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Mechanistic Empirical Modelling and Design of Geosynthetic Reinforced Flexible Pavement

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Abstract
Roads are considered as arteries and veins of a nation. The designing and development of roadways should be done with utmost care. An increase in population increases the traffic. This increase in traffic demands smooth, durable, strong and well maintained road pavement, thereby increasing the need for strengthening and improving efficiency of road network. In order to provide these functions the soil can be reinforced with suitable materials. Geosynthetics are used successfully to reinforce the soil structures and plays a significant role in modern pavement design and maintenance techniques. There are different types of geosynthetics among them the study focuses on the behavior of soil reinforced with geotextiles. Geotextiles improves the load bearing capacity and improves the drainage characteristics of the subgrade. This study focuses on the improvement in the performance of pavement subgrade reinforced with geotextiles, using empirical-mechanistic based software called KENPAVE. This software is used to calculate stresses and strain in rigid and flexible pavement. Premature failures like fatigue and rutting in flexible pavement cause severe distresses in the pavement. The analysis reveals that the stress strain characteristics are improved upon reinforcement. While reinforced subgrade is governed by failure due to fatigue, unreinforced subgrade fails by rutting.

Keywords: *Flexible pavement performance, Geosynthetics, Geotextile, KENPAVE*

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I. INTRODUCTION

The main structural function of a pavement is to support the loads induced by traffic and to distribute these loads safely to the foundation. The performance of highway pavements is governed by the strength and stiffness of the pavement layers. Heavy traffic demands strong, smooth, durable and well maintained road pavement and hence healthy and strengthened road network is essential for socioeconomic development of a country. Due to disproportionality between number of repetition of heavy traffic loads and structural strength of pavement, pavement deformation or distress is increasing. Roads often have to be constructed across this weak and compressible soil. Whenever a road needs to be built on such soil with low CBR value, settlement may take place during or after construction, with serious consequence in the lifespan of the road. It is therefore a common practice to distribute the traffic loads in order to decrease the stress on the soil sub-grade. This is generally done by placing a reinforcement layer. The strength of the soil may also be increased by using soil stabilization technique. Polymeric materials also called geosynthetics, which include fabrics, grids, composites, or membranes are also used to improve subgrade behaviour. Geo-synthetics increase the strength of sub-grade soil and modify some of its properties so that strength and lifespan of the road is increased. In this study to design a reinforced flexible pavement with different traffic loading the mechanistic computer program KENLAYER is used. KENLAYER is based on the multi-layer linear elastic Burmister model.

II. LITERATURE REVIEW

2.1 Role of geosynthetics in pavement subgrade

Implementing geosynthetics in flexible pavements is known to increase the performance, service life, load carrying capacity, improve the strength, reduce the rut depth and cost and also gives ideas about the function and advantages of geosynthetics (Manasa and Ballari, 2019). The analysis would be designed in a particular feature to experience as large a percentage increase as possible in service for the smallest possible percentage increase in cost. It was found that at the same subgrade strength and same base thickness, the cost effectiveness ratio will increase with an increase in the thickness of HMA layer. The cost effectiveness also increases even if the subgrade CBR is less than 2% with a base layer thinner than 250mm and an HMA thickness less than 100mm. In case of subgrade strength overall design method suggests that with an increase of subgrade strength from CBR=0.5% to 6%, the cost- effectiveness ratio would decrease.

Durability of pavement depends on the stability of the underlying soils. The existing soil at a particular location may not be suitable for the construction due to poor bearing capacity and higher compressibility or even sometimes excessive swelling. Soil reinforcement is a well- known procedure for improving the properties of problematic soil. Geogrids provide interlocking of aggregate at the subgrade interface, provided that the aggregate locks into the grid structure that are of sufficient rigidity and geometry.

In a study done by Keerthi et.al (2018) the engineering properties of locally available clayey soil by soil reinforcement technique by placing geogrid in different stages is identified. Index properties, compaction properties of black cotton soil and sandy gravel soil change in strength properties unreinforced and reinforced soil specimen by CBR after 4 days soaking and optimum position of geogrid placed in the CBR is determined. Basic laboratory test like wet sieve analysis, consistency limits and indices (Liquid limit (LL), Plastic limit (PL), Plasticity index (PI)) and modified proctor test was conducted on black cotton soil and sandy gravel soil. For modified proctor test the geogrid is placed at 40% height of specimen in CBR mould. From the results it is observed that the swelling of BC soil reinforced with geogrid was decreased by 8.3% compared to conventional BC soil. Also the strength of sandy gravel soil reinforced with geogrid increased to 10.12% which is due to the good internal friction between the geogrid material and soil particles of sandy gravel soil.

Singh et al. (2012) conducted CBR and UCC test to determine the optimum position of geogrid. One type of clayey soil was selected for this study. The index properties: liquid limit, plastic limit and plasticity index were determined. To reinforce a sample, the geogrid was placed in a single layer at different positions like 20%, 40%, 60% and 80% of the specimen height from the top surface. A total of five samples of unreinforced and reinforced type were tested after soaking in water for four days. The result obtained shows that the CBR of soil increases by 50-100% when it is reinforced with a single layer of geo- grid. The amount of improvement depends upon the type of soil and position of geogrid.

