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Effect of Elastic Moduli of Asphalt Layer onFlexible Pavement: A Numerical Study

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ABSTRACT

Background: one of the negative effects of the urbanization is increasing number of the vehicles and consequently overusing the pavement structures. This phenomenon damages the pavement structures in a shorter time. Young modulus or elastic modulus is a parameters that defines the capacity of a pavement layer to distribute a stresses due to weight of the vehicles.**Objective:** in this study to investigate loading capacity of a flexible pavement structure, a series of the elastic moduli of surface layer namely 1000, 2000, 3000, 4000 and 5000 MPa according to the vehicle weights and speed designed and performed.**Results**a series of result for deflections and major, minor and intermediate stresses acquired.**Conclusion:** it was concluded that major stress and intermediate stress follow an increasing trend by increasing the stresses and minor stresses has a peak point at the middle and under $E_{surface}$ = 3000 MPa.

INTRODUCTION

Determination of deflections and strains in a flexible pavement structure is more complicated in compare with rigid pavement especially when more than two layers are required. However many studies carried out to investigate impact of effective parameters in flexible pavement such asLoulizi *et al*. (2002), Gedafa (2006), Abdel-Motaleb (2009),Ferrotti *et al*. (2011),Tchemou (2011), Jeong *et al*. (2011),Vasudevan *et al*. (2012), El Ayadi (2012),Mensching (2013), Liu *et al*. (2014), Hirato *et al*. (2014), Chun *et al*. (2015),Bilodeau *et al*. (2015) still there are deficiencies to understand behavior of the flexible pavement under stresses.

There are many methods to calculate the deflection value of the flexible pavement. For instance, in an experimental study, Seed*et al*. (1967) determined deflection of a flexible pavement using a repeated loading triaxial apparatus. In another case using modelling application the deflections of a pavement was determined by Chegenizadeh *et al*., (2016a; 2016b).

Elastic layer design concepts were introduced by Dorman and Metcalf (1965) for the first time. To design a multilayered flexible pavement Yoder and Witczak (1975) introduced some assumptions. They supposed that each layer has a homogenous materials properties, each layer has a specified thickness except the bottom layer and they are infinite in horizontal direction, there is a friction between each layer at interface edges, there is no shearing surface forceand theelastic modulus (E) and Poisson ratio (μ)characterize the stresses. To calculate deflection of each point subjected to a normal stress equation (1) is applicable in one direction.

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$$\varepsilon_z = \frac{1}{E}[\sigma_z - \mu(\sigma_x + \sigma_y)] \quad (1)$$

Where $\varepsilon_z$the strain in Z-axis, E is the elastic modulus, σ_z is the normal stress in Z-axis, σ_x is the normal stress in X-axis and σ_y is the normal stress in Y-axis and μ is the Poisson ratio. This equation is extendable to calculate deflection for X-axis and Y-axis (Yoder and Witczak, 1975). The three existing normal stresses (σ_z, σ_x, σ_y) are the main stresses and classified as major stress (σ_1), intermediate stress(σ_2) and minor stress (σ_3).

Equation (2) shows that modulus elasticity of a material could be defined as applied stresses divided by strains.

$$E = \frac{\sigma}{\varepsilon} \quad (2)$$

This study aims to investigate effects of a series of the E of surface layer ($E_{surface}$) on deflection behavior of a three-layered flexible structure using kenlayer application (Huang, 1993).

Methodology:

To investigate effects of the E of surface layer on a three layer flexible pavement structure, 5 different elastic modulus were applied including 1000, 2000, 3000, 4000 and 5000 MPa figured out. The material applied for first layer considered as asphalt with 5 cm thickness. The underneath layer thickness was considered as 10 cm and the third layer infinite. Each layer was considered as a homogenous layer and the Poisson ratio was considered as 0.35, 0.35 and 0.3 respectively. Three points was defined as observation point for recording the deflection namely 0, 6 and 14 cm. Ten response point numbers considered to investigate effects of the E of surface layer ($E_{surface}$). Table 1 illustrates the coordination of each response points (Huang, 1993).

