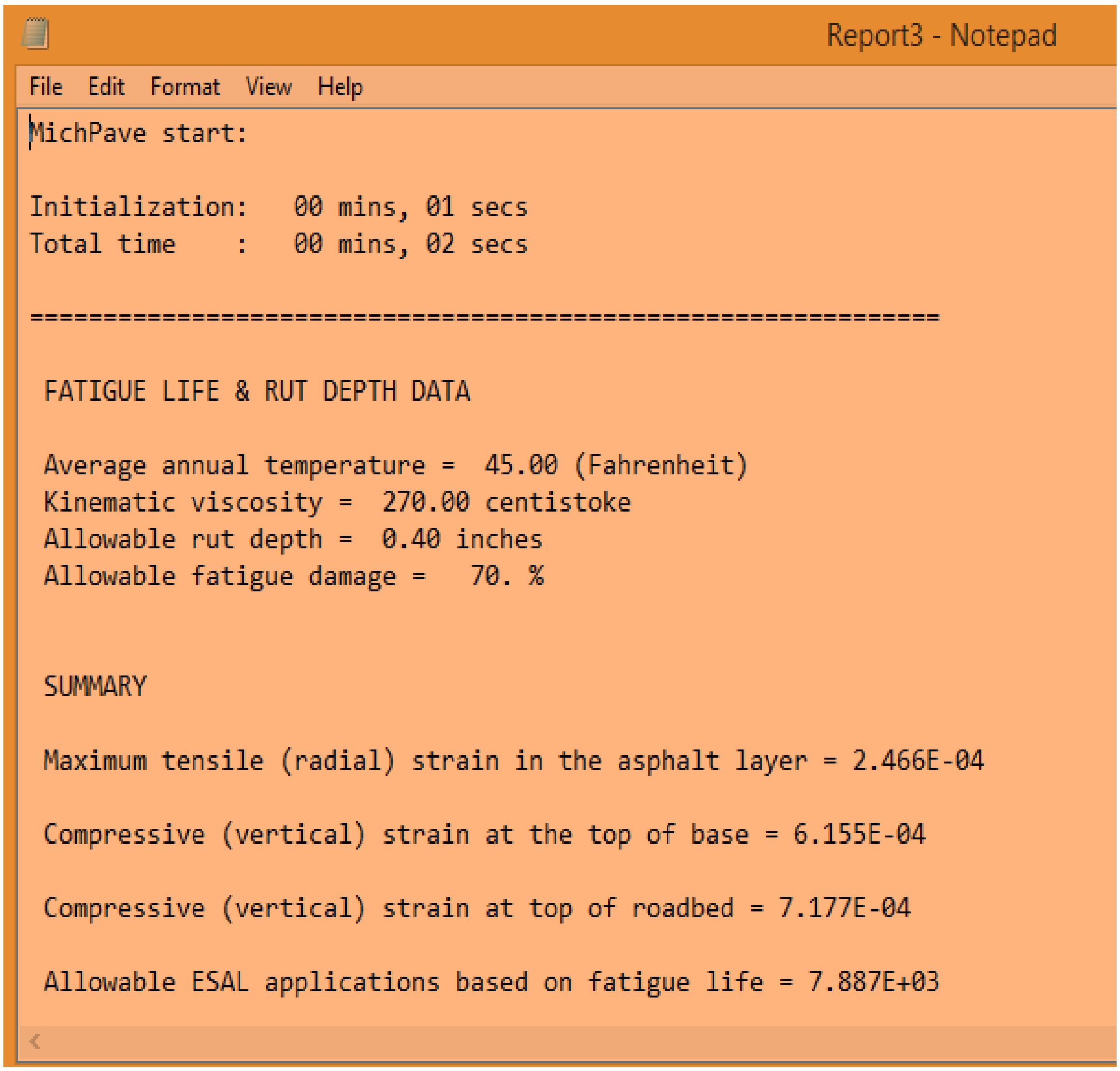


Figure 3.7 User Interface of Michigan software

3.5.4.2.1 MICHIGAN FLEXIBLE PAVEMENT DESIGN SYSTEM(MFPDS) OUTPUTS

- Horizontal tensile strains at the bottom of Asphaltic base layer.
- Vertical compressive strains at top of sub grade.
- Allowable ESALs for fatigue and Rutting