2.2 Empirical-Mechanistic Analysis using KENPAVE

Premature failures like rutting and fatigue in the flexible pavement NHA (N-55) (Jamshoroto Sehwan) section of road in Pakistan has been studied by Rind and Sami (2019). The section of road taken for test has five layer sand it is a two-lane road including a wearing coarse (5cm), AC Base course (16.5cm), Aggregate Base course (30cm), Fill material (30cm) and a Subgrade. Various probable cross-sections that is used in Pakistan for AC wearing course and AC base course are considered by varying their thickness +25% and - 25%. By varying the thickness with each other there was a total of 12 cross-section. Every cross- section is checked for maximum horizontal tensile strain at the bottom of bituminous layer (ε_h) and maximum vertical compressive strain at the top of sub-grade layer (ε_v). The software output identified a section that gave maximum allowance for number of load repetitions in terms of fatigue failure (N_f) that is 9.30E+08 cycles of tandem axle load and rutting failure (Nr), that is 1.21 E+10 cycles of tandem axle load. Ashish et al. (2019) analysed the plastic deformation of unbound granular material for base and sub-base layer under variable cyclic load repetitions and variable dry densities. Shebin et al. (2018) studied the non linearity in damage of the flexible pavement and the best tyre configuration for a load without failure was found. These data's are provided as input to the software. The load was varied at 8t, 16t, 25t, 40t, 50t, 60t, 70t, 80t, 90t, 100t and from the stress value at different points the maximum value in each load case was taken. The construction of low volume roads connecting villages has enormously increased with the introduction of Pradhan Mantri Gram Sadak Yojana (PMGSY) in 2000. IRC has issued guidelines for the design and construction of low volume flexible pavements in 2007 (IRC SP 72). It divides low volume roads into gravel/aggregate surfaced roads (unpaved), flexible pavements (paved) and rigid pavements. Paved low volume roads are supposed to carry a sizable volume of truck and bus traffic and the maximum number of Equivalent Single Wheel Load (ESWL) applications is limited to one million.

III. ANALYSIS USING KENPAVE SOFTWARE

3.1 General

The various input parameters for the KENLAYER used in LAYERINP menu and their brief description is given below in Table 1.

Table 1: General input parameters of KENLAYER

MATL	Material Type	RC	Radial coordinates
NDAMA	Damage Analysis	LOAD	Type of loading
NPY	No. of periods per year	NR	No. of radial coordinates to
DEL	Tolerance for numerical	NOLAY	be analyzed under a single
NL	Integration	ITENOL	wheel
NZ	No. of Layers	RCNOL	No. of layers

ICL	No. of Z coordinates for	XPTNOL	Max. no. of iterations
NSTD	Analysis	YPTNO	Radial coordinate for
NBOND	Interface Bonding	XPT	X coordinates of point to be
NLBT	No. of layers for bottom	YPT	analyzed
NLTC	Tension	ZC	X coordinates of points to be
NUNIT	No. of layers for top	LAYNO	analyzed
CP	Compression	ZCNOL	Z or vertical coordinates
NCALY	Type of nonlinear layer	NVL	No. of viscoelastic layers
DUR	Load Duration	NTYME	No. of time duration for
SLD	Slope of load distribution	DELNOL	Tolerance for nonlinear analysis

3.2 KENLAYER Analysis Method

There are three methods of analysis based on the nature of material namely linear, nonlinear and viscoelastic. Besides these, there is damage analysis in which any of the three methods can be incorporated for the prediction of pavement design life.

3.2.1 Linear Elastic analysis

Layered elastic model can compute stresses, strains and deflections at any point in a pavement structure resulting from the application of a surface load. Layered elastic models assume that each pavement structural layer is homogeneous, isotropic and linearly elastic. Linear elastic analysis in KENLAYER is the simplest analysis method. In this method general input parameters are layer thickness, elastic modulus, poisson's ratio of material and load information. The output obtained includes stresses, strains and deformations at required locations.

3.2.2 Non Linear Elastic Analysis

According to Huang first the system is considered to be linear and the stresses due to multiple wheel loads are superimposed. From the stresses, thus computed a new set of moduli for each nonlinear layer is then determined. The system is considered linear again and the process is repeated until the moduli converge to a specified tolerance. The resilient modulus is elastic modulus based on the recoverable strain under repeated loads.

3.2.3 Visco-elastic Analysis

In visco-elastic analysis material possesses both the elastic property of a solid and viscous behavior of a liquid Hot Mix Asphalt (HMA) is analyzed as a visco-elastic material. Direct method for analyzing viscoelastic layer systems under static loads is to assume the visco-elastic layer to be elastic with a modulus varying with the loading time and the elastic modulus is the reciprocal of the creep compliance at that loading time.

3.2.4 Damage Analysis

The damage caused by fatigue cracking and permanent deformation in each period over all load groups is summed up to evaluate the design life. The damage analysis is based on the horizontal tensile strain at the bottom of a specified asphalt layer and the vertical compressive strain on the surface of a specified layer, usually subgrade. The damage ratios for fatigue cracking and permanent deformation are evaluated. Damage ratio(Dr)which is the ratio between the predicted and allowable number of repetitions. The design life, which is equal to 1/Dr, is evaluated both for fatigue cracking and for permanent deformation, and the one with a shorter life controls the design and shortest design life is found out to be for maximum damage ratio.

IV. RESULT AND DISCUSSION

4.1 Analysis Of Stress, Strain and Deflection

A flexible pavement designed by IRC guidelines is considered as 5 layered structure. Pavement sections are designed using linear analysis for subgrade CBR 2% and 3.5% with different traffic varying from 10 to 100msa as shown in Table 2 and 3.

