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STRESS AND STRAIN ON STATE ROAD IB33 IN SERBIA

Abstract

In the pavement structure, stresses and deformations occur due to the effect of the environment and traffic load. The stresses that will occur mostly depend on the traffic load, the type of materials used, the modulus of elasticity of the materials used, the thickness of the layers... Due to the effect of the environment and traffic on the pavement, damage and the creation of permanent deformations, i.e. ruts, occur. If these damages are not repaired in time, the damage will develop even faster. In this paper, the traffic load on the road Požarevac - Veliko Gradište - Golubac was analyzed, the possible damage that may occur due to the effect of that load, as well as the method of maintaining that roadway in order to prevent major damage to the roadway structure.

Keywords: stress, strain, flexible pavement, traffic load, ruts, potholes

НАПОНИ И ДЕФОРМАЦИЈЕ НА ДРЖАВНОМ ПУТУ IБ33 У РЕПУБЛИЦИ СРБИЈИ

Сажетак

У коловозној конструкцији јављају се напони и деформације усљед дејства средине и саобраћајног оптерећења. Напони који ће се јавити највише зависе од сабраћајног оптерећења, врсте материјала, модула еластичности материјала, дебљине слојева... Усљед дејства средине и саобраћаја на коловоз, долази до оштећења и стварања трајних деформација (колотрага). Уколико се та оштећења не санирају на вријеме долази до њиховог бржег развоја. У овом раду је анализирано саобраћајно оптерећење на путном правцу Пожаревац – Велико Градиште – Голубац, могућа оштећења до којих може доћи усљед дејства саобраћаја као и методе одржавања тог коловоза како би се спријечила већа оштећења.

Кључне ријечи: напон, деформације, флексибилан коловоз, саобраћајно оптерећење, колотраг, ударна рупа

1. INTRODUCTION

Pavement structures are the most important part of our transportation infrastructure, serving as the most important and expensive part of our roads, highways, etc. While these surfaces may appear as simple layers of asphalt or concrete, they are subject to complex forces that affects their performance and durability. Understanding the concepts of stress and strain in pavement structures is essential for ensuring their durability, safety, and economic efficiency.

In this research, we will talk about the fundamental principles of stress and strain as they apply to pavement engineering. We will explore how various loads and environmental factors impact these structures and the importance of proper design and maintenance to prevent premature deterioration.

Before delving into the specifics of pavement engineering, it is crucial to define stress and strain.

Stress is a measure of the internal resistance within a material to deformation when subjected to an external force or load. In the context of pavement, stress is the force applied per unit area, usually expressed in units of Pascals (Pa) or pounds per square inch (psi) [1]. Understanding how stress is distributed within the layers of a pavement structure is essential for assessing its load-bearing capacity.

Strain is the measure of deformation experienced by a material in response to stress. It describes how much a material's shape changes when subjected to external forces. In pavement engineering, strain helps us understand how the layers of a pavement structure deform under the influence of traffic loads and environmental conditions [2].

2. THE SIGNIFICANCE OF STRESS AND STRAIN IN PAVEMENT

Stress and strain are very important in pavement engineering for several reasons [3]:

- Safety: Excessive stress or strain in a pavement structure can lead to cracks and surface deformations, which pose safety hazards for road users.
- Durability: The ability of a pavement to withstand repeated loading without deterioration depends on how stress and strain are distributed and managed.
- Economic Efficiency: Properly designed and maintained pavements with optimal stress and strain management can have longer service lives, reducing maintenance and rehabilitation costs.
- Environmental Impact: Pavement distress, such as rutting or cracking, can lead to increased fuel consumption and vehicle emissions. Minimizing these issues is essential for environmental sustainability.

In the subsequent sections, will be presented the types of stress and strain in pavement structures, how they are redistributed, and the factors that influence them. Also, will be discuss strategies for designing and maintaining pavements to mitigate stress and strain-related issues, ensuring safer and more resilient road networks.

The most important factors that influence on stress and strain values and distribution are:

- Traffic Load
- Environmental (temperature, freezing point etc.)
- Materials and thickness of layers in structure
- Condition of the pavement structure.