Table 1:the coordination of each response point number.

Response Point Number	X - Points	Y - Points
1	0.00	0.00
2	0.00	3.3
3	0.00	6.7
4	8.00	0.00
5	8.00	3.3
6	8.00	6.7
7	16.00	0.00
8	16.00	3.3
9	16.00	6.7
10	24.00	0.00

RESULTS AND DISCUSSION

The acquired results for deflections including Vertical displacements, major stresses, minor stresses and intermediate stresses under 1000, 2000, 3000, 4000 and 5000 MPaelastic moduli of surface layer shown in Table 2, 3, 4, 5 and 6 respectively. (In results and discussion section the stresses are in kPa unit unless stated.)

Deflections under$E_{surface}$ = 1000 Mpa:

The acquired deflection values under 1000 MPaelastic moduli of surface layer shown in Table 2. The maximum recorded vertical displacement was 0.07 cm that could be seen in point number 1, 2 and 3. The minimum observed vertical displacement was 0.05 cm that recorded from point number 7 to 10. The point number 4, 5 and 6 possess 0.06 cm vertical displacement. The maximum recorded vertical stress was 80 that was observed at point number 1 and 2 at 0.00 vertical coordinate. The maximum and minimum recorded major stress was 155.266and 3.164 at point number 2 and 10 at 0.00 6.00 vertical coordinates respectively. The maximum minor stress was 77.153 at point number 2 and vertical coordinate 0.00 and the minimum was -10.683 at point number 10 at 0.00 vertical coordinate. 137.606 was the maximum recorded intermediate stress at point number 1 and 0.00 vertical coordinate and the minimum was -6.628 at point number 3 14.00 vertical coordinate.

Table 2: Deflection values under $E_{surface}$ = 1000 MPa

Point No.	Vertical Coordinate	Vertical Displacement(cm)	Vertical Stress(kPa)	Major Stress(kPa)	Minor Stress(kPa)	Intermediate stress(kPa)
1	0.00	0.007	80.000	152.603	74.825	137.606
	6.00	0.007	25.589	26.195	-0.017	1.811
	14.00	0.006	8.663	8.952	-6.927	-6.127
2	0.00	0.007	80.000	155.266	77.153	128.509
	6.00	0.007	23.760	23.782	-0.201	4.329
	14.00	0.006	9.204	9.271	-7.457	-6.552
3	0.00	0.007	0.000	91.939	-2.918	37.787
	6.00	0.007	20.274	20.279	-0.341	6.492
	14.00	0.006	9.335	9.344	-7.628	-6.628
4	0.00	0.006	0.000	43.877	-2.101	14.736
	6.00	0.006	9.518	15.763	-1.656	1.122
	14.00	0.006	6.455	7.363	-4.926	-3.363
5	0.00	0.006	0.000	39.925	-1.152	19.527
	6.00	0.006	9.461	15.257	-1.544	2.037
	14.00	0.006	6.872	7.639	-5.279	-3.713
6	0.00	0.006	0.000	35.724	0.040	22.114
	6.00	0.006	8.975	14.491	-1.509	2.624
	14.00	0.006	6.999	7.720	-5.372	-3.830
7	0.00	0.005	0.000	19.977	-9.158	-0.659
	6.00	0.006	2.108	6.745	-1.016	0.684
	14.00	0.005	3.680	5.029	-2.963	0.879
8	0.00	0.006	0.000	21.301	-9.306	-0.515
	6.00	0.006	2.240	6.999	-0.875	0.600
	14.00	0.005	3.894	5.217	-3.275	0.881
9	0.00	0.006	0.000	22.189	-8.525	0.319
	6.00	0.006	2.275	7.066	-0.810	0.570
	14.00	0.006	3.971	5.285	-3.387	0.883
10	0.00	0.005	0.000	15.414	-10.683	0.002
	6.00	0.005	1.017	3.164	-0.156	1.553
	14.00	0.005	2.697	3.701	-2.158	2.755

