Jimma University

Jimma Institute of Technology

Post Graduate Studies

School of Civil and Environmental Engineering

Department of Civil Engineering

Highway Engineering MSc Program

Analysis of Stress- Strain and Deflection of Flexible Pavements Using Finite Element Method Case study On Bako-Nekemte Road

A Thesis Submitted To The School Of Graduate Studies Of Jimma University In Partial Fulfillment Of The Requirements For The Degree Of Masters Of Science In Civil Engineering (Highway Engineering)

By

Shiferaw Garoma Wayessa

November, 2016

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By

Shiferaw Garoma Wayessa

Advisor: Professor Emer T. Quezon

Co-advisor: Mr. Tarekegn Kumela (MSc)

November, 2016

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this Thesis entitled "*Analysis of Stress- Strain and Deflection of Flexible Pavements Using Finite Element Method Case study on Bako- Nekemte Road*". This thesis is my original work, and has not been presented for a degree in this or any other University.

Name: Shiferaw Garoma Wayessa

Signature: _____________Date _______________

November, 2016

Jimma, Ethiopia

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ABSTRACT

In Ethiopia the number and type of traffic increases from day to day. This enforces the construction of road infrastructures that needs economical and safe design of roads. Most roads found in Ethiopia are flexible pavements. Nowadays, the failure of surface of flexible pavement roads are common before the expected design period. For the example Bako-Nekemte road/ has become a critical issue in our country.

The most common parameters that cause stress, strain and deflection of the roads are loads and pressures that come from vehicles. Moreover, modulus of elasticity, Poisson's ratio and thickness of each layer needs to be characterized. Further, the load magnitude, contact pressure (or load radius) and location are defined for each load (wheel) considered. Finite element method (FEM) is a numerical analysis technique to obtain the stress-strain and deflection of each pavement layers. Analytical method usually uses layers thickness, loads, elastic modulus and Poisson's ratio of the pavement materials as design parameters.

The objective of this research was to study the sensitivity of the road parameters in analyzing the major causes of failure in asphalt pavement layers fatigue cracking and rutting deformation which came due to the critical tensile strains at the bottom of the asphalt layer and the critical compressive strains on the top of subgrade using the finite element method by relating the standard specification of ERA and laboratory test result.

This thesis studied the analysis of stress-strain and deflection of flexible pavements using Everstress finite element method. The Ever stress program will take into account any stress dependent stiffness characteristics. This thesis dealt with ways to reduce deflections by varying the design configuration, such as increasing the HMA modulus, the base modulus, sub base modulus, the subgrade modulus and increasing thickness of each layers. Based on type of materials to use the value of elastic modulus and poison's ratio are various in each layers, in layer 1 is varied from 1500 to 3500 MPa, in layer 2 is varied from 200 to 1000MPa, in layer 3 is varied from 100 to 250 MPa and in layer 4 is varied from 20MPa to 150MPa.

As observed throughout study analysis of laboratory test result and standard specification result, the vertical deflection reduces as the modulus increases at all values of Elastic modulus. Therefore at the maximum elastic modulus horizontal strain in layer 1 is 0 microstrain and the average vertical strain in the layer 1 is 24.5 microstrain. The average vertical strain in the layer 2 is -11 microstrain while the average vertical strain in the layer 3 is -171.7 microstrain. Vertical strain at depth 0mm in layer 4 is -253.1 microstrain and at 150mm in layer 4 is -214.4 microstrain. The minimum elastic modulus horizontal strain in layer 1 is 7.2 microstrain and the average vertical strain in the layer 1 is 97.6 micro strain. The average vertical strain in the layer 2 is -28.3 microstrain while the average vertical strain in the layer 3 is -429.4 microstrain. Vertical strain at depth 0mm in layer 4 is -1237.7 microstrains and at 150mm in layer 4 is -1000.5 microstrain. In general as the elastic modulus of each layers and layers thickness increases stress-strain and deflection in each layers decreases.

Keywords*: Finite element analysis, flexible pavement, Layers thickness, modulus and Vertical surface deflections.*

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ACRONYMS

AADT	Average Annual Daily Traffic
AASHTO	American Association Society Highway and Transportation Office
ASTM	America Society soil Test Method
CBR	California Bearing Ratio
DAR Win	Design, Analysis, and Rehabilitation for windows
ELMOD	Evaluation of Layer Moduli and Overlay Design
ERA	Ethiopian Road Authority
ESAL	Equivalent Standard of Axle Load
ETH	Ethiopia
FE	Finite Element
FEA	Finite Element Analysis
FEM	Finite Element Method
FWD	Weight Deflect meter
HMA	Hot Mix Asphalt
USA	United States of America

UNITS CONVERTERS

The default system unit of engineering is English unit; however, the system of units can be changed in any of the main modules. System International (SI) or English units may be selected.

English	**System International SI**	**acronyms**
Length		
✓ 1 in	= 25.400 mm	inch = millimeters
✓ 1 ft.	= 0.3048 m =0.305m	feet = meters
✓ 1 mi	= 1.609344 km = 1.609km	miles = kilo meters
Weight		
➢ 1 lb.	= 4.448222 N =4.448N	pounds = newton
➢ 1 lb.	= 0.454kg, 1KN=102Kg	pound = kilogram
➢ 224.8 lb.	= 1KN	
➢ 1 kip	= 1000 lbs.	kilo pounds = pound
➢ 1 kip	= 4.448222 KN = 4.448 KN	kilo pound = kilo newton

Pressure (Modulus)

- 1 psi(pounds per square inch) = 6.894757 kPa = 6.895KPa(kilopascal)
- 1 ksi = 1000 psi = 6.894757 MPa=6.895KPa
- 145psi = 1MPa

CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Nowadays the number and type of traffic increases from day to day at global level. In developing countries like Ethiopia, the traffic changes from time to time. This enforces to develop the construction of road infrastructures, which needs economical and safe design of roads. The most common type of pavement used in Ethiopia is flexible pavement. A flexible pavement is one that has low flexural strength and transmit load to subgrade soil through lateral distribution of stress with increasing depth. Deformation of subgrade soil is the factor that affects the strength and smoothness of flexible pavement.

There is still widespread use of essentially empirical design methods, ranging from systematic order of structural designs for various combinations of traffic loads and road layers strength, to regression based design charts, which incorporate such factors as material characteristics, properties, and bearing capacity. Complementing these structural designs is a large variety of distress prediction models (e.g. fatigue damage and rutting damage). (Ralph H.; Susan T.;Guy D.& David H, 2007).

The major causes of failure in asphalt pavement are fatigue cracking caused by excessive horizontal tensile strain at the bottom of asphalt layer due to repeated traffic loading and rutting deformation, caused by densification and shear deformation of subgrade. In the design of asphalt pavements, it is necessary to determine the minimum pavement thickness required to withstand the expected traffic such that fatigue and rutting strains are within the allowable minimum (Taneerananon, 2014).

The aim of this paper was to study the sensitivity of the road parameters (dimension, layers thickness, elastic modulus, Poisson's ratio, loads and pressures). To control the vertical surface deflections which caused the critical tensile strains at the bottom of the asphalt layer and the critical compressive strains on the top of subgrade using the finite element method by relating the standard specification of road condition from the existing documented data. These variables can use to improve pavement performance.

In the analysis of flexible pavement, axle loads on the surface of the pavement produce two different types of strains, which are believed to be most critical for design purposes. These are the horizontal tensile strains at the bottom of the asphalt layer, and the vertical compressive strain at the top of the subgrade layer. If the horizontal tensile strain is excessive, cracking of the surface layer will occur and the pavement will fail due to fatigue. If the vertical compressive strain is excessive, permanent deformations are observed at the surface of the pavement structure (from overloading the subgrade) and pavement fails due to rutting (Gupta, 2014).

1.2. Statement of the Problem

Road surface failure is a critical issue on the flexible pavement where it involves a very high maintenance cost every year. One of the reasons causing these failures are fatigue cracking and rutting deformation due to improper or error of pavement elastic modulus and layers thickness design. The most common causes of fatigue cracking and rutting deflection are due to stress or strain. Most of the flexible pavement roads in our country are begun to failure before expected period. The road from Bako-Nekemte is constructed before four years ago that is until now not handover but it is started to deteriorate.

In our country, it is not common to use software based design of flexible pavements rather than the design agencies practice the method by referring the hardcopy of design guideline manual (AASHTO and ERA) and calculation. Mistakes are mostly occurred or error cannot be fully avoided in the design that influences the quality of the design and development of the science. Manual design method has a problem in doing many alternatives for comparison as flexible pavement design involves different nomograph, charts, tables and formulas. Therefore, it was complex and time taking practice which may result in unsafe or uneconomical design.

The use of FEM model through Everstress allows the model to accommodate the load dependent stiffness of the road layers, granular and subgrade materials which most of the models still use linear elastic theory as constitutive relationship. The load come from vehicles must be distributed properly otherwise it-enforced deflection of the road.

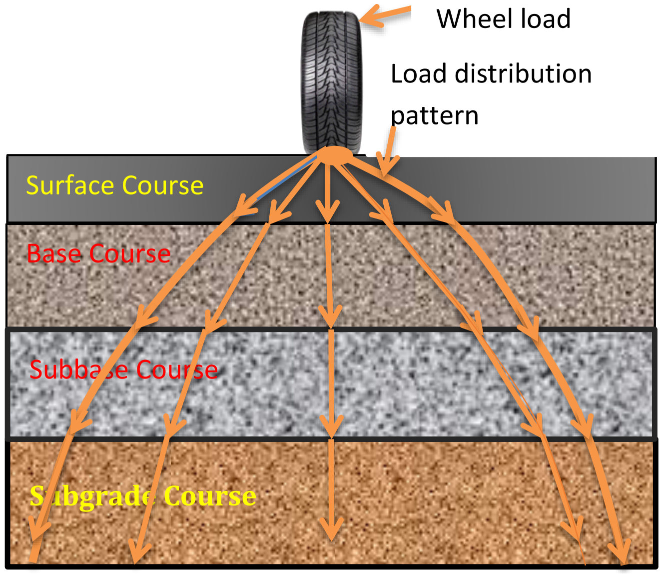

Figure 1.1 Load distributions along various layers

1.3. Research Questions

1. What are the parameters that cause stress-strain and deflection of flexible pavement?
2. How stress-strain and deflection of flexible pavement materials are analyzed using Ever Stress Finite Element software by using laboratory test result and ERA standard specification?
3. How the layers of flexible pavement are affected by vertical surface deflections and the critical horizontal tensile strains?

1.4. Objective of the Study

1.4.1. General Objective of Study

The general objective of this study is analysis of stress-strain and deflection of flexible pavements using finite element method software case study on Bako-Nekemte road.

1.4.2. Specific Objectives of the Study

- To identify the parameters that causes stress, strain and deflection of flexible pavement.

- To analyze the stress, strain and deflection of flexible pavement using finite element method software by using the laboratory test result and ERA standard specification
- To describe how the layers of flexible pavement are affected by vertical surface deflections and the critical horizontal tensile strains.

1.5. Scope of the study

The study focuses on the analysis of stress, strain and deflection of flexible pavements using software. This study took as the model Bako-Nekemte road that is represented others road throughout the country. The study attempts to address the method how to analysis stress, strain and deflection of flexible pavement, which is caused fatigue cracking or rutting deformation of the road.

The study focuses on analyzing the stress, strain and deflection of flexible pavement thickness, elastic modulus and poisons ratio design by using FEM, AASHTO and Ethiopian Roads Authority (ERA) manuals.

1.6. Significances of the study

The study adds knowledge on understanding the analysis of stress-strain and deflection of flexible pavement using finite element method in the case of Bako-Nekemte road. Therefore, the study may be significant for the following: The results would contribute to analyze the complex problems of stress-strain and deflection of flexible pavement using finite element software. The finding will also help to control fatigue cracking and rutting deflection by using configuration of design parameters.

The study would have significance to the government and privates companies to easily determine the fatigue cracking and rutting deformation. Finally, it is important to provide data on crack, characteristics, and cause and effect of flexible pavement damage; it used to develop countermeasures that could reduce the frequency and severity of excessive crack on asphalt pavement damage.

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

Road pavements are designed to limit the horizontal strain/ stress created at bottom of asphalt and vertical strain created at top of the subgrade level by the traffic travelling on the pavement surface so that the subgrade is not subject to significant deformations. The pavement spreads the concentrated loads of the vehicle wheels over a sufficiently large area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to any serious extent within a specified period (Gupta, 2014).

Asphalt pavement failures are occurred mostly in developing tropical countries like Ethiopia have been traced to any or combination of geological, design, construction, and maintenance problems. Therefore, the purpose of this paper is to use the empirical procedure (layered elastic analysis) to investigate failure due to fatigue cracking and rutting deformation in flexible pavements designed by finite element software procedures (Emmanuel O., 2009).

2.2. Flexible Pavement layers properties

Flexible road pavements are intended to limit the stress created at the subgrade level by the traffic traveling on the pavement surface, so that the subgrade is not subject to significant deformations. In effect, the concentrated loads of the vehicle wheels are spread over a sufficiently larger area at subgrade level. At the same time, the pavement materials themselves should not deteriorate to such an extent as to affect the riding quality and functionality of the pavement.

These goals must be achieved throughout a specific design period. The deterioration of paved roads caused by traffic results from both the magnitude of the individual wheel loads and the number of times these loads are applied. It is necessary to consider not only the total number of vehicles that will use the road but also the wheel loads (or, for convenience, the axle loads) of these vehicles. Equivalency factors are used to convert traffic volumes into cumulative standard axle loads. Traffic classes are defined for paved roads, for pavement design purposes, by ranges of cumulative number of equivalent standard axles (ESAs) (ERA, 2001).

In order to limit the stress created at the subgrade level by the traffic traveling on the pavement surface, material layers are usually arranged in order of descending load bearing capacity with the highest load bearing capacity material (and most expensive) on the top and the lowest load bearing capacity material (and least expensive) at the bottom.

2.3. Material Characterization of Road Layers

Most of road layer is three or four layers depend on engineering properties of soil. Assuming three layers of pavement asphalt surface, granular base, and subgrade. In case of Bako-Nekemte four layers pavement asphalt surface, crush rock base course, granular subbase, and capping/subgrade layer.

All pavement materials were assumed to respond linearly and elastically to the applied load as static load were applied in the linear distribution step. Elastic properties (modulus of elasticity and Poisson's ratio) were obtained from existing laboratory result and from previous investigation (equations and standard). Some random material properties were also given to understand the pavement response under different condition (Zaghloul S and White, T., 1993).

2.4. Flexible Pavement Layers and Materials properties.

Surface Course: Obviously, surface course is the layer in contact with traffic loads and normally contains the highest quality of materials. Surface course play an important role in characteristics of friction, smoothness, noise control, rut and shoving resistance and drainage. Furthermore, surface course serves to prevent the entrance of excessive quantities of surface water into the underlying base, sub base, and subgrade. The top structural layer of material is sometimes subdivided into two layers (Lanham, 1996).

1. Wearing Course: This is the top layer in pavement structure and direct contact with traffic loads. A properly designed preservation program should be able to identify pavement surface distress while it is still confined to the wearing course.

2. Binder Course: The purpose of this layer is to distribute load from wearing course. This layer provides the bulk of the HMA structure.

Base Course: The base course is a course of specified material and design thickness, which supports the structural course and distributes the traffic loads to the sub base or subgrade. It provides additional load distribution and contributes to drainage and frost resistance. A wide range of materials can be used as unbound road bases including crushed quarried rock, crushed and screened, mechanically stabilized, modified or naturally occurring `as dug' gravels. Their suitability for use depends primarily on the design traffic level of the pavement and climate.

Sub base Course: The sub base course is constructed between the base course and the subgrade. The sub base generally consists of lower quality materials than the base course but better than the subgrade soils. The sub base consists of granular material - gravel, crushed stone, reclaimed material or a combination of these materials.

It enables traffic stresses to be reduced to acceptable levels in the subgrade, it acts as a working platform for the construction of the upper pavement layers, and it acts as a separation layer between subgrade and base course. Under special circumstances, it may also act as a filter or as a drainage layer. For a pavement constructed over a high quality, stiff subgrade may not need the additional features offered by a sub base course.

Subgrade layer: Subgrade support is characterized by the subgrade resilient modulus (E).The Resilient Modulus (E) is a measurement of the stiffness of the roadbed soil AASHTO. A material's resilient modulus is actually an estimate of its modulus of elasticity (E). While the modulus of elasticity is stress divided by strain for a slowly applied load, resilient modulus is stress divided by strain for rapidly applied loads, like those experienced by pavements.

It is recognized that many agencies do not have equipment for performing the resilient modulus test. Therefore, suitable factors are reported which can be used to estimate E from standard CBR and soil index test results or values. A widely used empirical relationship developed by Heukelom and Klomp (1962) and used in the 1993 AASHTO Guide is equation 2.1

E/Mr. (psi/MPa) = 1500*CBR/10.342CBR [AASHTO 93] -----------------------------------2.1

2.5. Properties of Unbound Materials in layers

The following table gives guidance on the selection of unbound materials for use as base course, sub base, capping and selected subgrade layers.

Table 2.1 Properties of Unbound Materials

Code	Description	Summary of Specification
GB1	Fresh, crushed rock	Dense graded, un weathered crushed stone, non-plastic parent fines
GB2	Crushed weathered rock, gravel or boulders	Dense grading, < 6, soil or parent fines
GB3	Natural coarsely graded granular material, including processed and modified gravels	Dense grading, PI < 6 CBR after soaking > 80
GS	Natural gravel	CBR after soaking > 30
GC	Gravel or gravel-soil	Dense graded; CBR after soaking > 15

Source: AASHTO

Notes: .These specifications are sometimes modified according to site conditions; material type and principal use. GB = Granular base course, GS = Granular sub-base, GC = Granular capping layer

2.6. Accumulated 80KN Equivalent Single Axle Loads ESAL.

The predicted loading is simply the predicted number of 80 KN ESALs for the pavement experience over its design lifetime. The Accumulated 80KN Equivalent Single Axle Loads (ESAL) is the traffic load information used for pavement thickness design. The accumulation of the damage caused by mixed truck traffic during a design period is referred to the Accumulated 80KN Equivalent Single Axle Loads ESAL.

2.6.1. Load data from equivalent standard axles per vehicle class.

The number of equivalent standard axles (ESA) of an axle is related to the axle load as follows:

$ESA = (L/8160)^n$ (for loads in kg) --2.2

or $ESA = (L/80)^n$ (for loads in KN) --2.3

Where: *ESA* = number of equivalent standard axles (ESAs)

L = axle load (in kg or KN)

n = damage exponent (n = 4.5),

1wheel load = 2axle load, 1KN=102Kg

Table 2.2 Equivalency Factors for Different Axle Loads (Flexible Pavements)

Wheel load (10^3	Axle load (10^3 kg)	Axle load (10^3 KN)	Equivalence factor(ESA)
1.5	3	0.03	0.01
2.0	4	0.04	0.04
2.5	5	0.05	0.11
3.0	6	0.06	0.25
3.5	7	0.07	0.50
4.0	8	0.08	0.91
4.5	9	0.09	1.55
5.0	10	0.10	2.50
5.5	11	0.11	3.93
6.0	12	0.12	5.67
6.5	13	0.13	8.13
7.0	14	0.14	11.3
7.5	15	0.15	15.5
8.0	16	0.16	20.7
8.5	17	0.17	27.2
9.0	18	0.18	35.2
9.5	19	0.19	44.9
10.0	20	0.20	56.5

Source: ERA 2001

2.7. Overview of Ethiopian Roads Authority (ERA) pavement design Manual

This manual gives recommendations for the structural design of flexible pavement and gravel roads in Ethiopia. The manual is intended for engineers responsible for the design of new road pavements and is appropriate for roads that are required to carry up to 30 million cumulative equivalent standard axles in one direction. This upper limit is suitable at present for the most trafficked roads in Ethiopia.

ERA manual which also known as overseas road notes was developed by Transport Research Laboratory (TRL) to design flexible pavement thickness besides understanding the behaviors of road building material, also interaction in pavement structural layers design. In advance, overseas road notes is confident to be applying in tropical and sub-tropical regions associated with climate and various types of material and reliable road maintenance To give satisfactory service, a flexible pavement must satisfy a number of structural criteria or considerations; some of the important considerations are:

1. The subgrade should be able to sustain traffic loading without excessive deformation; this is controlled by the vertical compressive stress or strain at this level.
2. Bituminous materials and cement-bound materials used in road base design should not crack under the influence of traffic; this is controlled by the horizontal tensile stress or strain at the bottom of the road base.
3. The road base is often considered the main structural layer of the pavement, required to distribute the applied traffic loading so that the underlying materials are not overstressed. It must be able to sustain the stress or strain generated within itself without excessive or rapid deterioration of any kind.
4. In pavements containing a considerable thickness of bituminous materials, the internal deformation of these materials must be limited; their deformation is a function of their creep characteristics,
5. The load spreading ability of granular sub base and capping layers must be adequate to provide a satisfactory construction platform.

2.8. Effect of Vertical Surface Load of Wheel

Applied wheel load can be used to verify vertical contact stress, while there is no equilibrium control on the two measured horizontal and vertical contact stresses. The accuracy of measured vertical contact stresses is far better since they are established by direct equilibrium. Many researchers have not used horizontal contact stresses to be able to compare the result with traditional model.

Measuring horizontal contact stresses on real flexible pavements is very difficult unless on rigid surfaces instead. Horizontal contact stresses are very small relative to vertical contact stresses. Experimental measurements have documented that when a tire load is applied on a pavement surface, three contact stress components (vertical, transverse, and longitudinal) are generated under each tire rib. These contact stresses do not change uniformly throughout the tire imprint area as the load or tire inflation pressure change (De Beer M, Fisher C and Jooste F, 1997).

2.9. Effect of Tire Contact Stresses

Tires serve many important purposes for a traveling vehicle including providing support the vehicle against road roughness, controlling stability, generating maneuvering forces, and providing safety, among others. Tire-pavement interaction is important for pavement design because the tire imprint area is the only contact area between the vehicle and the pavement at which the actual distribution of contact stresses is transferred to the pavement surface. There are two important factors in the tire-pavement interaction mechanism: the contact area and the contact stresses. Many researchers have used a circular or equivalent rectangular contact area in pavement loading analysis (Huang Y.H., 1993).

The tensile strains in the asphalt layer under actual contact stresses were quite different from those under uniform contact stresses, depending on the combination of load and tire inflation pressure and the conventional uniform load assumption underestimated pavement responses at low tire inflation pressures and overestimated pavement responses at high tire pressures (Machemehl R, Wang F & Prozzi J, 2005).

2.10. Effect of Basic Layers Materials Properties

Mechanistic design procedure are based on the assumption that a pavement can be modeled as multi-layered elastic or viscos-elastic structure on an elastic or viscos-elastic foundation. The properties of each layers thickness, elastic modulus and poisons ratio was most important because it identified the layer strength weather it could carry the load come from vehicle.

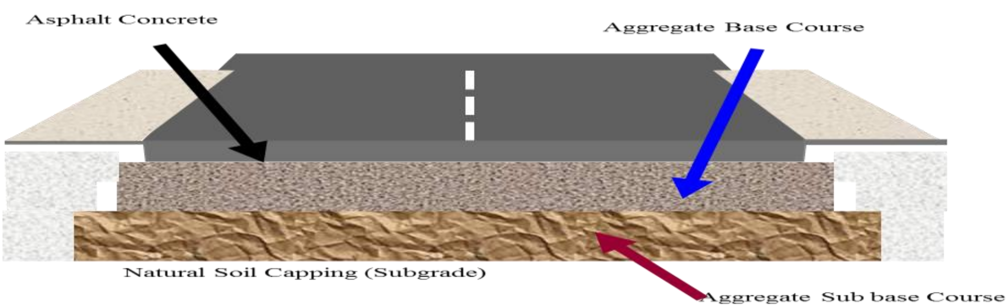

Figure 2.1 Basic layers of various materials

1) Layered System Concepts

The basic advantages of a mechanistic-empirical pavement design method over a purely empirical one are. It can be used for both existing pavement rehabilitation and new pavement construction it accommodates changing load types. It can better characterize materials allowing for: Better utilization of available materials, Accommodation of new materials, and an improved definition of existing layer properties. It is generally accepted that pavements are best modeled as a layered system, consisting of layers of various materials (concrete, asphalt, granular base, sub-base etc.) resting on the natural subgrade. The behavior of such a system can be analyzed using the classical theory of elasticity (Burmister, 1945).

