ANALYSES OF THE INFLUENCE OF MATERIAL CHARACTERISTICS ON PAVEMENT DESIGN

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Abstract: Currently, only empirical design methods are used in the application of well-known standards for pavement structure design. Given this fact, it is assumed that material characteristics correspond to average quality materials. Thus, the aim of this study included examining the influence of material characteristics on pavement design analyzing changes in the cement bound base layer (CBL) characteristics with respect to the occurrence of cracks and changes in the asphalt layer given typical seasonal changes. The study involved varying CBL modulus as 15 GPa, 10 GPa, and 5 GPa. Additionally, the moduli of asphalt layers were varied from 6 MPa to 2 MPa to simulate real conditions in pavement structure life. The analyses indicated that there was a significant difference in pavement behavior with respect to changes in material characteristics. Given these significant differences, it is extremely important to properly define material characteristics while using empirical design methods. Proper material characterization combined with the utilization of empirical and analytical methods increases the possibility of reducing layers thickness to design cost-effective structures.

Keywords: pavement structure; stress; strain; displacement; design methods

ANALIZA UTJECAJA KARAKTERISTIKA MATERIJALA NA DIMENZIONIRANJE KOLNIČKE KONSTRUKCIJE

Sažetak: Prilikom dimenzioniranja kolničke konstrukcije, u suvremenoj se praksi primjenjuju poznati standardi unutar empirijskih metoda dimenzioniranja. Pritom se svojstva materijala pretpostavljaju s obzirom na prosječnu kvalitetu standardnih cestograđevnih materijala, bez dodatne analize eventualnih promjena tijekom vremena i zbog naprezanja. Svrha ovoga rada je istražiti utjecaj svojstava materijala na projektiranje kolničke konstrukcije kroz analizu utjecaja promjena karakteristika cementom stabiliziranih nosivih slojeva (CSS/CBL) nakon pojave pukotina u sloju i kroz analizu utjecaja promjena u ponašanju asfaltnih slojeva tijekom uobičajenih izmjena godišnjih doba. Za potrebe analize mijenjane su vrijednosti modula elastičnosti cementom stabiliziranih slojeva (CSS/CBL) i asfaltnih slojeva kako bi se simulirali stvarni uvjeti tijekom projektnog razdoblja. Analize su pokazale da postoji značajna razlika u ponašanju kolničke konstrukcije pri promjeni svojstava materijala. Zbog toga je bitno pravilno definirati karakteristike materijala prilikom korištenja empirijskih metoda projektiranja. Uz pravilnu karakterizaciju materijala i usporedno korištenje empirijskih i analitičkih metoda, postoji mogućnost smanjenja debljina pojedinih slojeva kolničke konstrukcije u svrhu dobivanja racionalnije konstrukcije

Ključne riječi: kolnička konstrukcija; naprezanje; deformacija; pomaci; metode dimenzioniranja

1 INTRODUCTION

A pavement structure is a system composed of different materials that are inbuilt into multiple compacted and interconnected layers. The main task of a pavement includes bearing traffic loads and transmitting the loads to the sub-base while performing load reduction to limit the deformation of the sub-base, and thereby of the pavement structure.

Asphalt pavements consist of asphalt surfacing and base courses. Base courses are typically bound by a type of hydraulic binder (usually cement) or they are mechanically compacted into a compact base layer. The Croatian national standard for asphalt pavement design (HRN U.C4.012) specified that asphalt pavements are divided into the following three types (Figure 1):

- Type 1: asphalt layers (surface and base courses) + unbound, mechanically compacted base course
- Type 2: asphalt layers (surface and base courses) + hydraulically bound base course
- Type 3: asphalt layers (surface and base courses) + hydraulically bound base course + unbound, mechanically compacted base course

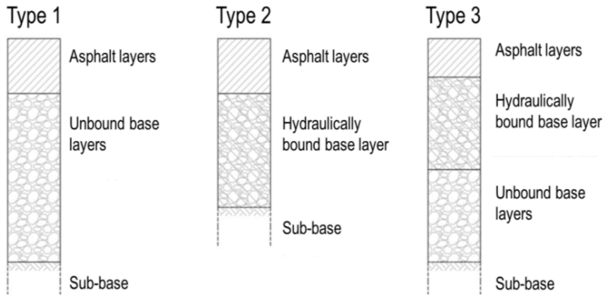


Figure 1 Types of asphalt pavements based on the HRN U.C4.012 standard

Roads that are designed to bear light traffic loads can be constructed without the use of a hydraulically bound base layer (Type 1) by directly constructing the wearing asphalt layer on a layer of mechanically compacted material (crushed stone or gravel).

Within asphalt pavements, quality of inbuilt materials decreases with increases in depth. Additionally, the structure possesses a certain flexibility due to the characteristics and dimensions of inbuilt materials. Deflection under heavy traffic is in a range of 0.5 mm if the pavement structure is properly designed and constructed [1].

Observations on the behavior of pavements over a very short period indicate that the behavior can be considered as elastic. The construction bends under the influence of a traffic load and returns to its original state on cessation of the load. Long-term heavy traffic gradually leads to material fatigue causing the formation of plastic deformation and cracks. A pavement structure can withstand a specified anticipated design period without major damage if it is properly designed and maintained.