Table 2: Pavement design parameters for unreinforced section

Layers	Course	Thickness(in)	Modulus of elasticity(psi)
1st	Surface course-asphalt concrete mixture	4	350000
2nd	Base course-asphalt treated base	6	150000
3rd	Sub base-Aggregates	6	85000
4th	Sub base-crushed aggregate	12	120000
5th	Subgrade	-	2900

Table 3: Pavement design parameters for reinforced section

Layers	Course	Thickness(in)	Modulus of elasticity(psi)
1st	Surface course-asphalt concrete mixture	4	350000
2nd	Base course-asphalt treated base	6	150000
3rd	Sub base-Aggregates	6	85000
4th	Sub base-crushed aggregate	12	120000
5th	Subgrade	-	2900

Required data (material properties and parameters like unit weights of each layer, elastic moduli, Poisson's ratio, load information, locations of pavement responses, fatigue and rutting models and load repetitions) for each designed pavement is entered in LAYERINP for the analysis purposes (Figure 1). With all these information the analysis is done. After providing the input parameters into the software the file obtained as output is saved with a file name. With this the program starts processing the input file. After the process completion there is message on the screen of completion and two new file are generated, in the same working directory, one having LAY format and other TEXT file. The text file obtained is the output for the input provide. Further "LGRAPH" icon can be used to view the plan and cross section of the pavement along with important input and output information. The input, output information are shown in Figure 1 to 4. The pavement section details are shown in Figure 5.

```
Length and displacement in in., stress and modulus in psi
unit weight in pcf, and temperature in F

THICKNESSES OF LAYERS (TH) ARE : 4  6  6  12
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.2  0.3  0.4  0.4  0.45
VERTICAL COORDINATES OF POINTS (ZC) ARE:  0  4  10  16  28
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :    1  3.500E+05   2
1.500E+05
   3  8.500E+04   4  1.200E+05   5  5.000E+03

LOAD GROUP NO. 1  HAS 2  CONTACT AREAS
CONTACT RADIUS (CR)--------------- =  4.1
CONTACT PRESSURE (CP)------------- =  85
NO. OF POINTS AT WHICH RESULTS ARE DESIRED (NPT)-- =  3
WHEEL SPACING ALONG X-AXIS (XW)------------------- =  0
WHEEL SPACING ALONG Y-AXIS (YW)------------------- =  13

RESPONSE PT. NO. AND (XPT, YPT) ARE:  1   0.000   0.000  2   0.000
6.500
  3   0.000  13.000
```

Figure 1: Screenshot Of Input Data For Unreinforced pavement

POINT NO.	VERTICAL COORDINATE	VERTICAL DISP.	VERTICAL STRESS (STRAIN)	MAJOR PRINCIPAL STRESS (STRAIN)	MINOR PRINCIAL STRESS (STRAIN)	INTERMEDIATE P. STRESS (HORIZONTAL P. STRAIN)
1	0.00000	0.01998	85.000	101.118	89.661	98.807
	(STRAIN)		1.419E-04	1.812E-04	1.419E-04	1.733E-04
1	4.00000	0.01925	46.047	46.152	-16.817	-12.519
	(STRAIN)		1.483E-04	1.486E-04	-6.727E-05	-6.727E-05
1	10.00000	0.01821	14.342	14.686	-7.640	-4.450
	(STRAIN)		1.191E-04	1.221E-04	-7.140E-05	-7.140E-05
1	16.00000	0.01754	6.658	7.405	-0.315	-0.268
	(STRAIN)		7.756E-05	8.986E-05	-3.729E-05	-3.652E-05
1	28.00000	0.01672	0.589	0.589	-13.378	-12.540
	(STRAIN)		9.130E-05	9.131E-05	-7.165E-05	-7.165E-05
2	0.00000	0.01933	0.000	59.700	35.270	47.376
	(STRAIN)		3.959E-05	1.233E-04	3.959E-05	8.109E-05
2	4.00000	0.01897	18.161	29.829	-5.069	18.161
	(STRAIN)		3.774E-05	7.774E-05	-4.191E-05	-4.191E-05
2	10.00000	0.01835	13.864	13.864	-7.548	-1.292
	(STRAIN)		1.101E-04	1.101E-04	-7.546E-05	-7.546E-05
2	16.00000	0.01767	7.355	7.355	-0.191	0.561
	(STRAIN)		8.478E-05	8.478E-05	-3.950E-05	-3.950E-05
2	28.00000	0.01679	0.620	0.620	-14.192	-13.636
	(STRAIN)		9.792E-05	9.792E-05	-7.488E-05	-7.488E-05
3	0.00000	0.01998	85.000	101.118	89.661	98.807
	(STRAIN)		1.419E-04	1.812E-04	1.419E-04	1.733E-04
3	4.00000	0.01925	46.047	46.152	-16.817	-12.519
	(STRAIN)		1.483E-04	1.486E-04	-6.727E-05	-6.727E-05
3	10.00000	0.01821	14.342	14.686	-7.640	-4.450
	(STRAIN)		1.191E-04	1.221E-04	-7.140E-05	-7.140E-05
3	16.00000	0.01754	6.658	7.405	-0.315	-0.268
	(STRAIN)		7.756E-05	8.986E-05	-3.729E-05	-3.652E-05
3	28.00000	0.01672	0.589	0.589	-13.378	-12.540
	(STRAIN)		9.130E-05	9.131E-05	-7.165E-05	-7.165E-05

Figure 2: Screenshot of Output Data for Unreinforced pavement

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Length and displacement in in., stress and modulus in psi
unit weight in pcf, and temperature in F

THICKNESSES OF LAYERS (TH) ARE : 4  6  6  12
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.2  0.3  0.4  0.4  0.45
VERTICAL COORDINATES OF POINTS (ZC) ARE:  0  4  10  16  28
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :    1  3.500E+05   2
1.500E+05
   3  8.500E+04   4  1.200E+05   5  5.000E+03

LOAD GROUP NO. 1  HAS 2  CONTACT AREAS
CONTACT RADIUS (CR)--------------- =  4.1
CONTACT PRESSURE (CP)------------- =  85
NO. OF POINTS AT WHICH RESULTS ARE DESIRED (NPT)-- =  3
WHEEL SPACING ALONG X-AXIS (XW)------------------- =  0
WHEEL SPACING ALONG Y-AXIS (YW)------------------- =  13