2.1. TRAFFIC LOAD

Flexible pavement structure is with an asphalt pavement cover and bearing layers of unbound natural or crushed stone aggregates, either partially or completely stabilized with a hydraulic binder. The load-bearing subbase layers have a significantly lower stiffness compared to the stabilized - bound ones and achieve an insignificant stress distribution on the foundation soil in the subgrade. The value of the stress depends mostly on the thickness of the bearing layers and not on the stiffness, it cannot differ significantly in the cases of Crushed stone Aggregate (CSA), and in this type of pavement structure it will depend mostly on the stiffness of the layer on which it is laid [4].

The passage of one traffic load causes damage of a different nature on pavement structures. Their subgrades, during each passage of the load, remember the permanent deformation as a function of the vertical stress to which it is subjected [5]. The accumulation of these deformations is transferred to the surface of the pavement and is depicted as a permanent deformation of the longitudinal and transverse profile. Such deformations are typical for pavements with unbound CSA, while in other cases the stresses on the pavement are of sufficiently moderate intensity that in normal cases permanent deformation remains on the pavement [4]. Figure 1 shows the behavior of the pavement structure under the influence of traffic load.

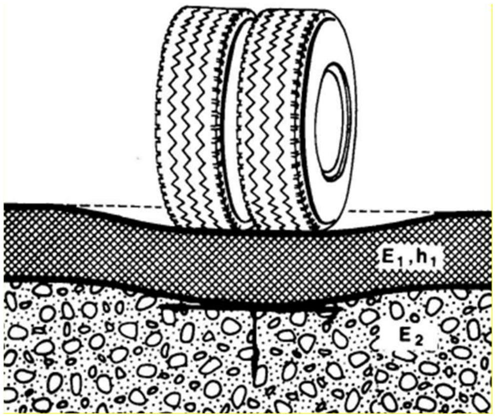


Figure 1. Scheme of mechanical behavior of flexible pavement structure under traffic load [6]

Figure 2 describes the vertical stresses, horizontal stresses and shear stresses in the bottom of the bound layers as well as the compressive and tensile stresses in the subbase layers and subgrade soils. This shows that the principal stresses σ1 and σ3 rotate before, under and after the wheel load. It is important to recognize there are compressive stresses in the bound layers in front of and behind the wheel load, while the stresses are strongly tensile under the wheel load [7].

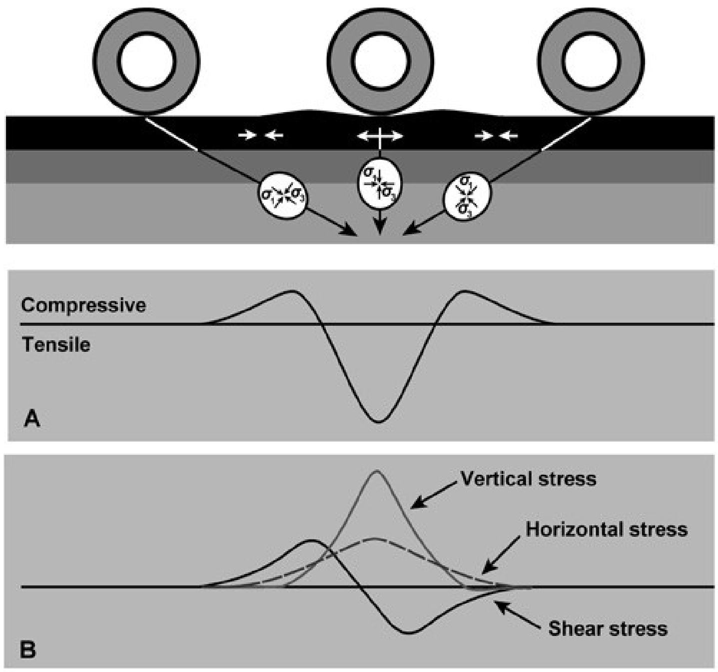


Figure 2. Strains (A) and Stresses (B) caused by a moving of tyre. Figure modified after Doré and Zubeck (2008) [6]

The tensile and compressive stresses induced on the pavement by heavy wheel loads decreases with increasing depth, also load duration, stress retention and stress area increases with increasing depth In order to take maximum advantage, pavement layers are usually arranged in order of descending load bearing capacity, with the highest load-bearing capacity material on the top and the lowest load-bearing capacity material at the bottom, as seen in flexible pavement [8].On figure 3 we can see stress on different layers in pavement structure.