Report3 - Notepad

File Edit Format View Help

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MichPave start:

Initialization:   00 mins, 01 secs
Total time    :   00 mins, 02 secs

==============================================================

 FATIGUE LIFE & RUT DEPTH DATA

 Average annual temperature =  45.00 (Fahrenheit)
 Kinematic viscosity =  270.00 centistoke
 Allowable rut depth =  0.40 inches
 Allowable fatigue damage =   70. %


 SUMMARY

 Maximum tensile (radial) strain in the asphalt layer = 2.466E-04

 Compressive (vertical) strain at the top of base = 6.155E-04

 Compressive (vertical) strain at top of roadbed = 7.177E-04

 Allowable ESAL applications based on fatigue life = 7.887E+03
```

Figure 3.8 Michigan software report

CHAPTER 4

RESULTS AND CONCLUSIONS

4.1 Introduction

The results of the research are the outputs of the software used. The results are drafted in the form of histograms that shows the variation between the optimized and AASHTO design pavement structure. The results include the thickness variation, damage ratio variation, tensile and compressive strength difference, service life and cost variations for both designs. The graphs are generated using excel sheets. The data for calculation of structure number and thickness are based on the AASHTO equation.

4.2 Thicknesses variation for the designs

This histogram shows the variation of thickness for AASHTO design and mechanistic design. Y-axis has asphaltic layer thickness while X-axis has the number of ESALs in millions. The asphaltic concrete thickness is reduced by increasing the thicknesses of base and sub base material. The use of quality material in base