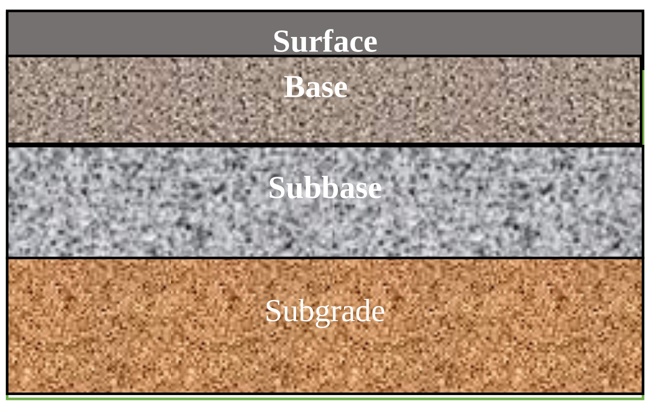

Figure 2.2 Cross-section Basic layers of various materials

Subgrade rutting is a longitudinal wheel-path depression that occurs when the subgrade exhibits permanent deformation or lateral migration due to loading. In this case, the pavement settles into the subgrade ruts, causing surface depressions in the wheel path. Usually, the vertical compressive strain on top of the subgrade is related to subgrade rutting for the case that the shear capacity of subgrade soil is not exceeded by the applied load (Institute Asphalt, 1982).

2.11. Elastic modulus of each component of the road

Although the correlation between elastic modulus (E) and 'strength' is very poor (usually much too poor for use in design calculations) the simple relationship, between E and the

California Bearing Ratio (CBR, a simple measure of strength not modulus) is almost universally used to estimate the elastic modulus of road layers component materials.

E = a*CBR---2.4

CBR = California Bearing Ratio

a = Constant, it varies due to layers of pavement properties.

This leads to significant inaccuracies. Fatigue in bituminous materials has been much researched in the laboratory. The major problem that arises is that laboratory conditions are quite different to field conditions.

In view of all the problems associated with the mechanistic method it is perhaps surprising that the method is used so frequently with apparent success. There are several reasons for this. First the ‘errors’ in the mechanistic method itself are systematic rather than random. This means that the relative differences in the results for different pavements are much more meaningful than the absolute values. If the method is calibrated by comparison with measured performance, then sensible conclusions may be drawn. This assumption requires that the calibration is ‘correct’ and this means that the performance of the pavements used for calibration must be thoroughly understood (e.g., the origin of cracks must be known with certainty).

Secondly, most pavements will not differ much from those that should have been used to calibrate the mechanistic model. For example, roads with granular unbound bases and structural HMA surfacing’s will normally consist of an unbound sub-base and road base of materials meeting standard specifications and of thickness ranging from about 250 mm up to 500 mm. The thickness of the HMA surfacing will be between, say, 50 mm and 100mm.

2.11.1. Stress

If a given load is applied to a material a contact stress will occur. This stress is equal to the load divided by the loading object’s contact area. Stress essentially provides a method of normalizing load and area for testing and design purposes. When a wheel load is applied to a pavement, locations under the load experience different levels of stress based on their depth from the surface and distance from the applied loading. Vertical stress at a point in the pavement system due to the applied load. The intensity of internally distributed forces experienced within the pavement structure at various points. Stress has units of force per unit area (pa) that mean Force per unit area (Shane Buchanan, 2007).

$$\sigma = \frac{Load}{Area} = \frac{P}{A}$$

Units: MPa, psi, ksi

Types: bearing, shearing, axial

2.11.2. Strain

Strain is often described as the ratio of an object's deformation to its original dimension in the same direction. Strain can be calculated for any desired direction (e.g., vertical, horizontal, longitudinal, etc.).The unit displacement due to stress, usually expressed as a ratio of change in dimension to the original dimension (mm/mm) or Strain Ratio of deformation caused by load to the original length of material(Shane Buchanan, 2007).

$$\varepsilon = \frac{Changess\ in\ Length}{Original\ Length} = \frac{\Delta L}{L}$$

Units: Dimensionless

2.11.3. Stiffness/elastic materials

One important item to remember is that resilient modulus is a stiffness measurement, not the strength, of a material. Ultimate shear strength for granular material is typically determined using a triaxial shear procedure. Resilient modulus can be determined at many combinations of applied loading and confinement. Ultimate strength or stress is the point where failure occurs under loading. A good example of the difference between stiffness and strength can be seen with concrete. Up to a given "failure" stress, a concrete can withstand stress with very slight deformation. However, at some stress, the concrete "fails" or "breaks" and the ultimate strength is determined. Resilient modulus is used to characterize pavement materials under loading conditions that will not result in "failure" of the pavement system. Pavements are designed to withstand various magnitudes of design axle (single, tandem, tridem, and quadem) load applications. By varying layer thicknesses and stiffness, the pavement system can be designed to carry the design axle load applications during its service life (Shane Buchanan, 2007).

$$Stiffness = \frac{stress}{strain} = \frac{\sigma}{\varepsilon}$$

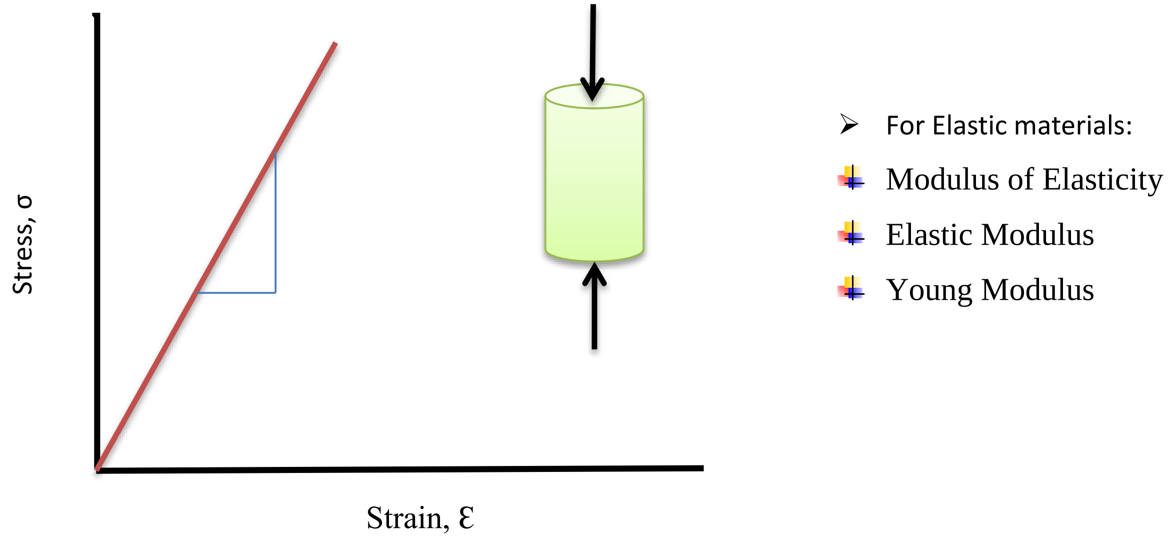

Figure 2.3 Diagram of stress and strain shown elastic materials.

Stress vs. Strain of a Material in Compression:

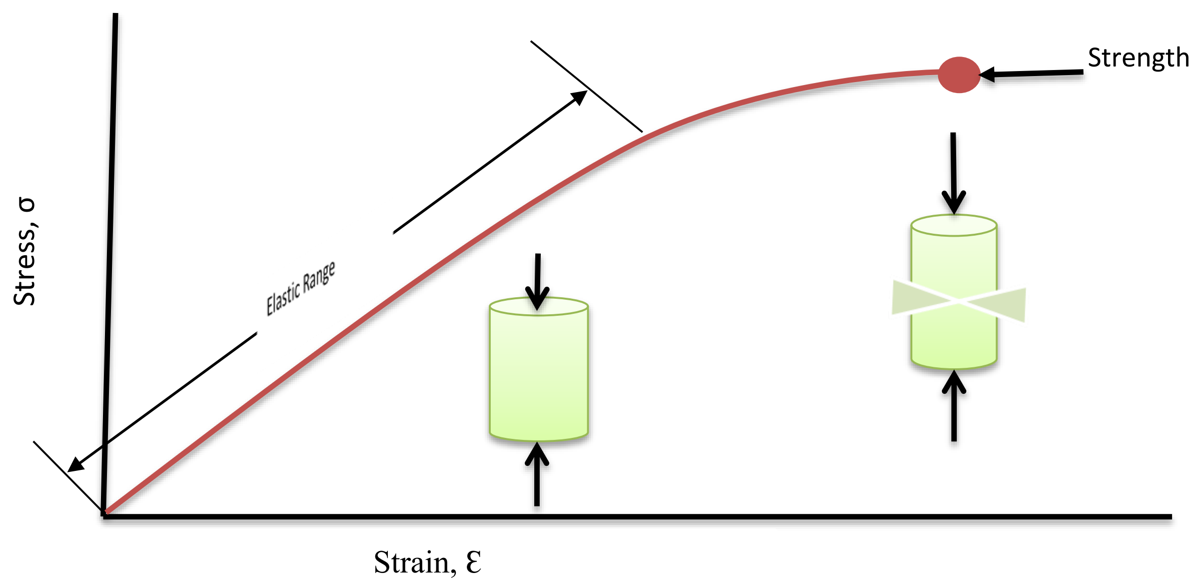

Figure 2.4 Diagram of stress verses strain in compression

2.11.4. Deflection (Δ)

The linear change in dimension. Deflection is expressed in units of length (mm) From fundamental engineering mechanics, the equation for calculating the mid span deflection:

$\Delta = \frac{PL^3}{48EI}$, where, Δ = Measured mid span deflection, mm (in), *P*=Applied load, N (lbf), *L*= Length of the beam, mm (in), *I*= Moment of inertia for a rectangular beam ($I = bh^3/12$), mm^4 (in^4),*E* =Elastic modulus of the layer, MPa (lbf/in^2).

By substituting the known values of Δ, P, L, b, and h, the elastic modulus of the layers (E) can be back calculated. While similar in concept, the process is more complicated for pavements because pavement deflection is affected by subgrade resilient modulus as well as the moduli of the pavement layers (all unknown values).

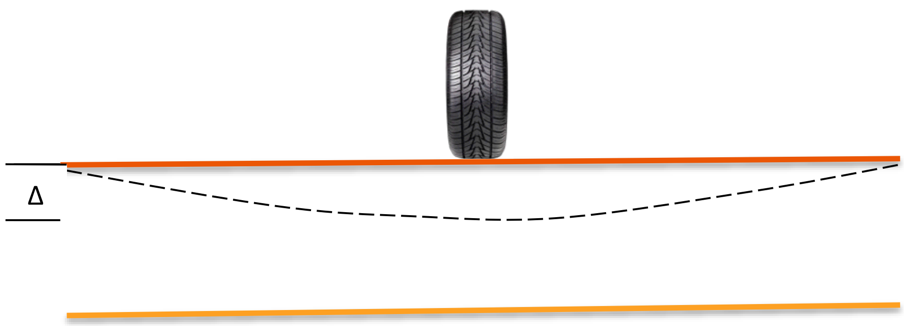

Figure 2.5 Diagram of layer deflection properties.

Since the mid-1960s, pavement researchers have been refining mechanistically based design methods. While the mechanics of layered systems are well developed, there remains much work to be done in the areas of material characterization and failure criteria. The horizontal strain is used to predict and control fatigue cracking in the surface layer. With respect to asphalt concrete pavements, the current failure criteria used are the horizontal tensile strain at the bottom of the asphalt concrete layer and the vertical strain at the top of the subgrade layer. While test methods and failure criteria for predicting fatigue cracking are maturing. There has been very little effort placed on the refinement of the subgrade failure criteria.

2.11.5. Base/subbase Elastic Modulus Determination

The determination of elastic modulus of base material used in the study was crushed rock materials of elastic modulus of 300MPa or 74%CBR by using the following equation. The elastic modulus was determined by correlation with CBR (Ola S.A, 1980) as presented in equation 2.5

$E\ (psi) = 250(CBR)^{1.2}$--2.5

2.11.6. Subgrade Elastic Modulus Determination

The subgrade elastic modulus was determined in accordance to the AASHTO Guide (AASHTO, 1993) in order to reflect actual field conditions using correlation with CBR as shown equation 2.6. (Asphalt Institute of Soil Manual for the Design of Asphalt Structure is used to convert the CBR and R values to the elastic modulus values, classified under the unified classification system or when the resilient modulus is less than 206.80Mpa.

E. (psi/lbin^2) (MPa) = 1500 CBR (10.342CBR) ---2.6

Where, E. = Elastic modulus MPa (psi)

CBR = California Bearing Ratio

Table 2.3 Typical moduli values for common paving materials.

Material	General range (MPa)	Typical value (MPa)
Hot-Mix Asphalt	1,500 - 4000	3,000
Portland Cement Concrete	20,000 - 55,000	30,000
Asphalt-Treated Base	700 - 6,000	1,500
Cement-Treated Base	3,500 - 7,000	5,000
Lean Concrete	7,000 - 20,000	10,000
Granular Base	100 – 350	200
Granular Subgrade Soil	50 – 150	100
Fine-Grained Subgrade Soil	20 – 50	30

Source: AASHTO 1993

2) Highly temperature dependent: The modulus values are based on pavement temperatures in the range 20 ºC to 30 ºC (68 ºF to 86 ºF).

The following table shows material properties, elastic modulus values and Poisson’s ratio values and their comment.

Table 2.4 ***Material characteristics for mechanistic analysis.***

Material	Parameter	Value	Comment
Asphaltic concrete wearing course and binder course	Elastic modulus (MPa)	3000	A balance between a value appropriate for high ambient temperatures and the effect of ageing and embrittlement
	Volume of bitumen	10.5%	In Bako-Nekemte road case 4.9%
Asphaltic concrete road base	Elastic modulus	3000	
	Volume of bitumen	9.5%	In Bako-Nekemte road case 4.9%
Granular road base	Elastic modulus (MPa) Poisson's ratio	300 0.30	For all qualities with CBR > 80%
Granular sub-base	Elastic modulus (MPa) Poisson's ratio	175 0.30	For CBR ≥30%
Capping layer	Elastic modulus (MPa) Poisson's ratio	100 0.30	For CBR ≥15%
Subgrades S1 S2 S3 S4 S5 S6	Elastic modulus in MPa	 28 37 53 73 112 175	Poisson's ratio for all subgrades was assumed to be 0.4

Hydraulically stabilized material	Elastic modulus (MPa)	CB1 = 3500 CB2 = 2500 CS	Poisson ratio assumed to be 0.25 The modulus of CS is assumed to decrease with time hence a conservative low value of 1000MPa has been used

CB1=stabilized road base CS= stabilized sub base

Source: ERA 2013

2.1. Characteristics of each Design Chart of ERA 2013

The catalogue includes designs for very weak subgrades (S1) but such subgrades are very difficult to deal with and it is likely that a special investigation is needed to determine the best solution. In all of the charts, the basic granular sub-base of GS quality material and the hydraulically stabilized sub-base material CS are interchangeable.

Table 3.7 shows the computed subgrade strains in comparison with the criteria. It is noted that, for the weaker subgrades, the criteria are more easily met. For each traffic level, it is recognized that a single subgrade criterion for all subgrades cannot be correct and that weaker subgrades require criteria that are more conservative. The thicknesses of the pavement layers in this Chart provide a degree of safety for the weaker subgrade classes.

Table 2.5 ***Strain criterion in the subgrade class and traffic Categories.***

Subgrade class	T3	T4	T5	T6
	1.5 MESA	1.5 – 3.0 MESA	3 – 6 MESA	6 – 10 MESA
Strain criterion	805	720	645	595
S1	610	540	480	425
S2	715	625	545	480
S3	770	665	575	530
S4	765	705	650	555
S5	745	680	630	575
S6	700	665	665	625

Source: ERA 2013 (Chart A)

2.12. Poison’s ratio of basic component of road data according to AASHTO 193

Poisson's ratio is a measure of the **Poisson effect**, the phenomenon in which a material tends to expand in directions perpendicular to the direction of compression. Conversely, if the material is stretched rather than compressed, it usually tends to contract in the directions transverse to the direction of stretching. The Poisson's ratio of a stable, isotropic, linear elastic material will be greater than −1.0 or less than 0.5 because of the requirement for Young's modulus, the shear modulus and bulk modulus to have positive values. For Poisson’s ratio, the common practice is to use typical value based on the type of material. The typical values for various materials are given in table 3.4.

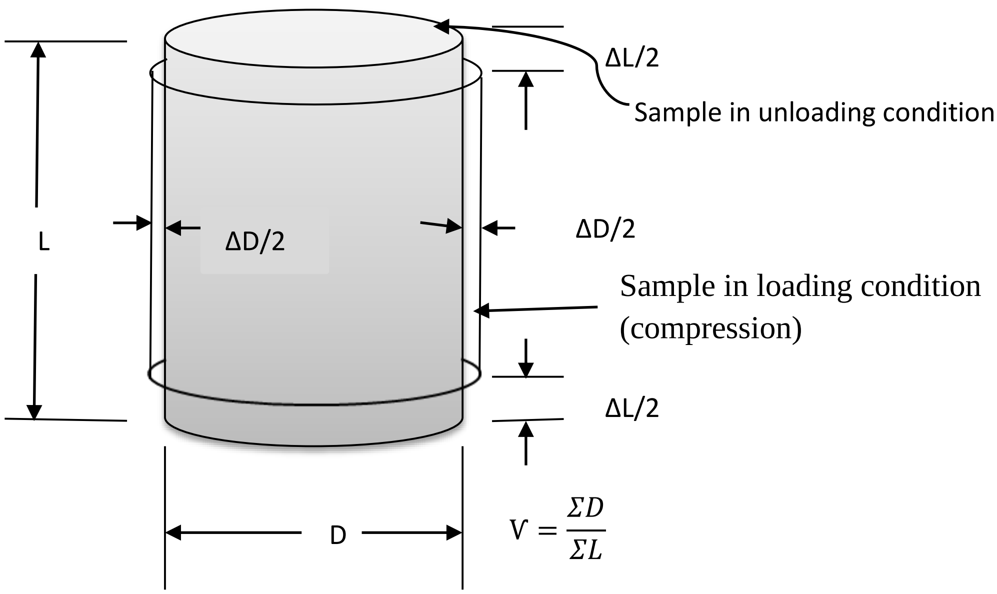

Figure 2.6 Poisons ratio structures and the way to calculate

Table 2.6 Typical Poisson ratio values.

Material	General range	Remarks	Typical value
HMA/Asphalt Treated Base	0.15 - 0.45	Highly dependent on temperature; use low value (0.15) for cold temperatures (less than 30 ºC [86 ºF]) and high value (0.45) for warm pavement 50 ºC (122 ºF)	0.35
Portland cement Concrete	0.10 - 0.20	No remarks	0.15

Cement stabilized Base	0.15 - 0.30	Degree of cracking in stabilized layer tends to increase value towards 0.30 From sound (crack free) value of 0.15.	0.20
Granular base /sub base	0.30 - 0.40	Use lower value for crushed material and high value for unprocessed rounded gravels/sands.	0.35
Subgrade soils	0.30 - 0.50	The values depend on type of subgrade soil. For cohesion less soils, use value near 0.30. A value of 0.50 is approached for very plastic clays (cohesive soils).	0.40

Source: AASHTO 1993

2.13. Wheel pressures of vehicles

The study by (Markshek, Chen, & Hudso, 1986)questions a commonly made assumption that contact pressure approximately equals tire inflation pressure. The study showed that increased tire pressure produced proportionally smaller gross contact areas. This suggests that the commonly made assumption of equal pressure becomes increasingly less valid. This suggests that some contact areas will have pressures greater than calculated for a uniform pressure. Extraordinary high tire pressures mean that asphalt concrete layers, which are nearest to the surface in a pavement structure, may not be immune to rutting.

2.14. Fatigue Criteria

Fatigue cracking is caused by repeated relatively heavy load applications, usually lower than the strength of the paving material. Bottom-up fatigue cracking usually starts at the bottom of the asphalt layers of relatively thin flexible pavements (less than 150mm) or at the bottom of the individual asphalt layer if poor bonding conditions exist.

The use of the layered elastic analysis concept is necessary. It is based on the elastic theory and can be used to investigate excessive horizontal tensile strain at the bottom of the asphalt layer (fatigue cracking) and excessive vertical compressive strain on top of the subgrade (Rutting deformation) in asphalt pavement in order to design against fatigue and rutting (Yang, 1973).The number of repetitions as suggested by Asphalt Institute in the following form represents the relationship between fatigue failure of asphalt concrete and tensile strain at the bottom of asphalt concrete layer $N_f=0.0796\left(\frac{1}{\varepsilon t}\right)^{3.291}\left(\frac{1}{E}\right)^{0.854}$ Where N_f =number of load repetitions to prevent fatigue cracking. ε_t=tensile strain at the bottom of asphalt layer. E_1 = elastic modulus of asphalt layer

2.15. Rutting Criteria

Rutting is the permanent deformation occurring in the pavement structure, including rutting in asphalt layers (primary rutting), rutting in unbound base layers, and subgrade (secondary) rutting. Primary rutting in asphalt layers includes two types of deformation: volume reduction caused by traffic densification, and permanent movement at a constant volume or variation caused by shear flow.

The accumulation of permanent deformation in the asphalt layer is very sensitive to the layer's resistance to shape distortion (i.e., shear) and relatively insensitive to volume change. Their study indicates that the rutting in asphalt layers is caused principally by shear flow rather than volumetric densification; especially under loading of slow moving vehicles at high temperature. The rutting in asphalt layers to shear stresses and shear strains in the asphalt layer instead of compressive strain.

The number of load applications as suggested by Asphalt Institute in the following form represents the relationship between rutting failure and compressive strain at the top of subgrade:$Nr= 1.365\times10^{-9}\left(\frac{1}{\varepsilon c}\right)^{4.477}$,Where Nr = number of load repetitions to limit rutting. ε_c = vertical compressive strain at the top of subgrade.

2.15.1. Rutting in Flexible Pavements

Rutting is a longitudinal surface depression in the wheel path accompanied, in most cases, by pavement or the underlying layer upheaval along the sides of the rut. Significant rutting can lead to major structural failure and hydroplaning, which is a safety hazard. Rutting can occur in all layers of the pavement structure and results from lateral distortion and densification. Moreover, rutting represents a continuous accumulation of incrementally small permanent deformations from each load application. Eisemann and Hilmar studied asphalt pavement deformation phenomenon using wheel tracking device and measuring the average rut depth as well as the volume of displaced materials below the tires and in the upheaval zones adjacent to them. They concluded that: 1. in the initial stages of traffic, the increase of irreversible deformation below the tires is distinctly greater than the increase in the upheaval zones. Therefore, in the initial phase, traffic compaction or densification is the primary mechanism of rut development.

2. After the initial stage, the volume decrease below the tires is approximately equal to the volume increase in the adjacent upheaval zones. This indicates that most of the compaction under traffic is completed and further rutting is caused essentially by shear deformation, i.e., distortion without volume change. Thus, shear deformation is considered the primary mechanism of rutting for the greater part of the lifetime of the pavement.

2.15.2. Causes of Rutting in Flexible Pavements

Generally, the causes of rutting in asphalt pavements are accumulation of permanent deformation in the asphalt-surfacing layer and permanent deformation of subgrade. In the past subgrade, deformation was considered the primary cause of rutting and many pavement design methods applied limiting criteria on vertical strain at the subgrade level. However, recent research indicates that most of the rutting occurs in the upper part of the asphalt-surfacing layer. These causes of rutting can act in combination, i.e., the rutting could be the sum of permanent deformation in all layers (Garba, 2002).

2.15.3. Rutting Caused by Weak Asphalt Mixture

Rutting resulting from accumulation of permanent deformation in the asphalt layer is now considered the principal component of flexible pavement rutting. This is because of the increase in truck tire pressures and axle loads, which puts asphalt mixtures nearest the pavement surface under increasingly high stresses. Brown and Cross-reported on an extensive national study of rutting in hot mix asphalt pavements in United States.

The study was initiated in 1987 to evaluate pavements from all areas of the United States encompassing various climatic regions, containing aggregates of differing origins and angularity, encompassing different specifying agencies and construction practices and a large sample size to make the study results national in scope. The study involved collection of pavement core samples for material characterization, measurement of rut depth and layer thicknesses, and investigation to determine the location of rutting.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1. Description of Study setting/Area

The Federal Democratic Republic of Ethiopia in accordance with road sector development strategy has intended to upgrade the Gedo-Nekemte road as part of its Road Sector Development Program II that include Bako-Nekemte road before four (4) years ago. The Gedo-Nekemte road project has been using as country's truck road network connects the capital city Addis Ababa with Nekemte town. Nowadays the road started to deteriorate at several places before expected design period.

The study is carried out on the Bako-Nekemte road found in the eastern Wollega districts of the Oromia Regional State. The area exhibit moderate to cold climate conditions and connects the town such as Bako, Ano, Sire, Cheri, Jalele, Chingi, Gaba Jimata, Gute and Nekemte. The total length of the road is about 84 km asphalt pavement. Bako-Nekemte road is used as the center of the road network for Western part of Ethiopia. The design standard of the road is DS_3 asphalt concrete paved and its functional classification is truck road with AADT 1000-5000 with the design period of 20 years.