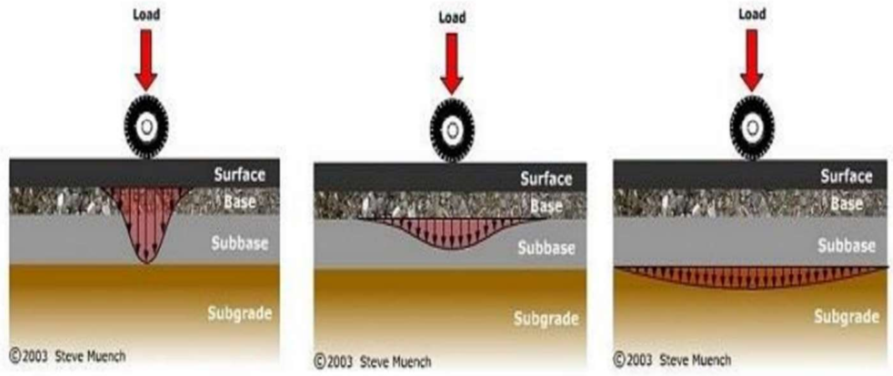


Figure 3. Typical Flexible Pavement and Load Distributions [9]

2.2. ENVIRONMENTAL

Since different layers of the pavement structure are heated differently, temperature is one of the most important factors that affect changes in stress and deformation of pavement structures, and high and low temperatures cause impacts in the pavement. In addition to temperature and solar radiation, wind also affects pavement structures. These environmental influences are different for each location, so they have different effects in different locations.

Temperature affects the mechanical and rheological properties of all materials in the pavement structure, with the greatest impact on asphalt layers. Asphalt is a material that has highly elastic characteristics at high temperatures, and highly plastic characteristics at low temperatures. The behavior of asphalt can be represented by certain rheological models that are made up of differently connected Newtonian and Hooke elements (dampers and springs) (Figure 4). At high temperatures, Newton's elements come into greater expression, i.e. flow, and at low temperatures Hooke's elements, i.e. plasticity [10].

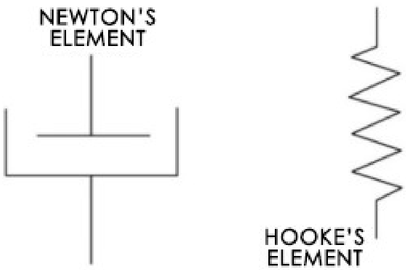


Figure 4. Basic rheological models of asphalt behavior [10]

A big problem occurs in the winter months when the water freezes in the layers that are sensitive to frost (subbase, subgrade), ice lens forms, which causes the pavement to rise in those places and cracks appear.

Fractures in flexible structure caused by thermal effects are a problem, both in climatic areas with low temperatures, and in climatic zones where large variations in daily temperatures are noticeable [11]. Due to the effect of low temperatures, thermal stresses are equalized with the tensile strength of the materials from which the pavement is made. In this way, the bonds within the bitumen itself and the bonds between the bitumen and the aggregates break - the structure breaks [12]. Figure 5 shows the fracture temperatures.

In the case of flexible pavement structures, the influence of temperature manifests itself in two ways, through:

- extremely high dependence of the modulus of rigidity - elasticity on temperature, i.e. variable load capacity during different seasons;
- extremely small dependence of the pavement structures (temperature stresses) on temperature changes [12].

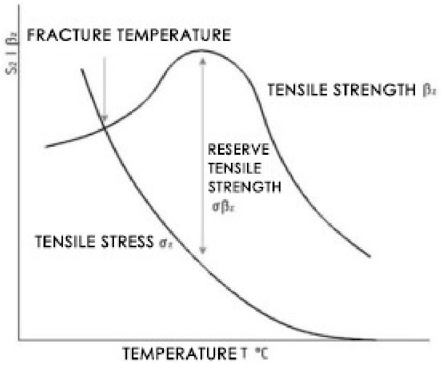


Figure 5. Determination of tensile strength as a function of temperature [11]

2.3. MATERIALS AND THICKNESS OF LAYERS IN STRUCTURE

All the technical properties of mineral stone materials, hydraulic and hydrocarbon binders, and the type and quality of the material in the subgrade affect the damage to the pavement during exploitation. How an asphalt material will behave under the influence of traffic load depends primarily on its three fundamental mechanical properties: stiffness, resistance to fatigue under repeated tensile stresses from bending and resistance to the occurrence of permanent deformations [12].