and sub base also helps in reducing the top layer thickness. The difference of thicknesses for higher ESALs is less because of the restricted design thicknesses for higher ESALs. The primary goal of the research was to reduce the thickness which is achieved using the linear Integer Program.

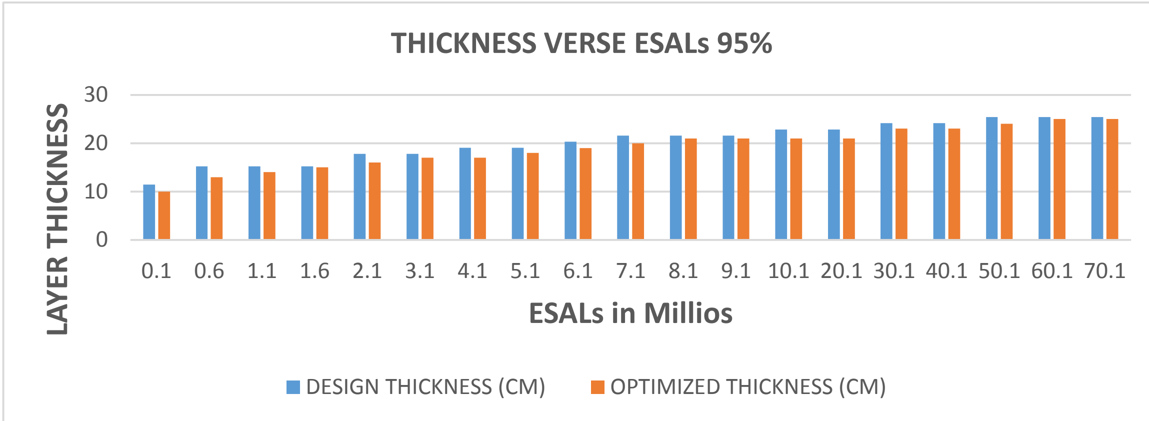

Figure 4.1 Thicknesses verses Number of ESALs Graph

4.3 Tensile strain

The graph shows the variation of tensile strain for different ESALs. The reduction of asphalt layer thickness caused increase in tensile strain.

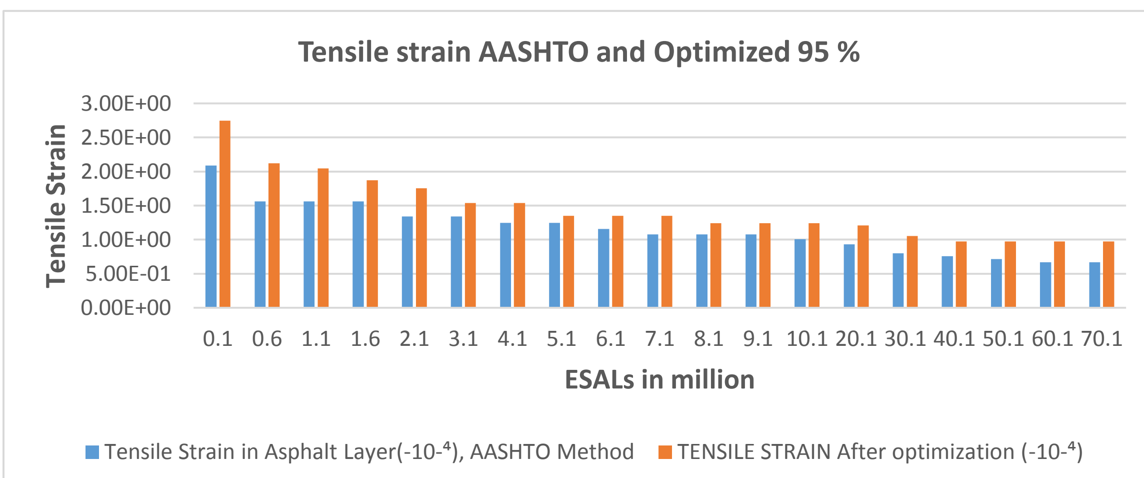

Figure 4.2 Tensile strain verses ESALs Graph

4.4 Compressive strain

Similarly, the compressive strain for optimized mechanistic design also increased because of top layer thickness reduction.

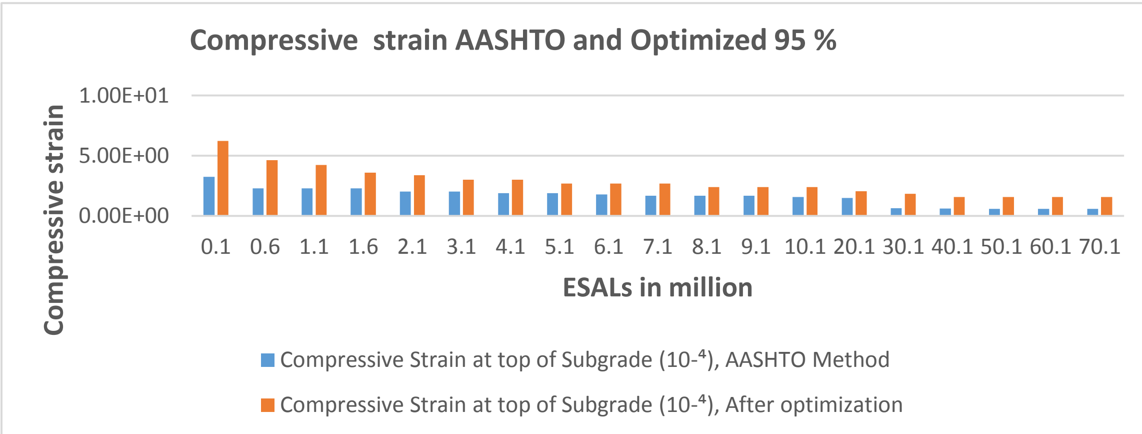

Figure 4.3 compressive strain verses ESALs Graph

4.5 Damage ratios

4.5.1 Fatigue

The pavement usually fails in fatigue due to increased number of load repetitions. It causes series of interconnected cracks in HMA. The histogram below shows the variation of fatigue for both designs. the damage ratio for optimized design increased due to thickness reduction. With the increase in number of ESALs the damage ratio decreases because the thickness for higher ESALs is larger than lower ESALs.

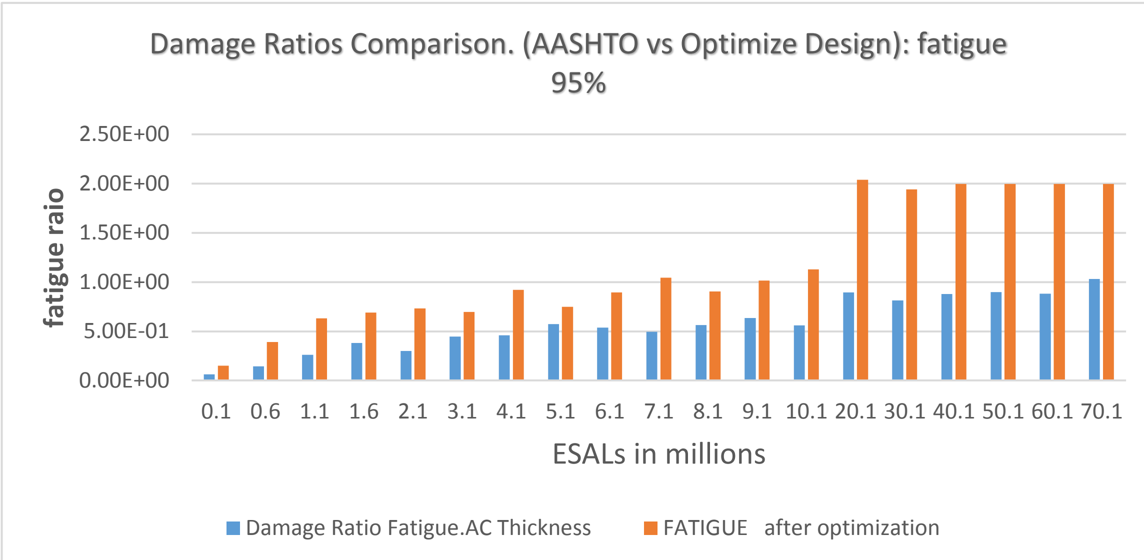

Figure 4.4 fatigue damage ratio verses ESALs

4.5.2 Rutting

like fatigue the rutting deflection for mechanistic design increased because of top layer thickness reduction.

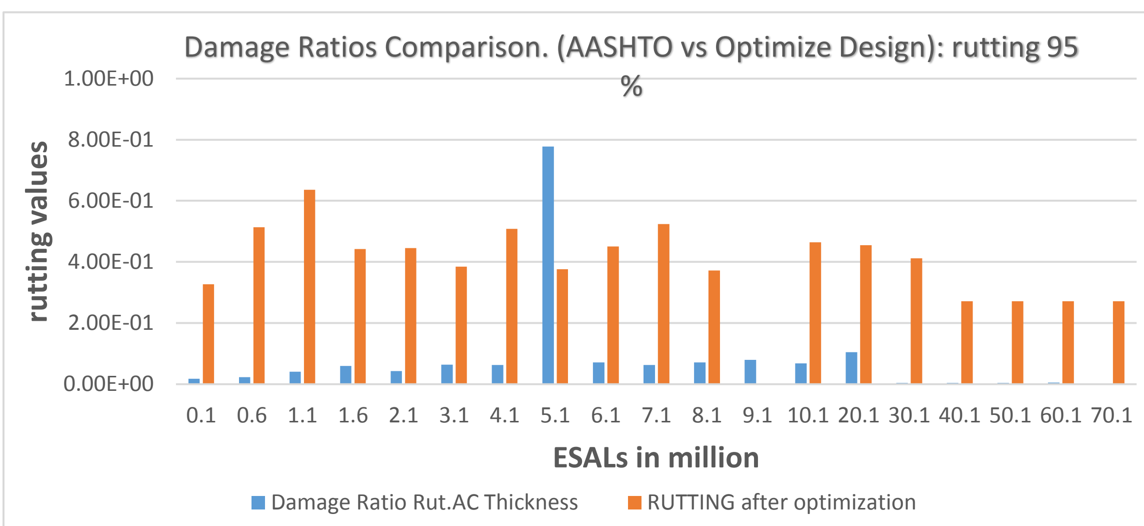

Figure 4.5 Rutting damage ratio verses ESALs Graph

4.6 Service life