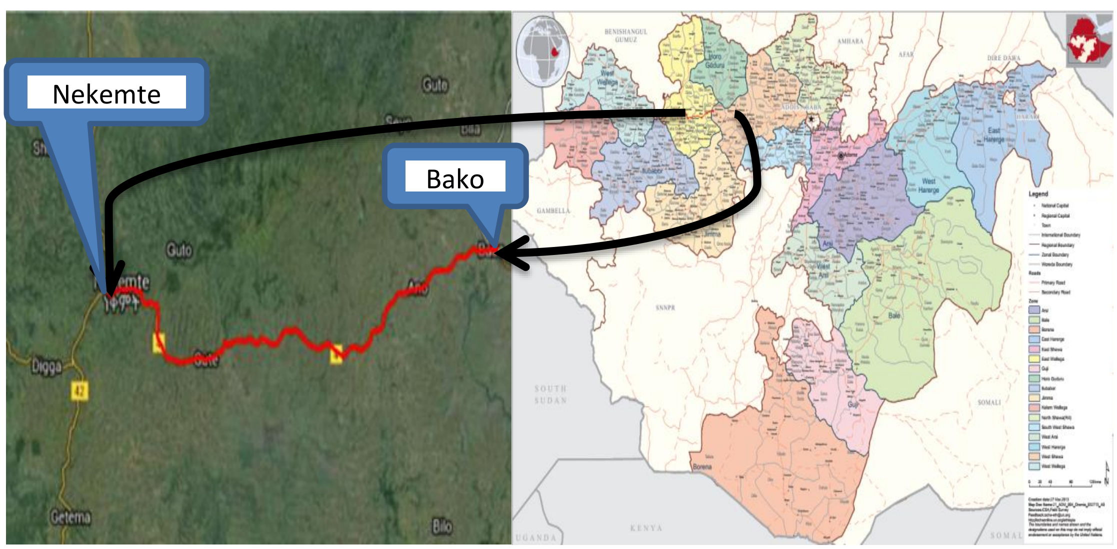

Figure 3.1 Study Area, Bako-Nekemte Road

3.2. Design of the study

For this study, analytical, applied, descriptive, quantitative, and qualitative types of research, approach is adopted directly or indirectly. It is quantitative and qualitative approach because the conclusion of the findings depends on the manipulation of those data. It is similarly analytical, applied and descriptive because it systematically identifies numerical analysis and addresses the practical cause, problem, and their solution. It describes the input data, process, output and the methodology. The methodology of this work has the following components.

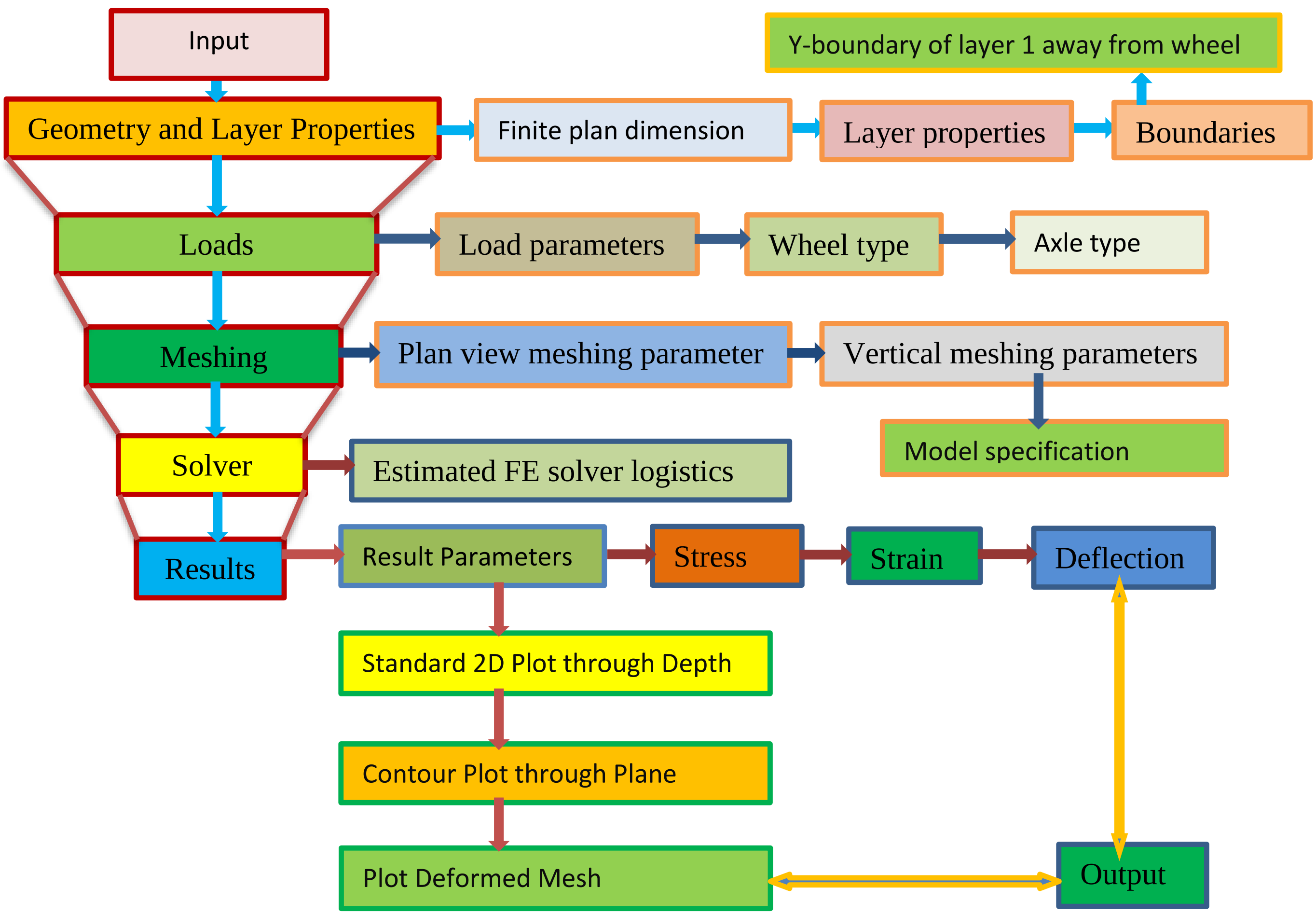

Figure 3.2 The structure of finite element analysis methods of Input, Process, and Output

1. Data collection: Data must be collected from primary source and secondary sources. Most data are obtained from standard specification of AASHTO, ERA, and Existing Laboratory result and laboratory test result and from different institution equations.

3.3. Field Observation and Laboratory Test

Most type of distress along Bako-Nekemte road is rutting deflection. The most cause of rutting deflection along Bako-Nekemte is due to speed breakers and un expected overload in case of Didesa sugar factory and Abay grand dam transport materials.

Figure 3.3 Field observation

3.4. Assumptions of Analytical Solutions to the State Of Stress or Strain.

1) The material properties of each layer are homogenous,
2) Each layer has finite thickness except for the lower layer
3) All layers are infinite in lateral directions
4) Each layer is isotropic (having the same magnitude or properties when measured in different direction).
5) Full friction is developed between layers at each interface
6) The stress solution are characterized by two material properties for each layer (E &υ)

3.5. Basic Component of layers in Bako-Nekemte road

Bako–Nekemte asphalt concrete consist the following component of layers, which is different thickness. The thickness of each layers are the same throughout Bako-Nekemte road except at some places where there is capping layers where California bearing ratio is less than fifteen. The components are surface course, base course, sub base course, and subgrade course. (Source: Bako-Nekemte road upgrade document)

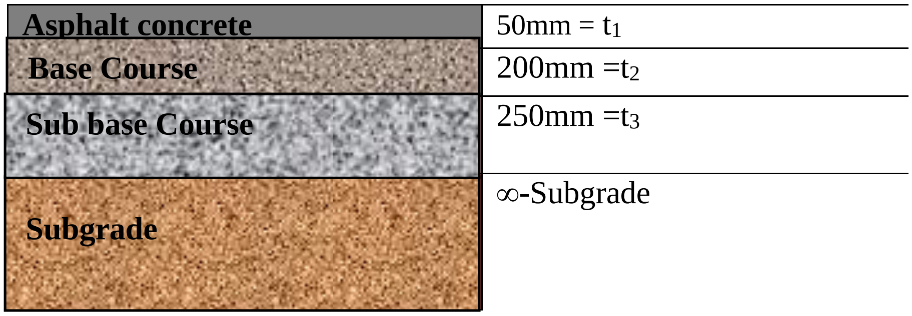

Figure 3.4 *Basic Component of layers in Bako-Nekemte road*

3.6. Type of Soil through Studying Area

According the observations made on the natural soil surface and on exposed soils of cut slopes as well as investigations and laboratory testing result for sub-grade and materials study, the predominant soil type along the Bako - Nekemte road is well-drained reddish to brown clay with short sections of black cotton soil at and near river crossings. Most of the soils along the roadside appear suitable for the use in the proposed road construction works. Generally, Bako-Nekemte soil properties are good for construction of the road except around river and stream.

3.7. Characteristics of Climate through Studying Area

The climate in the project area can be described as temperate in general. The project road runs through one of the highest rainfall areas in the country with a mean annual rainfall ranging from 1,200 to 2,000 mm. Rainfall in the project area has a typical uni-modal characteristics with the rainy season extending from May to October.

During the rainy season, May to October, ITCZ is positioned to the north of the project area and during the dry season, its position is in the south. Table 3.2 below shows a summary of the prevailing temperatures with an indication of the general weather condition in the project corridor and the figure below shows the mean annual rainfall including monthly distribution for one location in the project corridor, namely Nekemte.

Table 3.1 General weather Condition

Months	Mean Precipitation	Mean Temperature	General weather condition
Oct-Jan	100-300mm	15-21^{0}C	Dry warm & cool at night
Feb-May	300-400mm	16-21^{0}C	Warm: dry to humid
Jun-Sep	700-1200mm	15-20^{0}C	Cool,rainy,foggy

Source: Nekemte Meteorology agency

3.8. Sampling process

3.8.1. Sampling procedure

The definition of targeting population has been in line with the objectives of the analysis of stress-strain and deflection of flexible pavements using finite element method. A sampling frame would be from the laboratory test result.

3.8.2. Sampling Technique of Research Study

The sample inspections selected may be provided by an estimate of the analysis of stress-strain and deflection of flexible pavements. By using the sampling technique to collect data from site (distress area), depend on the mean severe area, laboratory result, standard of specification of AASHTO or ERA, and laboratory staffs who know property of materials of the road. These collected data are input data, the output will be analyzed using ever stress software.

3.9. Study Variables

3.9.1. Dependent Variables

- Stress, strain and deflection.

3.9.2. Independent variable

- Road Layer Thickness
- Elastic Modulus data
- Poisons Ratio data
- Vehicle Load/wheel load

3.9.2.1. Road Layers properties

The flexible pavement consists of the following four layers in the case of Bako-Nekemte asphalt road. Those are:

a) Surface course: - The surface course is the top course of an asphalt pavement that is also called the wearing course. It is constructed from dense graded hot-mix asphalt, which has smooth and skid resistant riding surface.

b) Base course: - This is the layer beneath the surface course composed of well-graded crushed stones (unbounded), granular materials mixed with binder or stabilized material. It provides a level surface for laying the surface layer

c) Sub base course: - It is the layer of material beneath the base course constructed using local and cheaper materials for economic reason on the top of capping layer. It facilitates drainage of free water that may be accumulated below the pavement.

d) Capping layer: - It is the layer of material laid on the subgrade constructed using the soil, which has improved bearing capacity. It is present at some place where soil-bearing capacity is very low.

e) Subgrade: The vehicle load and the weight of the pavement rest on the foundation. It is an in-situ or a layer of selected material compacted to the desirable density near the optimum moisture content.

The division of GM and SM groups into subdivisions of d and u is on basis of Atterberg limits; suffix d (e.g. GMd) will be used when the liquid limit is 25 or less and the plasticity index is 5 or less; the suffix u will be used otherwise.

Table 3.2 Recommended Plasticity Characteristics for Granular Sub-Bases (GS)

Climate	Typical Annual	Liquid Limit	Plasticity Index	Linear Shrinkage
Moist tropical and wet tropical	> 500	< 35	< 6	< 3
Seasonally wet tropical	> 500	< 45	< 12	< 6
Arid and semi-arid	< 500	< 55	< 20	< 10

Source: ERA 2001

Elastic Modulus of road component.

The flexible pavement road of Bako- Nekemte has four layers component which were surface layer, base layers, subbase layer and subgrade layer. It is difficult to get elastic modulus of each component of flexible pavement directly. Most of the time elastic modulus of road layers could be determine from California bearing ratio test result. The CBR value could change by using different institution of laboratory test equations. The most popular equations throughout the world is $E=250CBR^{1.2}$ (1500CBR) Psi result.

Poisons Ratio

For Poisson's ratio, the common practice is to use typical value based on the type of material.

$$V = \frac{\Sigma D}{\Sigma L}$$

Where $\Sigma D = \frac{\Delta D}{D} = is\ strain\ along\ diametrical\ (horizontal) axis.$,

$\Sigma L = \frac{\Delta L}{L} = is\ strain\ along\ longitudinal\ (vertical) axis.$

Vehicle Load/wheel load

The predicted loading is simply the predicted number of 80 KN ESALs for the pavement experience over its design lifetime. The Accumulated 80KN Equivalent Single Axle Loads (ESAL) is the traffic load information used for pavement thickness design. The accumulation of the damage caused by mixed truck traffic during a design period is referred to the accumulated 80KN Equivalent Single Axle Loads (ESAL). For this thesis the accumulated 40KN Equivalent Dual Axle Loads (ESAL) that loads can be distributed due to tandem 20KN in case Bako-Nekemte road analysis using finite element method software.

3.10. Types of distress and Cause of distress

The purpose of this paper is to develop an approach for achieving an economic, balanced and quality based evaluation of the various components of the flexible pavement. The methodology is based on the damage analysis concept that has been performed to evaluate rutting on different pavement moduli and Poisson's ratio by using the finite element programs. There are various modes of failure of flexible pavement.

Most type of distress along Bako-Nekemte road is rutting deflection. The most cause of rutting deflection along Bako-Nekemte is due to speed breakers and an expected overload in case of Didesa sugar factory and Abay grand dam transport materials.

3.11. Data Collection

Data collection process was performed using both primary and secondary data collection techniques to get the required information.

3.11.1. Primary data collection

The data was collected on field survey by observation and took samples from distress area for laboratory test of CBR values and elastic modulus.

3.11.2. Secondary data collection

Existing available data describing the system have been gathered from different archival documents/literatures (journals, reports, researches, textbooks and case studies), data from ERA like road layers thickness, vehicle load, wheel pressure and etc.

3.11.3. Data processing and analysis

After successful collection of data has been arranged, then data collected according the context of the research and analysis the data using the pavement software, Microsoft excel and other road tools**.** From the result, we analyzed all the factors affecting flexible pavement road, then evaluate the factors according to their magnitude of their effect and according to their urgency.

The collected data from the study area (road condition survey, distress area), laboratory result and standard specification of AASHTO and ERA were analyzed and interpreted to charts, graphs, figures and tabular formats using excel and other road tools to evaluate the major factors affecting flexible pavement road problem on which needs engineering and scientific solutions.

Everstress or Everseries is a free program that was developed by the Washington State Department of Transportation for paving design purposes. The program can analyze a pavement containing up to five layers (this study uses four) and its primary purpose is to estimate stress, strain and deflection within a layered pavement system due to a static load or loads.

Before talking about what needs to be input into the program, the basic structure of a pavement should be discussed. Typically, it consists of four layers. One layer of hot mix asphalt, a base layer, a subbase layer and then the ground which is called the subgrade layer. To simplify the Everstress input a four layers pavement will be considered with each layers of modulus of elasticity. The thickness of the layers can vary, but a typical pavement design, and the one that was used for analysis in Bako-Nekemte road has an HMA layer that is 50mm thick, a base that is 200mm, a subbase that is 250mm thick and the subgrade thickness is considered infinite.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction to analysis

The analysis of stress, strain and deflection of flexible pavements using finite elements method by using different software. The evaluation of each flexible pavements layers thickness, elastic modulus, poison's ratio, traffic load and tire pressures are input parameters. The analysis was done by using Everstress FE programming language. The program can analyze a pavement structure containing up to 5 layers, 20 loads, and 50 evaluation points. The Ever stress program will also take into account any stress dependent stiffness characteristics.

The following tables shown Laboratory test result CBR taken from existing document which was did during road construction of Bako-Nekemte road. At the same station, current laboratory test result of CBR values have done and took the mean values of each tables. Samples collected at the place of deteriorate area and un deteriorate areas and compare CBR value of existing document with current CBR values. CBR values changed to elastic modulus by using equation of 2.1, 2.5 and 2.6

4.2. Laboratory Test Result From Bako-Nekemte Road For Base Course.

The following tables shown the Californian bearing ratio values of base course which was collected from three different places and took the average values of each tables. The sample was collected in range of existing laboratory result from existing documentary because of to compare with current test result.

Table 4.1 CBR values of base course materials from laboratory test result.

California Bearing Ratio Test
Test Method : AASHTO T-193

Blows	Load (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	3.68	7.19	27.6	36.1
30	6.21	13.64	46.5	68.4
65	18.51	38.98	138.7	194.9

avg.CBR	E.(Mpa)
31.81	109.5306
57.49	222.8633
166.8	800.033
85.36	358.1206

Blows	Load (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	6.02	10.03	45.1	50.1
30	12.3	21.2	91.9	105.4
65	20.1	30.1	150.3	149.8

avg.CBR	E.(Mpa)
47.6	177.6911
98.65	426.0433
150.1	704.7263
98.77	426.648

Blows	Load (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	8.34	13.60	62.5	68.0
30	12.44	21.29	93.2	106.5
65	16.29	26.68	122.0	133.4

avg.CBR	E.(Mpa)
65.22	259.2712
99.83	432.166
127.7	580.774
97.59	420.53

4.3. Laboratory Test Result From Bako-Nekemte Road For Subbase Course.

The following tables shown the Californian bearing ratio values of subbase course which was collected from three different places. The sample was collected in range of existing laboratory result from existing documentary because of to compare with current test result.

Table 4.2 CBR values of subbase course materials from laboratory test result.

CALIFORNIA BEARING RATIO TEST
TEST METHOD : AASHTO T-193

Blows	Load (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	1.44	2.44	10.8	12.2
30	3.29	6.21	24.6	31.2
65	3.41	4.87	25.5	24.4

avg.CBR	E.(MPa)
21.494	32.29363
27.901	112.6007
28.953	132.86255
29.449	155.27093

Blows	Load (KN)		CBR (%)	
	2.54mm	5.08mm	2.54mm	5.08mm
10	2.7	3.6	19.9	18.1
30	3.1	4.2	23.6	21.1
65	6.4	7.6	48.2	37.8

avg.CBR	E.(Mpa
19	59.02576
25.35	71.72496
45	157.2894
40.117	145.46999

Blows	Load KN		CBR %		avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	2.57	3.73	19.2	18.7	18.945	58.82078
30	7.58	12.48	56.8	62.4	59.625	232.8366
65	9.45	16.33	70.83	81.66	76.245	312.7454
					51.605	195.7796

4.4. Laboratory Test Result From Bako-Nekemte Road For Subgrade Course.

The following tables shown the Californian bearing ratio values of base course which was collected from three different places. The sample was collected in range of existing laboratory result from existing documentary because of to compare with current test result.

Table 4.3 CBR values of subgrade course materials from laboratory test result.

CALIFORNIA BEARING RATIO TEST
TEST METHOD : AASHTO T-193
Subgrade Course

Blows	Load (KN)		CBR (%)		avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	0.66	0.96	4.94	4.82	4.88	50.46896
30	1.33	1.72	10	8.6	9.3	96.1806
65	1.85	2.44	13.86	12.22	13.04	134.8597
					9.073333	93.83641

Blows	Load (KN)		CBR(%)		avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	0.62	0.88	5.67	5.4	5.535	46.90097
30	0.93	1.25	7.1	6.3	6.7	69.2914
65	1.58	2.14	11.8	10.68	11.24	116.2441
					7.825	80.92882

Blows	Load (KN)		CBR(%)		Avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	0.68	0.94	5.4	5.6	5.5	56.9535
30	1.1	1.45	6.5	6.7	6.6	68.9494
65	1.58	2.5	6.8	8.68	7.74	80.04708
					6.6133	68.395333

4.5. Laboratory Test Result of Road Existing Document for Base Course.

The following tables shown the Californian bearing ratio values of base course which was collected from three different places. The sample was taken from existing laboratory test result from existing documentary and took average of each tables.

Table 4.4 CBR values of base course materials from existing document.

California Bearing Ratio Test, Test Method: AASHTO T-193
Sampling Station 72+200
Representing Section 72+000-73+500
PURPOSE: Base Course

Blows	Load	KN	CBR (%)		Avg. CBR	E. Mpa
	2.54mm	5.08mm	2.54mm	5.08mm		
10	3.678	7.186	27.553	36.057	31.81	109.530
30	6.212	13.642	46.530	68.448	57.49	222.863
65	18.514	38.976	128.679	174.88	151.8	714.483
Avg.	9.468	19.935	67.587	93.128	80.36	333.097

Sampling Station 82+100
Representing Section 80+000-83+400
Purpose: Base Course

Blows	Load	KN	CBR (%)		Avg.CBR	E. Mpa
10	8.34	13.6	52.45	57.98	55.22	212.327
30	12.44	21.29	90.2	93.46	91.83	390.947
65	16.29	26.68	100.02	103.4	101.7	441.950
Avg.	12.357	20.523	80.89	84.946	82.92	345.874

Sampling Station 102+580
Representing Section 102+000-103+400
Purpose: Base Course

Blows	Load (KN)		CBR(%)		Avg. CBR	E. (Mpa
	2.54mm	5.08mm	2.54mm	5.08mm		
10	6.0151	10.025	45.0904	50.1255	47.61	177.7267
30	12.253	21.164	91.8508	98.3989	95.12	407.8403
65	20.05	30.075	120.301	109.777	115	512.3339
Avg.			85.7475	86.1006	85.92	360.9733

4.6. Laboratory Test Result of Road Existing Document for Subbase Course.

The following tables shown the Californian bearing ratio values of subbase course which was collected from three different places. The sample was gotten in existing laboratory result from existing documentary and took average of each tables.

Table 4.5 CBR values of sub base course materials from existing document.

California Bearing Ratio Test, Test Method:AASHTO T-193
Sampling Station 72+200
Representing Section 72+000-73+500
Purpose: Subbase Course

Blows	Load (KN)		CBR(%)		Avg.CBR	E. (Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	1.43724	2.436	24.76584	26.22278	25.494	83.998
30	3.2886	6.2118	31.63371	35.16809	33.401	116.157
65	3.4104	4.872	30.54607	29.36	29.953	101.922
Avg.	2.71208	4.5066	28.98187	30.25029	29.616	150.547

Blows	Load (KN)		CBR(%)		Avg. CBR	E. (Mpa)
10	2.65392	3.6024	22.87955	21.07526	21.977	70.2925
30	3.1464	4.1952	26.56854	24.04967	25.309	83.2663
65	6.4296	7.55136	49.1618	42.7568	45.959	170.367
Avg.			32.86996	29.29391	31.082	143.548

Blows	Load	KN	CBR(%)		Avg.CBR	E. (Mpa)
10	2.57	3.73	19.24	18.65	18.945	58.8208
30	7.58	12.48	56.84	62.41	59.625	232.837
65	9.45	16.33	70.83	81.66	76.245	312.745
Avg.	6.533333	10.84667	48.97	54.24	51.605	195.78

4.7. Laboratory Test Result of Road Existing Document for Subgrade Course.

The following tables shown the Californian bearing ratio values of subgrade course which was collected from three different places. The sample was gotten in existing laboratory result from existing documentary and took average of each tables.

Table 4.6 CBR values of subgrade course materials from existing document.