2.4. CONDITION OF THE PAVEMENT STRUCTURE

The current pavement condition as well as its maintenance also have a significant impact on the stresses and deformations in the pavement. Namely, if the roadway structure is not properly maintained, potholes and bumps are created, if they are not repaired under the influence of a wheel that hits a pothole or bump, even greater stresses are created in the roadway than in a structure in which there is no damage. Roadex Network shows how bumps can affect pavement. The magnitude of stresses and strains is also affected by how smooth and even the road surface is. This is due to the fact that uneven bumps can cause impact loads to the pavement due to the suspension system of trucks. Because of this the stresses and strains after a bump can be substantially higher than the corresponding values on the normal surface, what we can see on Figure 6. This may cause a faster deterioration of the pavement due to water from the top of the wet base course pumping up through the pavement [7]. They also showed that with a traffic speed of 80-100 km/h, one bump has an effect on the pavement for almost 200 m.

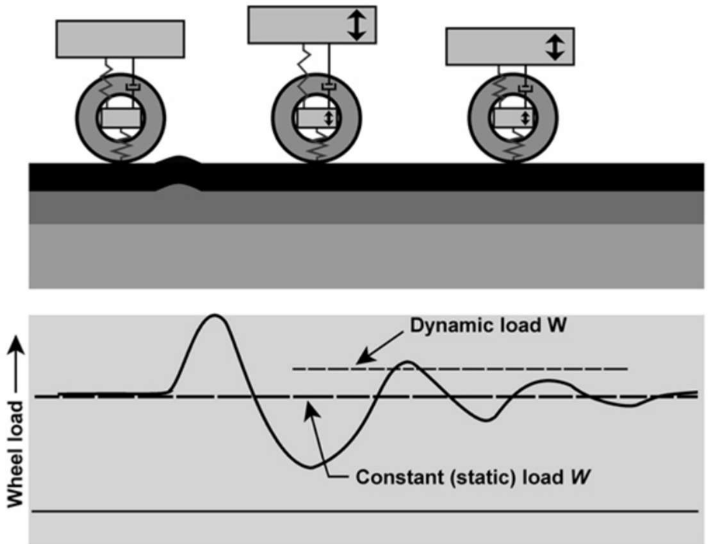
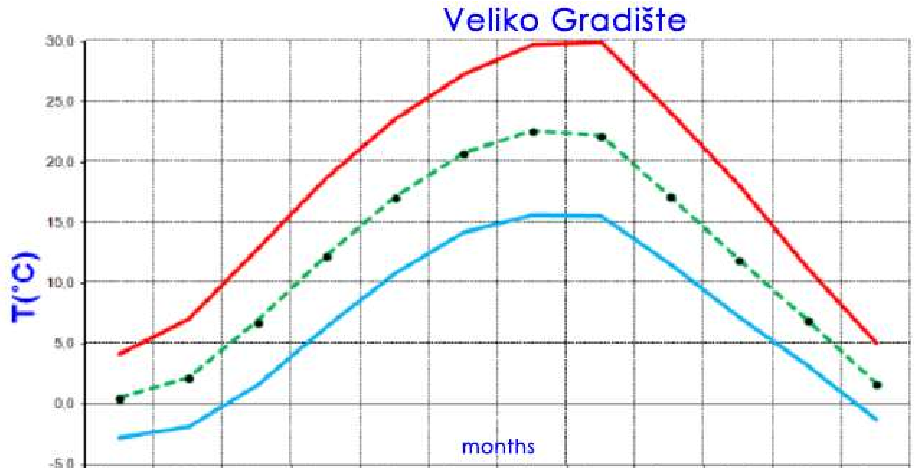