RESPONSE PT. NO. AND (XPT, YPT) ARE:  1   0.000   0.000  2   0.000
6.500
  3   0.000  13.000
```

Figure 3: Screenshot of Input Data for Reinforced Pavement

POINT NO.	VERTICAL COORDINATE	VERTICAL DISP.	VERTICAL STRESS (STRAIN)	MAJOR PRINCIPAL STRESS (STRAIN)	MINOR PRINCIPAL STRESS (STRAIN)	INTERMEDIATE P. STRESS (HORIZONTAL P. STRAIN)
1	0.00000	0.01511	85.000	118.315	114.936	116.056
	(STRAIN)		1.945E-04	2.060E-04	1.945E-04	1.982E-04
1	4.00000	0.01415	46.075	46.175	-17.970	-13.649
	(STRAIN)		1.497E-04	1.500E-04	-6.993E-05	-6.993E-05
1	10.00000	0.01310	14.454	14.783	-7.674	-4.467
	(STRAIN)		1.200E-04	1.228E-04	-7.179E-05	-7.179E-05
1	16.00000	0.01243	6.854	7.588	0.013	0.044
	(STRAIN)		7.692E-05	8.900E-05	-3.577E-05	-3.525E-05
1	28.00000	0.01166	0.852	0.853	-11.806	-10.997
	(STRAIN)		8.311E-05	8.311E-05	-6.457E-05	-6.457E-05
2	0.00000	0.01436	0.000	57.548	35.270	45.244
	(STRAIN)		4.203E-05	1.184E-04	4.203E-05	7.623E-05
2	4.00000	0.01398	18.191	28.581	-6.326	18.191
	(STRAIN)		3.926E-05	7.488E-05	-4.480E-05	-4.480E-05
2	10.00000	0.01335	13.982	13.982	-7.591	-1.333
	(STRAIN)		1.111E-04	1.111E-04	-7.590E-05	-7.590E-05
2	16.00000	0.01267	7.563	7.563	0.146	0.900
	(STRAIN)		8.405E-05	8.405E-05	-3.811E-05	-3.811E-05
2	28.00000	0.01184	0.898	0.898	-12.489	-11.951
	(STRAIN)		8.895E-05	8.895E-05	-6.724E-05	-6.724E-05
3	0.00000	0.01511	85.000	118.315	114.936	116.056
	(STRAIN)		1.945E-04	2.060E-04	1.945E-04	1.982E-04
3	4.00000	0.01415	46.075	46.175	-17.970	-13.649
	(STRAIN)		1.497E-04	1.500E-04	-6.993E-05	-6.993E-05
3	10.00000	0.01310	14.454	14.783	-7.674	-4.467
	(STRAIN)		1.200E-04	1.228E-04	-7.179E-05	-7.179E-05
3	16.00000	0.01243	6.854	7.588	0.013	0.044
	(STRAIN)		7.692E-05	8.900E-05	-3.577E-05	-3.525E-05
3	28.00000	0.01166	0.852	0.853	-11.806	-10.997
	(STRAIN)		8.311E-05	8.311E-05	-6.457E-05	-6.457E-05

Figure 4: Screenshot of Output Data for Reinforced pavement

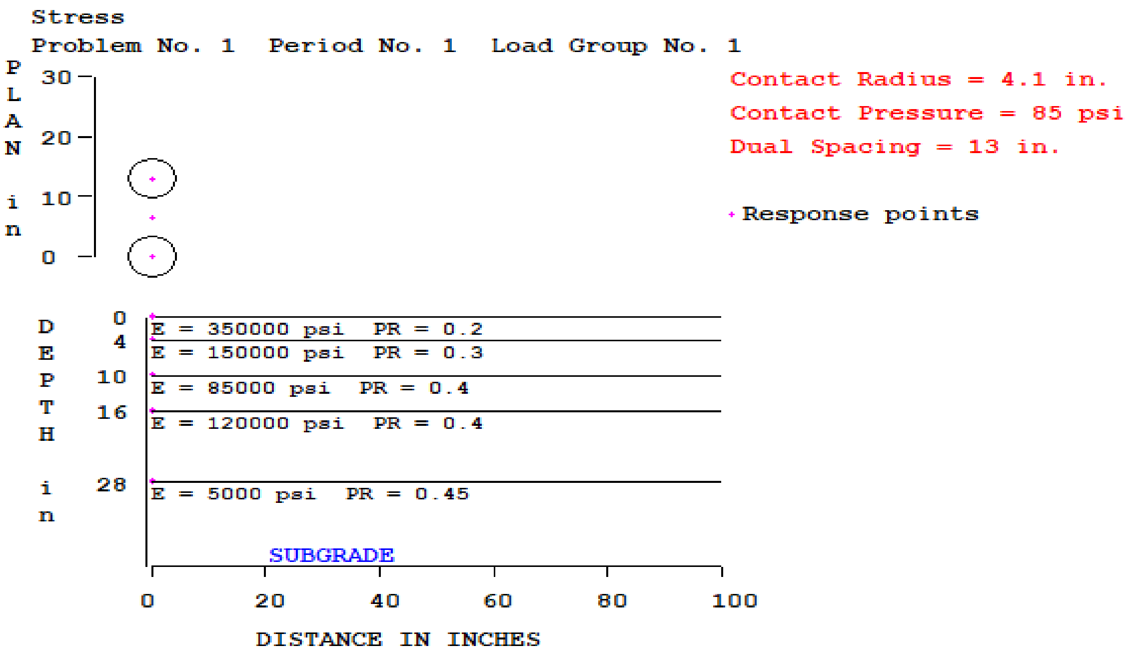


Figure 5: Plan and Cross Section of Pavement

4.2 Analysis of Damage Ratio and Design Life

Damage analysis is also carried out to assess serviceable life of the designed pavements. When all the necessary data for analysis is entered in LAYERINP the outputs namely vertical stresses, deflections, compressive and tensile strains are obtained at critical locations. Also the allowable load repetitions for fatigue and rutting failure, damage ratios for layer 2 and layer 5 and design life for the pavement compositions are obtained by damage analysis. Fatigue is due to accumulation of tensile strain at the bottom of bituminous layer as shown in Figure 6 (point A, B) whereas rutting is due to excessive vertical