California Bearing Ratio Test, Test Method: AASTO T-193
Sampling Station 72+200
Representing Section 72+000-73+500
Purpose: Subgrade Course

Blows	Load (KN)		CBR (%)		Avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	0.58464	0.80388	4.379326	4.033517	4.20642	43.50281
30	2.9232	3.92196	15.89663	13.67868	14.7877	152.9339
65	4.6284	5.8464	14.66966	11.232	12.9508	133.9375
Avg.	2.71208	3.52408	11.64854	9.648064	10.6483	110.1247

Purpose: Subgrade Course

Blows	Load(KN)		CBR (%)		Avg.CBR	E.(Mpa)
10	0.623	0.87665	4.666667	4.398645	4.53266	46.87673
30	0.9345	1.2549	7	6.296538	6.64827	68.7564
65	1.5753	2.136	11.8	10.68	11.24	116.2441
Avg.	1.0442667	1.422517	7.822222	7.125061	7.47364	81.2924

Blows	Load (KN)		CBR (%)		Avg.CBR	E.(Mpa)
	2.54mm	5.08mm	2.54mm	5.08mm		
10	0.65928	0.9648	4.942129	4.824	4.88306	50.50065
30	1.33464	1.72056	10.0048	8.6028	9.3038	96.21989
65	1.8492	2.44416	13.86207	12.2208	13.0414	134.8745
Avg			9.602999	8.5492	9.0761	93.86502

4.8. The Parameters that Causes Stress, Strain And Deflection

The program can be used to estimate stress, strain and deflection within a layered pavement systems subjected to various parameters wheel/axle load combinations. The modulus of elasticity, Poisson's ratio, and thickness must be defined for each layer. Further, the load magnitude, contact pressure (or load radius) and location must be defined for each load (wheel) considered. AASHTO, 1993 and Ethiopian Road Authority, 2013 (ERA) design methods are incorporated in the development of the analysis. This section describes how use input the required variables and analyzes for all pavements thickness design methods.

A typical flexible pavement section can be idealized as a multi-layered system consisting of asphalt layers resting on soil layers having different material properties. Methods of designing flexible pavements can be classified into several categories: Empirical method with or without a soil test, limiting shear failure, and the mechanistic empirical method. However, mechanistic design is becoming more prevalent, which requires the accurate evaluation of stresses and strains in pavements due to wheel and axle loads.

4.9. The Effect of vertical load on Layers of Flexible Pavement

The main cause of vertical surface deflections and the horizontal tensile strains in layers of flexible pavements were vertical loads. The detrimental effects of axle load and tire pressure on various pavement sections are investigated by computing the tensile strain ($\mathcal{E}_t$) at the bottom of the asphalt layer and the compressive strain ($\mathcal{E}c$) at the top of the subgrade. Then, damage analysis is performed using the two critical strains to compute pavement life for fatigue cracking and permanent deformation (rutting). Sensitivity Analyses demonstrate the effect of various parameters on flexible pavement.

In the analysis of flexible pavement, axle loads on the surface of the pavement produce two different types of strains, which are believed to be most critical for design purposes. These are the horizontal tensile strains; $\mathcal{E}_t$ at the bottom of the asphalt layer, and the vertical compressive strain; εc at the top of the subgrade layer. If the horizontal tensile strain $\mathcal{E}_t$ is excessive, cracking of the surface layer will occur and the pavement will fail due to fatigue. If the vertical compressive strain $\mathcal{E}c$ is excessive, permanent deformations are observed at the surface of the pavement structure from overloading the subgrade and pavement fails due to rutting.

Multilayered elastic theory program is used for linear elastic materials in the determination of stresses, strains and deflections. Critical response locations are shown in Figure 4.1:

1. Tensile horizontal strain at the top of the asphalt layer, used to determine fatigue cracking in the asphalt layer.

2. Compressive vertical stress/strain at mid-depth of asphalt layer, used to determine rutting in the asphalt layer.

3. Tensile horizontal strain at a depth of 50mm from the asphalt layer surface and at the bottom of each bound or stabilized layer, used to determine fatigue cracking in the bound layers.

4. Compressive vertical stress/strain at mid-depth of each unbound base/subbase layer, used to determine rutting of the unbound layers. Rutting in chemically stabilized base/subbase layers, bedrock, and concrete fractured slab materials is assumed zero.

Compressive vertical stress/strain at the top of the subgrade and 250mm below the top of the subgrade, used to determine subgrade rutting.

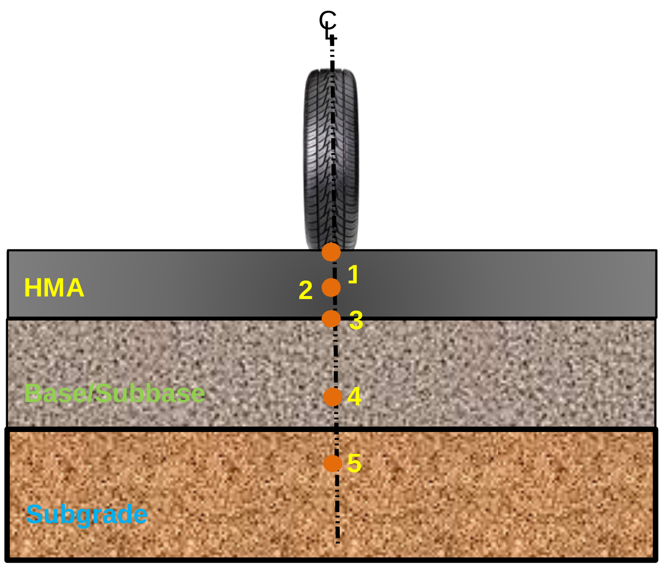

Figure 4.1 Critical asphalt pavement responses locations

4.10. Result Analysis and Discussion

Standard specification result from ERA

A typical cross section consists of asphalt layer thickness (t_1 = 50mm) with elasticity modulus (E_1=3000MPa) at the surface course layer, and base layer thickness (t_2 = 200mm) with elasticity modulus (E_2=300MPa) between surface course layer and subbase course layer, resting on sub-base layer thickness (t_3=250mm) with elasticity modulus (E_3=175MPa) between base course layer and subgrade layer. In addition, subgrade layer thickness (t_4=∞mm) with elasticity modulus (E_4=73MPa) at the bottom of subbase course layer is considered a section with reference components. Different probability cross sections that may be used in Bako-Nekemte Roads are considered for analysis through varying the reference components.

Laboratory test result:-A typical cross section consists of asphalt layer thickness (t_1 = 50mm) with elasticity modulus (E_1=3000MPa) at the surface course layer, and base layer thickness (t_2 = 200mm) with elasticity modulus (E_2=401.6MPa) between surface course layer and subbase course layer, resting on sub-base layer thickness (t_3=250mm) with elasticity modulus (E_3=183.6MPa) between base course layer and subgrade layer. In addition, subgrade layer thickness (t_4=∞mm) with elasticity modulus (E_4=81.05MPa) at the bottom of subbase course layer is considered a section with reference components

Depending different countries design standard specification, Asphalt institution, and different institution of laboratory test (AASHTO, ASTM, BS, ERA and from CBR values by using equations). The value of elastic modulus and poison's ratio are various in each layers, E_1 is varied from 1500 to 3500 MPa, E_2 is varied from 200 to 1000MPa , E_3 is varied from 100 to 250 MPa and E_4 is varied from 20MPa to 150MPa.

Materials in each layer are characterized by a modulus of elasticity (E) and a Poisson's ratio (υ). Poisson's ratio; υ is considered as 0.35, 0.30, 0.30 and 0.30 for asphalt layer, base course, sub-base course and subgrade course, respectively. Traffic is expressed in terms of repetitions of single axle load 80KN applied to the pavement on two sets of dual tires. The investigated contact pressure is 690KPa. The dual tire is approximated by two circular plates with radius 100mm and spaced at 350mm center to center.

Table 4.7 ***Typical moduli value for common paving materials***

Materials	General range (MPa)	Poison's ratio range	Typical value (MPa)	Poison's ratio
HMA	1500-4000	0.15-0.45	3000	0.35
PCC	20000-55000	0.10-0.20	30000	0.15
Asphalt-treated base	700-6000	0.15-0.45	1500	0.35
Lean concrete	7000-20000	0.15-0.30	10000	0.20
Cement treated base	3500-7000	0.15-0.30	5000	0.20
Granular base	100-350	0.30-0.40	200	0.35
Granular subgrade	50-150	0.30-0.40	100	0.35

Fine grained subgrade soil	20-50	0.30-0.50	30	0.40

Source: AASHTO.

There are many different institutions Test for California Bearing Ratio Design Standard specifications of Road component and layers thickness of the road throughout the world. Such as Asphalt Institution, American Association Society Highway and Transportation Office, Ethiopia Road Authority etc.

Table 4.8 Some Institution (Asphalt institute, AASHTO&ERA) Test Design Standard of specifications

Layer no	Materials	CBR	Elastic modulus (MPa)	Poison's ratio	Thickness of pavement layer (mm)		
					Asphalt institute CBR	AASHTO CBR	ERA CBR
1	Surface (Asphalt Concrete)	-	5000	0.35	100	50	50
2	Base (crushed rocks materials)	80	824	0.40	182	150	150
3	Sub base(granular materials)	30	309	0.45		200	200
4	Subgrade	8	82.4	0.45		-	-

The following table shows road component characteristics like elastic modulus, poison's ratio and their typical values which is taken from ERA 2013.

Table 4.9 Pavement Material Properties (source: ERA 2013)

Material	Elastic modulus (MPa)	Poisson's ratio
Asphalt surface	3000	0.35
Base course layer	300	0.30
Subbase layer	175	0.30
Subgrade layer	73	0.35

The following table show Bako-Nekemte road pavement materials properties from laboratory test result and ERA standard specification result. The result is calculated by using the equation of elastic modulus ($E=250CBR^{1.2}$ or $1500CBR$) and poisons ratio ($V = \Sigma D / \Sigma L$).

Table 4.10 Pavement material properties and thickness

Road properties	Layers thickness	Laboratory Test Result			Standard Specification Result		
		CBR	E. MPa	V	CBR %	Mr. MPa	V
Asphalt	50	-	3000	0.30	-	3000	0.35
Base course	200	93.91	401.6	0.30	>80	300	0.30
Subbase course	250	48.91	183.6	0.30	>30	175	0.30
Subgrade course		7.84	81.05	0.35	>15	73	0.40

The following table shows the road layers properties and the general range of elastic modulus, poison's ratio of different materials based type of materials in case of Bako-Nekemte road. The range decided after analysis has done using software for each layers of the road depending types of materials used and types of soil.

Table 4.11 Pavement Material Result Modulus Range used in analysis

Material	Elastic modulus (MPa)	Poisson's ratio
Asphalt surface	1500-3500	0.35
Base course layer	200-1000	0.30
Subbase layer	100-250	0.30
Subgrade layer	20-150	0.30

Source: laboratory test

4.11. Starting Everstress Finite Elements

The main graphical user interface is the first screen that the user sees when EverstressFE opens for the first time, as shown in Figure 4.2. It gives access to the file, inputs (layers thickness, elastic modulus, poison ratio, axle load, tire pressure, tire spacing, axle spacing) and output and help menu bars. Meanwhile, when the main graphical user interface begins the first show is Tips dialogue box to provide introduction, direction and improve users understanding about software. After reading the Tips click > **file** to open the dialogue box. After exiting the tips, dialogue box the main graphical user interface appears (Figure 4.2) which contains the menu bar.

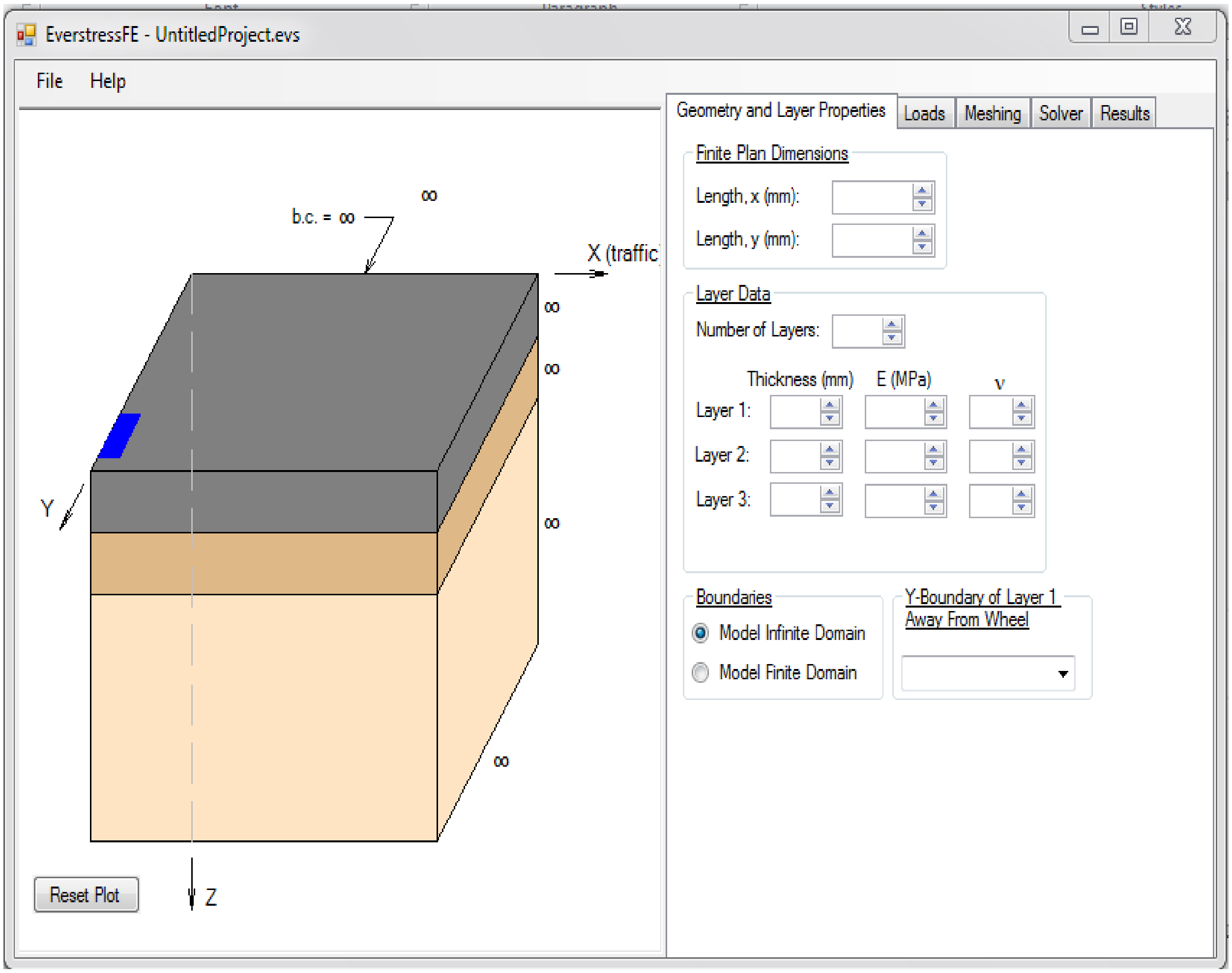

Figure 4.2 The first of face Everstress finite element software

To begin a new project, select **inputs** which gives dropdown list of different input submenus > click **geometry and layers properties > contains finite plan dimension>layer data>boundaries** > start feeding the thickness. The layers thickness configuration of flexible pavement have main role in fatigue cracking and rutting deflection depending axle load and wheel pressures. Before start analysis of input parameters first adjust all in put materials as there category.

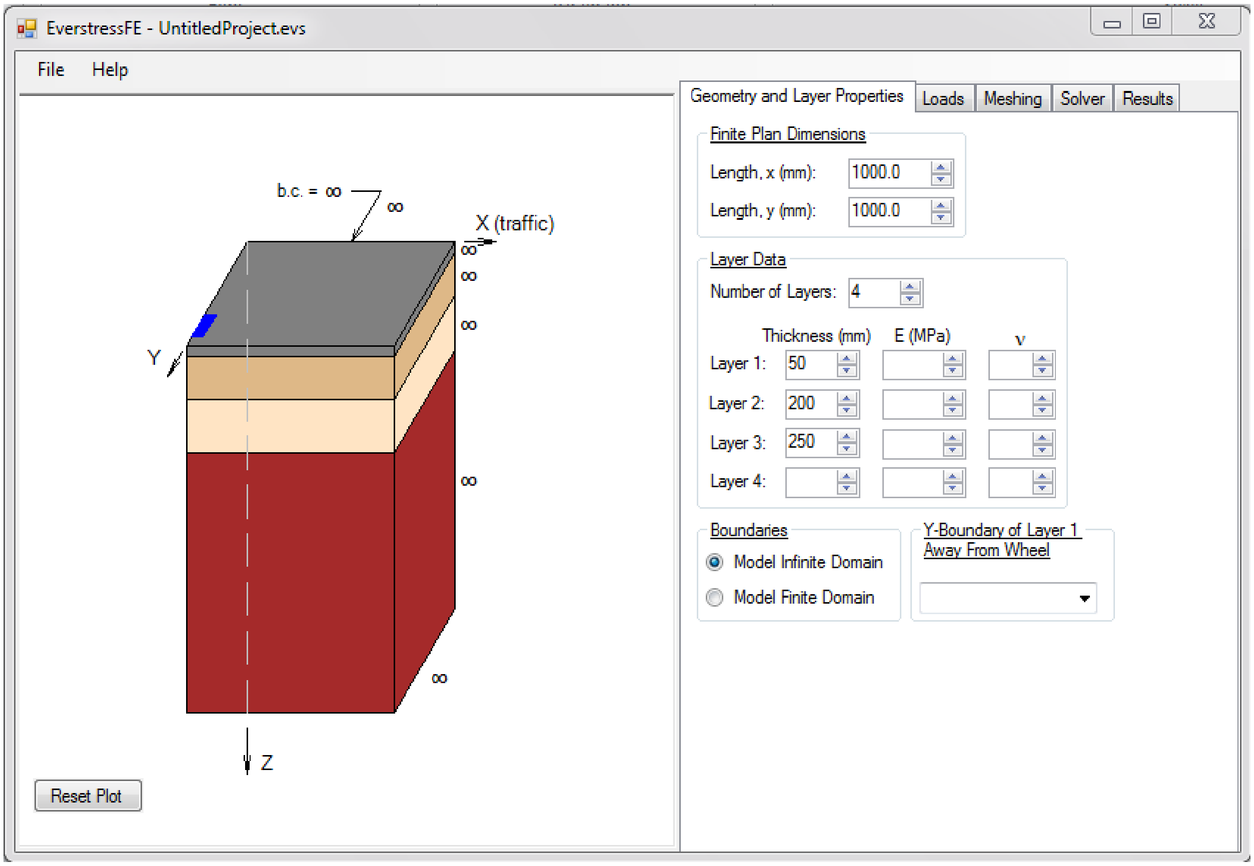

Figure 4.3 Feature of geometry and layer properties

4.12. Elastic Modulus of Pavement Layers E_{AC}, E_{BS}, E_{SB} and E_{SG}

Elastic modulus of pavement layers dialogue box will appear when the user select **inputs** from the main user interface and click > **Moduli of Pavement Layers**. Elastic Modulus of asphalt concrete (E_{AC}), base course (E_{BS}) subbase course (E_{SB}) and subgrade (E_{SG}) are used to determine the structural layer stress, strain and deflection. The designer utilized in the four variables.

Effective roadbed resilient modulus of the subgrade dialogue box (Figure 4.4) appears when the user select **inputs** from the main user interface. This is to determine the effective roadbed soil resilient modulus, MR. The thesis key in roadbed resilient modulus for each month mean values to consider the variability of the property due season and select Average values. The CBR value is key in MR calculation by using equation (2.6) and compare with standard of AASHTO and ERA.

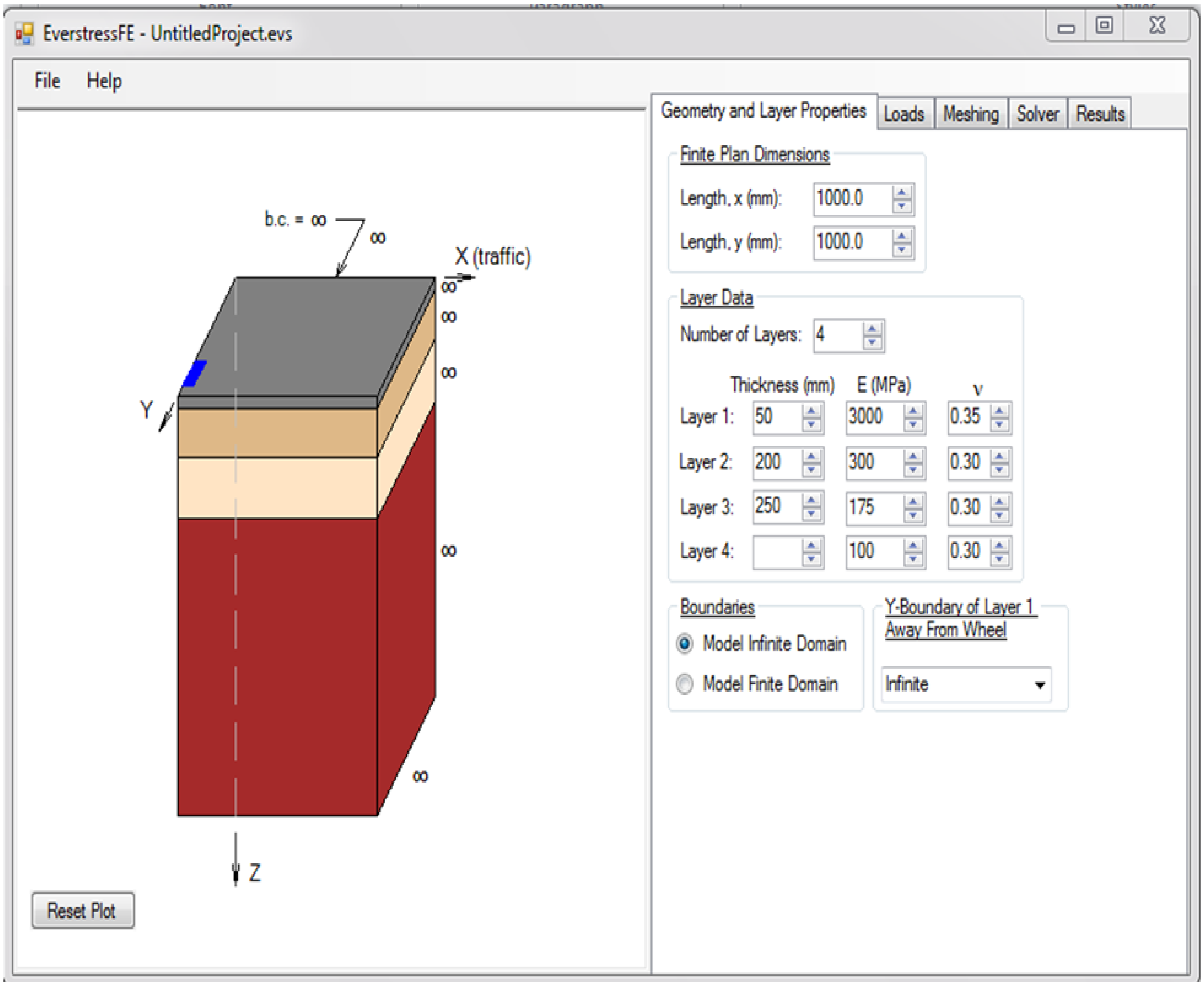

Figure 4.4 Elastic Modulus of Pavement Layers E_{AC}, E_{BS}, E_{SB} and E_{SG}

Click **loads**>start feeding load parameters, The ESAL input data is keyed in the input menu bar dropdown submenu bar dialogue boxes. The parameters that are feed are traffic data, resilient modulus of pavement layers, and roadbed resilient modulus.

These inputs are important in order to determine rutting deflection and fatigue cracking depending cumulative 80KN ESAL and standard normal deviate. The designer will key in the required variables and select the parameters that are presented in a dropdown list like load parameters, wheel type and axle type. The determination of equivalent standard axle load are the most important to balance bearing capacity of the road. The vertical load comes from vehicles must be balanced with the strength of road otherwise the road start deflecting and cracking.