Figure 6. The effect of an uneven bump and how it loads the pavement after the bump. The oscillating load levels after the event can be much higher than the constant (theoretical) load. Figure modified after Doré and Zubeck (2008)[7]

3. STRAIN AND STRESS IN PAVEMENT ON STATE ROAD IB33

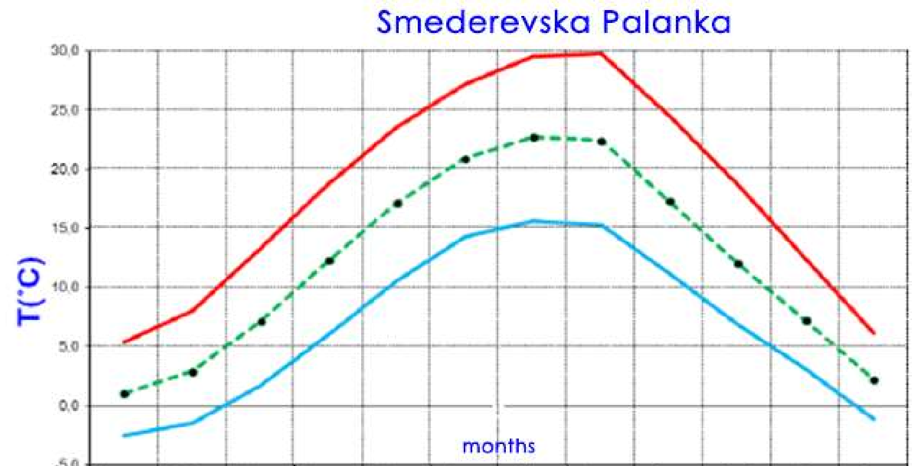
In this review we analyzed stress and strain on state road IB33 from toll plaza Pozarevac to Pozarevac (km 0+000- km 13+184). This location is in Central Serbia near locations Veliko Gradište, Velika Plana, Smederevo, Smederevska Palanka and Belgrade. This road is important because it is connection to important tourist attractions and it is one of connection between Serbia and Romania. In that part of Serbia live around 300.000 people and it is important to control stain and stress on that road, to keep road in good conation.

The mean value of the annual sum of precipitation for Veliko Gradiste is 669.8mm and for Smederevska Palanka is 669.5mm. In figure 7 and 8 we can see temperature by months in Veliko Gradiste and Smederevska Palanka. This parameters are important for pavement design, to know for witch weather conditions we are designing pavement structure.



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T maximum	4,1	7,0	12,8	18,7	23,5	27,3	29,7	29,9	24,2	18,1	11,3	5,0
T minimally	-2,8	-1,9	1,5	6,3	10,8	14,2	15,6	15,5	11,6	7,2	3,2	-1,3
T average	0,5	2,2	6,8	12,3	17,1	20,8	22,6	22,2	17,2	11,9	6,9	1,7

Figure 7. Mean monthly temperatures for the synoptic station Veliko Gradiste (1991-2020) [14]



	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
T maximum	5,3	8,0	13,3	18,8	23,5	27,2	29,5	29,8	24,5	18,7	12,4	6,1
T minimally	-2,6	-1,5	1,7	6,0	10,5	14,3	15,6	15,3	11,2	6,8	3,1	-1,2
T average	1,0	2,9	7,1	12,3	17,1	20,9	22,7	22,4	17,3	12,0	7,2	2,2

Figure 8. Mean monthly temperatures for the synoptic station Smederevska Palanka (1991-2020) [14]

In figure 9 we can see frost index for Belgrade for season 2011/2012. This parameter we are using to know frost line and which material we need to use for pavement structure and for subgrade.

