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

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Abstract: In Ethiopia the failure of roads are before handover period. 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.

Keywords: Finite Element Analysis, Flexible Pavement, Layers Thickness, Modulus and Vertical Surface Deflections

1. Introduction

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.

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.

1.1. 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.

1.2. Research Questions

a) What are the parameters that cause stress-strain and deflection of flexible pavement?
b) 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?
c) How the layers of flexible pavement are affected by vertical surface deflections and the critical horizontal tensile strains?

1.3. Objective of the Study

1.3.1. 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.

1.3.2. Specific Objectives of the Study

a) To identify the parameters that causes stress, strain and deflection of flexible pavement.
b) 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.
c) To describe how the layers of flexible pavement are affected by vertical surface deflections and the critical horizontal tensile strains.

2. Research Methodology

Finite element method (FEM) is a numerical analysis technique to obtain the stress-strain and deflection of each pavement layers.

2.1. Study Area

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.

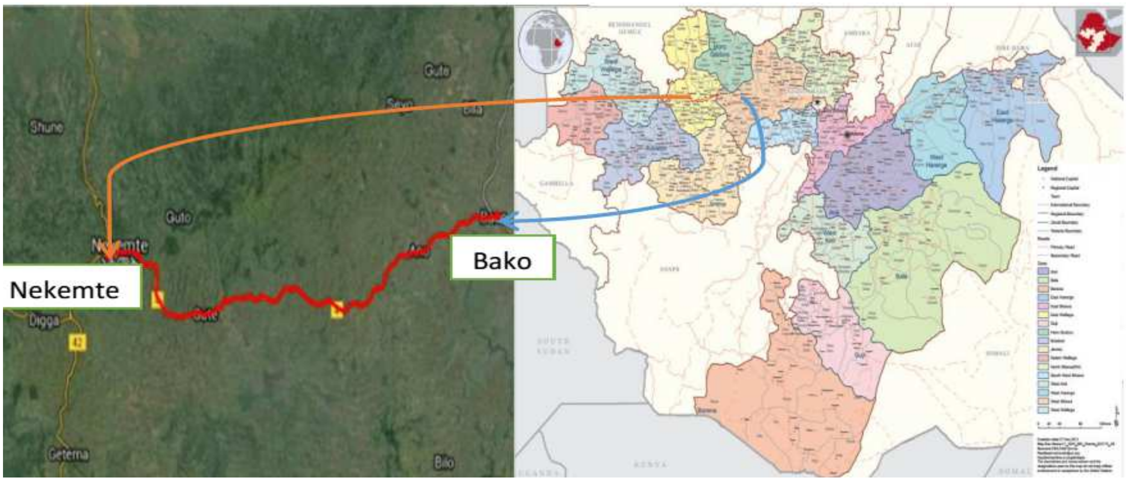

Figure 1. *Map of the research study area.*

2.2. Design Method of the Study

It is similarly analytical because it systematically identifies numerical analysis and addresses the practical cause, problem, and their solution. Analytical method usually uses layers thickness, loads, elastic modulus and Poisson's ratio of the pavement materials as design parameters.

2.3. Assumptions of Analytical Solutions to the State of Stress or Strain

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

2.4. 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)

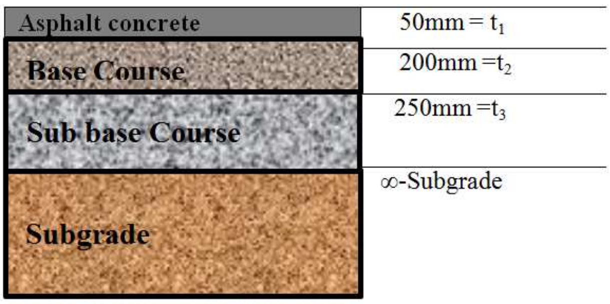

Figure 2. *Basic Component of layers in Bako-Nekemte road.*

2.5. 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.

2.6. 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.