The analysis of pavement structures is more complex when compared with many other engineering structures as it involves a multilayer system composed of different materials that change their properties depending on external factors under a dynamic load. The basic material properties to calculate stresses and strains in pavement design include dynamic modulus of elasticity (E) and Poisson´s ratio (μ). The determination of these properties depends on material influences such as humidity and temperature. Thus, dynamic modulus is determined at different temperatures for asphalt because temperature has a significant effect, and the modulus is determined at different humidity levels for materials wherein humidity has a significant effect [1].

The elastic modulus of a subgrade depends on humidity and compaction. In contrast, the modulus of an unbound base layer depends on the type of material, compaction, layer thickness, and the modulus of a subgrade.

A cement bound base layer (CBL) involves rigid materials with a high modulus of elasticity. Aggregate grading, the amount of binder used, and compactness influence elastic modulus. Several previous studies examined CBL properties and characterization of materials [2-5]. Cracks that occur in a CBL reduce the value of laboratory modules (by sometimes more than 50%). Therefore, modules inferior to those obtained by laboratory tests are adopted for analysis purposes.

Asphalt mixes when subjected to traffic and environmental conditions display highly complex behavior. Specifically, the response to stress can be elastic, viscous, or plastic and can also include microdamage and fracture. Additionally, behavior is dependent on stress state, temperature, and boundary conditions to which the material is subjected either in the laboratory or in the field [6]. Numerous studies demonstrated a significant effect of temperature on the mechanical and rheological properties of asphalt mixes [7-13]. It is necessary for asphalt mixes to possess properties including stress distribution, stability during permanent deformation resistance, resistance to cracking, and resistance to freeze-thaw and moisture damage such that they can perform satisfactorily in pavement systems [6].

As indicated by the above discussion, the correct choice of elastic modulus value is very important for precise calculations in mechanistic pavement design. Thus, the elastic modulus should be a representative value of the layers of pavement structure over time.

Several empirical and theoretical methods were proposed by extant research for proper pavement design, and some of these are presented and compared in the present study. The aim of this study included using a layered elastic model to compare two types of pavement design methods, namely national Croatian empirical and analytical methods, and analyzing the benefits of proper design method selection with respect to proper material characterization.

2 EMPIRICAL METHODS FOR PAVEMENT DESIGN

In practice, most pavement structural designs involve using empirical methods. These methods are based on the results of systematic observations on pavement performance [14]. Observations are usually performed on existing road sections, or on test sections that are specifically designed for this purpose, or more recently on specially constructed sections for accelerated experimental load testing. Some of the first design curves based on road tests were designed in the 1960s [15]. These methods are very widespread in engineering practice due to their efficiency and easy to use operation features although they possess limitations [16].

Limitations in empirical approach of pavement design have become more apparent primarily due to the prevalence of increasing traffic trends in highways relative to volume and axle loads given that the construction and characteristics of heavy vehicles considerably differ from those of vehicles that existed when these empirical methods were first proposed. The second problem relates to the application of new materials, particularly waste materials and industrial by-products, as their characteristics and behavior when inbuilt in a pavement layer are largely unexplored.

The **C**alifornia **B**earing **R**atio (CBR) method was an early pavement design approach developed in the years 1928–1929 by the California Highway Department [17]. Initially, this method did not involve traffic as a parameter, it was introduced later as a correction factor [18]. Within this method, three main variables are considered, namely load, subgrade strength expressed by CBR value, and total pavement thickness. The design procedure is very easy and fast, and it begins with the estimation of subgrade strength and the volume of traffic involved. When the CBR value of the soil is known, the appropriate thickness of construction required above the soil for different traffic conditions is determined using design charts. Thickness design charts are developed based on observations of a number of sections with respect to the subgrade CBR value for the most critical moisture condition.

The AASHO Road Test (**A**merican **A**ssociation of **S**tate **H**ighway **O**fficials) was conducted from 1956–1961 in Ottawa, Illinois, and it is one of the largest and most successful controlled civil engineering experiments with results that continue to be used widely across the world [19]. The primary purpose of the tests involved determining the relationship between axle loading and pavement structure with respect to pavement performance to provide an engineering basis for establishing maximum axle load limits. Pavement performance in this context was defined as the service provided by the pavement or the number of load repetitions that were carried to an unserviceable level. The AASHO Road Test assigned a quantitative value for the importance of pavement surface thickness in increasing the number of load repetitions that were carried to pavement failure. It also provided quantitative information on the relative damaging effect of heavy loads and equations to generate load equivalencies called ESALs (**E**quivalent **S**tandard **A**xle **L**oad). The **P**resent **S**erviceability **I**ndex (PSI) was introduced, and it directly related pavement failure to riding quality and rider satisfaction.

In Croatia, pavement design is conducted in accordance with standard HRN. U.C4.012, which is used since 1981 [20]. The basis for this empirical method includes the AASHO Road Test and the resulting AASHO design method. The input parameters include design period (usually 20 years for asphalt pavements), traffic load, sub-base load-bearing capacity (usually expressed by CBR), and the quality of designed materials for pavement courses. The HRN U.C4.012 method is essentially equivalent to a simplified AASHO design method with an adopted PSI value = 2,5 and a regional factor that account for the influence of climate influence on the pavement adopted as R = 2 (in AASHO, the regional factor ranges between 0.5 and 5 in which higher values represent hashed climate conditions). The design procedure relies on two diagrams based on the type of pavement type to be designed.