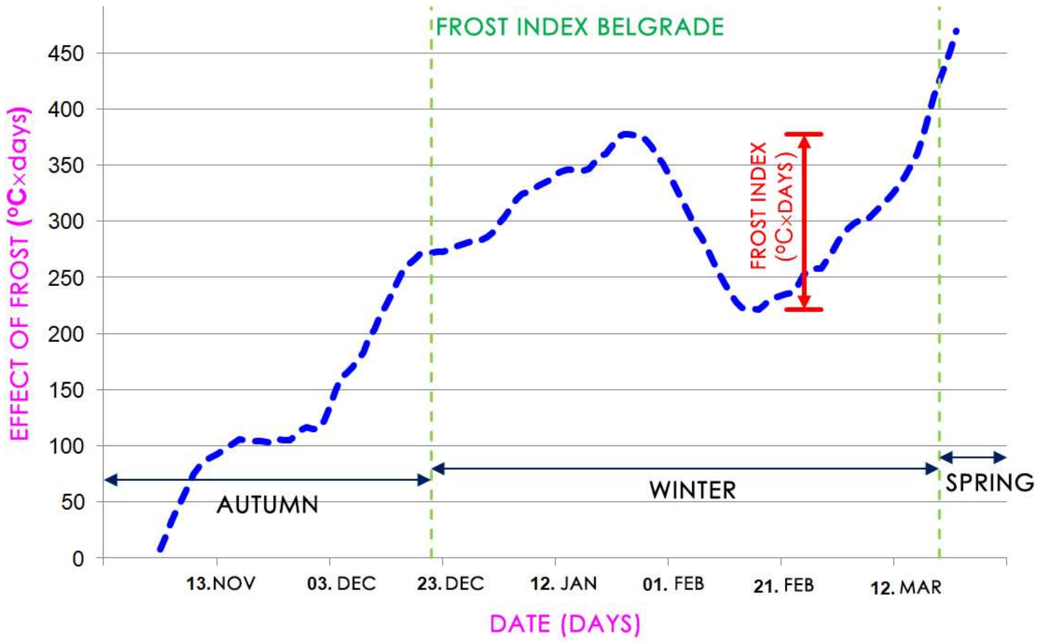


Figure 9. Graphic display of frost index calculations for the weather station Belgrade (season 2011/2012)[14]

The equivalent traffic load was calculated for the project period of 20 years. In accordance with standards SRPS U.C4.010 and SRPS U.C4.015 traffic load is expressed in equivalent standard axles of 82 kN. Traffic analysis was performed based on traffic forecasts for the period from 2025 to 2044. , input data for this analysis we get from Preliminary design (Highway institute) and from PE „Roads of Serbia". In table 1 we can see traffic forecast [15]. In that table we can see annual average daily traffic (AADT) by years, also there are number of each type of vehicle by year. There we have bus (BUS) , light truck (LT), medium truck (MT) , heavy truck (HT) and semi-trailer truck (TT).

Table 1. Traffic forecast from toll plaza Pozarevac to Pozarevac (bypass)

Year	AADT	BUS	LT	MT	HT	TT
2025	2123	277	390	456	301	699
2026	2185	279	403	471	311	720
2027	2246	283	415	486	321	740
2028	2307	286	429	501	330	761
2029	2370	290	442	517	340	781
2030	2429	293	454	531	351	802
2031	2490	295	467	546	361	822
2032	2552	299	480	561	370	843
2033	2612	302	492	576	380	863
2034	2674	305	505	591	390	884
2035	2735	310	519	607	395	905
2036	2792	313	532	621	401	924
2037	2853	318	546	637	407	945
2038	2911	322	558	653	413	965
2039	2973	327	572	669	419	985
2040	3031	331	585	684	425	1006
2041	3091	335	599	700	431	1026
2042	3150	339	612	716	437	1046
2043	3208	344	623	730	442	1066
2044	3267	348	639	746	448	1087

The equivalent traffic load for this part of state road IB33 is 15 518 025 equivalent standard axles of 82 kN and for pavement design we take number of 16 000 000 equivalent standard axles.

According to design pavement structure was with 50cm subbase of crushed stone aggregate (30 cm 0/63mm Ev2 ≥ 140 MPa and 20 cm 0/31,5mm Ev2 ≥ 180 MPa),14cm in two layer of binder course (7cm with BIT50/70 and 7cm with Pmb 45/80-65) and 4cm surface course of SMA11s, on figure 14 we can see typical cross section of pavement structure. In table 2 we can see modulus of elasticity and Poisson's coefficient of all materials in this pavement structure.