Deflections under$E_{surface}$ = 2000 MPa:

Table 3 reveals the acquired results of the deflections under $E_{surface}$ = 2000 MPa. Similar to Table 1 the maximum and minimum vertical displacements was 0.007 and 0.005 cm for the same points but different vertical coordinates. Also the recorded vertical stress was 80 similar to Table 1 belongs to points number 1 and 2 at 0.00 vertical coordinates. Maximum recorded major stress was 204.270 at point number 1 and vertical coordinate 0.00. The minimum major stress was 2.970 at point number 10 at 6.00 vertical coordinate. 81.085 was the maximum minor stress and -19.392 was the minimum minor stress. In intermediate stresses, 182.803 at point number 1 and vertical number.

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Table 3 Deflection values under $E_{surface}$ = 2000 MPa

Point No.	Vertical Coordinate	Vertical Displacement (cm)	Vertical Stress(kPa)	Major Stress(kPa)	Minor Stress(kPa)	Intermediate stress(kPa)
1	0.00	0.007	80.000	204.270	81.085	182.803
	6.00	0.006	19.515	20.134	-0.048	1.052
	14.00	0.006	7.468	7.710	-5.846	-5.500
2	0.00	0.007	80.000	203.502	77.148	168.535
	6.00	0.007	18.898	18.908	-0.132	2.768
	14.00	0.006	7.941	8.005	-6.252	-5.955
3	0.00	0.007	0.000	141.074	-1.317	76.909
	6.00	0.007	17.080	17.086	-0.195	4.016
	14.00	0.006	8.078	8.089	-6.386	-6.082
4	0.00	0.006	0.000	73.516	1.781	36.033
	6.00	0.006	8.997	13.165	-0.989	0.771
	14.00	0.006	5.917	6.508	-4.668	-3.078
5	0.00	0.006	0.000	69.143	1.431	41.727
	6.00	0.006	9.251	13.025	-0.771	1.299
	14.00	0.006	6.289	6.762	-5.044	-3.357
6	0.00	0.006	0.000	63.673	1.229	43.260
	6.00	0.006	9.070	12.658	-0.698	1.629
	14.00	0.006	6.413	6.845	-5.164	-3.454
7	0.00	0.005	0.000	33.516	-12.289	-0.089
	6.00	0.005	2.830	6.405	-0.749	0.573
	14.00	0.005	3.750	4.574	-3.169	0.525
8	0.00	0.006	0.000	35.523	-13.016	-0.561
	6.00	0.006	3.026	6.643	-0.449	0.356
	14.00	0.005	3.957	4.738	-3.478	0.519
9	0.00	0.006	0.000	36.606	-12.416	0.053
	6.00	0.006	3.090	6.715	-0.240	0.186
	14.00	0.005	4.033	4.798	-3.592	0.516
10	0.00	0.005	0.000	24.149	-19.392	-0.196
	6.00	0.005	1.505	2.970	-0.374	1.869
	14.00	0.005	2.895	3.076	-2.502	2.600

Deflections under$E_{surface}$ = 3000 MPa:

Table 3 reveals the deflection values under $E_{surface}$ = 3000 MPa. The maximum and minimum observed vertical displacement values was 0.006 cm for the point numbers from 1 to 6 and 0.005 cm for the point numbers 7 to 10. The maximum recorded vertical stress was 80 at point number 1 and 2 at 0.00 vertical coordinate. The maximum major stress was243.367 at point number 2 at 0.00 vertical coordinate and the minimum major stress was 2.832 at point number 10 and 6.00 cm vertical displacement. The maximum observed minor stress was 87.112 at point number 2 at 0.00 vertical coordinate. The minimum recorded minor stress was -24.329 at point number 10 at 0.00 vertical coordinate. The maximum intermediate stress was 210.703 at point number 1 and 0.00 vertical coordinate. The minimum intermediate stress was -5.549 at point number 3 at 14.00 cm vertical coordinate.