settlement as a result of vertical compressive stresses(point C). The predicted numbers of load repetitions (design traffic) are divided by the allowable load repetitions to calculate the damage ratio. The maximum damage ratio signifies the type of failure in pavement i.e. fatigue or rutting. If the damage ratio is less than 1 then design is acceptable otherwise the design is rechecked for thickness and material properties again.

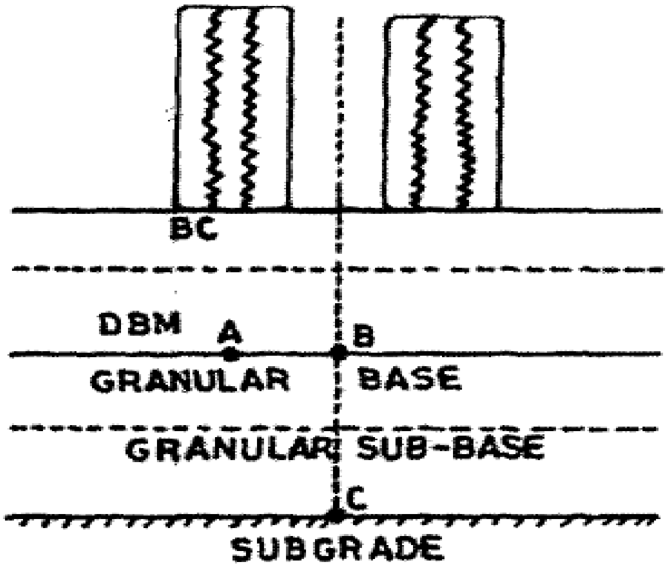
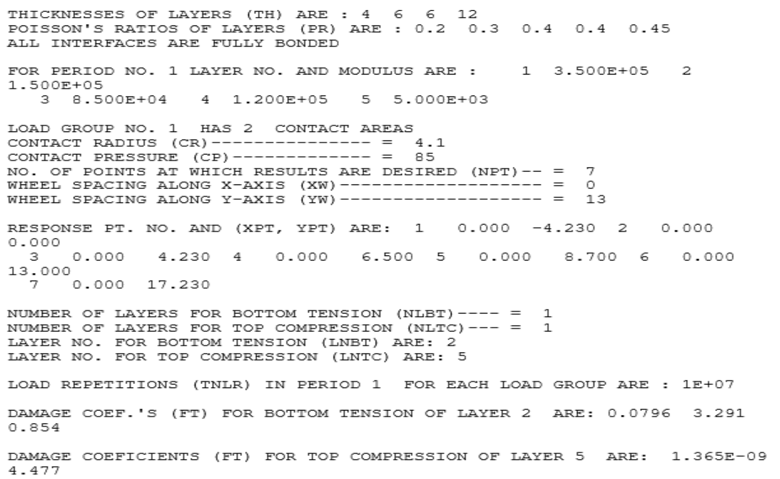


Figure 6: Critical Pavement Responses in Pavement Layer

The critical location A is at critical point (0, 0) which is at the centre of the wheel and the location C is at the point (0, 6.5) that is at the half of the spacing between the wheel.

The vertical stresses are obtained at the bottom of bituminous layer (layer 2) and deflections on the top of subgrade (layer 5) for all the unreinforced pavements and reinforced pavement is shown below.



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THICKNESSES OF LAYERS (TH) ARE : 4   6   6   12
POISSON'S RATIOS OF LAYERS (PR) ARE : 0.2   0.3   0.4   0.4   0.45
ALL INTERFACES ARE FULLY BONDED

FOR PERIOD NO. 1 LAYER NO. AND MODULUS ARE :     1   3.500E+05   2
1.500E+05
   3   8.500E+04   4   1.200E+05   5   5.000E+03

LOAD GROUP NO. 1  HAS 2  CONTACT AREAS
CONTACT RADIUS (CR)--------------- =  4.1
CONTACT PRESSURE (CP)------------- =  85
NO. OF POINTS AT WHICH RESULTS ARE DESIRED (NPT)-- =  7
WHEEL SPACING ALONG X-AXIS (XW)------------------- =  0
WHEEL SPACING ALONG Y-AXIS (YW)------------------- =  13

RESPONSE PT. NO. AND (XPT, YPT) ARE:  1   0.000  -4.230  2   0.000
0.000
  3   0.000   4.230  4   0.000   6.500  5   0.000   8.700  6   0.000
13.000
  7   0.000  17.230

NUMBER OF LAYERS FOR BOTTOM TENSION (NLBT)---- =  1
NUMBER OF LAYERS FOR TOP COMPRESSION (NLTC)--- =  1
LAYER NO. FOR BOTTOM TENSION (LNBT) ARE: 2
LAYER NO. FOR TOP COMPRESSION (LNTC) ARE: 5

LOAD REPETITIONS (TNLR) IN PERIOD 1  FOR EACH LOAD GROUP ARE : 1E+07

DAMAGE COEF.'S (FT) FOR BOTTOM TENSION OF LAYER 2  ARE: 0.0796  3.291
0.854

DAMAGE COEFICIENTS (FT) FOR TOP COMPRESSION OF LAYER 5  ARE:  1.365E-09
4.477
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Figure 7: Screenshot of Input Data for Analysis of Damage And Design Life

POINT NO.	VERTICAL COORDINATE	VERTICAL DISP.	VERTICAL STRESS (STRAIN)	MAJOR PRINCIPAL STRESS (STRAIN)	MINOR PRINCIAL STRESS (STRAIN)	INTERMEDIATE P. STRESS (HORIZONTAL P. STRAIN)
1	10.00000	0.01765	10.250	12.171	-5.535	-3.094
	(STRAIN)		8.175E-05	9.840E-05	-5.506E-05	-5.506E-05
1	28.00010	0.01646	0.553	0.570	0.119	0.132