3 ANALYTICAL METHODS FOR PAVEMENT DESIGN

Limitations in the empirical approaches of pavement design are more apparent primarily due to the increasing traffic trends in highways relative to volume and axle loads. This is because the construction and the characteristics of heavy vehicles differ from vehicles that existed at the time when the empirical methods were formulated. The second problem involves the application of new materials, particularly waste materials and industrial by-products as their characteristics and behavior continue to be insufficiently explored especially when these materials are inbuilt in a pavement layer. Therefore, there is a need for a more flexible approach in the design of pavement structures by applying analytical methods.

The basis for analytical pavement design involves the use of mathematical models to calculate stresses and strains in pavement structure as a response to vehicle loads. The calculated stresses and strains are used for evaluating pavement damage evaluation and consequently estimating pavement life. There are two approaches in analytical pavement design. The first approach involves a layered elastic model that uses a semi-infinite multilayer elastic system for pavement approximation. The second approach corresponds to a finite element model that also uses a semi-infinite multilayer elastic system for approximating the pavement, although each layer is also divided vertically and horizontally in the network system. The input data for both methods are similar. The material properties are expressed as Young´s modulus (E) and Poisson´s ratio (μ) and the thickness of each layer and load. However, material properties in the finite element model are treated as closer to viscoelastic or plastic characteristics, albeit to an elastic state. The finite element method also accounts for material anisotropy and a thin interlayer in the pavement responses [16]. Unlike the layered elastic model, a finite element model can also be used to simulate moving or dynamic load. The output data from both models are the same and include stress, strain, and displacements.

Analytical methods for pavement structure analysis are used to study the effect of axle load and increases in pavement layer thicknesses in addition to the effect of the variation in temperature and elastic moduli of pavement layers on overall pavement life [20, 21]. These analyses entail the usage of different computer programs. **Bi**tumen **S**tress **A**nalysis in **R**oads (BISAR) software developed in 1989 by Shell Petroleum Company [22] is often used as the software owing to its simplicity. A pavement structure is presented as a layered elastic model by using a semi-infinite multilayer elastic system for pavement approximation. A vehicle load can be presented as one or more circular areas (wheel) in both vertical and horizontal axles for stress, strain, and displacement calculations. The pavement layers and number of loads are limited to a maximum of ten. The interconnection between pavement layers assumes full or partial sliding friction or the absence of friction. Another very powerful and widely used software is termed as CIRCLY. This software was designed in Australia and it is used for over two decades. This program implements a rigorous flexible pavement design methodology that incorporates state-of-the-art pavement material properties and performance models. It is possible to calculate cumulative damage on a pavement including the whole traffic spectrum by using CIRCLY. The software includes its own database to eliminate the need to constantly re-key information and it also lets a user to define material properties and loadings. Its ability to generate graphs of displacement, strain, or stress in two-dimensional or three-dimensional form is an advantage when compared to BISAR.

In the present study, possible reduction in layer thickness was analyzed by comparing pavement thickness design when an empirical (HRN U.C4.012) method was used with those when analytical methods (BISAR and CIRCLY software) were used.

4 PAVEMENT STRUCTURE ANALYSES

4.1 Pavement structure analyses by empirical methods (HRN and AASHO)

It was assumed that there was a heavy traffic load of 4 × 10^6 ESALs and subgrade bearing capacity of CBR=5%. Given these assumptions, pavement analyses were performed in accordance with the Croatian standard HRN.U.C4.012 and AASHO design method for 2 asphalt pavement structures, namely an asphalt pavement structure with a cement stabilized base layer (CBL) (Type 3 structure) and an asphalt pavement structure without a cement stabilized base layer (CBL) (Type 1 structure). Structural numbers (designed SN_D and of adopted pavement structures SN_A) for the HRN and AASHO methods include the following:

HRN: (Type 1) $SN_A = 12.60 > SN_D = 10.02$ (Type 3) $SN_A = 11.40 > SN_D = 11.34$

AASHO: (Type 1) $SN_A = 12.20 > SN_D = 10.16$ (Type 3) $SN_A = 11.10 > SN_D = 10.16$

The pavement structures adopted for further analyses are presented in Figure 2.

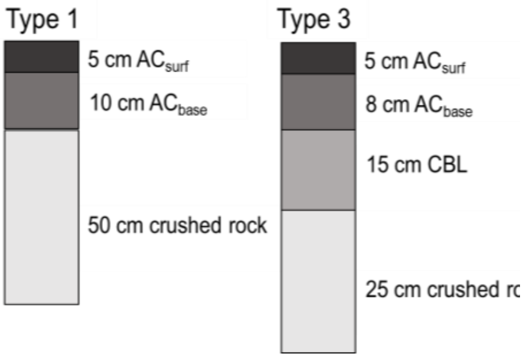


Figure 2 Analyzed pavement structures

It was observed that both structures fulfilled bearing capacity requirements for given traffic load and subgrade bearing capacity. The designer determined the type of construction to be constructed by accounting for local materials available, financial resources, and investor demands. However, there were no real analyses and consideration of material characteristics within the specified design procedure. Thus, the main aim of analyses presented in the present study included defining to which extent material characteristics affected pavement structure behavior under traffic loads. For this purpose, the modulus of elasticity of asphalt and CBL were varied to simulate seasonal changes for asphalt layers and crack occurrences in CBL.