Table 4: Deflection values under $E_{surface}$ = 3000 MPa

Point No.	Vertical Coordinate	Vertical Displacement (cm)	Vertical Stress(kPa)	Major Stress(kPa)	Minor Stress(kPa)	Intermediate stress(kPa)
1	0.00	0.006	80.000	235.168	81.120	210.703
	6.00	0.006	16.372	16.953	0.089	0.803
	14.00	0.005	6.761	6.971	-5.174	-4.948
2	0.00	0.006	80.000	243.367	87.112	207.377
	6.00	0.006	16.155	16.183	0.045	2.120
	14.00	0.006	7.177	7.238	-5.508	-5.377
3	0.00	0.006	0.000	173.703	-1.381	105.666
	6.00	0.006	14.965	14.974	0.009	3.010
	14.00	0.006	7.305	7.320	-5.579	-5.549
4	0.00	0.006	0.000	94.402	1.552	50.693
	6.00	0.006	8.444	11.564	-0.580	0.720
	14.00	0.005	5.556	5.989	-4.380	-2.803
5	0.00	0.006	0.000	91.353	1.431	58.213
	6.00	0.006	8.780	11.543	-0.294	1.045
	14.00	0.006	5.891	6.219	-4.739	-3.036
6	0.00	0.006	0.000	84.303	-0.953	58.250
	6.00	0.006	8.711	11.321	-0.194	1.255
	14.00	0.006	6.005	6.297	-4.859	-3.119
7	0.00	0.005	0.000	45.656	-12.545	-0.270
	6.00	0.005	3.221	6.044	-0.543	0.703
	14.00	0.005	3.768	4.337	-3.163	0.310
8	0.00	0.005	0.000	49.028	-12.808	-0.439
	6.00	0.005	3.440	6.254	-0.212	0.480
	14.00	0.005	3.965	4.486	-3.455	0.300
9	0.00	0.006	0.000	48.856	-14.272	-2.018
	6.00	0.006	3.515	6.320	0.103	0.212
	14.00	0.005	4.039	4.541	-3.564	0.296
10	0.00	0.005	0.000	33.055	-24.329	-0.290
	6.00	0.005	1.910	2.832	-0.379	2.144
	14.00	0.005	3.025	3.138	-2.599	2.054

Deflections under$E_{surface}$ = 4000 MPa:

Tale 5 shows the deflection values under 4000 MPa. The maximum recorded vertical displacement was 0.006 cm and the minimum vertical displacement was 0.005 cm. The maximum vertical stress was 80.00 at point number 1 and point number 2 at 0.00 vertical point. The maximum major stress was 267.144 at point number 2 at 0.00 vertical displacement. The minimum major stress was 2.808. The minor stress was 85. The maximum minor stress was 85.786 at point number 2 at 0.00 vertical coordinate and the minimum minor stress was -26.546 at point number 10 at 0.00 vertical displacement. The maximum observed intermediate stress was 229.366 at point number 2 and 0.00vertical coordinate and the minimum intermediate stress was -4.941 at point number 3 at 14.00 cm vertical coordinate.