The service life for both designs is drafted in the form of histogram. The thickness reduction resulted into the reduction of service life. The reduction of service life was in a range of 1 to 3 % with an average of 2 % of ASSHTO design service life.

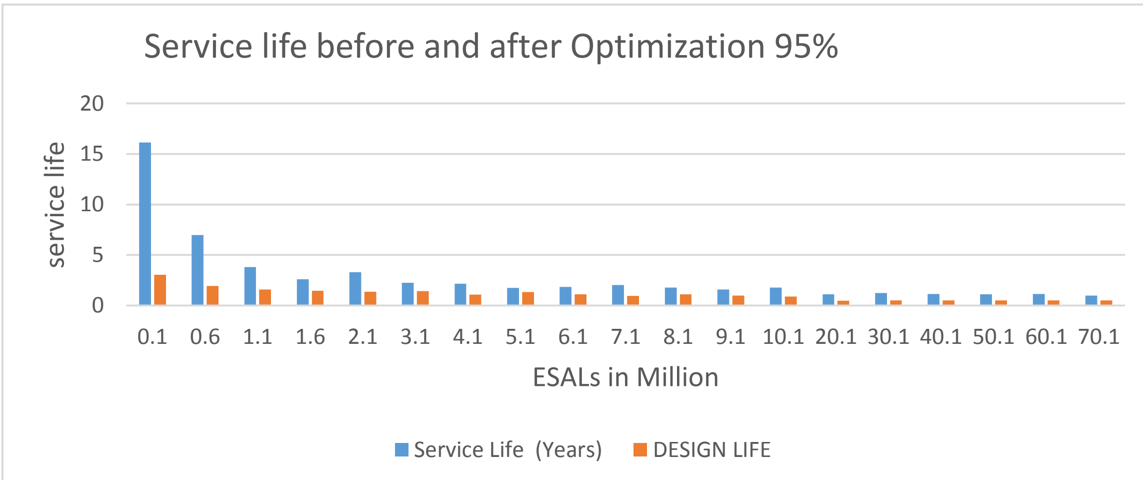

Figure 4.6 service life verses ESALs Graph

4.7 Cost

The goal of the research was to reduce the cost of the structure. The histogram shows the variation of cost for both designs. The optimization of pavement structure resulted in 5% to 9% reduction of total pavement cost.

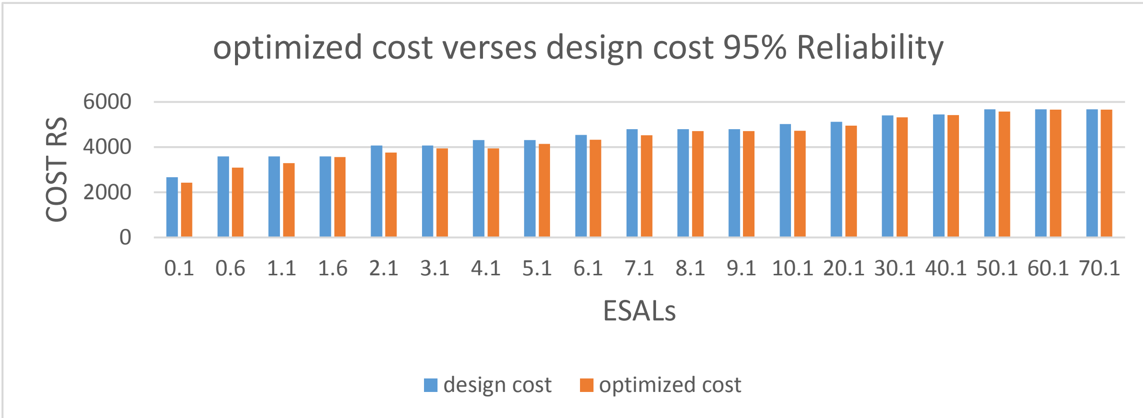

Figure 4.7 cost analysis verses ESALs Graph

4.8 Conclusions

After thoroughly analyzing the data and interpreting the results from the software, it can be found that mechanistic design is more feasible than AASHTO design. The mechanistic design approach is more reliable and have wide range of applications. It incorporates varies parameters as variable which were previously i.e. AASHTO design has taken as constants or have been neglected. The method does not neglect minor factors which can cause the minor alterations in the pavement structure. The effect of material properties, the impacts of weather and traffic are taken as variables in this method. Based on this method we came to the conclusions that are mentioned afore. The top asphaltic concrete layer thickness can be reduced using quality base and sub base material and by increasing the base and sub base thickness. For the results carried here the design is recommended for ESALs upto20 million. As the asphalt is the costly material among others, because of reduction in asphalt layer thickness the cost of the pavement