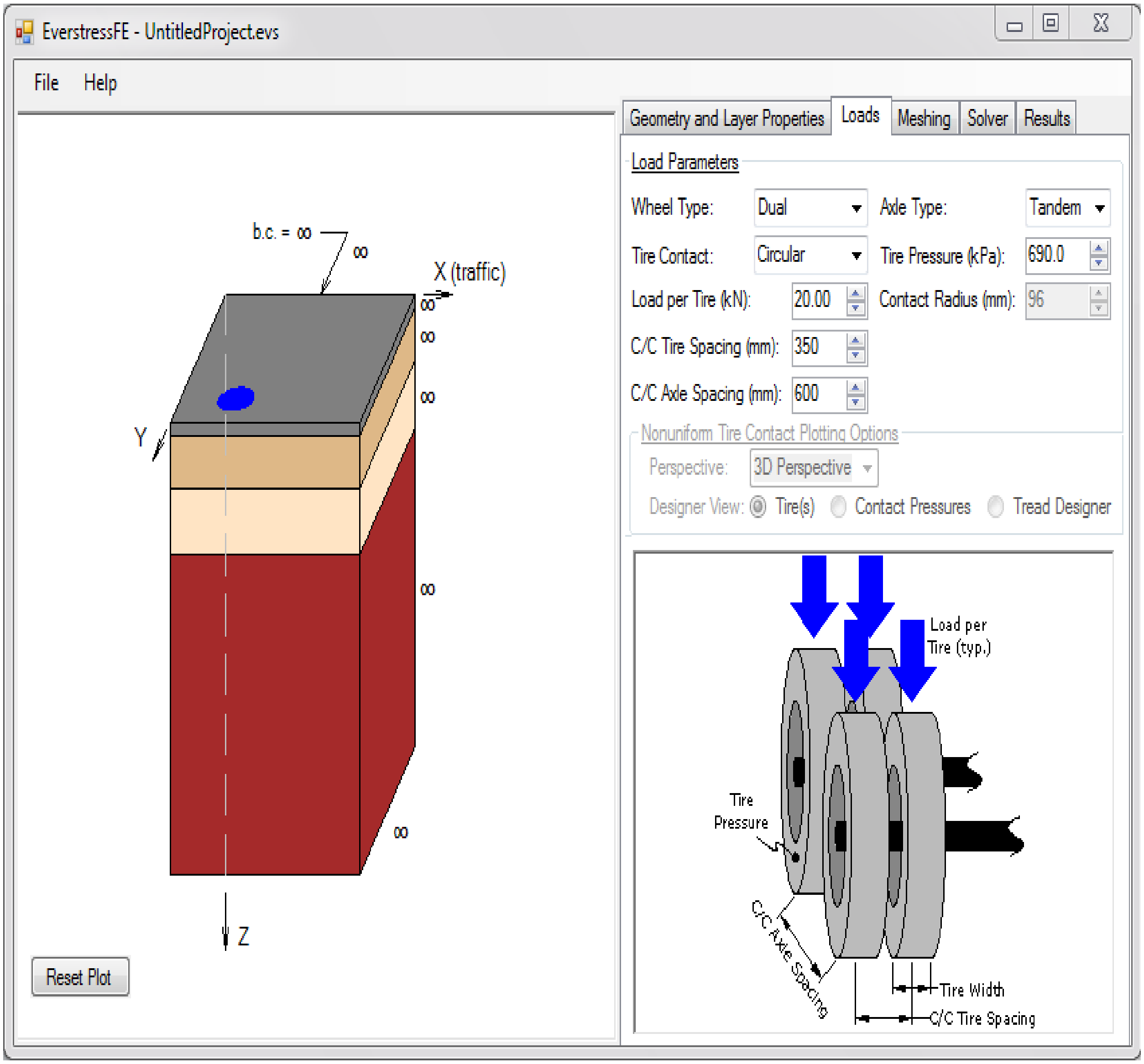

Figure 4.5 load parameters, wheel type and axle type

Click **mesh** > to start feeding plan meshing parameters and go to the other inputs required. One per four symmetric meshes with quadratic elements. To minimize computational time, one per four symmetric models is employed. This thesis can specify a mesh with a locally refined region as shown below or a simple grid mesh. In either case, 20-noded solid, quadratic elements are used to model the soil materials as they provide a good balance between computational time and accuracy.

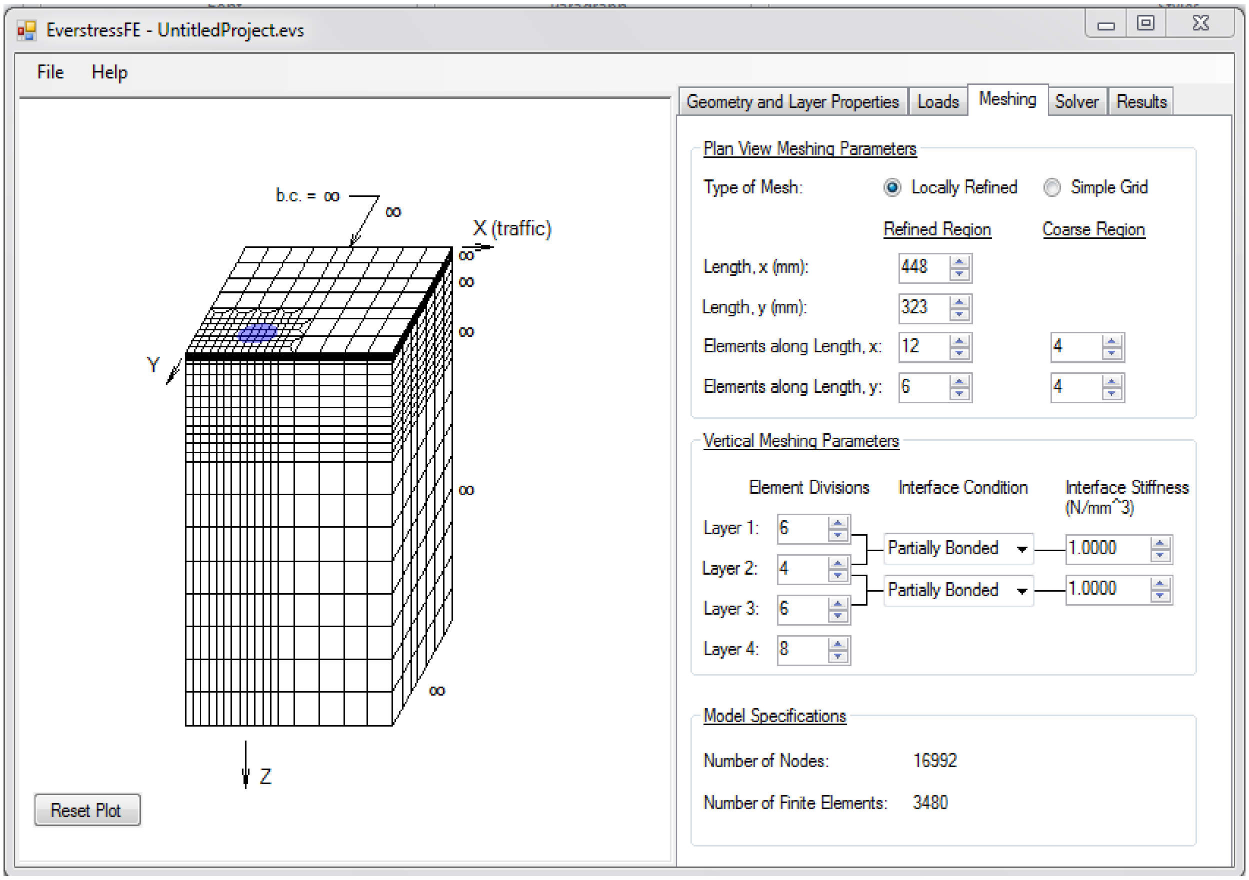

Figure 4.6 plan view meshing parameters and vertical meshing parameters

Feeding all the inputs required, select **solver** >it start to analysis all input data. After data analysis finished > click **Back** button in the dialogue box to return to the main user interface. In addition, similar procedures will be followed to the other submenus (AASHTO Design and ERA Design) in the Output menu bar. To see the comparison of the two methods results against stress, strain, deflection and to get help from EverstressFE follow similar procedures as clarified above.

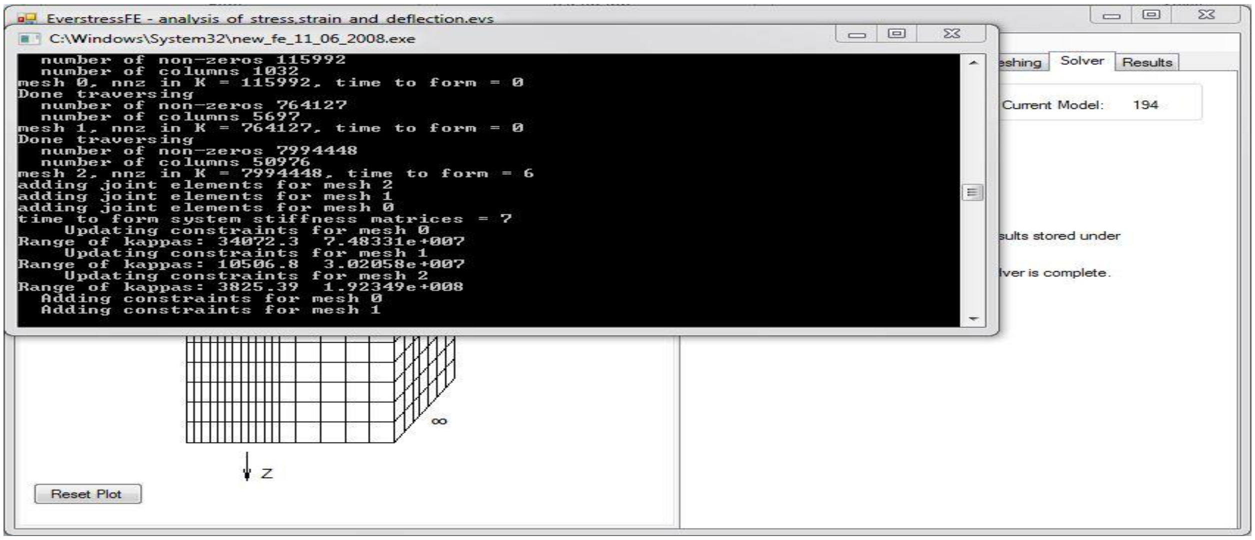

Figure 4.7 Analysis properties of all input data using software

4.13. Result of Everstress finite element

Click result > start to display the output data and get the strain, shear and deflection analyzed for surface, base, subbase and subgrade layers. The result of strain along x-axis, y-axis, and z-axis (Ɛxx, Ɛyy and Ɛzz) was shown in the figure below. It show horizontal strain at the bottom of asphalt layer that is the source fatigue cracking and vertical strain at the top of subgrade which is the source of permanent rutting deflection.

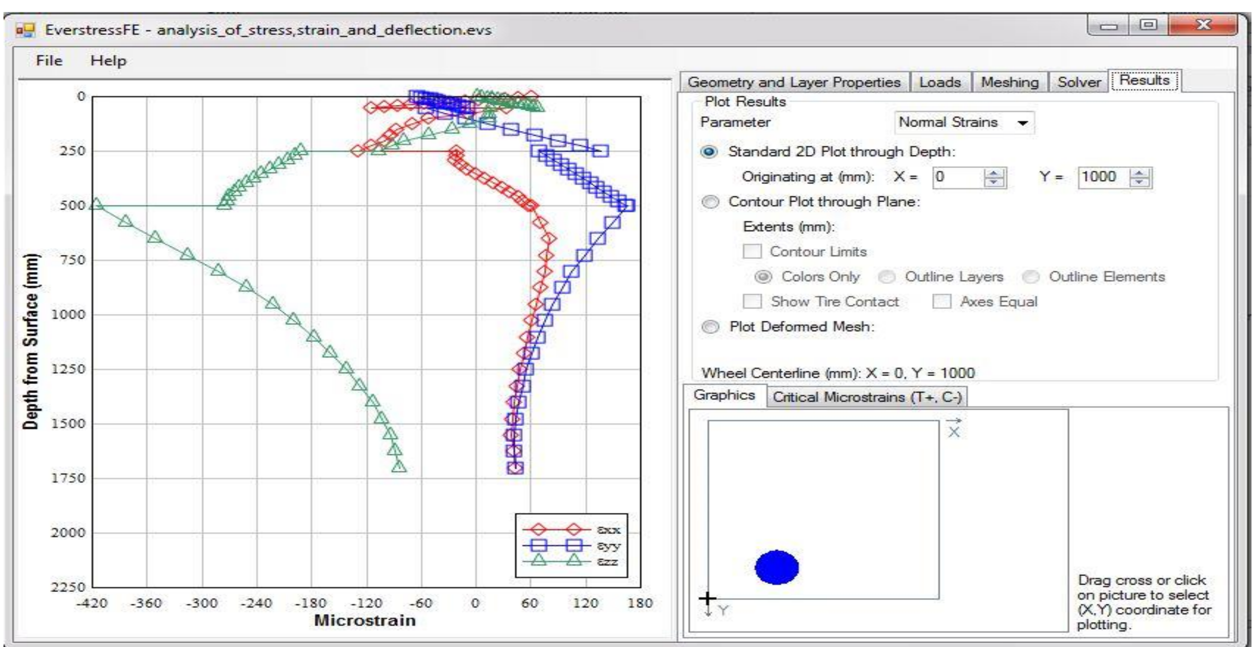

Figure 4.8 Output of normal strain (Ɛxx, Ɛyy and Ɛzz), shear strain and deflection

Click > contour plot through plane which show different plot result, parameters, plane xyz with color pictures and graphics. Minimum Z = -244.0934 at X = 300 and Y = 0, Maximum Z = 269.0878 at X = 300 and Y = 251, Mean = 3.841375 and Standard deviation = 82.3691.

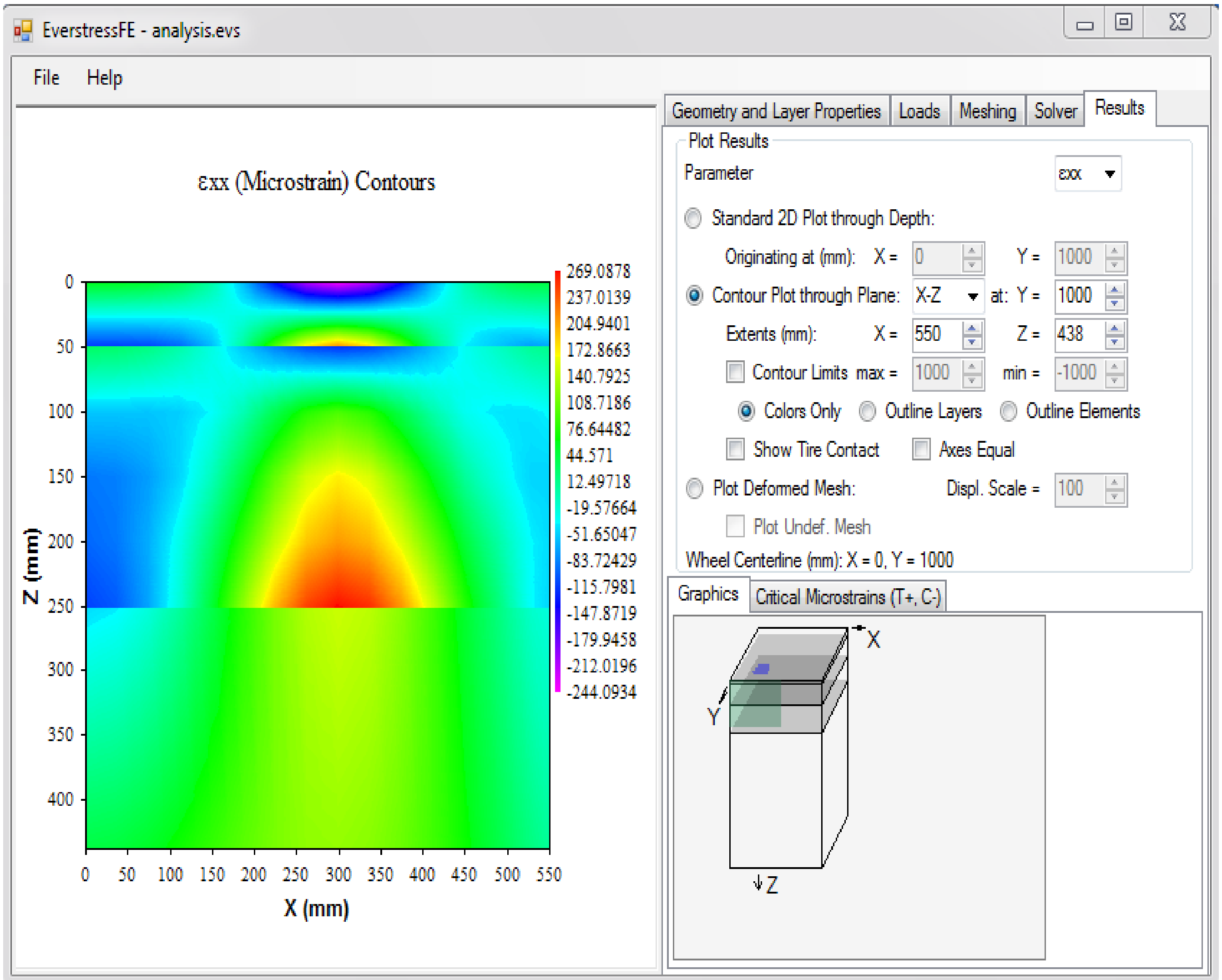

Figure 4.9 contour plots through plane and show where the layer of road affected

The following figure show the deflection of flexible pavement under the center of wheel load when the load applied on it.

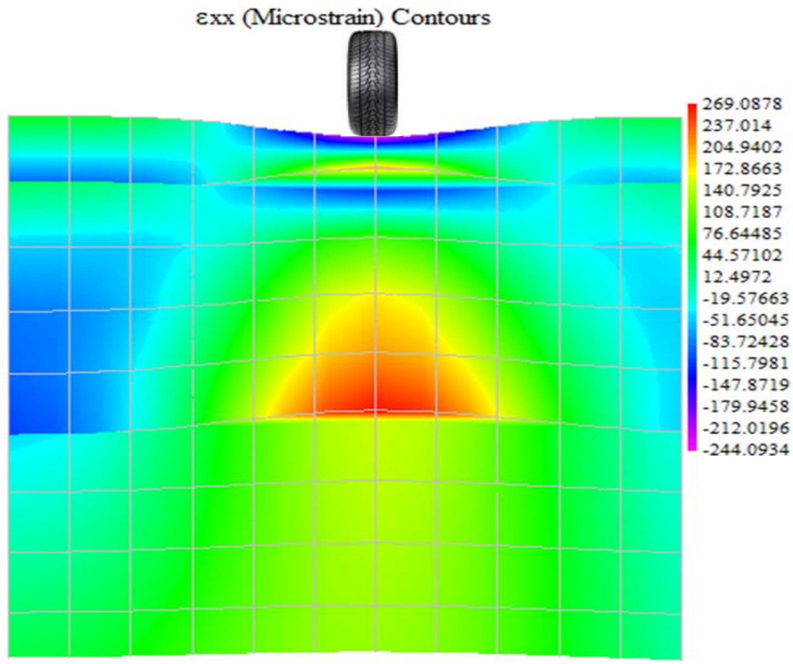

Figure 4.10 The diagram show deflection of road at the center of wheel.

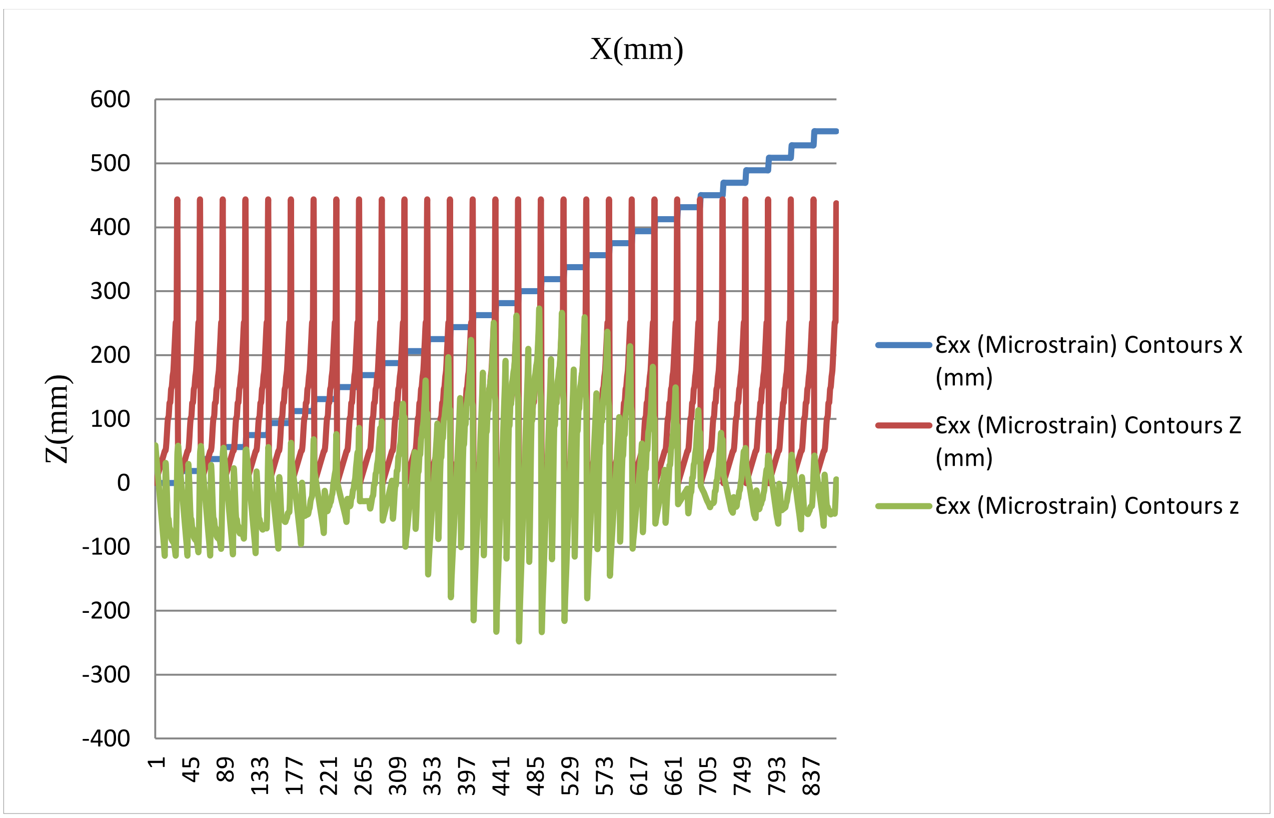

Figure 4.11 The graph shows the properties of strain on X-Z plane.

Contour plot through plane that show different plot results, maximum, minimum, mean and their graphics are presented as the following in different diagram,

The analysis is being carried out using the finite element computer package Visual FEA. The results indicate that displacements under loading are closest to mechanistic methods. This thesis study is being under taken to incorporate the material properties of the pavement layers and the moving traffic load, in the analysis of the flexible pavement, using the finite element method. The following table shows the road layers properties and the general range of elastic modulus, poison's ratio and their typical values of different materials.

Comparison of laboratory test result and standard specification of CBR procedure of elastic modulus, poison's ratio of different materials in case of Bako-Nekemte road, by using EverstressFE to check stress, strain and deflection of each layers parameters.

Table 4.12. **Result of layered elastic analysis using EverstressFE**

CBR procedure	Layer No.	Depth: Z Position (mm)	Horizontal tensile strain at the bottom of the asphalt Layer(microstrain)		Vertical compressive strain at the top of subgrade(microstrain)	Shear stress of in the flexible pavement (microstrain)			Deflection in the flexible pavement (mm)		
			Ɛxx	Ɛyy	Ɛzz	ɣxy	ɣyz	ɣzx	ux	uy	uz
Standard Specification Result	1	0	-260.3	230.6	0.6	0.4	-42.8	0.4	-0.002	0	0.6
	1	49	185.4	-348.6	49.8	0.02	4.2	-7.8	-0.004	0	0.6
	2	51	118.4	-285.1	9.6	0.03	-0.7	-26.1	0.009	0	0.6
	2	249	277.9	84.2	-385.1	0.06	-5.7	-114.4	0.02	0	0.6
	3	251	276.2	83.5	-384.6	0.06	-5.6	-113.2	0.02	0	0.6
	3	499	170.1	205.1	-330.2	0.07	-0.2	-109.5	0.04	0	0.5
	4	501	169.3	209.2	-328.4	0.07	-0.2	109.1	0.04	0	0.5
Laboratory Test Result	1	0	-217.3	185.2	1.3	-0.2	-0.2	0.4	-0.002	0	0.6
	1	49	156.3	-311.1	48.5	-0.04	4.1	-8.1	-0.0001	0	0.6
	2	51	-81.6	-84.7	-27.3	0.04	0.06	-51.5	-0.01	0	0.6
	2	249	253.1	80.2	-311.3	0.04	-3.4	-72.7	0.02	0	0.5
	3	251	244.2	80.4	-330.4	0.03	-2.9	-84.4	0.02	0	0.5
	3	499	140.1	155.2	-323.1	0.02	-0.4	-118.2	0.03	0	0.4
	4	501	140.0	155.8	-320.2	0.02	-0.4	-118.0	0.03	0	0.4

Comparison of general range of elastic modulus of different materials in case of Bako-Nekemte road, which has been taken from finite element software by using laboratory test result and standard specification to check stress, strain and deflection of each layers parameters. The following tables shown the properties of strain in each layer of the road as well as it shown where maximum strain and minimum strain were presented. As the elastic modulus of asphalt concrete increases horizontal strain and vertical strain distributes as following table.

Table 4.13 The properties of horizontal and vertical strain when elastic modulus of asphalt concrete varies.