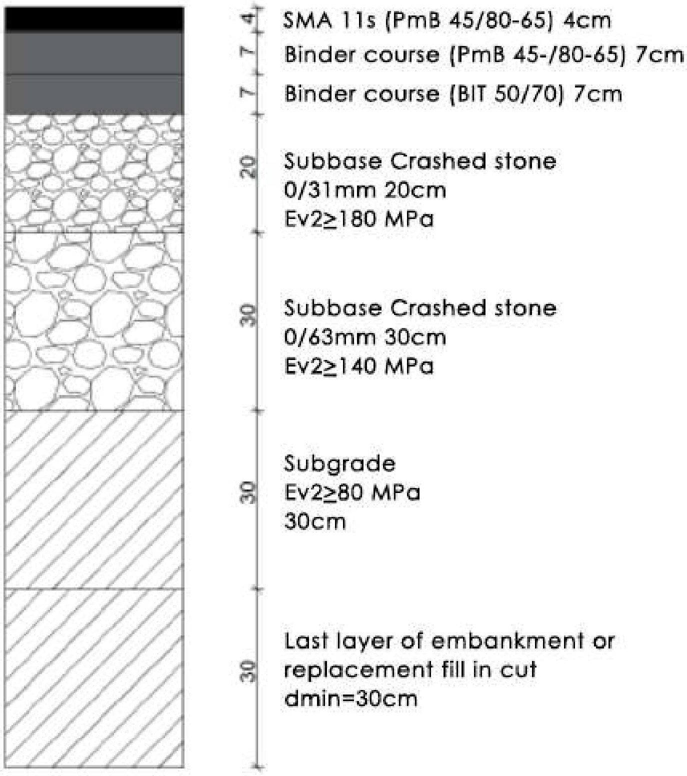


Figure 10. Typical cross section of pavement structure [14]

Table 2. Material characteristics in pavement structure

d (cm)	Layer	E (MPa)	ν
4	SMA11s	3600	0.35
7	Binder course (PmB 45/80-65)	4800	0.35
7	Binder course (BIT 50/70)	5340	0.35
20	Subbase Crushed stone 0/31mm	500	0.40
30	Subbase Crushed stone 0/63mm	230	0.40
	Subgrade	80	0.40

In BISAR 3.0 Shell's software is calculated stress and deformation on this road with this pavement structure under calculated traffic load for this road, below is software output data. The program calculates the eigen values and eigen vectors of the stress and strain tensors, the principal stresses and strains and the corresponding principal directions. The maximum and minimum principal values represent the maximum and minimum normal stresses and strains.

BISAR 3.0 - Block Report

Pozarevac - Golubac

0+000 - 13+184

Structure

Layer Number	Thickness (m)	Modulus of Elasticity (MPa)	Poisson's Ratio
1	0.040	3.600E+03	0.35
2	0.070	4.800E+03	0.35
3	0.070	5.340E+03	0.35
4	0.200	5.000E+02	0.40
5	0.300	2.300E+02	0.40
6		8.000E+01	0.40

Loads

Load Number	Vertical Load (kN)	Vertical Stress (MPa)	Horizontal (Shear) Load (kN)	Horizontal (Shear) Stress (MPa)	Radius (m)	X-Coord (m)	Y-Coord (m)	Shear Angle (Degrees)
1	2.000E+01	5.774E-01	0.000E+00	0.000E+00	1.050E-01	0.000E+00	-1.575E-01	0.000E+00
2	2.000E+01	5.774E-01	0.000E+00	0.000E+00	1.050E-01	0.000E+00	1.575E-01	0.000E+00