	(STRAIN)		1.489E-04	1.576E-04	-6.773E-05	-6.773E-05
2	10.00000	0.01821	14.342	14.686	-7.640	-4.450
	(STRAIN)		1.191E-04	1.221E-04	-7.140E-05	-7.140E-05
2	28.00010	0.01672	0.589	0.596	0.120	0.133
	(STRAIN)		1.628E-04	1.663E-04	-7.165E-05	-7.165E-05
3	10.00000	0.01839	14.194	14.198	-7.697	-2.080
	(STRAIN)		1.142E-04	1.142E-04	-7.555E-05	-7.555E-05
3	28.00010	0.01683	0.611	0.612	0.121	0.134
	(STRAIN)		1.709E-04	1.714E-04	-7.397E-05	-7.397E-05
4	10.00000	0.01835	13.864	13.864	-7.548	-1.292
	(STRAIN)		1.101E-04	1.101E-04	-7.546E-05	-7.546E-05
4	28.00010	0.01679	0.620	0.620	0.123	0.136
	(STRAIN)		1.736E-04	1.736E-04	-7.488E-05	-7.488E-05
5	10.00000	0.01838	14.177	14.180	-7.689	-2.037
	(STRAIN)		1.140E-04	1.140E-04	-7.555E-05	-7.555E-05
5	28.00010	0.01682	0.611	0.612	0.121	0.134
	(STRAIN)		1.711E-04	1.715E-04	-7.404E-05	-7.404E-05
6	10.00000	0.01821	14.342	14.686	-7.640	-4.450
	(STRAIN)		1.191E-04	1.221E-04	-7.140E-05	-7.140E-05
6	28.00010	0.01672	0.589	0.596	0.120	0.133
	(STRAIN)		1.628E-04	1.663E-04	-7.165E-05	-7.165E-05
7	10.00000	0.01765	10.250	12.171	-5.535	-3.094
	(STRAIN)		8.175E-05	9.840E-05	-5.506E-05	-5.506E-05
7	28.00010	0.01646	0.553	0.570	0.119	0.132
	(STRAIN)		1.489E-04	1.576E-04	-6.773E-05	-6.773E-05

Figure 8: Screenshot of Output Data obtained for Unreinforced Section

POINT NO.	VERTICAL COORDINATE	VERTICAL DISP.	VERTICAL STRESS (STRAIN)	MAJOR PRINCIPAL STRESS (STRAIN)	MINOR PRINCIAL STRESS (STRAIN)	INTERMEDIATE P. STRESS (HORIZONTAL P. STRAIN)
1	10.00000	0.01258	10.352	12.207	-5.572	-3.061
	(STRAIN)		8.257E-05	9.865E-05	-5.544E-05	-5.544E-05
1	28.00010	0.01143	0.792	0.822	0.136	0.155
	(STRAIN)		1.295E-04	1.382E-04	-6.074E-05	-6.074E-05
2	10.00000	0.01310	14.454	14.783	-7.674	-4.467
	(STRAIN)		1.200E-04	1.228E-04	-7.179E-05	-7.179E-05
2	28.00010	0.01166	0.852	0.864	0.137	0.157
	(STRAIN)		1.428E-04	1.464E-04	-6.457E-05	-6.457E-05
3	10.00000	0.01329	14.311	14.315	-7.731	-2.113
	(STRAIN)		1.151E-04	1.151E-04	-7.595E-05	-7.595E-05
3	28.00010	0.01178	0.887	0.888	0.138	0.159
	(STRAIN)		1.505E-04	1.510E-04	-6.675E-05	-6.675E-05
4	10.00000	0.01335	13.982	13.982	-7.591	-1.333
	(STRAIN)		1.111E-04	1.111E-04	-7.590E-05	-7.590E-05
4	28.00010	0.01184	0.898	0.898	0.141	0.163
	(STRAIN)		1.522E-04	1.522E-04	-6.724E-05	-6.724E-05
5	10.00000	0.01329	14.294	14.297	-7.724	-2.070
	(STRAIN)		1.149E-04	1.149E-04	-7.595E-05	-7.595E-05
5	28.00010	0.01178	0.887	0.889	0.138	0.159
	(STRAIN)		1.506E-04	1.511E-04	-6.679E-05	-6.679E-05
6	10.00000	0.01310	14.454	14.783	-7.674	-4.467
	(STRAIN)		1.200E-04	1.228E-04	-7.179E-05	-7.179E-05
6	28.00010	0.01166	0.852	0.864	0.137	0.157
	(STRAIN)		1.428E-04	1.464E-04	-6.457E-05	-6.457E-05