4.2 Analyses of pavement structure by analytical methods (BISAR and CIRCLY software)

For CBL, the modulus of elasticity is usually adopted as 10 000 MPa for the post-cracked state. In a recent study [23], the values of compressive strength, tensile strength, and dynamic modulus of elasticity (measured by ultrasound pulse velocity method) for cement stabilized gravel with 4% cement content were measured and obtained as 3.31 MPa, 0.61 MPa and 13.89 GPa, respectively. Thus, with respect to stress and strain analyses, the variations in the values of dynamic modulus of elasticity included 15 GPa, 10 GPa, and 5 GPa to define crack propagation on pavement stress/strain state. With respect to the Type 1 pavement structure, the influence of seasonal change was analyzed by varying the modulus of elasticity based on seasonal change from 6 GPa to 2 GPa. With respect to asphalt layers and subgrades, material characteristics were predicted based on engineering practice and extant studies [20, 24, 25]. All input parameters are presented in Table 1 while the ESAL model is presented in Figure 3.

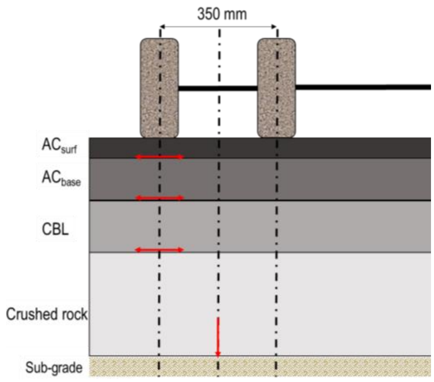


Figure 3 ESAL design model

Table 1 Input parameters for pavement structure stress/strain analyses

Season		WINTER		SUMMER		SPRING / AUTUMN	
Material	**Thickness [cm]**	**E [MPa]**	**υ**	**E [MPa]**	**υ**	**E [MPa]**	**υ**
Pavement structure Type 1							
AC surf	*5*	*6000*	*0.35*	*2000*	*0.48*	*4000*	*0.43*
AC base	*10*	*5000*	*0.35*	*3000*	*0.48*	*4500*	*0.43*
crushed rock	*50*	*400*	*0.35*	*400*	*0.35*	*400*	*0.35*
subgrade	*-*	*50*	*0.35*	*50*	*0.35*	*50*	*0.35*
Pavement structure Type 3							
AC surf	*5*	*6000*	*0.35*	*2000*	*0.48*	*4000*	*0.43*
AC base	*8*	*5000*	*0.35*	*3000*	*0.48*	*4500*	*0.43*
CBL	*15*	*15000*	*0.25*	*15000*	*0.25*	*15000*	*0.25*
crushed rock	*25*	*400*	*0.35*	*400*	*0.35*	*400*	*0.35*
subgrade	*-*	*50*	*0.35*	*50*	*0.35*	*50*	*0.35*
AC surf	*5*	*6000*	*0.35*	*2000*	*0.48*	*4000*	*0.43*
AC base	*8*	*5000*	*0.35*	*3000*	*0.48*	*4500*	*0.43*
CBL	*15*	*10000*	*0.25*	*10000*	*0.25*	*10000*	*0.25*
crushed rock	*25*	*400*	*0.35*	*400*	*0.35*	*400*	*0.35*
subgrade	*-*	*50*	*0.35*	*50*	*0.35*	*50*	*0.35*
AC surf	*5*	*6000*	*0.35*	*2000*	*0.48*	*4000*	*0.43*
AC base	*8*	*5000*	*0.35*	*3000*	*0.48*	*4500*	*0.43*
CBL	*15*	*5000*	*0.25*	*5000*	*0.25*	*5000*	*0.25*
crushed rock	*25*	*400*	*0.35*	*400*	*0.35*	*400*	*0.35*
subgrade	*-*	*50*	*0.35*	*50*	*0.35*	*50*	*0.35*

E – dynamic modulus of elasticity [MPa]; υ – Poisson Ratio

Critical cross-sections within pavement structures corresponded to the bottom of asphalt and CBL layers (in which horizontal tensile stress and strain were analyzed) as well as the top of the subgrade (in which vertical compressive stress and strain were analyzed). The results are presented in Table 2 and Figure 4. Additionally, the BANDS software was used to determine an allowable number of ESAL that cause the fatigue of asphalt layers [20]. Furthermore, the PCA Model (Portland Cement Association Model) [20, 26] was used based on the SR (ratio of equivalent stress to CBL flexural strength) to determine the allowable number of ESALs causing fatigue damage of CBL. With respect to CBL flexural strength, a value of 0.7 MPa was adopted based on previous research data [27]. According to the PCA fatigue model, there are three equations for the number of allowed ESLA applications causing failure N and they included the following:

for SR ≥ 0.55 $$log N = 11.737 - 12.077\, SR \quad (1)$$

for 0.45 < SR < 0.55 $$N = \frac{4.257}{SR - 0.4325} \quad (2)$$

for SR ≤ 0.45 N = *unlimited* (3)

