Investigation of Longitudinal Slope Asphalt Pavement Surface Strain Characteristics

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ABSTRACT

Using Abaqus finite element modeling software, a structural model of asphalt pavement was created in order to investigate the changes in shear and tensile stresses of the material under vehicle movement loads on long longitudinal slopes.On a range of slopes, driving speeds, temperatures, and braking coefficients, a single factor analysis was performed. According to the computation results, the maximum tensile strain rises as road slope, driving speed, and braking coefficient increase, but it falls as temperature increases. Similarly, the maximum shear strain increases as temperature, braking coefficient, and driving speed increase, but it decreases as driving speed increases.The highest tensile strain and maximum shear strain, which both occur in the intermediate layer, are found around 5 and 6 cm, respectively, from the road surface when the car is moving smoothly. To optimize the road performance of the asphalt surface layer in long and long longitudinal slopes, specific enhancements to the shear and tensile characteristics of the middle layer can be made during the design phase. There will be considerable shear strain on the road surface while the car is braking and the braking coefficient is high.Targeted improvements in the upper layer of asphalt concrete's shear resistance are required during the design phase.

Keywords: Strain Characteristic, Asphalt Pavement, FEM, Longitudinal Slope, Tensile Stresses.

1. Introduction

World's transportation infrastructure is expanding at an accelerated rate, and more highways are being built in high-altitude and plateau regions. Long longitudinal slope sections are unavoidable due to the limitations of the terrain, and even the length and slope of the slope surpass the limits stated in the current requirements [1].In contrast to the small ramp pavement, the long longitudinal slope section has much more serious diseases like rutting and displacement. This is primarily because the vehicle speed is lower and frequent acceleration and braking occurs while driving on the long longitudinal slope section.Because of the slow start of the uphill section and the braking during the downhill section, the asphalt concrete in the long longitudinal slope section will not only produce serious ruts but also shear failure when driving. This is because the uphill and downhill sections create larger horizontal shear stresses on the top and inside of the asphalt pavement surface than on the flat section. There are several causes for this devastation. It is connected to technical factors such route line type, pavement structure type, and construction quality in addition to traffic volume and vehicle loading.

Numerous academics have studied the mechanical characteristics of asphalt pavement with a long longitudinal slope in recent years using the finite element approach. Using the finite layer program 3DMove Analysis, Shi Tingwei et al. [2] created a three-dimensional finite layer analysis model of an asphalt pavement with a long longitudinal slope. It has been discovered that the maximum shear stress peak in the asphalt pavement would significantly rise in response to the vehicle's accelerating or braking. Because the largest shear stress peaks occur 0–4 cm below the road surface, it is especially crucial to enhance the long longitudinal slope asphalt surface's upper portion's anti-rutting capabilities.Zhou Taohong et al. [3] modeled typical structures using Aansys software based on the analysis of common diseases and the definition of heavy load conditions. They also computed and analyzed the typical structure's surface deflection, tensile stress, compressive stress, and shear stress under various axle loads, as well as the damage to the pavement structure. Yang Zhenzi et al. [4] conducted a quantitative analysis of the effects of high temperatures and severe traffic loads on the structural stress and surface deflection of asphalt pavement using ANSYS software. Using Ansys finite element software, Li Yanchun et al. [5] created a three-dimensional finite element model.The strain variation rule of a large longitudinal slope of asphalt pavement under various situations may be derived by applying a pulse load. Using a three-dimensional finite element model, Jun Fu et al. [6] examined the connection between shear stress and load, pavement depth, interlayer contact condition, and modulus. By calculating the equilibrium speed of heavy-duty vehicles in the long longitudinal slope section under the equilibrium state, Zhou Yaxin et al. [7] simplified the load distribution model. In accordance with the commonly used pavement structure in China, a three-dimensional finite element model of asphalt pavement was established to compare and analyze the mechanical response of asphalt pavement under various slope, temperature, and thickness of the asphalt layer.According to Ruan Luming et al. [8], the usual heavy-duty trucks and their ascending speed characteristics are determined by first analyzing the traffic situation in Chongqing. A detailed analysis of the contact characteristics between the heavy-duty vehicle's tire and the road surface is conducted, and a simplified model of tire grounding for heavy-duty vehicles is provided. Next, the variables influencing the asphalt pavement structure's reaction indices in the long longitudinal slope section are examined. Lastly, using the Miner fatigue rule as a basis, the fatigue damage variation rule of the asphalt layer in high temperature months is examined.