Table 5: Deflection values under $E_{surface}$ = 4000 MPa

Point No.	Vertical Coordinate	Vertical Displacement (cm)	Vertical Stress(kPa)	Major Stress(kPa)	Minor Stress(kPa)	Intermediate stress(kPa)
1	0.00	0.006	80.000	251.016	72.294	225.148
	6.00	0.006	14.355	14.893	0.206	0.686
	14.00	0.005	6.262	6.450	-4.738	-4.461
2	0.00	0.006	80.000	267.144	85.786	229.366
	6.00	0.006	14.314	14.355	0.183	1.762
	14.00	0.005	6.634	6.693	-5.066	-4.815
3	0.00	0.006	0.000	198.582	-1.381	129.063
	6.00	0.006	13.448	13.459	0.160	2.460
	14.00	0.005	6.753	6.770	-5.163	-4.941
4	0.00	0.006	0.000	112.038	1.516	63.533
	6.00	0.006	7.967	10.438	-0.323	0.738
	14.00	0.005	5.281	5.617	-4.124	-2.578
5	0.00	0.006	0.000	110.453	1.795	72.646
	6.00	0.006	8.323	10.468	0.011	0.932
	14.00	0.005	5.585	5.827	-4.461	-2.780
6	0.00	0.006	0.000	104.011	-0.352	73.155
	6.00	0.006	8.305	10.317	0.137	1.064
	14.00	0.005	5.691	5.900	-4.576	-2.852
7	0.00	0.005	0.000	57.197	-10.721	-0.270
	6.00	0.005	3.450	5.736	-0.399	0.848
	14.00	0.005	3.759	4.182	-3.100	0.155
8	0.00	0.005	0.000	61.571	-10.876	-0.523
	6.00	0.005	3.675	5.920	-0.099	0.674
	14.00	0.005	3.947	4.319	-3.375	0.143
9	0.00	0.005	0.000	62.118	-11.855	-1.679
	6.00	0.005	3.755	5.979	0.103	0.524
	14.00	0.005	4.016	4.369	-3.478	0.139
10	0.00	0.005	0.000	42.117	-26.546	-0.290
	6.00	0.005	2.216	2.808	-0.334	2.259
	14.00	0.005	3.107	3.203	-2.615	1.639

Deflections Under$_{surface}$ = 5000 MPa:

Table 5 shows the deflection values for pavement under $E_{surface}$ = 5000 MPa. The maximum and the minimum recorded vertical displacement values was 0.006 cm and 0.005 cm. the maximum recorded vertical stress was 80 at point number 1 and 2 at 0.00 vertical coordinate. The maximum observed major stress was 287.136 at point number 2 at 0.00 vertical coordinate. The minimum major stress was 2.885 at point number 10 at vertical coordinate 6.00 cm. the maximum minor stress was 85.926 at point number 2 at 0.00 vertical coordinate. The minimum minor stress was -26.821 at point number 10 at 0.00 vertical coordinate. The maximum intermediate stress was 249.094 at point number 2 at 0.00 vertical coordinate. The minimum intermediate stress was -4.475 at point number 3 at 14.00 cm vertical coordinate.

Table 6: Deflection values under $E_{surface}$ = 5000 MPa

Point No.	Vertical Coordinate	Vertical Displacement (cm)	Vertical Stress(kPa)	Major Stress(kPa)	Minor Stress(kPa)	Intermediate stress(kPa)
1	0.00	0.006	80.000	269.237	71.614	242.907
	6.00	0.006	12.918	13.417	0.294	0.623
	14.00	0.005	5.880	6.052	-4.408	-4.061
2	0.00	0.006	80.000	287.136	85.926	249.094
	6.00	0.006	12.966	13.017	0.285	1.535
	14.00	0.005	6.218	6.275	-4.721	-4.367
3	0.00	0.006	0.000	216.188	-5.004	145.191
	6.00	0.006	12.294	12.309	0.270	2.112
	14.00	0.005	6.327	6.347	-4.818	-4.475
4	0.00	0.006	0.000	123.917	-3.265	70.286
	6.00	0.006	7.561	9.590	-0.154	0.776
	14.00	0.005	5.058	5.330	-3.903	-2.395
5	0.00	0.006	0.000	128.084	3.061	85.988
	6.00	0.006	7.917	9.643	0.209	0.882
	14.00	0.005	5.337	5.524	-4.218	-2.573
6	0.00	0.006	0.000	120.765	-0.479	85.573
	6.00	0.006	7.927	9.533	0.364	0.950
	14.00	0.005	5.435	5.591	-4.327	-2.637
7	0.00	0.005	0.000	68.081	-7.829	-0.270
	6.00	0.005	3.589	5.480	-0.292	0.967
	14.00	0.005	3.736	4.065	-3.020	0.037
8	0.00	0.005	0.000	73.052	-8.210	-0.970
	6.00	0.005	3.814	5.642	-0.029	0.842
	14.00	0.005	3.914	4.193	-3.279	0.024
9	0.00	0.005	0.000	74.509	-8.454	-1.431
	6.00	0.005	3.894	5.694	0.121	0.747
	14.00	0.005	3.980	4.240	-3.375	0.019
10	0.00	0.005	0.000	51.204	-26.821	-0.130
	6.00	0.005	2.443	2.885	-0.277	2.233
	14.00	0.005	3.157	3.243	-2.595	1.325