Allowable ESAL repetitions for fatigue subgrade strain development were calculated according to the Shell Pavement Design Manual [20] as follows:

$$\varepsilon = 2.8 * 10^{-2} N^{-0.25} \quad (4)$$

Table 2 Results of pavement structure stress/strain analyses

Season	WINTER			SUMMER			SPRING / AUTUMN		
Material	σ [MPa]	ε [μm/m]	No. ESAL	σ [MPa]	ε [μm/m]	No. ESAL	σ [MPa]	ε [μm/m]	No. ESAL
Pavement structure Type 1									
AC surf	-	0.08642	∞	-	17.38	∞	-	3.652	∞
AC base	0.6741	103.30	9270000	0.5679	134.10	*6310000*	0.6962	109.20	*8490000*
subgrade	0.00966	0.2186	2.692E+20	0.01084	0.04213	*1.95E+23*	0.01	0.08897	*9.81E+21*
Pavement structure Type 3									
AC surf	-	0.9059	∞	-	37.80	*7.35E+09*	-	11.07	*9.8E+11*
AC base	-	-	∞	-	-	∞	-	-	∞
*CBL/**15GPa***	0.6359	33.90	*5.833217*	0.6876	36.69	*0.748058*	0.6504	34.67	*3.279002*
subgrade	0.00757	148.50	*1.26E+09*	0.00887	174.00	*6.71E+08*	0.00794	155.60	*1.05E+09*
AC surf	-	-	∞	-	34.43	*1.17E+10*	-	9.298	∞
AC base	-	0.212	∞	-	-	∞	-	0.01353	∞
*CBL/**10GPa***	0.5154	41.47	*699.6445*	0.5567	44.89	*135.6233*	0.528	42.49	*424.1226*
subgrade	0.00816	162.50	*8.81E+08*	0.0096	190.80	*4.64E+08*	0.00856	170.40	*7.29E+08*
AC surf	-	-	∞	-	29.30	*2.63E+10*	-	7.064	∞
AC base	-	14.61	*1.64E+11*	-	9.486	∞	-	14.51	*2.05E+11*
*CBL/**5GPa***	0.3496	57.17	*783511.8*	0.3761	61.79	*181049.3*	0.3588	58.74	*436093.3*
subgrade	0.00921	188.30	*4.89E+08*	0.01075	218.60	*2.69E+08*	0.00964	196.90	*4.09E+08*

5 DISCUSSION

5.1 Type 1 pavement structure

The results indicated that for a Type 1 pavement structure without CBL, there was an 81% increase in vertical strain at the subgrade level during winter when compared to summer (Table 2). Conversely, with respect to the asphalt layers, the increases in strains for ACsurf layer and the ACbase layer were approximately 100% and 23%, respectively, during summer (Figure 4). Hence, proper material definition should be considered when designing pavement structure and significant variations during seasonal changes should be accounted for.

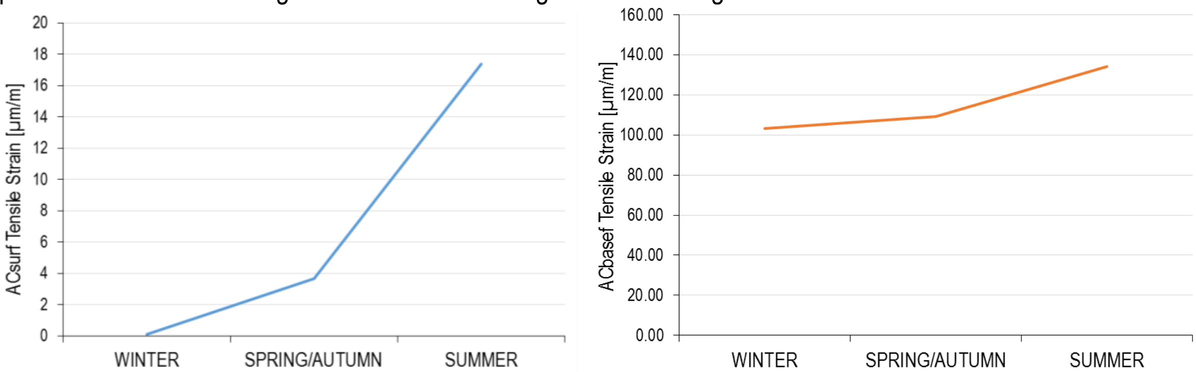


Figure 4 Tensile strains of asphalt layers based on season change

Figures 5 and 6 present vertical displacements at the bottom of asphalt layers and at the top of subgrades to illustrate load transfer through a pavement structure. As observed, there was a difference in the displacement envelope shape between summer and winter based on asphalt characteristics. In the summer, the modulus of asphalt was considered to be less than that in the winter, and thus there was a vertical displacement concentration below the wheel path even at the subgrade level with increasingly sharper envelope edges.