Position Number	Layer Number	X-Coord (m)	Y-Coord (m)	Depth (m)	Stresses XX (MPa)	Stresses YY (MPa)	Stresses ZZ (MPa)	Strains XX µstrain	Strains YY µstrain	Strains ZZ µstrain	Displacements UX (µm)	Displacements UY (µm)	Displacements UZ (µm)
1	1	0.000E+00	0.000E+00	4.000E-02	-2.828E-01	-3.164E-01	-2.662E-02	-4.520E+01	-5.782E+01	5.087E+01	0.000E+00	0.000E+00	2.658E+02
2	1	0.000E+00	-1.575E-01	4.000E-02	-4.782E-01	-4.403E-01	-5.392E-01	-3.760E+01	-2.341E+01	-6.046E+01	0.000E+00	5.489E+00	2.660E+02
3	2	0.000E+00	0.000E+00	1.100E-01	2.461E-02	-7.628E-02	-9.317E-02	1.748E+01	-1.089E+01	-1.564E+01	0.000E+00	0.000E+00	2.670E+02
4	2	0.000E+00	-1.575E-01	1.100E-01	-3.884E-03	-2.471E-02	-2.801E-01	2.141E+01	1.556E+01	-5.626E+01	0.000E+00	-5.345E-01	2.623E+02
5	3	0.000E+00	0.000E+00	1.800E-01	5.390E-01	3.126E-01	-7.867E-02	8.561E+01	2.836E+01	-7.055E+01	0.000E+00	0.000E+00	2.640E+02
6	3	0.000E+00	-1.575E-01	1.800E-01	5.841E-01	4.724E-01	-8.814E-02	8.419E+01	5.597E+01	-8.575E+01	0.000E+00	-6.737E+00	2.579E+02
7	4	0.000E+00	0.000E+00	3.800E-01	4.312E-02	3.684E-02	-3.370E-02	8.374E+01	6.615E+01	-1.314E+02	0.000E+00	0.000E+00	2.372E+02
8	4	0.000E+00	-1.575E-01	3.800E-01	4.029E-02	3.327E-02	-3.115E-02	7.887E+01	5.924E+01	-1.211E+02	0.000E+00	-1.009E+01	2.314E+02
9	6	0.000E+00	0.000E+00	6.800E-01	7.197E-04	3.988E-04	-1.296E-02	7.178E+01	6.616E+01	-1.675E+02	0.000E+00	0.000E+00	1.984E+02
10	6	0.000E+00	-1.575E-01	6.800E-01	6.767E-04	1.650E-04	-1.237E-02	6.948E+01	6.053E+01	-1.588E+02	0.000E+00	-1.012E+01	1.952E+02

As we can see in this report all deformation are satisfactory under calculated traffic load. This traffic load did not make any fracture in pavement structure. The maximum values of strain on bottom of asphalt layer depends of modulus of elasticity, volume if bitumen percentage of bottom asphalt layer and traffic load. The maximum value of strain on top of subgrade depends on traffic load and confidence level (here it is 95%). Here strain on bottom of asphalt layer is 85,6 μm and allowed value is 100 μm, and for top of subgrade value is 168 μm and allowed values is 269 μm .This pavement must have good maintenance plan to keep the strains and stresses that way. In table 3 is one of variant of maintenance strategy for this road, with which we can keep the strains and stresses like in BISAR report.

Table 3. Variant of maintenance of this road for next 20 years

Driving lane (% of subject area)	
Year of exploitation	Maintenance method
2	15% filling cracks
4	50% filling cracks
6	100% filling cracks
8	20% replacement of the wear layer 4cm
10	100% scraping 11cm
10	100% new binder course 7cm
10	100% new wear layer 4cm
12	15% filling cracks
14	50% filling cracks
14	20% replacement of the wear layer 4cm
16	100% filling cracks
18	20% replacement of the wear layer 4cm
20	100% new binder course 7cm
20	100% replacement of the wear layer 4cm

4. CONCLUSION

This study has examined the stress and strain characteristics of pavement materials depends of various conditions. The findings have provided valuable insights into the factors affecting pavement performance and durability. We have demonstrated that proper pavement design and maintenance strategies are crucial to mitigate the adverse effects of stress and strain, ultimately enhancing the safety and longevity of road infrastructure. In this study we analyzed strains and stress on state road IB33 form toll plaza Pozarevac to Pozarevac under predicted traffic load for next 20 years. We did that in BISAR 3.0 software and in report we got that all stresses and strains in this pavement structure under predicted traffic load are satisfactory, but we must have good maintenance plan if we want to keep that state in pavement structure for next years.

Future research should focus on conducting field experiments to validate these findings and further explore the complexities of pavement behavior. The significance of this research lies in its potential to improve the resilience and sustainability of our transportation networks, ensuring safer and more cost-effective infrastructure for the future.

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