structure is reduced up to 6% average. But the reduction in thickness caused reduction in service life up to 2% of ASSHTO design life. The results also represent the increase in tensile and compressive strength and increase in damage ratios i.e. fatigue and rutting. Overall, the reduction in cost and reduction in service life are feasible. The method provides opportunities for new researchers to entertain themselves with the wide spectrum of fields and dimensions it provides. We urge the new comers to invest their time and money in this field to make road construction cost effective.

4.9 Recommendation

The recommendations provided are based on the conclusions mention afore. After thorough analysis, we highly recommend the use of mechanistic empirical design method for future projects in Pakistan. In this research, certain parameters were kept constant and we recommend the new researchers to deal with these parameters as variables and proceed with their research. The recommendations are also provided in the form of a decision matrix as shown below.

4.10 SUMMARY

Research has been summarized in the form a decision matrix given below. Decision matrix shows the limitations on design and its application.

AD: AASHTO Design

OD: Optimized Design

Traffic Volume	Nominated ESALs	Cost	C Strain	Tensile Strain	Rutting	Fatigue	Service Life
<=50000	10000	OD	OD	OD	OD	OD	OD
50001-150000	100000	OD	OD	OD	OD	OD	OD
150001-500000	100000	OD	OD	OD	OD	OD	OD
500001-2000000	600000	OD	OD	OD	OD	OD	OD
	1100000	OD	OD	OD	OD	OD	AD
2000001-70000000	2100000	OD	OD	OD	OD	OD	AD
	3100000	OD	OD	OD	OD	OD	AD
	5100000	OD	OD	OD	OD	OD	AD
	6100000	OD	OD	OD	OD	OD	AD
>7000000	7100000	OD	OD	OD	OD	AD	AD