Comparison of the Stresses:

Fig. 1 reveals a comparison between major, minor and intermediate stresses under five elastic moduli of surface layer, variedfrom 1000 MPa to 5000 MPa at point number 1 at 0.00 vertical coordinate. It could be seen from the Fig. 1 that major stresses and intermediate following an increasing trend from 1000 MPa to 5000 MPa. The minimum and maximum figures in both stresses belongs to $E_{surface}$ = 1000 MPa and 5000 MPa respectively. In contrast, the maximum value for minor stress is at middle point ($E_{surface}$ = 3000 MPa) and the minimum point are 5000 MPa and 1000 MPa with 71.614 and 74.825 respectively.

Fig. 2 shows a comparison between, major, minor and intermediate stresses under 1000, 2000, 3000, 4000 and 5000 MPa at point number 2 at 0.00 vertical coordinate. Similar to previous graph major and intermediate stress follow an increasing trend. The maximum value for major stress is equal to 287.136 under $E_{surface}$ = 5000 MPa and the minimum is equal to 155.266 and belongs to $E_{surface}$ = 1000 MPa. The maximum recorded intermediate stress rate, amongst five elastic moduli of surface layer, was 249.094 under 5000 MPa and the minimum rate was 128.509 under $E_{surface}$ = 1000 MPa. The minor stresses showed a similar trend to minor stress in point number one at 0.00 vertical coordinate. The observed peak point was 87.112 MPa under $E_{surface}$ = 3000 MPa.