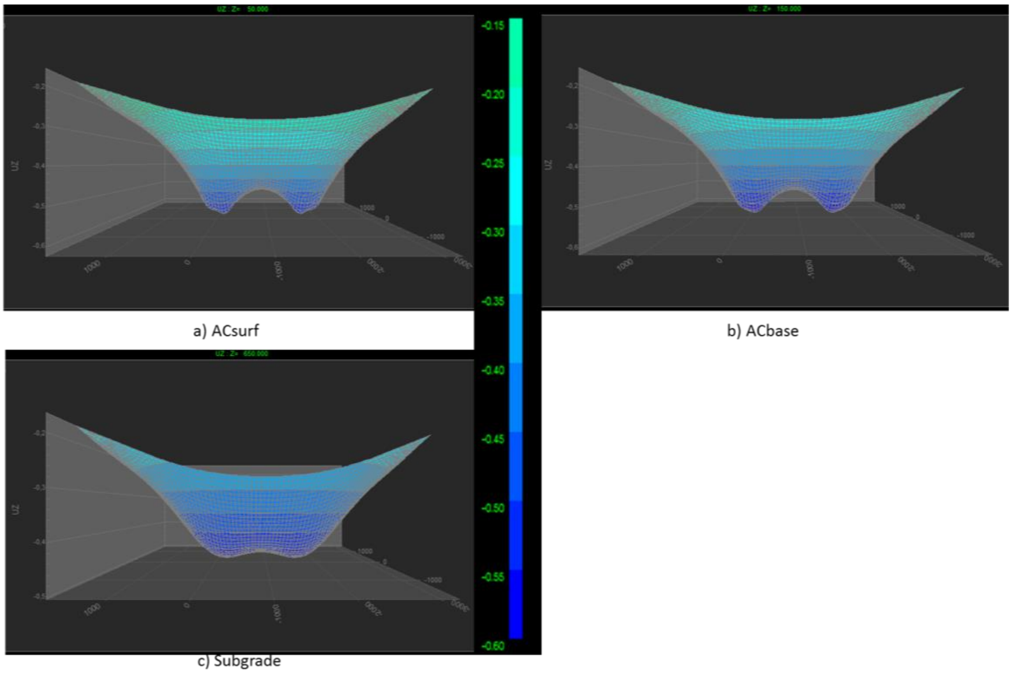


Figure 5 An illustration of the vertical displacement during winter (using CIRCLY software)

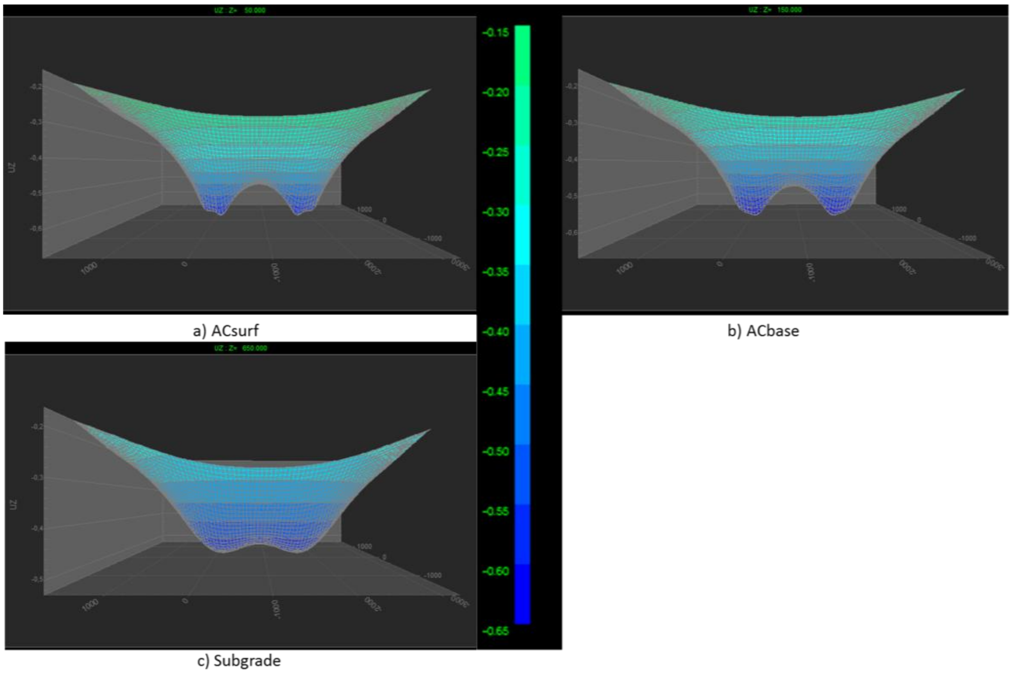


Figure 6 An illustration of the vertical displacement during summer (using CIRCLY software)

5.2 Type 3 pavement structure

As presented in Figure 7 and Table 2, a decrease in the CBL modulus of elasticity from 15 GPa to 5 GPa resulted in a decrease in the ACsurf strain value. Simultaneously, there was an increase in the subgrade strain value by approximately 27%. Higher values of CBL moduli indicated a more rigid foundation for asphalt layers that resulted in higher horizontal strains. However, strains at the subgrade level decreased with the increase in CBL modulus, which implied that pavement structure could be constructed in weaker soil when CBL was used.