The aforementioned academics' research demonstrates that the mechanical response of asphalt pavement with a long longitudinal slope and its affecting elements may be studied using the finite element approach. As a result, this study will develop a finite element model of long longitudinal slope asphalt pavement using Abaqus calculation software and explore the effects of temperature, braking coefficient, driving speed, and longitudinal slope on the tensile and shear strains of the pavement.

2. Examination of the Factors Affecting the Mechanical Model of the Longitudinal Slope Section

When traveling on asphalt, the car encounters a variety of resistances. Rolling resistance F_1, slope resistance F_2, air resistance F_3, and acceleration or deceleration resistance F4 are some examples of these resistances. The car's traction needs to match the total resistance it encounters while driving in order to reach a stable operational condition, which is:

$$F = F_1 + F_2 + F_3 + F_4 \tag{1}$$

Two driving states are possible when a vehicle is on a longitudinal slope: either it gradually accelerates to a stable speed and keeps it there after entering the hill, or it gradually decelerates to a stable speed and maintains it there.

3. The Long Longitudinal Slope Section's Asphalt Pavement Mechanics Model and Calculation Parameters

3.1 Finite Element Model Establishment

In order to maximize accuracy and computational efficiency, a three-dimensional model for mechanical response analysis is used in this research. Eight node hexahedral elements make up the model size. The following boundary conditions are taken for granted: the model's bottom surface is fully constrained, there is no longitudinal displacement on the front and rear sides, no lateral displacement on the left or right side, and the contact state between the layers is entirely continuous. Double circular loads are computed, with the tire ground pressure of 0.7 MPa serving as the standard load, the load circle radius being 106.5

mm, and the center distance between the two wheels being 319.5 mm.The road's lateral direction is denoted by X, the driving direction by Y, and the vertical direction by Z. The model's dimensions are 5 m × 10 m × 5 m, and Figure 1 depicts its construction. The ABAQUS subroutines DLOAD and UTRACLOAD apply the vertical moving load and the horizontal moving load, respectively.