Elastic modulus in asphalt concrete	Horizontal strain in layer 1	Average vertical strain in layer 1	Average vertical strain in layer 2	Average vertical strain in layer 3	Vertical strain at depth 0mm in layer 4	Vertical strain at depth 150mm in layer 4
1500	1.6	55.9	-9.6	-229.9	-451.8	-382.5
2000	13.3	46.2	-12.8	-229.7	-447.3	-377.4
2500	22	39.4	-15.6	-230.1	-444.3	-373.7
3000	28.7	34.3	-18.3	-230.8	-442.1	-370.8
3500	33.8	30.3	-21	-231.7	-440.5	-368.4

The following table show the properties of horizontal strain and vertical strain in base course layer when the elastic modulus increase.

Table 4.14 The vertical and horizontal strain in base layer as elastic modulus increases

Elastic modulus in base course	Horizontal strain in layer 1	Average vertical strain in layer 1	Average vertical strain in layer 2	Average vertical strain in layer 3	Vertical strain at depth 0mm in layer 4	Vertical strain at depth 150mm in layer 4
200	97.6	28.3	-30.8	-237.3	-4l7.8	-405.2
300	53	32.1	-20.4	-232.6	-456.2	-384.8
400	29.1	34.2	-18.3	-230.8	-442.4	-371
500	14.1	35.6	-17.4	-229.9	-431.8	-330.3
600	3.8	36.4	-16.7	-229	-422.9	-351.3
700	0	36.9	-15.9	-228.1	-415.1	-343.3
800	0	37.3	-15.1	-226.9	-407.8	-336.1
1000	0	37.5	-13.5	-223.9	-494.6	-323.3

The following tables shown the distribution of horizontal strain and vertical strain in subbase course layer in case of elastic modulus varies.

Table 4.15 The distribution of horizontal and vertical strain in subbase layer due to elastic modulus

Elastic modulus in subbase course	Horizontal strain in layer 1	Average vertical strain in layer 1	Average vertical strain in layer 2	Average vertical strain in layer 3	Vertical strain at depth 0mm in layer 4	Vertical strain at depth 150mm in layer 4
100	31.6	37.4	-49.1	-428.1	-475.4	-394.6
150	30.1	35.1	-28.6	-284.6	-455.3	-380.3
200	28	34	-14.1	-211.8	-436.2	-366.6
250	26.1	33.2	-3.2	-168	-419.3	-354.5

The following table show the properties of horizontal strain and vertical strain in subgrade course layer when the elastic modulus increase.

Table 4.16 The vertical and horizontal strain in subgrade layer as elastic modulus increases

Elastic modulus in subgrade course	Horizontal strain in layer 1	Average vertical strain in layer 1	Average vertical strain in layer 2	Average vertical strain in layer 3	Vertical strain at depth 0mm in layer 4	Vertical strain at depth 150mm in layer 4
20	0	56.5	-6.1	-235.3	-871.3	-704.2
50	15	42.2	-13.3	-230.1	-590	-485.7
100	34.3	30.9	-20.7	-232.1	-382.8	-324.4
150	44.2	25	-25.3	-236.4	-282.2	-244.9

The maximum horizontal strain in layer 1 is 28.8 micro strain and the average vertical strain in the layer 1 is 34.3 micro strain. The average vertical strain in the layer 2 is -18.3 microstrain while the average vertical strain in the layer 3 is -230.8 microstrain. Vertical strain at depth 0mm in layer 4 is -442.2 microstrain and at 150mm in layer 4 is -370.8 microstrain

The maximum horizontal strain in layer 1 is 50.2 micro strain and the average vertical strain in the layer 1 is 34.1 micro strain. The average vertical strain in the layer 2 is -22 microstrain while the average vertical strain in the layer 3 is -245.3 microstrain. Vertical strain at depth 0mm in layer 4 is -494.2 microstrain and at 150mm in layer 4 is -414.5 microstrain

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

From this work, it can be concluded that to the cause of stress, strain and deflection of flexible pavement was the load came from vehicles, axle load, wheel pressures (load), and elastic modulus of each road layers, road layers thickness and poison ratio.

The stress, strain and deflection of flexible asphalt pavement can be reduced by using various design parameters of each layers thickness: by increasing the hot mix asphalt modulus and its layer thickness, increasing the base course modulus and its layer thickness, increasing subbase course modulus and its layer thickness and increasing subgrade course modulus and its layer thickness. The value of elastic modulus are various in each layers, E_1 is varied from 1500 to 3500 MPa, E_2 is varied from 200 to 1000MPa, E_3 is varied from 100 to 250 MPa and E_4 is varied from 20MPa to 150MPa.

Therefore, at elastic modulus maximum in each layers, the maximum horizontal strain in layer 1 is 0 microstrain and the average vertical strain in the layer 1 is 24.6 micro strain. The average vertical strain in the layer 2 is -11 microstrain while the average vertical strain in the layer 3 is -171.8 microstrain. Vertical strain at depth 0mm in layer 4 is -253.3 microstrains and at 150mm in layer 4 is -214.7 microstrain.

The software can analysis of the stress, strain and deflection of asphalt concrete, base and subbase courses, subgrade course based on AASHTO guide 1993,laboratory test result, existing laboratory result and Ethiopian Roads Authority 2001/2013 manual. The result obtained by Everstress software is accurate, easy to analysis, as the software is verified using the sample examples analyzed in different manual which are in appendix I.

Hence, development of software to design the pavement thickness and elastic modulus are very important to save cost, time, and energy and decrease error. Thus, the design can be made in a very short time period of design process and help to minimize the error compared to manual calculation by using Everstress software. Moreover, the software gives gap for the designer or researcher to design many alternatives in short period of time compared to that of manual methods.

EverstressFE can be used to predict the performance of flexible pavement more easily and efficiently since, it is more user-friendly. Subgrade modulus is the key element that controls the excess vertical surface deflection in flexible pavement. Hence, more efforts are required for achieving high value of subgrade modulus as compared to other top layers of pavement. Base course and surface layer modulus have minor effects on the excess vertical surface deflection in flexible pavement.

This study has been carried out in order to compare flexible pavement performance using standard specification of AASHTO, ERA and FEM computer programs, respectively. Comparison of the output has been made to determine the governing distress and deterioration models.

As observed above analysis from laboratory test result and standard specification result, the vertical deflection reduces as the modulus increases at all values of E. The maximum horizontal strain in layer 1 is 28.8 micro strain and the average vertical strain in the layer 1 is 34.3 micro strain. The average vertical strain in the layer 2 is -18.3 microstrain while the average vertical strain in the layer 3 is -230.8 microstrain. Vertical strain at depth 0mm in layer 4 is -442.2 microstrain and at 150mm in layer 4 is -370.8 microstrain.

The maximum horizontal strain in layer 1 is 50.2 micro strain and the average vertical strain in the layer 1 is 34.1 micro strain. The average vertical strain in the layer 2 is -22 microstrain while the average vertical strain in the layer 3 is -245.3 microstrain. Vertical strain at depth 0mm in layer 4 is -494.2 microstrain and at 150mm in layer 4 is -414.5 microstrain.

5.2. Recommendation

This study was conducted in short time and limited budget, human labor, thus, there are still several improvements that can be made. In order to have complete software for flexible pavement thickness design and elastic modulus, extensive study and time frame is required.

Software is very important for design and analysis of new highway and existing highway without create error (mistake).So every institution in Ethiopia like Ethiopia Road Authority and Regional State Road Authority have to use software rather than hardcopy manual.

Therefore weather government or private design institution, construction institution and consultant institution must use software in future in case of road.

Rutting deflection and fatigue cracking are easily solved by EverstressFE, to analysis and check stress, strain and deflection of flexible pavement weather balance to each other.

Ethiopia road authorities have to consult all institution of construction to develop software for road and to use software for design and analysis of road.

The application of Everstress finite element can be used only where computer is provided in contrast to manual design. So the designer should equip himself with all the necessary hard copy materials if the condition doesn't allow him to use Everstress finite element.

EverstressFE executes AASHTO and ERA design manuals only so it limits the range of comparison for better design or research. Further study can be done to incorporate other design methods.

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Appendix I

Result from Everstress finite element analysis in table form

X (mr	Z (mn	z	X (mn	Z (mm	z	X (mm	Z (mm)	z	X (mn	Z (mm	z	X (mm)	Z (mm)	z	X (mm	Z (mm	z	X (mm	Z (mm	z	X (mm)	Z (mm)	z
0	0	58.5	56	126	-69	131	45.83	-70.3	205	20.8	-38.5	261.3	252	135.3	336	126	118	410.7	45.83	14.96	487	20.83	-11.1
0	4.17	44.2	56	151	-81	131	50	-78.5	205	25	-26.5	261.3	423	122.3	336	151	157	410.7	50	22.42	487	25	-18.7
0	8.33	30	56	156	-81	131	51	-13.1	205	29.2	-14.7	280	0	-228	336	156	161	410.7	51	-61.67	487	29.17	-26.2
0	12.5	15.6	56	176	-80	131	62.5	-20.5	205	31.3	-8.72	280	4.1667	-193	336	176	176	410.7	62.5	-47.46	487	31.25	-29.9
0	16.7	1.14	56	201	-79	131	93.75	-40.7	205	33.3	-2.79	280	8.3333	-157	336	201	196	410.7	93.75	-8.843	487	33.33	-33.7
0	20.8	-13	56	226	-83	131	101	-45.3	205	37.5	8.844	280	12.5	-122	336	226	225	410.7	101	0.117	487	37.5	-41.3
0	25	-28	56	251	-87	131	125	-38.2	205	41.7	20.47	280	16.667	-87.6	336	251	253	410.7	125	29.16	487	41.67	-48.9
0	29.2	-42	56	252	-32	131	126	-37.9	205	45.8	32.3	280	20.833	-53.1	336	252	140	410.7	126	30.35	487	45.83	-51.6
0	31.3	-49	56	423	44.3	131	151	-30.9	205	50	44.14	280	25	-18.6	336	423	120	410.7	151	59.58	487	50	-54.3
0	33.3	-57	74.7	0	52.2	131	156.3	-28.1	205	51	-68.6	280	29.167	15.8	354.7	0	-180	410.7	156.3	64.51	487	51	-13.4
0	37.5	-71	74.7	4.17	38.7	131	176	-17.6	205	62.5	-49.8	280	31.25	33	354.7	4.17	-153	410.7	176	82.94	487	62.5	-19.8
0	41.7	-85	74.7	8.33	25.1	131	201	-4.56	205	93.8	1.601	280	33.333	50.2	354.7	8.33	-125	410.7	201	106	487	93.75	-37.1
0	45.8	-99	74.7	12.5	11.6	131	226	3.52	205	101	13.51	280	37.5	84.55	354.7	12.5	-98	410.7	226	127.5	487	101	-41.1
0	50	-113	74.7	16.7	-1.9	131	251	11.6	205	125	41.8	280	41.667	118.9	354.7	16.7	-71	410.7	251	148.9	487	125	-33.1
0	51	27.9	74.7	20.8	-15	131	252	19.9	205	126	42.96	280	45.833	152.6	354.7	20.8	-44	410.7	252	87.47	487	126	-32.8
0	62.5	8.65	74.7	25	-29	131	423	71.4	205	151	71.71	280	50	186.4	354.7	25	-18	410.7	423	89	487	151	-24.9
0	93.8	-44	74.7	29.2	-42	149	0	2.89	205	156	75.95	280	51	-112	354.7	29.2	8.5	429.3	0	-35.44	487	156.3	-21.8
0	101	-56	74.7	31.3	-49	149	4.167	-2.87	205	176	91.88	280	62.5	-66.5	354.7	31.3	22	429.3	4.167	-33.33	487	176	-10.6
0	125	-73	74.7	33.3	-56	149	8.333	-8.64	205	201	112	280	93.75	56.68	354.7	33.3	35	429.3	8.333	-31.2	487	201	3.26
0	126	-74	74.7	37.5	-69	149	12.5	-14.1	205	226	133.2	280	101	85.27	354.7	37.5	61	429.3	12.5	-28.94	487	226	13
0	151	-91	74.7	41.7	-82	149	16.67	-19.5	205	251	154.5	280	125	121.5	354.7	41.7	88	429.3	16.67	-26.69	487	251	22.6
0	156	-91	74.7	45.8	-96	149	20.83	-24.7	205	252	92.14	280	126	123	354.7	45.8	114	429.3	20.83	-24.02	487	252	18.4
0	176	-94	74.7	50	-109	149	25	-29.9	205	423	104.8	280	151	161.1	354.7	50	140	429.3	25	-21.37	487	423	41.2
0	201	-98	74.7	51	15.3	149	29.17	-35	224	0	-138	280	156.25	164.8	354.7	51	-99	429.3	29.17	-18.71	506.5	0	38.4
0	226	-105	74.7	62.5	-1.3	149	31.25	-37.6	224	4.17	-119	280	176	179.1	354.7	62.5	-63	429.3	31.25	-17.38	506.5	4.167	29
0	251	-113	74.7	93.8	-46	149	33.33	-40.2	224	8.33	-99.4	280	201	197.6	354.7	93.8	37	429.3	33.33	-16.05	506.5	8.333	19.5
0	252	-46	74.7	101	-57	149	37.5	-45.5	224	12.5	-79.9	280	226	225.7	354.7	101	60	429.3	37.5	-13.66	506.5	12.5	10.2
0	423	36.5	74.7	125	-66	149	41.67	-50.8	224	16.7	-60.5	280	251	253.8	354.7	125	96	429.3	41.67	-11.26	506.5	16.67	0.87
18.7	0	57.9	74.7	126	-66	149	45.83	-56.3	224	20.8	-41.7	280	252	140.7	354.7	126	98	429.3	45.83	-9.196	506.5	20.83	-7.97
18.7	4.17	43.7	74.7	151	-75	149	50	-61.9	224	25	-22.8	280	423	123.8	354.7	151	135	429.3	50	-7.131	506.5	25	-16.8
18.7	8.33	29.5	74.7	156	-74	149	51	-25	224	29.2	-4.38	298.7	0	-243	354.7	156	140	429.3	51	-47.73	506.5	29.17	-25.7
18.7	12.5	15.1	74.7	176	-71	149	62.5	-27.9	224	31.3	4.847	298.7	4.1667	-205	354.7	176	156	429.3	62.5	-40.24	506.5	31.25	-30.1
18.7	16.7	0.79	74.7	201	-68	149	93.75	-36	224	33.3	14.08	298.7	8.3333	-167	354.7	201	177	429.3	93.75	-19.91	506.5	33.33	-34.5
18.7	20.8	-14	74.7	226	-70	149	101	-37.9	224	37.5	32.41	298.7	12.5	-130	354.7	226	205	429.3	101	-15.2	506.5	37.5	-43.3
18.7	25	-28	74.7	251	-72	149	125	-24.7	224	41.7	50.74	298.7	16.667	-92.7	354.7	251	232	429.3	125	8.972	506.5	41.67	-52.2
18.7	29.2	-42	74.7	252	-24	149	126	-24.1	224	45.8	69.23	298.7	20.833	-55.3	354.7	252	129	429.3	126	9.962	506.5	45.83	-57.6
18.7	31.3	-49	74.7	423	48.9	149	151	-11.2	224	50	87.72	298.7	25	-17.9	354.7	423	114	429.3	151	34.26	506.5	50	-63.1
18.7	33.3	-56	93.3	0	44.5	149	156.3	-7.66	224	51	-83.4	298.7	29.167	19.41	373.3	0	-145	429.3	156.3	38.94	506.5	51	-3.18
18.7	37.5	-71	93.3	4.17	32.1	149	176	5.32	224	62.5	-56.1	298.7	31.25	38.05	373.3	4.17	-124	429.3	176	56.38	506.5	62.5	-12.3
18.7	41.7	-85	93.3	8.33	19.8	149	201	21.4	224	93.8	17.98	298.7	33.333	56.68	373.3	8.33	-102	429.3	201	78.14	506.5	93.75	-37.2
18.7	45.8	-98	93.3	12.5	7.41	149	226	33.1	224	101	35.17	298.7	37.5	93.89	373.3	12.5	-81	429.3	226	96.22	506.5	101	-42.9
18.7	50	-112	93.3	16.7	-5	149	251	44.7	224	125	67.22	298.7	41.667	131.1	373.3	16.7	-60	429.3	251	114.3	506.5	125	-40.4
18.7	51	26.4	93.3	20.8	-17	149	252	37.1	224	126	68.55	298.7	45.833	168.2	373.3	20.8	-39	429.3	252	69.21	506.5	126	-40.3
18.7	62.5	7.4	93.3	25	-29	149	423	79.9	224	151	101.5	298.7	50	205.3	373.3	25	-19	429.3	423	77.69	506.5	151	-37.8
18.7	93.8	-44	93.3	29.2	-42	168	0	-26.7	224	156	105.7	298.7	51	-117	373.3	29.2	1.9	448	0	-6.408	506.5	156.3	-35.6
18.7	101	-56	93.3	31.3	-48	168	4.167	-27.1	224	176	121.6	298.7	62.5	-68.3	373.3	31.3	12	448	4.167	-9.16	506.5	176	-27.5
18.7	125	-72	93.3	33.3	-54	168	8.333	-27.5	224	201	141.9	298.7	93.75	63.46	373.3	33.3	22	448	8.333	-11.92	506.5	201	-17.4
18.7	126	-73	93.3	37.5	-66	168	12.5	-27.9	224	226	165.8	298.7	101	94.04	373.3	37.5	43	448	12.5	-13.75	506.5	226	-11.6
18.7	151	-89	93.3	41.7	-78	168	16.67	-28.2	224	251	189.8	298.7	125	130.8	373.3	41.7	63	448	16.67	-15.55	506.5	251	-5.87
18.7	156	-89	93.3	45.8	-90	168	20.83	-28.5	224	252	109.6	298.7	126	132.4	373.3	45.8	83	448	20.83	-18.54	506.5	252	2.15
18.7	176	-91	93.3	50	-102	168	25	-28.7	224	423	112.3	298.7	151	171.2	373.3	50	104	448	25	-21.53	506.5	423	28.7
18.7	201	-94	93.3	51	7.01	168	29.17	-28.9	243	0	-174	298.7	156.25	174.9	373.3	51	-89	448	29.17	-24.43	526	0	43.7
18.7	226	-101	93.3	62.5	-7.2	168	31.25	-29	243	4.17	-148	298.7	176	188.9	373.3	62.5	-59	448	31.25	-25.88	526	4.167	33.5