	10100000	OD	OD	OD	OD	AD	AD
	20100000	OD	OD	OD	OD	AD	AD
	30100000	OD	OD	OD	OD	AD	AD
	40100000	OD	OD	OD	OD	AD	AD
	50100000	OD	OD	OD	OD	AD	AD
	60100000	OD	OD	OD	OD	AD	AD
	70100000	OD	OD	OD	OD	AD	AD

Table 4.1 Decision Matrix of the results

ANNEX A

TABLES

Layer	ai	mi	E	SN	di	Revised di
Asphaltic Course, a1	0.41		E= 400,000 Psi	3.0	7.32	7.5
Granular Base Course, a2	0.12	1.0	E= 25,000 Psi	3.9	6.875	7
Granular Sub-Base, a3	0.098	1.0	E= 13,000 Psi	5.0	11.07	11.5
Sub Grade Resilient Modulus	5000 Psi					

Table 3.2 Structure-layer coefficients of different pavement layers

Traffic Volume	Nominated ESALs	Cost	C Strain	Tensile Strain	Rutting	Fatigue	Service Life
<=50000	10000	OD	OD	OD	OD	OD	OD
50001-150000	100000	OD	OD	OD	OD	OD	OD
150001-500000	100000	OD	OD	OD	OD	OD	OD
500001-2000000	600000	OD	OD	OD	OD	OD	OD
	1100000	OD	OD	OD	OD	OD	AD
2000001-70000000	2100000	OD	OD	OD	OD	OD	AD
	3100000	OD	OD	OD	OD	OD	AD
	5100000	OD	OD	OD	OD	OD	AD
	6100000	OD	OD	OD	OD	OD	AD
>7000000	7100000	OD	OD	OD	OD	AD	AD
	10100000	OD	OD	OD	OD	AD	AD
	20100000	OD	OD	OD	OD	AD	AD
	30100000	OD	OD	OD	OD	AD	AD
	40100000	OD	OD	OD	OD	AD	AD
	50100000	OD	OD	OD	OD	AD	AD
	60100000	OD	OD	OD	OD	AD	AD
	70100000	OD	OD	OD	OD	AD	AD

Figure 4.8 Decision Matrix of the results

Table 20.18
AASHTO-Recommended Minimum Thicknesses of Highway Layers

	Minimum Thickness (in.)	
Traffic, ESALs	Asphalt Concrete	Aggregate Base
Less than 50,000	1.0 (or surface treatment)	4
50,001–150,000	2.0	4
150,001–500,000	2.5	4
500,001–2,000,000	3.0	6
2,000,001–7,000,000	3.5	6
Greater than 7,000,000	4.0	6

Figure 2.4 AASHTO- Recommended Minimum Thicknesses of Highway layers

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