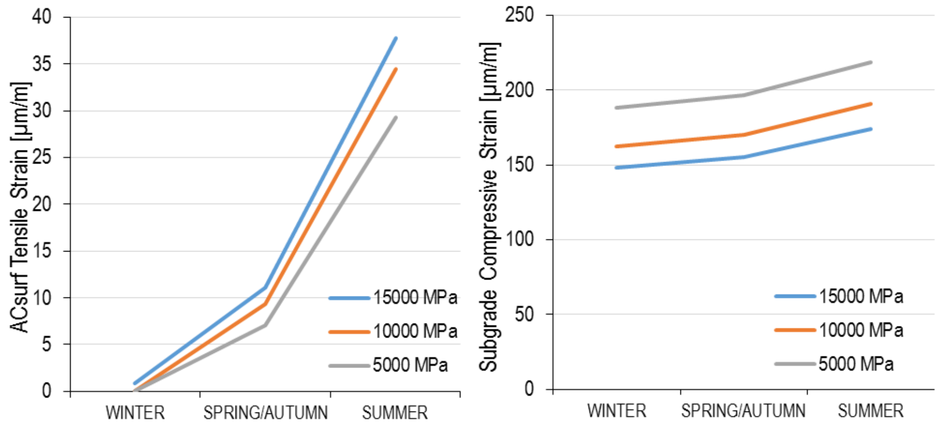


Figure 7 Correlation of strain at the bottom of the ACsurf layer and at the top of the subgrade level with respect to CBL modulus values

An increase in the CBL modulus values leads to an increase in the vertical displacement at the subgrade level for winter and summer. In the winter, the decrease in CBL modulus resulted in an increase in subgrade vertical displacement of approximately 27%. In contrast, the corresponding increase in summer was approximately 23%.

Analysis of the influence of CBL modulus on the stress/strain state (Figure 8) indicated that an increase in the modulus resulted in an increase in the horizontal stress (due to its higher rigidity) as well as a decrease in the horizontal strain. Additionally, it was observed that after the occurrence of the first crack as represented by a decrease in the modulus from 15 GPa to 10 GPa, there was a rapid increase in CBL horizontal strain (by 19%) and a decrease in horizontal stress (by 22%). Thus, the results indicated a stress increase and a strain increase at the subgrade level of 8% and 9%, respectively. Analysis of the influence of seasonal change on pavement stress/strain state indicated that CBL construction had a positive effect on reducing the sensitivity of the pavement to seasonal change. The average increase in vertical subgrade strain in the summer season was 16 % higher than that in the winter when CBL was constructed.

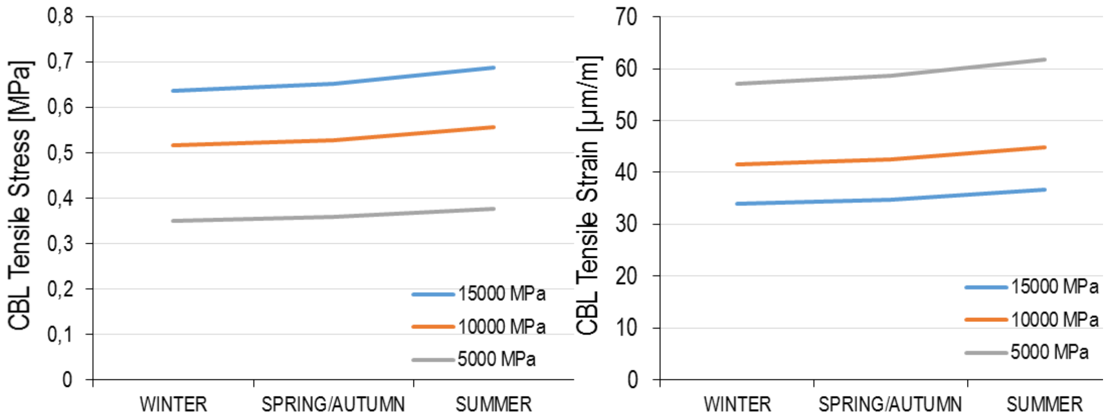
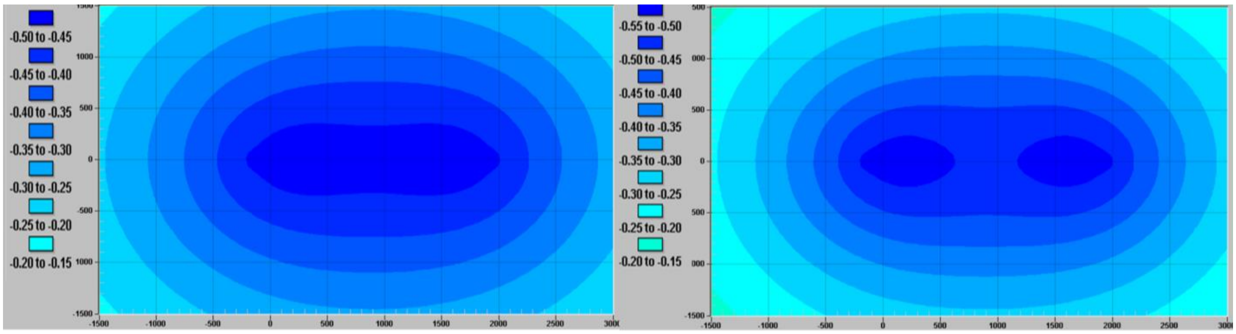