18.7	251	-108	93.3	93.8	-46	168	33.33	-29.1	243	8.33	-122	298.7	201	207.2	373.3	93.8	22	448	33.33	-27.32	526	8.333	23.3
18.7	252	-43	93.3	101	-55	168	37.5	-29.4	243	12.5	-96.4	298.7	226	236.2	373.3	101	41	448	37.5	-29.46	526	12.5	13.8
18.7	423	38.1	93.3	125	-59	168	41.67	-29.8	243	16.7	-71.1	298.7	251	265.1	373.3	125	76	448	41.67	-31.61	526	16.67	4.36
37.3	0	57.4	93.3	126	-59	168	45.83	-30.2	243	20.8	-46.2	298.7	252	146.1	373.3	126	78	448	45.83	-34.15	526	20.83	-5.15
37.3	4.17	43.2	93.3	151	-62	168	50	-30.7	243	25	-21.2	298.7	423	125.2	373.3	151	114	448	50	-36.69	526	25	-14.7
37.3	8.33	29.1	93.3	156	-61	168	51	-39.4	243	29.2	3.652	317.3	0	-231	373.3	156	119	448	51	-33.78	526	29.17	-24.2
37.3	12.5	14.8	93.3	176	-56	168	62.5	-35.6	243	31.3	16.07	317.3	4.1667	-195	373.3	176	136	448	62.5	-33.12	526	31.25	-29
37.3	16.7	0.53	93.3	201	-49	168	93.75	-25.3	243	33.3	28.5	317.3	8.3333	-159	373.3	201	159	448	93.75	-31.32	526	33.33	-33.8
37.3	20.8	-14	93.3	226	-48	168	101	-22.9	243	37.5	53.25	317.3	12.5	-123	373.3	226	185	448	101	-30.91	526	37.5	-42.7
37.3	25	-28	93.3	251	-47	168	125	-4.15	243	41.7	78.01	317.3	16.667	-87.9	373.3	251	211	448	125	-11.99	526	41.67	-51.8
37.3	29.2	-42	93.3	252	-10	168	126	-3.39	243	45.8	102.8	317.3	20.833	-52.7	373.3	252	119	448	126	-11.22	526	45.83	-61.8
37.3	31.3	-49	93.3	423	55.9	168	151	15.3	243	50	127.6	317.3	25	-17.6	373.3	423	108	448	151	7.751	526	50	-71.9
37.3	33.3	-57	112	0	36.9	168	156.3	19.2	243	51	-95.2	317.3	29.167	17.42	392	0	-105	448	156.3	12.15	526	51	7.03
37.3	37.5	-71	112	4.17	25.5	168	176	33.6	243	62.5	-60.5	317.3	31.25	34.93	392	4.17	-92	448	176	28.52	526	62.5	-4.38
37.3	41.7	-85	112	8.33	14.2	168	201	51.7	243	93.8	33.55	317.3	33.333	52.43	392	8.33	-78	448	201	48.88	526	93.75	-35.4
37.3	45.8	-98	112	12.5	3.14	168	226	66.8	243	101	55.38	317.3	37.5	87.41	392	12.5	-64	448	226	64.27	526	101	-42.5
37.3	50	-112	112	16.7	-7.9	168	251	81.9	243	125	89.33	317.3	41.667	122.4	392	16.7	-50	448	251	79.66	526	125	-45.4
37.3	51	24.8	112	20.8	-19	168	252	55.9	243	126	90.74	317.3	45.833	156.7	392	20.8	-35	448	252	50.95	526	126	-45.5
37.3	62.5	6.12	112	25	-30	168	423	88.6	243	151	126	317.3	50	191	392	25	-21	448	423	66.04	526	151	-48.5
37.3	93.8	-45	112	29.2	-41	187	0	-56.6	243	156	130	317.3	51	-113	392	29.2	-7.1	467.5	0	13.35	526	156.3	-47.2
37.3	101	-57	112	31.3	-46	187	4.167	-52.1	243	176	145.2	317.3	62.5	-67.3	392	31.3	-0.1	467.5	4.167	7.635	526	176	-42.5
37.3	125	-72	112	33.3	-52	187	8.333	-47.5	243	201	164.8	317.3	93.75	58	392	33.3	7	467.5	8.333	1.905	526	201	-36.7
37.3	126	-72	112	37.5	-63	187	12.5	-43	243	226	190.4	317.3	101	87.06	392	37.5	21	467.5	12.5	-3.599	526	226	-35.5
37.3	151	-87	112	41.7	-73	187	16.67	-38.5	243	251	216.1	317.3	125	124	392	41.7	35	467.5	16.67	-9.088	526	251	-34.4
37.3	156	-87	112	45.8	-84	187	20.83	-33.5	243	252	122.4	317.3	126	125.5	392	45.8	49	467.5	20.83	-14.67	526	252	-14.1
37.3	176	-89	112	50	-95	187	25	-28.5	243	423	117.3	317.3	151	164.4	392	50	63	467.5	25	-20.24	526	423	16.1
37.3	201	-90	112	51	-1.3	187	29.17	-23.4	261	0	-211	317.3	156.25	168.2	392	51	-75	467.5	29.17	-25.76	548	0	42
37.3	226	-97	112	62.5	-13	187	31.25	-20.8	261	4.17	-178	317.3	176	182.9	392	62.5	-53	467.5	31.25	-28.53	548	4.167	32.7
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37.3	252	-40	112	101	-53	187	37.5	-13.3	261	12.5	-115	317.3	226	230.5	392	101	20	467.5	37.5	-36.69	548	12.5	14.4
37.3	423	39.7	112	125	-52	187	41.67	-8.38	261	16.7	-82.8	317.3	251	259.1	392	125	52	467.5	41.67	-42.09	548	16.67	5.55
56	0	54.8	112	126	-51	187	45.83	-3.91	261	20.8	-51.3	317.3	252	143.1	392	126	54	467.5	45.83	-43.79	548	20.83	-3.33
56	4.17	40.9	112	151	-50	187	50	0.55	261	25	-19.8	317.3	423	122.7	392	151	87	467.5	50	-45.49	548	25	-12.2
56	8.33	27.1	112	156	-48	187	51	-53.9	261	29.2	11.5	336	0	-216	392	156	91	467.5	51	-23.58	548	29.17	-21.1
56	12.5	13.2	112	176	-40	187	62.5	-43.2	261	31.3	27.15	336	4.1667	-182	392	176	109	467.5	62.5	-26.69	548	31.25	-25.5
56	16.7	-0.7	112	201	-30	187	93.75	-14.3	261	33.3	42.81	336	8.3333	-148	392	201	132	467.5	93.75	-35.15	548	33.33	-29.9
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56	25	-29	112	251	-22	187	125	16.8	261	41.7	105.2	336	16.667	-83	392	251	180	467.5	125	-23.67	548	41.67	-47.1
56	29.2	-42	112	252	2.83	187	126	17.8	261	45.8	136.3	336	20.833	-50.3	392	252	103	467.5	126	-23.12	548	45.83	-56.8
56	31.3	-49	112	423	62.9	187	151	42.2	261	50	167.4	336	25	-17.7	392	423	98	467.5	151	-9.666	548	50	-66.5
56	33.3	-56	131	0	20	187	156.3	46.5	261	51	-107	336	29.167	14.84	410.7	0	-66	467.5	156.3	-5.916	548	51	10.8
56	37.5	-70	131	4.17	11.4	187	176	62.3	261	62.5	-64.9	336	31.25	31.1	410.7	4.17	-58	467.5	176	8.041	548	62.5	-0.27
56	41.7	-83	131	8.33	2.85	187	201	82.1	261	93.8	49.14	336	33.333	47.37	410.7	8.33	-51	467.5	201	25.37	548	93.75	-30.4
56	45.8	-97	131	12.5	-5.4	187	226	101	261	101	75.61	336	37.5	79.71	410.7	12.5	-44	467.5	226	38.26	548	101	-37.4
56	50	-110	131	16.7	-14	187	251	119	261	125	111.3	336	41.667	112.1	410.7	16.7	-37	467.5	251	51.15	548	125	-43.1
56	51	20.1	131	20.8	-22	187	252	74.7	261	126	112.8	336	45.833	144.3	410.7	20.8	-30	467.5	252	34.69	548	126	-43.4
56	62.5	2.41	131	25	-30	187	423	97.3	261	151	150.2	336	50	176.6	410.7	25	-22	467.5	423	53.65	548	151	-49.3
56	93.8	-46	131	29.2	-38	205	0	-96.4	261	156	154.1	336	51	-110	410.7	29.2	-15	487	0	28.3	548	156.3	-48.8
56	101	-57	131	31.3	-42	205	4.167	-85.5	261	176	168.6	336	62.5	-66.4	410.7	31.3	-11	487	4.167	20.34	548	176	-47.1
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56	126	-69	131	37.5	-54	205	12.5	-62.5	261	226	214.9	336	101	79.14	410.7	37.5	0.3	487	12.5	4.376	548	226	-45.7
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37.3	0	57.4	93.3	126	-59	168	45.83	-30.2	243	20.8	-46.2	298.7	252	146.1	373.3	126	78	448	45.83	-34.15	526	20.83	-5.15
37.3	4.17	43.2	93.3	151	-62	168	50	-30.7	243	25	-21.2	298.7	423	125.2	373.3	151	114	448	50	-36.69	526	25	-14.7
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37.3	12.5	14.8	93.3	176	-56	168	62.5	-35.6	243	31.3	16.07	317.3	4.1667	-195	373.3	176	136	448	62.5	-33.12	526	31.25	-29
37.3	16.7	0.53	93.3	201	-49	168	93.75	-25.3	243	33.3	28.5	317.3	8.3333	-159	373.3	201	159	448	93.75	-31.32	526	33.33	-33.8
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37.3	25	-28	93.3	251	-47	168	125	-4.15	243	41.7	78.01	317.3	16.667	-87.9	373.3	251	211	448	125	-11.99	526	41.67	-51.8
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37.3	31.3	-49	93.3	423	55.9	168	151	15.3	243	50	127.6	317.3	25	-17.6	373.3	423	108	448	151	7.751	526	50	-71.9
37.3	33.3	-57	112	0	36.9	168	156.3	19.2	243	51	-95.2	317.3	29.167	17.42	392	0	-105	448	156.3	12.15	526	51	7.03
37.3	37.5	-71	112	4.17	25.5	168	176	33.6	243	62.5	-60.5	317.3	31.25	34.93	392	4.17	-92	448	176	28.52	526	62.5	-4.38
37.3	41.7	-85	112	8.33	14.2	168	201	51.7	243	93.8	33.55	317.3	33.333	52.43	392	8.33	-78	448	201	48.88	526	93.75	-35.4
37.3	45.8	-98	112	12.5	3.14	168	226	66.8	243	101	55.38	317.3	37.5	87.41	392	12.5	-64	448	226	64.27	526	101	-42.5
37.3	50	-112	112	16.7	-7.9	168	251	81.9	243	125	89.33	317.3	41.667	122.4	392	16.7	-50	448	251	79.66	526	125	-45.4
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37.3	101	-57	112	31.3	-46	187	4.167	-52.1	243	176	145.2	317.3	62.5	-67.3	392	31.3	-0.1	467.5	4.167	7.635	526	176	-42.5
37.3	125	-72	112	33.3	-52	187	8.333	-47.5	243	201	164.8	317.3	93.75	58	392	33.3	7	467.5	8.333	1.905	526	201	-36.7
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37.3	226	-97	112	62.5	-13	187	31.25	-20.8	261	4.17	-178	317.3	176	182.9	392	62.5	-53	467.5	31.25	-28.53	548	4.167	32.7
37.3	251	-103	112	93.8	-45	187	33.33	-18.3	261	8.33	-146	317.3	201	201.9	392	93.8	6.4	467.5	33.33	-31.29	548	8.333	23.3
37.3	252	-40	112	101	-53	187	37.5	-13.3	261	12.5	-115	317.3	226	230.5	392	101	20	467.5	37.5	-36.69	548	12.5	14.4
37.3	423	39.7	112	125	-52	187	41.67	-8.38	261	16.7	-82.8	317.3	251	259.1	392	125	52	467.5	41.67	-42.09	548	16.67	5.55
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56	4.17	40.9	112	151	-50	187	50	0.55	261	25	-19.8	317.3	423	122.7	392	151	87	467.5	50	-45.49	548	25	-12.2
56	8.33	27.1	112	156	-48	187	51	-53.9	261	29.2	11.5	336	0	-216	392	156	91	467.5	51	-23.58	548	29.17	-21.1
56	12.5	13.2	112	176	-40	187	62.5	-43.2	261	31.3	27.15	336	4.1667	-182	392	176	109	467.5	62.5	-26.69	548	31.25	-25.5
56	16.7	-0.7	112	201	-30	187	93.75	-14.3	261	33.3	42.81	336	8.3333	-148	392	201	132	467.5	93.75	-35.15	548	33.33	-29.9
56	20.8	-15	112	226	-26	187	101	-7.53	261	37.5	74.02	336	12.5	-115	392	226	156	467.5	101	-37.11	548	37.5	-38.5
56	25	-29	112	251	-22	187	125	16.8	261	41.7	105.2	336	16.667	-83	392	251	180	467.5	125	-23.67	548	41.67	-47.1
56	29.2	-42	112	252	2.83	187	126	17.8	261	45.8	136.3	336	20.833	-50.3	392	252	103	467.5	126	-23.12	548	45.83	-56.8
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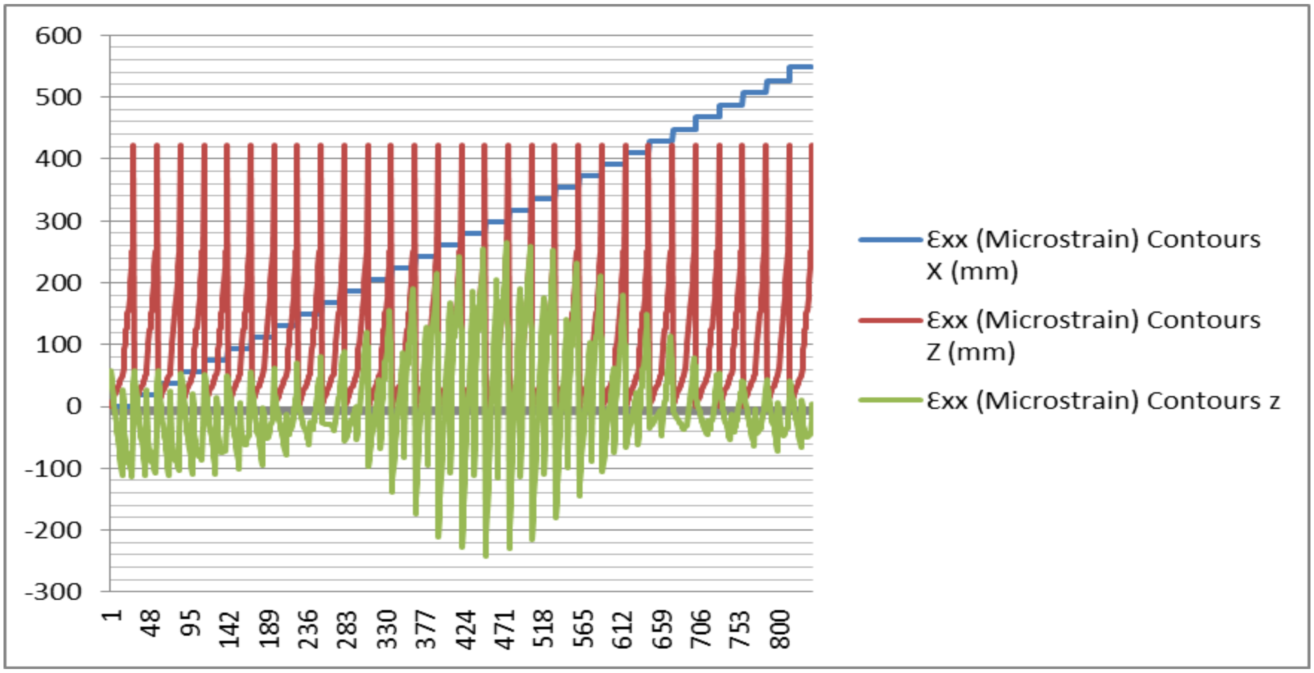
56	37.5	-70	131	4.17	11.4	187	176	62.3	261	62.5	-64.9	336	31.25	31.1	410.7	4.17	-58	467.5	176	8.041	548	62.5	-0.27
56	41.7	-83	131	8.33	2.85	187	201	82.1	261	93.8	49.14	336	33.333	47.37	410.7	8.33	-51	467.5	201	25.37	548	93.75	-30.4
56	45.8	-97	131	12.5	-5.4	187	226	101	261	101	75.61	336	37.5	79.71	410.7	12.5	-44	467.5	226	38.26	548	101	-37.4
56	50	-110	131	16.7	-14	187	251	119	261	125	111.3	336	41.667	112.1	410.7	16.7	-37	467.5	251	51.15	548	125	-43.1
56	51	20.1	131	20.8	-22	187	252	74.7	261	126	112.8	336	45.833	144.3	410.7	20.8	-30	467.5	252	34.69	548	126	-43.4
56	62.5	2.41	131	25	-30	187	423	97.3	261	151	150.2	336	50	176.6	410.7	25	-22	467.5	423	53.65	548	151	-49.3
56	93.8	-46	131	29.2	-38	205	0	-96.4	261	156	154.1	336	51	-110	410.7	29.2	-15	487	0	28.3	548	156.3	-48.8
56	101	-57	131	31.3	-42	205	4.167	-85.5	261	176	168.6	336	62.5	-66.4	410.7	31.3	-11	487	4.167	20.34	548	176	-47.1
56	125	-69	131	33.3	-46	205	8.333	-74.5	261	201	187.5	336	93.75	51.72	410.7	33.3	-6.9	487	8.333	12.38	548	201	-45
56	126	-69	131	37.5	-54	205	12.5	-62.5	261	226	214.9	336	101	79.14	410.7	37.5	0.3	487	12.5	4.376	548	226	-45.7
56	151	-81	131	41.7	-62	205	16.67	-50.6	261	251	242.4	336	125	116.3	410.7	41.7	7.5	487	16.67	-3.614	548	251	-46.3

Ɛxx (Microstrain) Contours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200
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-300
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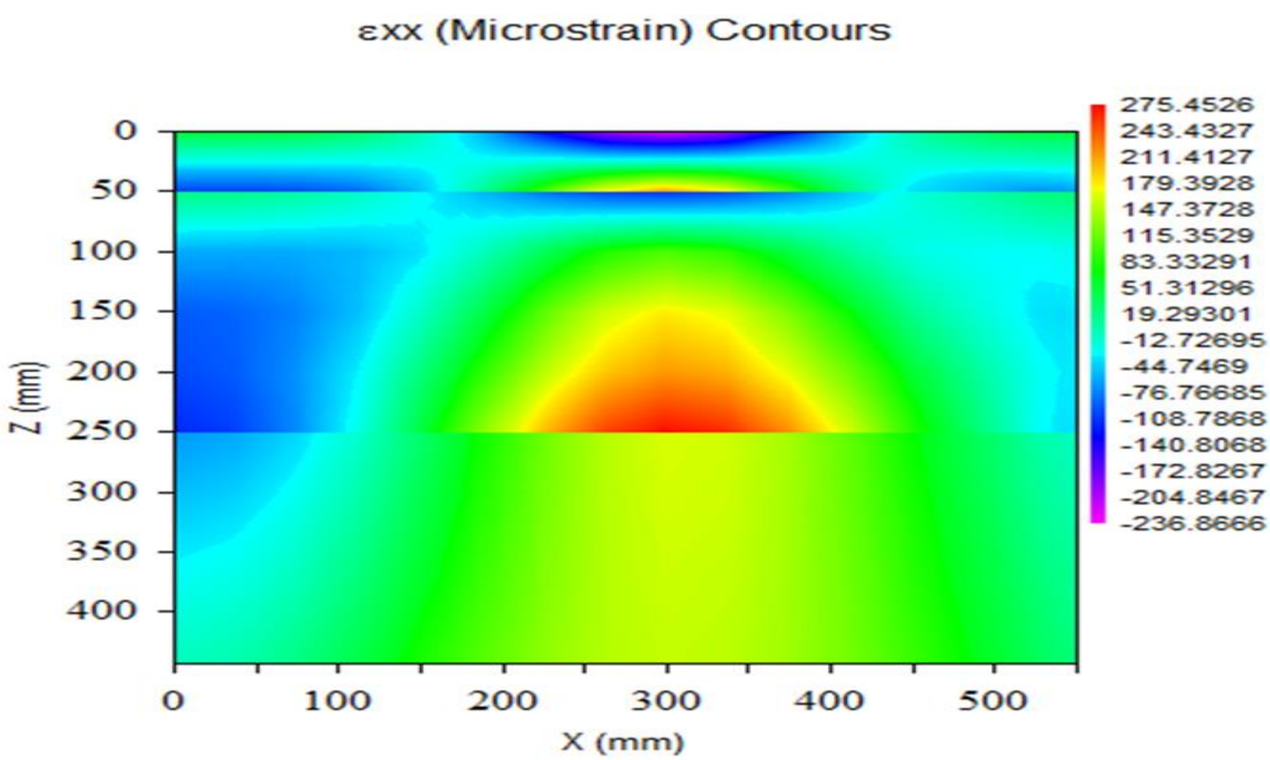
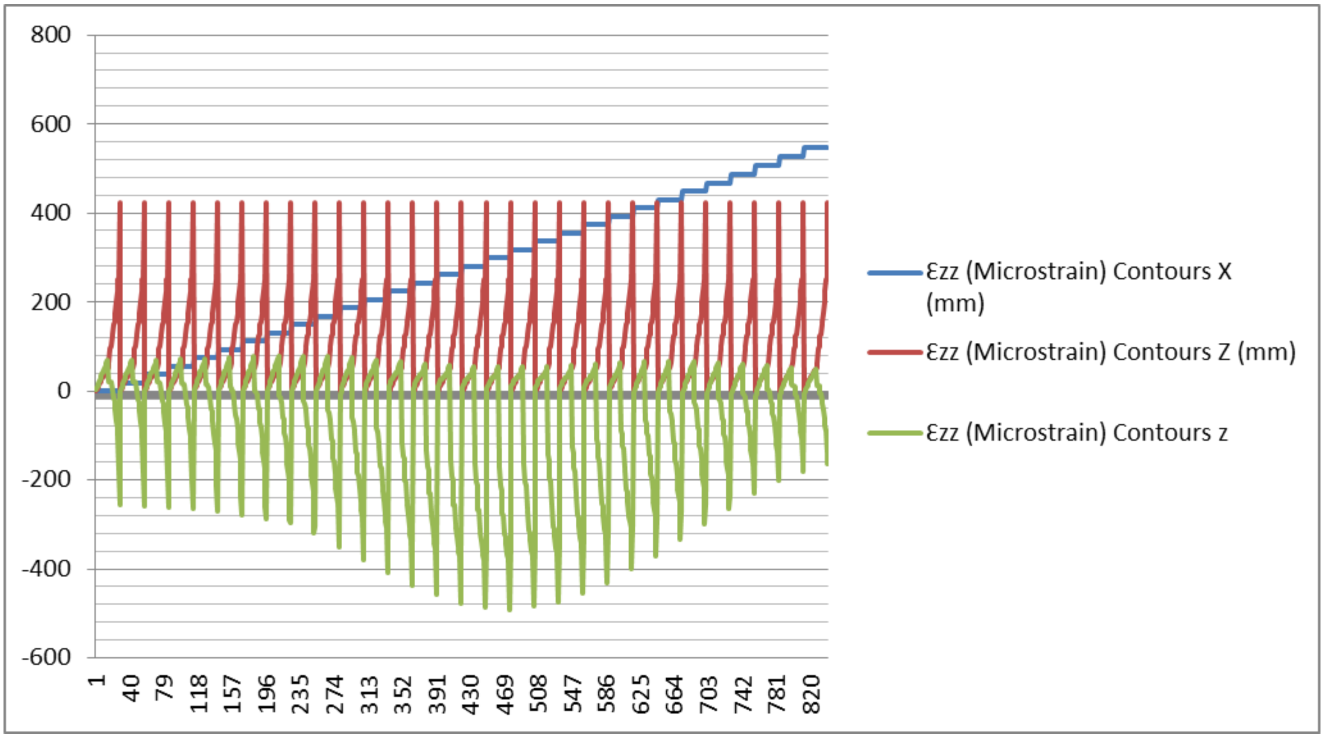
48
95
142
189
236
283
330
377
424
471
518
565
612
659
706
753
800
Ɛxx (Microstrain) Contours X (mm)
Ɛxx (Microstrain) Contours Z (mm)
Ɛxx (Microstrain) Contours z


εxx (Microstrain) Contours
Z (mm)
X (mm)
0
50
100
150
200
250
300
350
400
0
100
200
300
400
500
275.4526
243.4327
211.4127
179.3928
147.3728
115.3529
83.33291
51.31296
19.29301
-12.72695
-44.7469
-76.76685
-108.7868
-140.8068
-172.8267
-204.8467
-236.8666