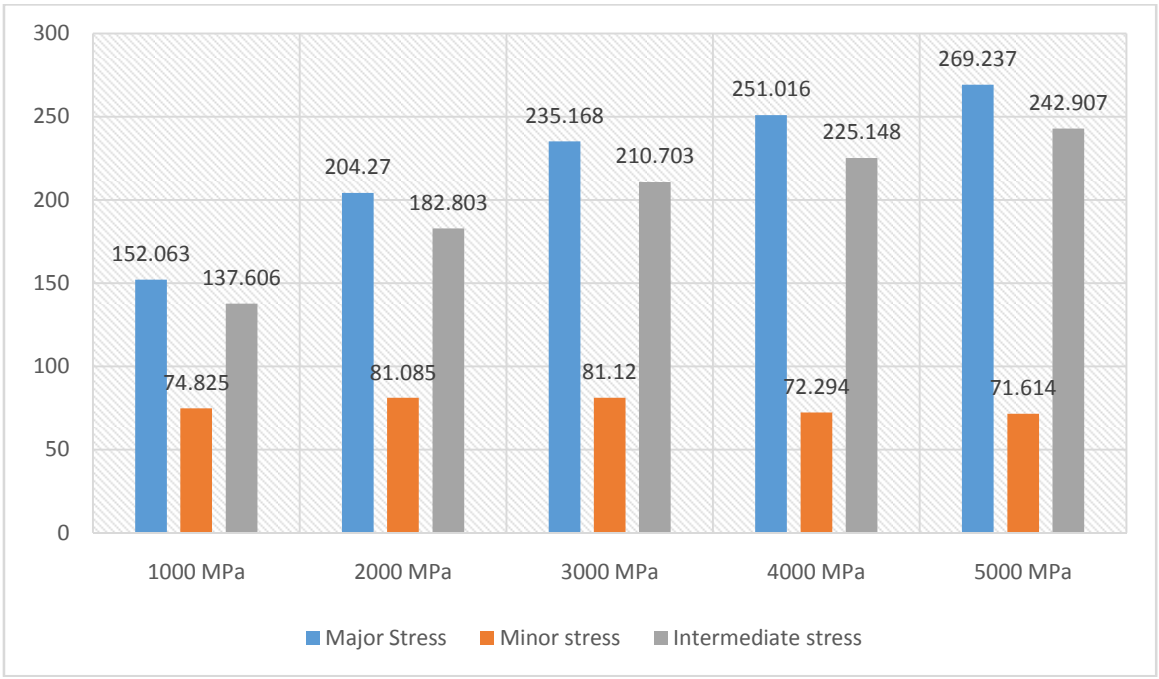

Fig. 1: comparison major, minor and intermediate stresses at point number 1 at 0.00 vertical coordinate

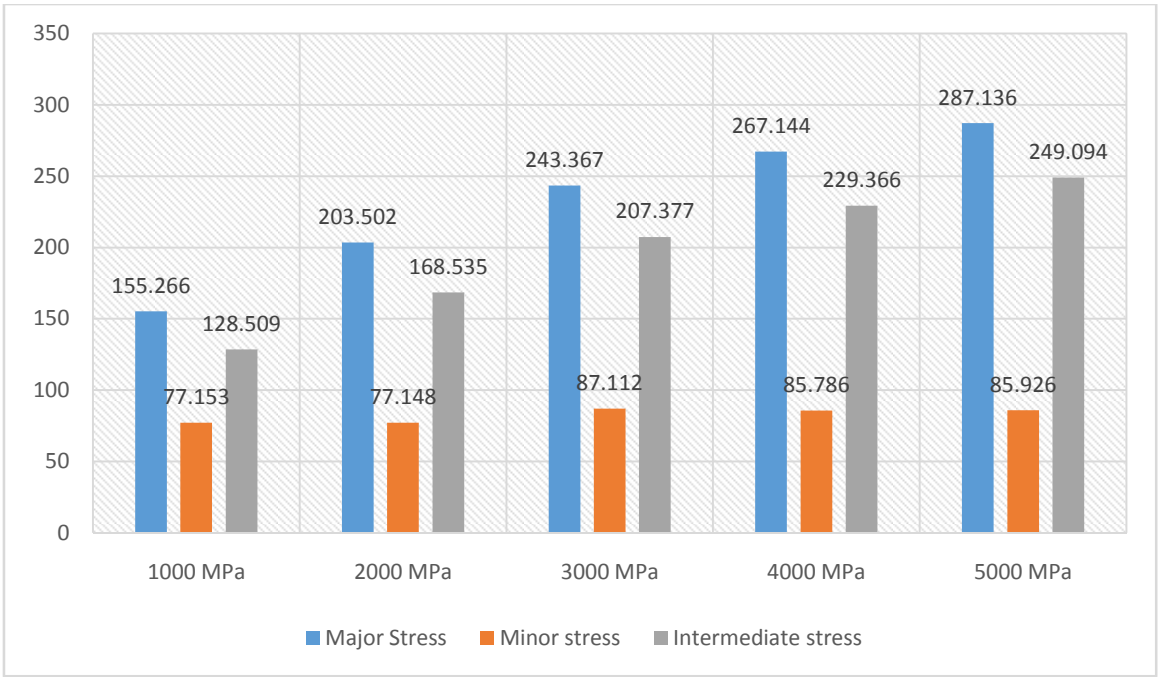

Fig. 2: comparison major, minor and intermediate stresses at point number 2 at 0.00 vertical coordinate

Conclusion:

A series of numerical simulation were conducted to find out the effect of elastic moduli. In this study, elastic moduli of surface layer were varied from 1000 MPa to 5000 MPain a flexible pavement structure to compare the deflection and major, minor and intermediate stresses.Kenlayersoftware was used to perform this study. The acquired results compared at point number one and two at 0.00 vertical coordinates. The results

showed that major stress and intermediate stress increase by increasing the E of surface layer ($E_{surface}$) while peak point at minor stresses happen under 3000 MPa stress.

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