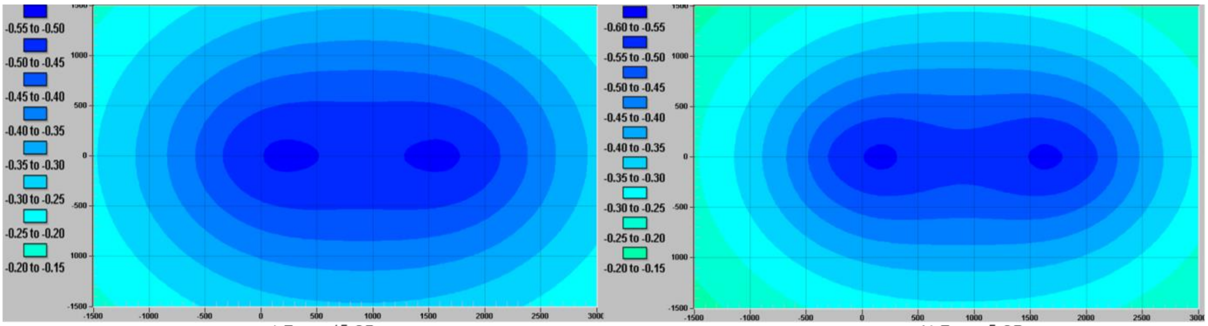
Figure 8 Correlation of stress and strain at the bottom of CBL with respect to its modulus of elasticity value

The analyses of potential rutting occurrence involved analyzing vertical displacement of the ACsurf layer. As shown in Figures 9 and 10, there was a concentration of vertical displacement within the wheels path for lower CBL modulus values. This effect was particularly significant in the summer when the probability for the occurrence of ruts is highest. In the summer, with respect to a CBL modulus of 15 GPa, the highest values of vertical displacement corresponded to 0.5 mm and occurred on an area of approximately 180 mm x 500 mm. With respect to a CBL modulus of 5 GPa, the highest vertical displacement corresponded to 0.6 mm and occurred on an area of approximately 150 mm × 300 mm.



a) E_{CBL} = 15 GPa b) E_{CBL} = 5 GPa

Figure 9 Vertical displacement at the bottom of the ACsurf layer in winter (using CIRCLY software)



a) E_{CBL} = 15 GPa b) E_{CBL} = 5 GPa

Figure 10 Vertical displacement at the bottom of the ACsurf layer in summer (using CIRCLY software)

5.3 Application of results of analytical analyses

The analysis of the number of ESAL causing fatigue damage indicated a possibility of reducing the thickness of asphalt layers based on analytical pavement design [28]. The total number of ESAL was assumed as 4×10^6 for empirical pavement structure design. When traffic load distribution was assumed as 35% in the summer, 15% in the winter, and 25% + 25% in spring and autumn, then the total number of ESAL during summer, winter and spring/autumn corresponded to 1.4×10^6, 0.6×10^6, and 1×10^6, respectively. As presented in Table 2, the Type 1 pavement structure involved an unlimited number of ESALs for the ACsurf layer while the ESAL number for the ACbase considerably exceeded that assumed for the empirical design. Similar results were obtained for the Type 3 pavement structure, and this suggested a possible reduction in its thickness. Conversely, there was a possibility of fatigue damage of CBL under assumed traffic. This was more or less expected since the occurrence of cracks in CBL was considered. However, it is necessary to exercise caution to a certain extent when designing pavement structure given the need to define material characteristics and expected design life. The analysis of subgrade stress/strain state also allows for the possibility of designing pavement structures with reduced layer thickness and reduced material characteristics.

6 CONCLUSION

Currently, only empirical design methods are used in practice for the application of well-known standards for pavement structure design. However, the use of these standards is not mandatory and does not preclude the use of other methods and especially the use of theoretical methods. The use of empirical design methods involves assuming that material characteristics correspond to those of average quality materials. Hence, the aim of the study involved examining the influence of material characteristics on pavement design. This was performed by analyzing changes in CBL characteristic given occurrences of cracks and changes in the asphalt layer due to seasonal changes. Even though both analyzed pavement structures satisfied the criteria set by empirical design standards, the results indicated a significant difference in pavement behavior given changes in material characteristics. The analysis of a type 1 pavement structure (without CBL) indicated a high strain increase during the summer for asphalt layers. Thus, there was a need for proper material definition when designing pavement structures in conjunction with the need to consider significant variations relative to seasonal changes. The analysis of pavement structure using CBL indicated a significant difference before and after the occurrence of the first crack within the layer. The reduction in the modulus led to a decrease in the ACsurf strain value. However, it also resulted in an increase in subgrade stress and strain values. Thus, it could be concluded that it is very important to properly define material characteristics when using empirical design methods. Proper material characterization and combined utilization of empirical and analytical methods allows for the possibility of reducing the thickness of a few layers to design cost-effective structures.

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