X (mn	Z (mn	z	X (mm)	Z (mm	z	X (mm)	Z (mm	z	X (mm	Z (mm	z	X (mm)	Z (mm)	z	X (mm)	Z (mm	z	X (mm)	Z (mm)	z	X (mm)	Z (mm)	z
0	0	2.151	56	226	-105	130.7	176	-130.3	205.3	151	-216	280	125	-266.2	354.67	93.75	-173.1	429.3	51	-46.75	487	156.25	-80.55
0	4.17	7.588	56	251	-122	130.7	201	-163.7	205.3	156.3	-223	280	126	-268.2	354.67	101	-180.9	429.3	62.5	-53.05	487	176	-103.5
0	8.33	12.95	56	252	-202	130.7	226	-182.1	205.3	176	-248	280	151	-312.9	354.67	125	-232.7	429.3	93.75	-70.17	487	201	-131.9
0	12.5	18.47	56	423	-266	130.7	251	-200.4	205.3	201	-279	280	156.3	-318	354.67	126	-234.7	429.3	101	-74.14	487	226	-147.2
0	16.7	24.13	74.667	0	-2.13	130.7	252	-289.7	205.3	226	-294	280	176	-337	354.67	151	-279.3	429.3	125	-115	487	251	-162.5
0	20.8	29.83	74.667	4.167	4.266	130.7	423	-296.5	205.3	251	-309	280	201	-360.2	354.67	156.3	-285	429.3	126	-116.6	487	252	-231.2
0	25	35.5	74.667	8.333	10.62	149.3	0	-6.616	205.3	252	-410	280	226	-369.5	354.67	176	-306.1	429.3	151	-155.8	487	423	-218.4
0	29.2	41.11	74.667	12.5	16.97	149.3	4.167	1.3094	205.3	423	-333	280	251	-378.8	354.67	201	-332	429.3	156.25	-162.8	506.5	0	-10.52
0	31.3	43.92	74.667	16.67	23.35	149.3	8.333	8.9538	224	0	10.58	280	252	-485.2	354.67	226	-342.7	429.3	176	-188.5	506.5	4.1667	-4.135
0	33.3	46.72	74.667	20.83	29.68	149.3	12.5	16.031	224	4.167	16.65	280	423	-349	354.67	251	-353.4	429.3	201	-220.2	506.5	8.3333	1.703
0	37.5	52.17	74.667	25	36.03	149.3	16.67	23.109	224	8.333	22.27	298.7	0	6.132	354.67	252	-454	429.3	226	-235.1	506.5	12.5	7.563
0	41.7	57.65	74.667	29.17	42.32	149.3	20.83	29.78	224	12.5	26.28	298.7	4.167	11.54	354.67	423	-327.9	429.3	251	-250.1	506.5	16.667	13.73
0	45.8	62.86	74.667	31.25	45.46	149.3	25	36.558	224	16.67	28.34	298.7	8.333	15.25	373.33	0	7.677	429.3	252	-334.6	506.5	20.833	19.25
0	50	68.07	74.667	33.33	48.6	149.3	29.17	43.196	224	20.83	30.59	298.7	12.5	17.94	373.33	4.167	13.29	429.3	423	-272.7	506.5	25	25.07
0	51	21.44	74.667	37.5	54.79	149.3	31.25	46.538	224	25	34.05	298.7	16.67	22.08	373.33	8.333	19.03	448	0	-9.727	506.5	29.167	30.79
0	62.5	21.39	74.667	41.67	61.02	149.3	33.33	49.896	224	29.17	38.02	298.7	20.83	24.77	373.33	12.5	23.46	448	4.1667	-2.013	506.5	31.25	33.55
0	93.8	21.24	74.667	45.83	67.15	149.3	37.5	56.835	224	31.25	40.11	298.7	25	27.91	373.33	16.67	25.36	448	8.3333	4.221	506.5	33.333	36.25
0	101	21.21	74.667	50	73.28	149.3	41.67	63.828	224	33.33	42.26	298.7	29.17	30.67	373.33	20.83	27.47	448	12.5	9.8711	506.5	37.5	42.15
0	125	3.62	74.667	51	14.26	149.3	45.83	71.421	224	37.5	47.28	298.7	31.25	31.92	373.33	25	30.38	448	16.667	16.403	506.5	41.667	47.76
0	126	2.87	74.667	62.5	13.22	149.3	50	79.014	224	41.67	52.87	298.7	33.33	33.07	373.33	29.17	33.77	448	20.833	22.469	506.5	45.833	52.19
0	151	-16.29	74.667	93.75	10.41	149.3	51	-23.68	224	45.83	59.36	298.7	37.5	36.88	373.33	31.25	35.65	448	25	28.917	506.5	50	56.61
0	156	-21.7	74.667	101	9.754	149.3	62.5	-28.33	224	50	65.85	298.7	41.67	40.5	373.33	33.33	37.65	448	29.167	35.222	506.5	51	3.686
0	176	-42.05	74.667	125	-13.8	149.3	93.75	-40.96	224	51	-106	298.7	45.83	47.27	373.33	37.5	42.3	448	31.25	38.299	506.5	62.5	2.258
0	201	-67.82	74.667	126	-14.8	149.3	101	-43.89	224	62.5	-117	298.7	50	54.03	373.33	41.67	47.75	448	33.333	41.326	506.5	93.75	-1.621
0	226	-84.38	74.667	151	-39.6	149.3	125	-81.72	224	93.75	-145	298.7	51	-156.3	373.33	45.83	54.12	448	37.5	47.719	506.5	101	-2.52
0	251	-100.9	74.667	156.3	-45.9	149.3	126	-83.25	224	101	-152	298.7	62.5	-171.7	373.33	50	60.49	448	41.667	53.657	506.5	125	-26.47
0	252	-177.8	74.667	176	-69.4	149.3	151	-120.6	224	125	-203	298.7	93.75	-213.3	373.33	51	-110.3	448	45.833	60.245	506.5	126	-27.46
0	423	-256.9	74.667	201	-98.9	149.3	156.3	-128.1	224	126	-204	298.7	101	-223	373.33	62.5	-121	448	50	66.833	506.5	151	-51.89
18.67	0	1.458	74.667	226	-117	149.3	176	-155.7	224	151	-249	298.7	125	-276.8	373.33	93.75	-150.1	448	51	-26.82	506.5	156.25	-57.56
18.67	4.17	7.046	74.667	251	-134	149.3	201	-189.9	224	156.3	-256	298.7	126	-278.8	373.33	101	-156.8	448	62.5	-31.48	506.5	176	-78.65
18.67	8.33	12.6	74.667	252	-216	149.3	226	-208.1	224	176	-279	298.7	151	-323.2	373.33	125	-207.2	448	93.75	-44.14	506.5	201	-104.9
18.67	12.5	18.29	74.667	423	-271	149.3	251	-226.2	224	201	-309	298.7	156.3	-328.1	373.33	126	-209.1	448	101	-47.08	506.5	226	-119.5
18.67	16.7	24.04	93.333	0	-4.02	149.3	252	-318.5	224	226	-322	298.7	176	-346.1	373.33	151	-253.6	448	125	-84.51	506.5	251	-134.1
18.67	20.8	29.81	93.333	4.167	2.849	149.3	423	-306	224	251	-335	298.7	201	-368.3	373.33	156.3	-259.8	448	126	-86.02	506.5	252	-197.3
18.67	25	35.56	93.333	8.333	9.702	168	0	-7.892	224	252	-438	298.7	226	-377	373.33	176	-282.6	448	151	-122.4	506.5	423	-200
18.67	29.2	41.27	93.333	12.5	16.4	168	4.167	0.4651	224	423	-340	298.7	251	-385.6	373.33	201	-310.6	448	156.25	-129.5	526	0	-7.092
18.67	31.3	44.12	93.333	16.67	23.12	168	8.333	8.781	242.7	0	7.044	298.7	252	-492.2	373.33	226	-322.6	448	176	-155.6	526	4.1667	-1.787
18.67	33.3	46.97	93.333	20.83	29.7	168	12.5	15.794	242.7	4.167	12.11	298.7	423	-348.7	373.33	251	-334.6	448	201	-187.8	526	8.3333	3.275
18.67	37.5	52.53	93.333	25	36.26	168	16.67	22.982	242.7	8.333	17.05	317.3	0	10.67	373.33	252	-432.2	448	226	-203.6	526	12.5	8.312
18.67	41.7	58.11	93.333	29.17	42.77	168	20.83	29.396	242.7	12.5	22.8	317.3	4.167	14.71	373.33	423	-317.7	448	251	-219.5	526	16.667	13.47
18.67	45.8	63.46	93.333	31.25	46.01	168	25	35.843	242.7	16.67	25.67	317.3	8.333	18.13	392	0	2.514	448	252	-299	526	20.833	18.51
18.67	50	68.81	93.333	33.33	49.26	168	29.17	42.176	242.7	20.83	28.2	317.3	12.5	22.07	392	4.167	8.831	448	423	-255.9	526	25	23.85
18.67	51	20.71	93.333	37.5	55.74	168	31.25	45.327	242.7	25	31.59	317.3	16.67	24.83	392	8.333	15.38	467.5	0	-11.84	526	29.167	29.13
18.67	62.5	20.53	93.333	41.67	62.25	168	33.33	48.467	242.7	29.17	34.72	317.3	20.83	26.8	392	12.5	19.82	467.5	4.1667	-4.248	526	31.25	31.66
18.67	93.8	20.03	93.333	45.83	68.79	168	37.5	55.191	242.7	31.25	36.6	317.3	25	29.16	392	16.67	23.2	467.5	8.3333	2.1762	526	33.333	34.12
18.67	101	19.91	93.333	50	75.34	168	41.67	61.908	242.7	33.33	38.69	317.3	29.17	31.2	392	20.83	26.66	467.5	12.5	8.3422	526	37.5	39.1
18.67	125	1.558	93.333	51	7.644	168	45.83	69.523	242.7	37.5	43.24	317.3	31.25	32.42	392	25	30.5	467.5	16.667	15.199	526	41.667	43.82
18.67	126	0.778	93.333	62.5	5.909	168	50	77.139	242.7	41.67	48.55	317.3	33.33	33.77	392	29.17	34.73	467.5	20.833	21.224	526	45.833	48.51
18.67	151	-19.11	93.333	93.75	1.194	168	51	-42.66	242.7	45.83	55.13	317.3	37.5	37.39	392	31.25	36.94	467.5	25	27.608	526	50	53.21
18.67	156	-24.64	93.333	101	0.101	168	62.5	-48.66	242.7	50	61.71	317.3	41.67	41.39	392	33.33	39.22	467.5	29.167	33.839	526	51	13.85
18.67	176	-45.42	93.333	125	-26.8	168	93.75	-64.99	242.7	51	-124	317.3	45.83	47.89	392	37.5	44.37	467.5	31.25	36.872	526	62.5	13.02
18.67	201	-71.69	93.333	126	-27.9	168	101	-68.77	242.7	62.5	-136	317.3	50	54.39	392	41.67	49.8	467.5	33.333	39.85	526	93.75	10.75
18.67	226	-88.44	93.333	151	-55.8	168	125	-110.1	242.7	93.75	-169	317.3	51	-150.4	392	45.83	56.84	467.5	37.5	46.467	526	101	10.23
18.67	251	-105.2	93.333	156.3	-62.4	168	126	-111.7	242.7	101	-177	317.3	62.5	-165	392	50	63.89	467.5	41.667	52.68	526	125	-9.202
18.67	252	-182.6	93.333	176	-87.2	168	151	-151.7	242.7	125	-229	317.3	93.75	-204.9	392	51	-88.5	467.5	45.833	58.053	526	126	-10.01
18.67	423	-258.7	93.333	201	-118	168	156.3	-159	242.7	126	-231	317.3	101	-214.1	392	62.5	-97.62	467.5	50	63.427	526	151	-30.41
37.33	0	0.855	93.333	226	-136	168	176	-186.3	242.7	151	-276	317.3	125	-267.7	392	93.75	-122.4	467.5	51	-16.65	526	156.25	-35.54
37.33	4.17	6.554	93.333	251	-155	168	201	-220	242.7	156.3	-282	317.3	126	-269.7	392	101	-128.1	467.5	62.5	-19.99	526	176	-54.68
37.33	8.33	12.27	93.333	252	-238	168	226	-237.2	242.7	176	-303	317.3	151	-314.2	392	125	-175.5	467.5	93.75	-29.07	526	201	-78.53
37.33	12.5	18.1	93.333	423	-279	168	251	-254.5	242.7	201	-330	317.3	156.3	-319.3	392	126	-177.3	467.5	101	-31.18	526	226	-92.07
37.33	16.7	23.92	112	0	-5.67	168	252	-349.7	242.7	226	-342	317.3	176	-338	392	151	-220.6	467.5	125	-64.13	526	251	-105.6
37.33	20.8	29.78	112	4.167	1.607	168	423	-315.5	242.7	251	-353	317.3	201	-360.9	392	156.3	-227.1	467.5	126	-65.46	526	252	-163.4
37.33	25	35.64	112	8.333	8.892	186.7	0	-8.13	242.7	252	-458	317.3	226	-369.9	392	176	-251.4	467.5	151	-97.91	526	423	-181.9
37.33	29.2	41.46	112	12.5	15.86	186.7	4.167	0.5498	242.7	423	-345	317.3	251	-378.9	392	201	-281	467.5	156.25	-104.5	548	0	-5.629
37.33	31.3	44.36	112	16.67	22.84	186.7	8.333	9.427	261.3	0	11.69	317.3	252	-484	392	226	-294.3	467.5	176	-129.1	548	4.1667	-0.889
37.33	33.3	47.25	112	20.83	29.65	186.7	12.5	16.197	261.3	4.167	15.11	317.3	423	-343.4	392	251	-307.7	467.5	201	-159.5	548	8.3333	3.632
37.33	37.5	52.92	112	25	36.44	186.7	16.67	23.316	261.3	8.333	18.75	336	0	9.499	392	252	-401.2	467.5	226	-175.3	548	12.5	8.167

37.33	41.7	58.61	112	29.17	43.17	186.7	20.83	29.341	261.3	12.5	24.87	336	4.167	12.87	392	423	-303.6	467.5	251	-191	548	16.667	12.82
37.33	45.8	64.08	112	31.25	46.53	186.7	25	35.322	261.3	16.67	27.22	336	8.333	16.71	410.67	0	-10.78	467.5	252	-265.1	548	20.833	17.32
37.33	50	69.55	112	33.33	49.9	186.7	29.17	41.231	261.3	20.83	28.97	336	12.5	22.96	410.67	4.167	-2.588	467.5	423	-237	548	25	22.05
37.33	51	19.98	112	37.5	56.67	186.7	31.25	44.13	261.3	25	31.26	336	16.67	25.41	410.67	8.333	5.922	487	0	-12.11	548	29.167	26.73
37.33	62.5	19.69	112	41.67	63.49	186.7	33.33	46.991	261.3	29.17	33.03	336	20.83	27.15	410.67	12.5	12.07	487	4.1667	-4.955	548	31.25	28.98
37.33	93.8	18.9	112	45.83	70.44	186.7	37.5	53.424	261.3	31.25	34.44	336	25	29.25	410.67	16.67	18.64	487	8.3333	1.337	548	33.333	31.17
37.33	101	18.72	112	50	77.39	186.7	41.67	59.786	261.3	33.33	36.2	336	29.17	30.81	410.67	20.83	24.07	487	12.5	7.5727	548	37.5	35.71
37.33	125	-0.416	112	51	1.026	186.7	45.83	67.525	261.3	37.5	40.04	336	31.25	32.12	410.67	25	29.45	487	16.667	14.308	548	41.667	40.01
37.33	126	-1.227	112	62.5	-1.42	186.7	50	75.263	261.3	41.67	44.81	336	33.33	33.79	410.67	29.17	34.83	487	20.833	20.15	548	45.833	44.1
37.33	151	-21.87	112	93.75	-8.06	186.7	51	-61.63	261.3	45.83	51.19	336	37.5	37.46	410.67	31.25	37.52	487	25	26.327	548	50	48.18
37.33	156	-27.52	112	101	-9.6	186.7	62.5	-69.1	261.3	50	57.57	336	41.67	42.07	410.67	33.33	40.22	487	29.167	32.363	548	51	12.73
37.33	176	-48.74	112	125	-39.9	186.7	93.75	-89.4	261.3	51	-142	336	45.83	48.41	410.67	37.5	46.41	487	31.25	35.29	548	62.5	12.23
37.33	201	-75.56	112	126	-41.1	186.7	101	-94.12	261.3	62.5	-156	336	50	54.75	410.67	41.67	52.36	487	33.333	38.157	548	93.75	10.86
37.33	226	-92.49	112	151	-72	186.7	125	-138.8	261.3	93.75	-193	336	51	-144.4	410.67	45.83	59.83	487	37.5	44.612	548	101	10.54
37.33	251	-109.4	112	156.3	-79	186.7	126	-140.6	261.3	101	-202	336	62.5	-158.2	410.67	50	67.29	487	41.667	50.715	548	125	-5.52
37.33	252	-187.5	112	176	-105	186.7	151	-183.1	261.3	125	-255	336	93.75	-195.9	410.67	51	-66.68	487	45.833	55.368	548	126	-6.193
37.33	423	-260.6	112	201	-138	186.7	156.3	-190.3	261.3	126	-257	336	101	-204.7	410.67	62.5	-74.28	487	50	60.02	548	151	-23.14
56	0	-0.704	112	226	-156	186.7	176	-217.2	261.3	151	-302	336	125	-258	410.67	93.75	-94.92	487	51	-6.482	548	156.25	-27.5
56	4.17	5.369	112	251	-175	186.7	201	-250.2	261.3	156.3	-307	336	126	-260	410.67	101	-99.71	487	62.5	-8.745	548	176	-43.76
56	8.33	11.43	112	252	-261	186.7	226	-266.5	261.3	176	-327	336	151	-304.7	410.67	125	-144	487	93.75	-14.89	548	201	-64.01
56	12.5	17.54	112	423	-287	186.7	251	-282.8	261.3	201	-352	336	156.3	-309.9	410.67	126	-145.7	487	101	-16.32	548	226	-76.41
56	16.7	23.66	130.67	0	-6.4	186.7	252	-381	261.3	226	-362	336	176	-329.4	410.67	151	-187.7	487	125	-44.78	548	251	-88.81
56	20.8	29.74	130.67	4.167	1.204	186.7	423	-324.9	261.3	251	-372	336	201	-353.2	410.67	156.3	-194.6	487	126	-45.94	548	252	-141.2
56	25	35.84	130.67	8.333	8.673	205.3	0	4.3975	261.3	252	-478	336	226	-362.7	410.67	176	-220.2	487	151	-74.39	548	423	-163.8
56	29.2	41.89	130.67	12.5	15.73	205.3	4.167	11.476	261.3	423	-349	336	251	-372.2	410.67	201	-251.5						
56	31.3	44.9	130.67	16.67	22.79	205.3	8.333	18.432	280	0	9.812	336	252	-475.8	410.67	226	-266.1						
56	33.3	47.91	130.67	20.83	29.58	205.3	12.5	23.292	280	4.167	14.16	336	423	-338.1	410.67	251	-280.7						
56	37.5	53.84	130.67	25	36.41	205.3	16.67	27.353	280	8.333	17.76	354.7	0	6.551	410.67	252	-370.1						
56	41.7	59.8	130.67	29.17	43.12	205.3	20.83	31.111	280	12.5	22.08	354.7	4.167	10.99	410.67	423	-289.5						
56	45.8	65.61	130.67	31.25	46.49	205.3	25	35.449	280	16.67	25.22	354.7	8.333	15.72	429.33	0	-10.88						
56	50	71.42	130.67	33.33	49.87	205.3	29.17	40.177	280	20.83	27.37	354.7	12.5	21.21	429.33	4.167	-2.669						
56	51	17.12	130.67	37.5	56.74	205.3	31.25	42.562	280	25	30.01	354.7	16.67	23.52	429.33	8.333	4.959						
56	62.5	16.45	130.67	41.67	63.66	205.3	33.33	44.961	280	29.17	32.19	354.7	20.83	25.86	429.33	12.5	11.05						
56	93.8	14.63	130.67	45.83	70.93	205.3	37.5	50.566	280	31.25	33.48	354.7	25	28.78	429.33	16.67	17.79						
56	101	14.21	130.67	50	78.2	205.3	41.67	56.414	280	33.33	34.89	354.7	29.17	31.55	429.33	20.83	23.33						
56	125	-7.137	130.67	51	-11.3	205.3	45.83	63.484	280	37.5	38.64	354.7	31.25	33.29	429.33	25	29.04						
56	126	-8.036	130.67	62.5	-14.8	205.3	50	70.554	280	41.67	42.76	354.7	33.33	35.27	429.33	29.17	34.6						
56	151	-30.77	130.67	93.75	-24.4	205.3	51	-84.02	280	45.83	49.28	354.7	37.5	39.47	429.33	31.25	37.34						
56	156	-36.72	130.67	101	-26.6	205.3	62.5	-92.98	280	50	55.8	354.7	41.67	44.54	429.33	33.33	40.06						
56	176	-59.06	130.67	125	-60.7	205.3	93.75	-117.3	280	51	-149	354.7	45.83	51.08	429.33	37.5	46.34						
56	201	-87.21	130.67	126	-62.1	205.3	101	-123	280	62.5	-164	354.7	50	57.62	429.33	41.67	52.28						
			130.67	151	-96.2	205.3	125	-170.6	280	93.75	-203	354.7	51	-127.3	429.33	45.83	59.67						
			130.67	156.3	-103	205.3	126	-172.4	280	101	-213	354.7	62.5	-139.7	429.33	50	67.06						

Ɛzz (Microstrain) Contours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430
469
508
547
586
625
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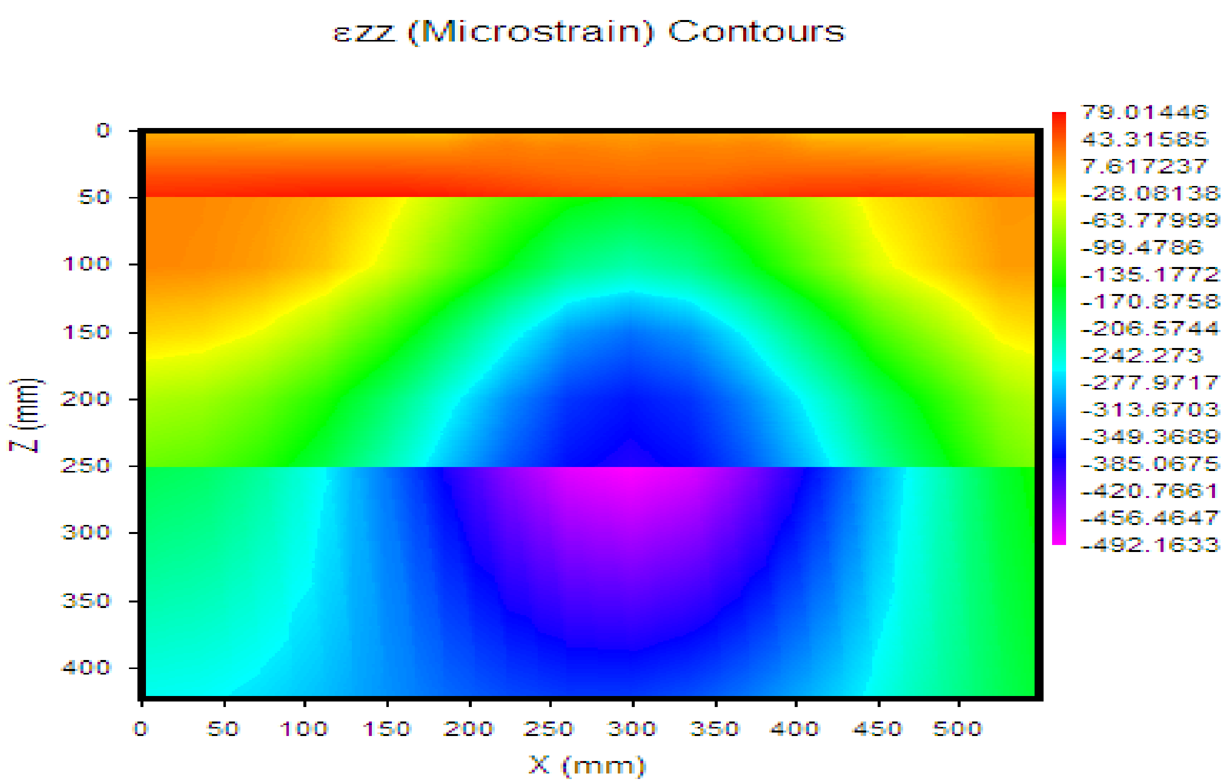
703
742
781
820
Ɛzz (Microstrain) Contours X (mm)
Ɛzz (Microstrain) Contours Z (mm)
Ɛzz (Microstrain) Contours z


εzz (Microstrain) Contours
Z (mm)
X (mm)
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7.617237
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-99.4786
-135.1772
-170.8758
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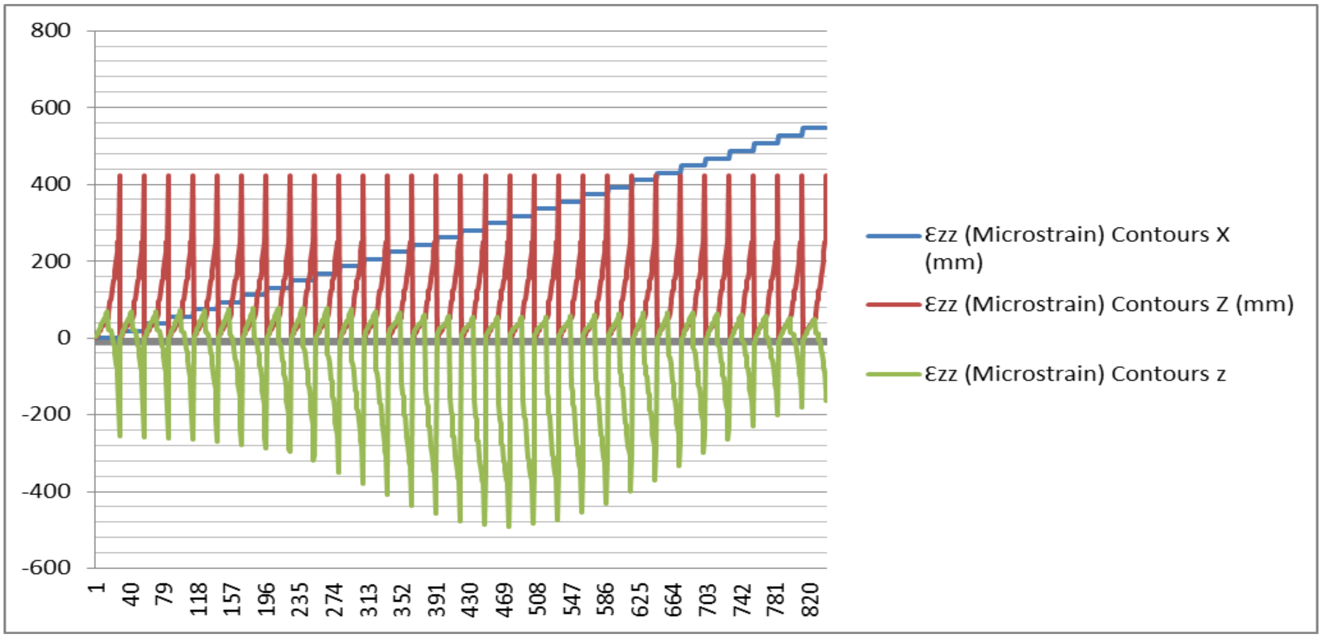
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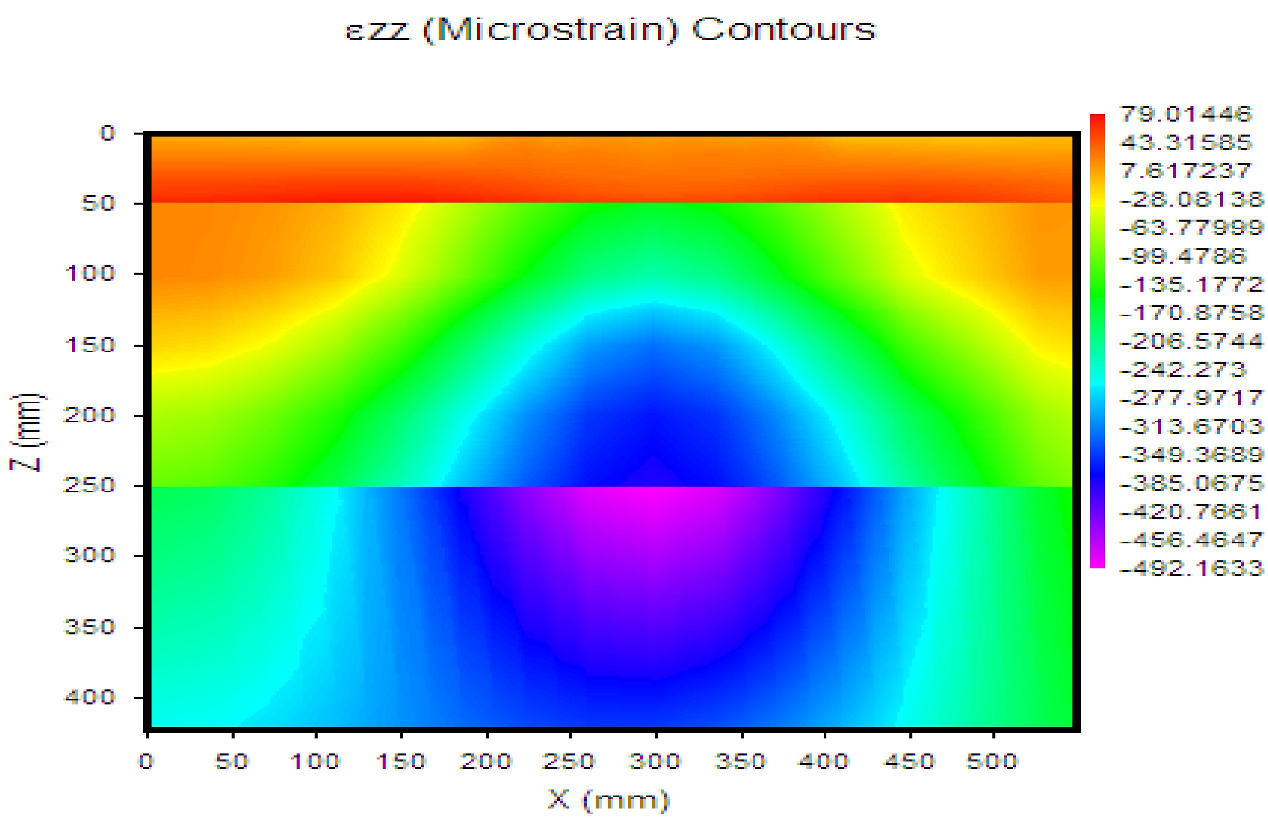
Ɛzz (Microstrain) Contours X (mm)
Ɛzz (Microstrain) Contours Z (mm)
Ɛzz (Microstrain) Contours z


εzz (Microstrain) Contours
Z (mm)
X (mm)
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7.617237
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