2.7. 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.

2.8. 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.

2.9. 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.

2.10. 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.

2.11. 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

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

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

3. Results and Discussion

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

3.1. 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 1. *CBR values of base course materials from laboratory test result.*

California Bearing Ratio Test						
Test Method: AASHTO T-193						
Blows	**Load (KN)**		**CBR (%)**		**avg. CBR**	**E.(Mpa)**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**		
10	3.68	7.19	27.6	36.1	31.81	109.5306
30	6.21	13.64	46.5	68.4	57.49	222.8633
65	18.51	38.98	138.7	194.9	166.8	800.033
					85.36	358.1206
Blows	**Load (KN)**		**CBR (%)**		**avg. CBR**	**E.(Mpa)**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**		
10	6.02	10.03	45.1	50.1	47.6	177.6911
30	12.3	21.2	91.9	105.4	98.65	426.0433
65	20.1	30.1	150.3	149.8	150.1	704.7263
					98.77	426.648
Blows	**Load (KN)**		**CBR (%)**		**avg. CBR**	**E.(Mpa)**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**		
10	8.34	13.60	62.5	68.0	65.22	259.2712
30	12.44	21.29	93.2	106.5	99.83	432.166
65	16.29	26.68	122.0	133.4	127.7	580.774
					97.59	420.53

3.2. 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 2. *CBR values of subbase course materials from laboratory test result.*

California Bearing Ratio Test						
Test Method: Aashto T-193						
Blows	**Load (KN)**		**CBR (%)**		**avg. CBR**	**E.(MPa)**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**		
10	1.44	2.44	10.8	12.2	21.494	32.29363
30	3.29	6.21	24.6	31.2	27.901	112.6007
65	3.41	4.87	25.5	24.4	28.953	132.86255
					29.449	155.27093
Blows	**Load (KN)**		**CBR (%)**		**avg. CBR**	**E.(Mpa**
	2.54mm	**5.08mm**	**2.54mm**	**5.08mm**		
10	2.7	3.6	19.9	18.1	19	59.02576
30	3.1	4.2	23.6	21.1	25.35	71.72496
65	6.4	7.6	48.2	37.8	45	157.2894
					40.117	145.46999

California Bearing Ratio Test						
Test Method: Aashto T-193						
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

3.3. 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 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

3.4. 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.

3.5. 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 Ɛc 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 3.

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.