7	10.00000	0.01258	10.352	12.207	-5.572	-3.061
	(STRAIN)		8.257E-05	9.865E-05	-5.544E-05	-5.544E-05
7	28.00010	0.01143	0.792	0.822	0.136	0.155
	(STRAIN)		1.295E-04	1.382E-04	-6.074E-05	-6.074E-05

Figure 9: Screenshot of Output Data Obtained for Reinforced Section

The tensile strains and compressive strain are determined at critical locations (where these values are maximum) i.e. at bottom of bituminous layer and at top of subgrade respectively for all the pavement sections.

Table 4: Tensile and compressive strain of unreinforced section

Type of pavement	Tensile Strain(Bottom of layer 2)	Compressive Strain(Topof layer 5)
Unreinforced	-7.555E-05	1.736E-04
Reinforced	-7.595E-05	1.522E-04

The allowable number of loads repetitions for fatigue and rutting failure are determined to evaluate the type of failure (fatigue and rutting) in pavement structure as shown in table 1.5.

Table 5: Allowable number of loads repetitions for fatigue (N_f) and rutting (N_r)

Type of pavement	Allowable load repetition (N_f)- Bottom of layer 2	Allowable load repetition (N_r)- Top of layer 5
Unreinforced	1.110E+08	9.358E+07
Reinforced	1.091E+08	1.683E+08

The damage ratios obtained for bituminous (at the bottom of layer 2) and subgrade (at the top of layer 5) layers are given in Table 6 and 7 for all the pavements designed for CBR 2% & CBR 3.5% and design traffic 10-100msa.

Table 6: Damage Ratio for unreinforced pavement

Traffic in msa	Bottom of layer 2	Top of layer 5
10	9.009E-02	1.069E-01
20	1.802E-01	2.137E-01
30	2.703E-01	3.206E-01
50	4.504E-01	5.343E-01
100	9.009E-01	1.069E+00

Table 7: Damage Ratio for reinforcedpavement

Traffic in msa	Bottom of layer 2	Top of layer 5
10	9.167E-02	5.943E-02
20	1.833E-01	1.189E-01
30	2.750E-01	1.783E-01
50	4.584E-01	2.971E-01
100	9.167E-01	5.943E-01

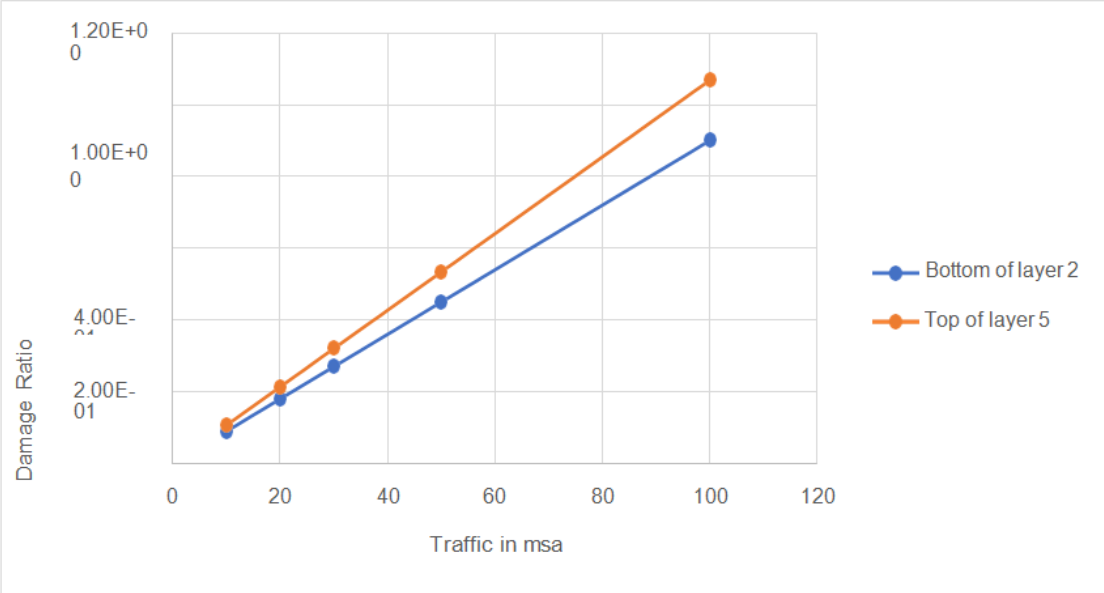

Figure 10: Damage Ratios of Unreinforced Flexible Pavement For Different Traffic (msa)

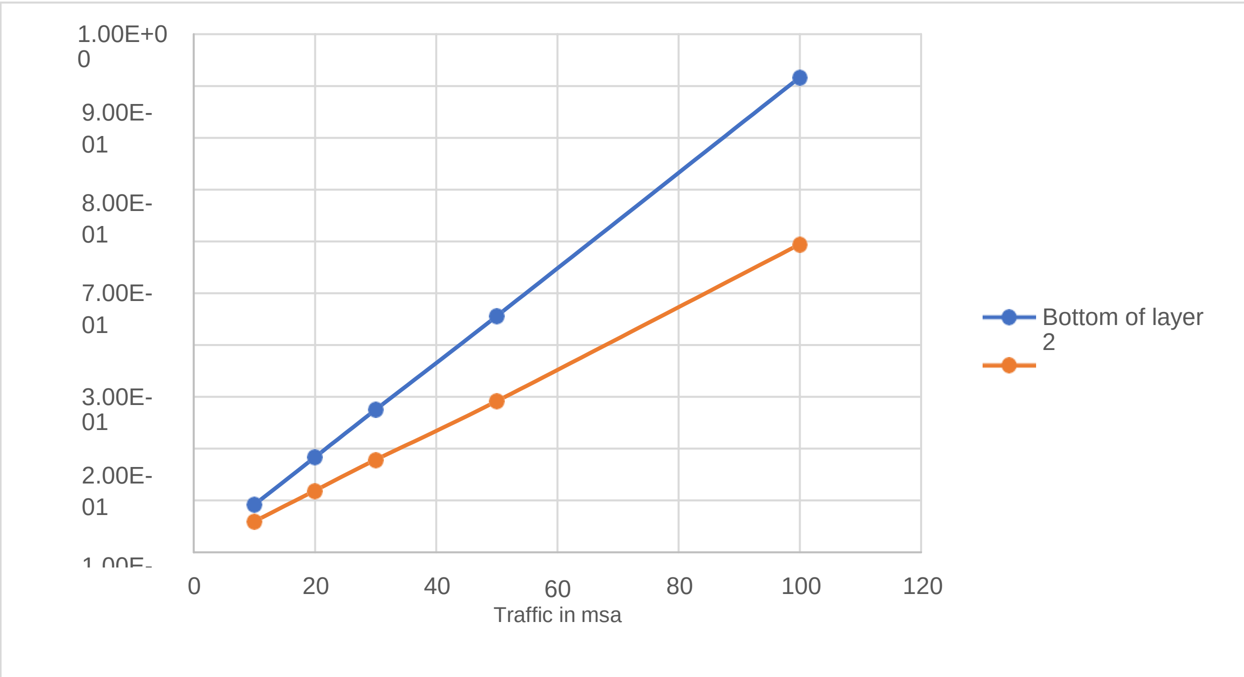

Figure 11: Damage Ratios of Unreinforced Flexible Pavement for Different Traffic (msa)

The design life of a pavement is governed by the maximum damage ratio and can be obtained as the reciprocal of the maximum damage ratio. The maximum damage ratio is obtained and shown in Table 8.

Table 8 Maximum damage ratio for reinforced and unreinforced pavement

Traffic in msa	Reinforced pavement	Unreinforced pavement
10	9.167E-02	1.069E-01
20	2.750E-01	2.137E-01
30	1.833E-01	3.206E-01
50	4.584E-01	5.343E-01
100	9.167E-01	1.069E+00

The design life obtained for reinforced and unreinforced pavement as shown in Table 9.

Table 9: Design life of reinforced and unreinforced pavement