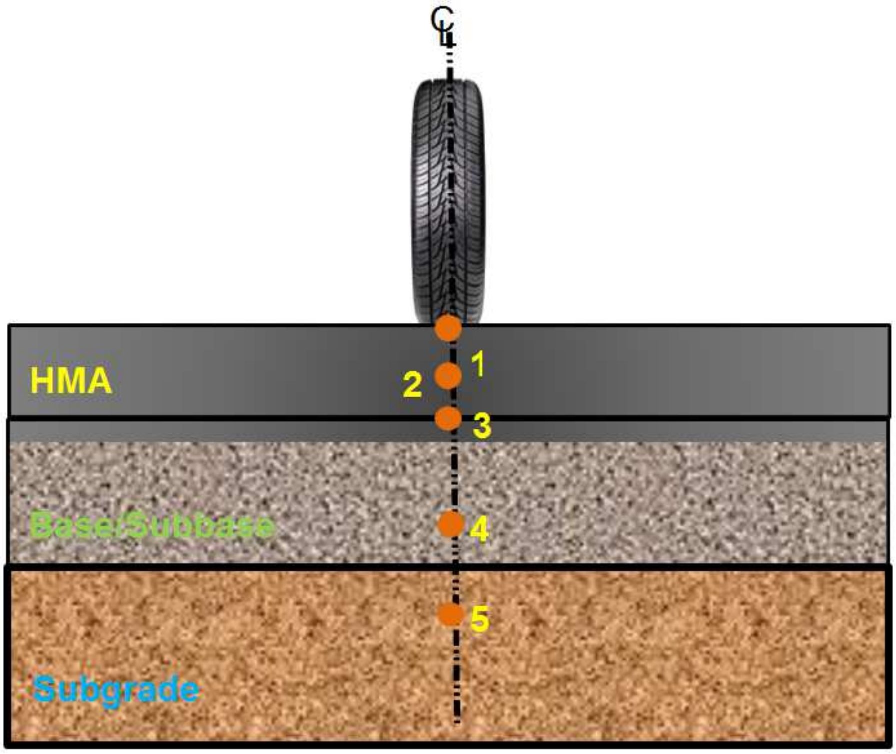

Figure 3. *Critical asphalt pavement responses locations.*

3.6. 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 ($t_4 = \infty$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 ($t_4 = \infty$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. *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 5. *Some Institution (Asphalt institute, AASHTO&ERA) Test Design Standard of specifications.*

Layer n	Materials	CBR	Elasticmodulus (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	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 6. *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 7. *Pavement material properties and thickness.*

Road properties	Layers thickness (mm)	Laboratory Test Result			Standard Specification Result		
		CBR	E. MPa	V	CBR %	Mr. MPa	V
Asphalt concrete	50	-	3000	0.300	-	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 8. *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

3.7. 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.

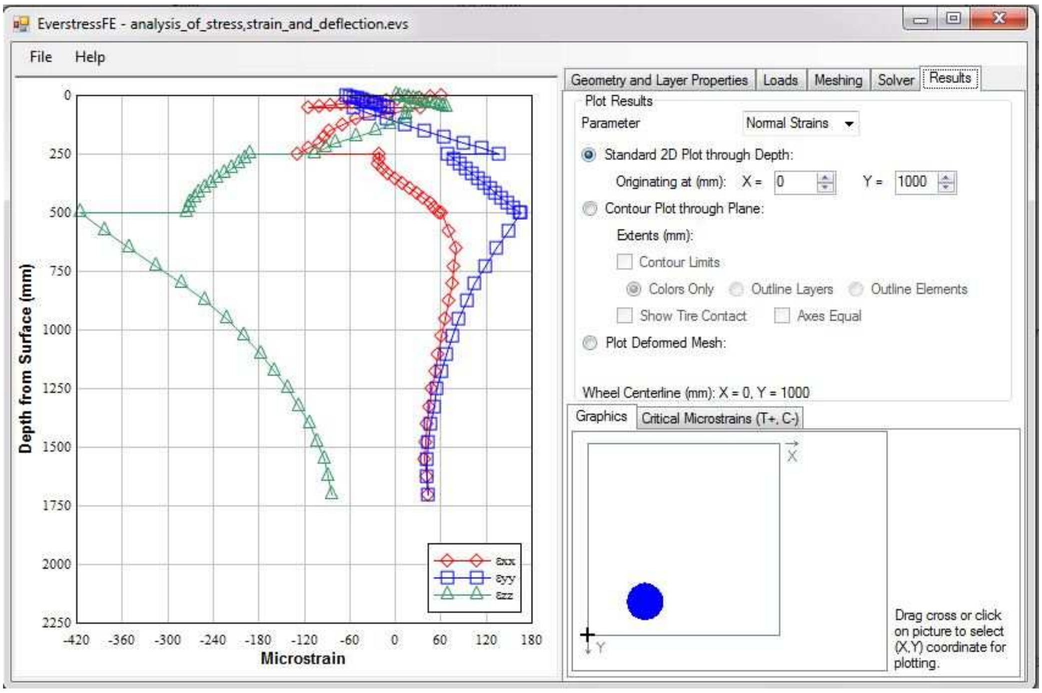

Figure 4. Output of normal strain (Ɛxx, Ɛyy and Ɛzz), shear strain and deflection.

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.