Traffic in msa	Design life(years) Unreinforced pavement	Design life(years) Reinforced pavement	% increase in design life
10	9.36	10.91	14
20	4.38	5.45	14
30	3.12	3.64	14
50	1.87	2.18	14
100	.94	1.09	14

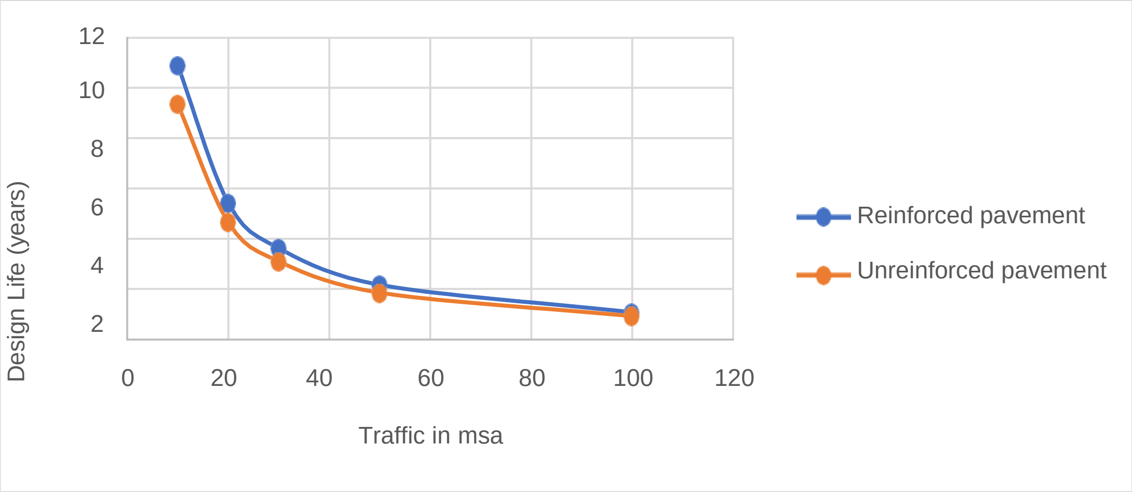

Figure 12: Design life of reinforced and unreinforced pavement

The graphical representation of design life of reinforced and unreinforced pavement is shown in Figure 12.

Analysis reveals that reinforced flexible pavements designed for different traffic have higher life than the unreinforced pavement. Also the unreinforced pavement can only take load upto 100msa with low design life. So the unreinforced composition needs reconsideration. KENLAYER analysis results shows that the pavement responses and pavement design life get affected when the pavement is reinforced and unreinforced. The pavement responses such as stress, tensile strain, compressive strain and deflections are less for reinforced pavement than the unreinforced pavement. The maximum damage (damage ratio) in reinforced flexible pavements occurs at the bottom of bituminous layer, which represents the fatigue failure. Thus the design life of reinforced flexible pavements depends on fatigue life or on the life of bituminous layer. The maximum damage ratio in unreinforced pavement occurs at the top of subgrade, which represents rutting failure. Thus the design life of unreinforced flexible pavement depends on rutting life.

V. CONCLUSION

The deflection and stresses of flexible pavement both in unreinforced and reinforced condition are determined using KENPAVE software. KENLAYER analysis shows that pavement responses and design life get enhanced for unreinforced pavement when it is reinforced. The maximum tensile strains occur at point A i.e. at the bottom of layer 2. The maximum deflection occurs at the point C i.e. at the top of subgrade layer. Deflections arising in reinforced pavement are comparatively less than the unreinforced pavement. Damage ratio obtained for the sections are less than 1 thus there is no need for redesign. Damage ratio is found maximum at the bottom of bituminous layer due to fatigue failure for reinforced pavement. The design life of reinforced pavement structure is governed by the fatigue life. Damage ratio is found maximum at the top of subgrade layer due to fatigue failure for reinforced pavement. The design life of unreinforced pavement structure is governed by the rutting life. Design life of reinforced pavement is 14% more for different traffic loading compared to unreinforced pavement.

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