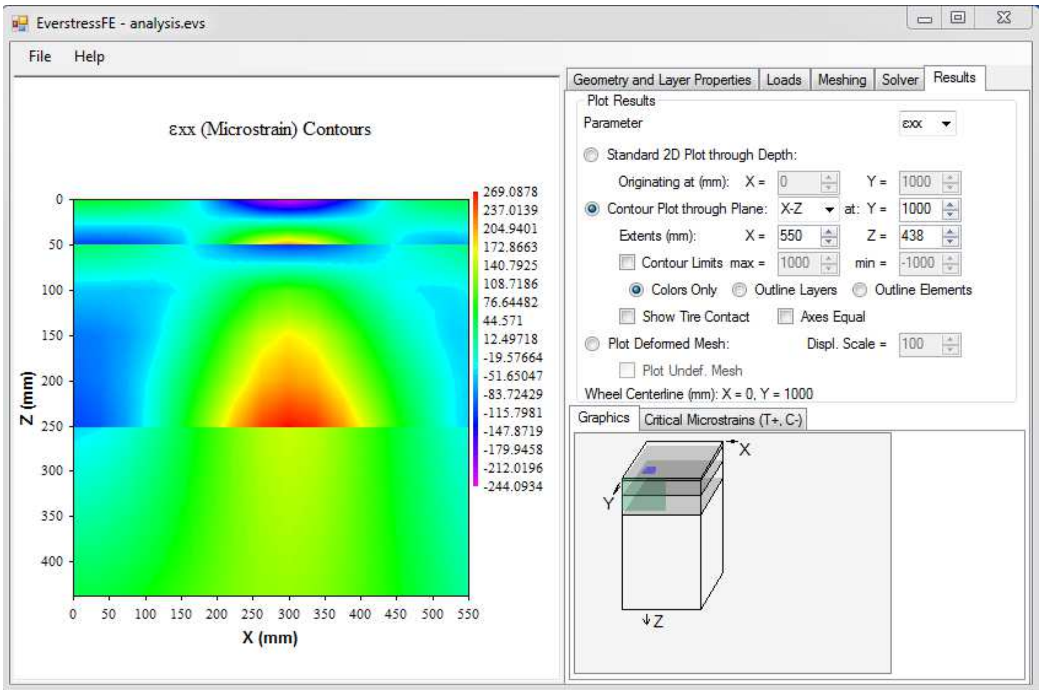

Figure 5. contour plots through plane and show where the layer of road affected.

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

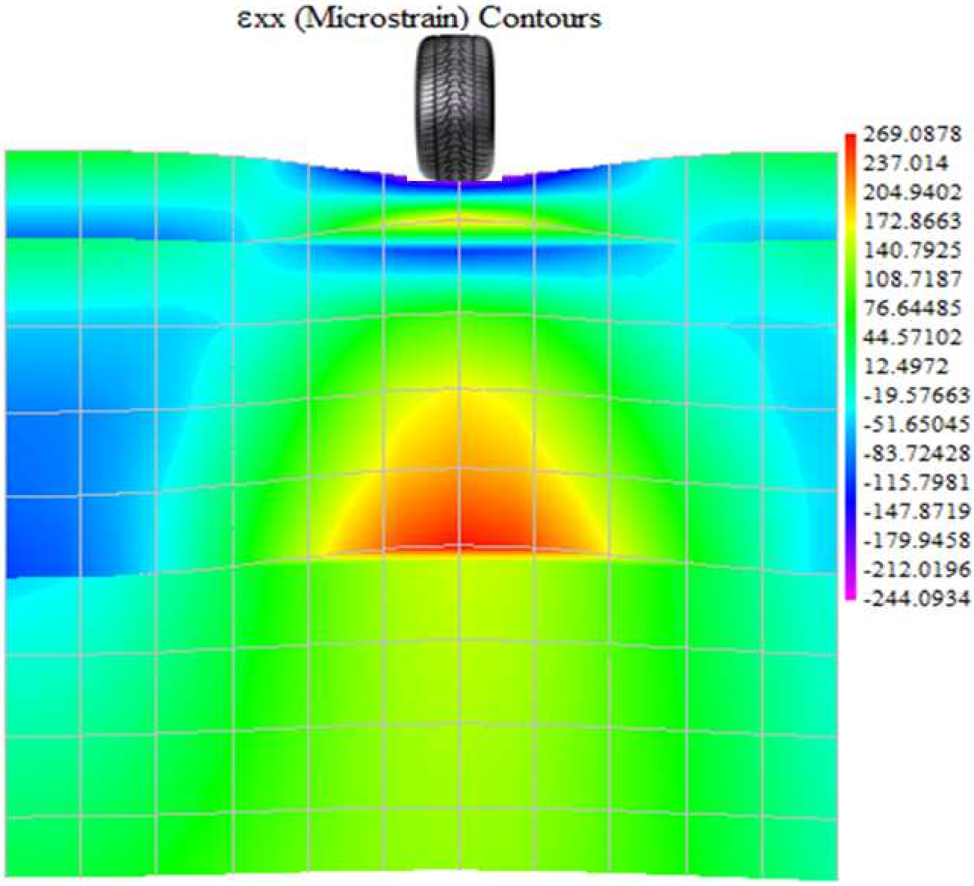

Figure 6. *The diagram show deflection of road at the center of wheel.*

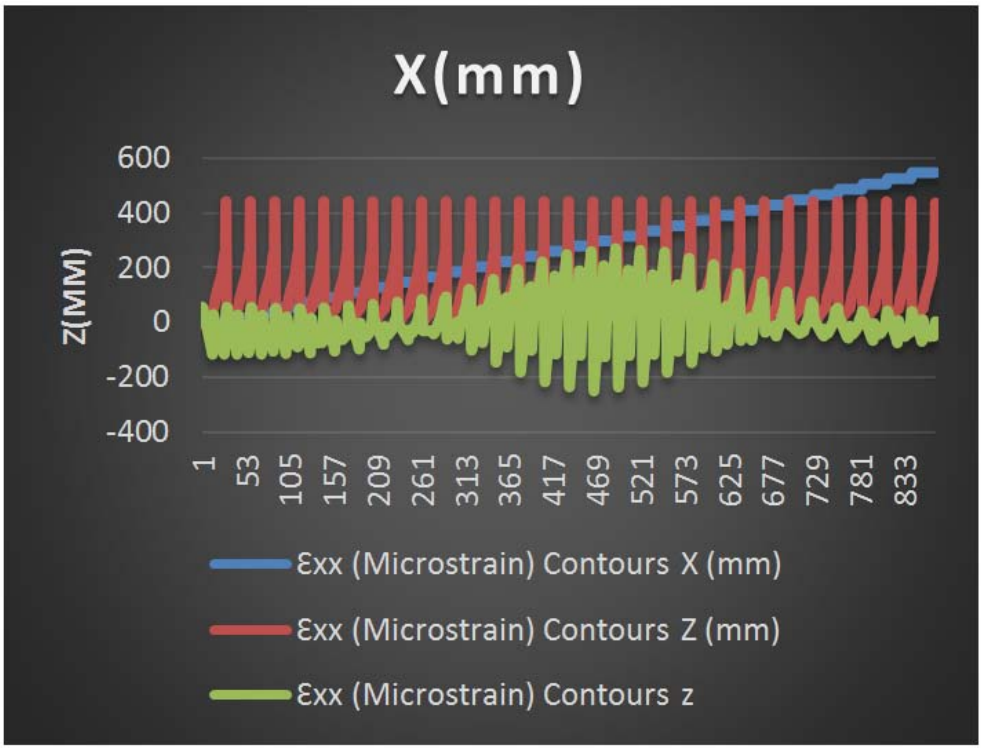

Figure 7. *The graph shows the properties of strain on X-Z plane.*

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 9. *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	γxy	γyz	γzx	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 10. *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 11. *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	-417.8	-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 12. *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 13. *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.

4. 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. 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.

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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