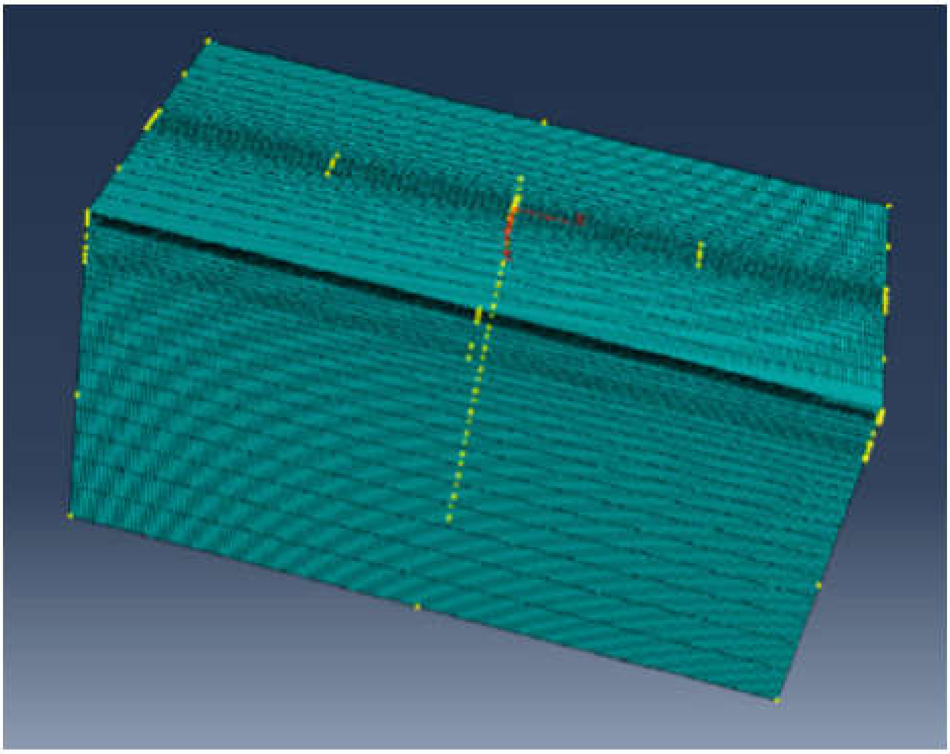
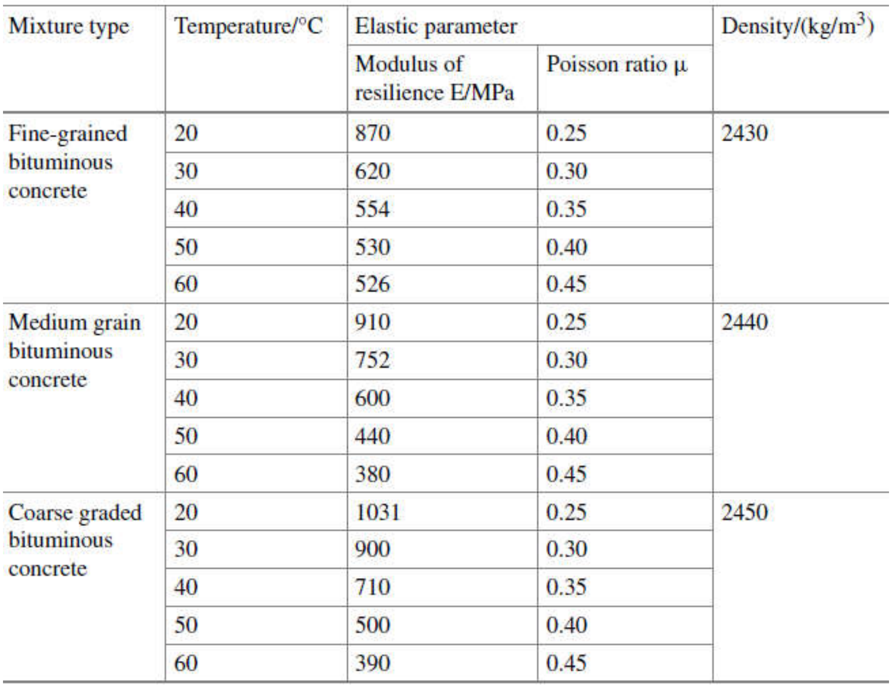


Fig. 1. Finite element model of pavement structure.

3.2 Finding of Asphalt Pavement Surface Material Invariable

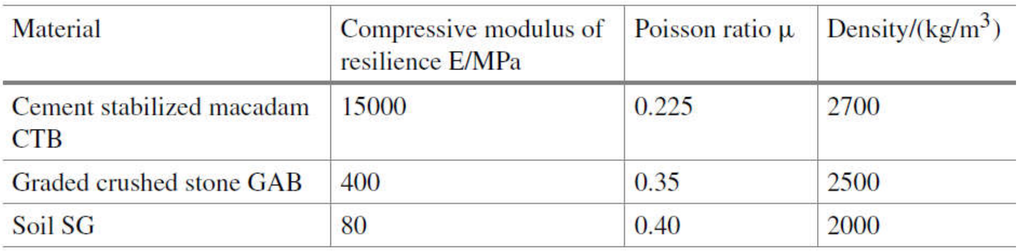
Table 1 displays the characteristics of the asphalt mixture at various temperatures in Table 2.

Table 1. Asphalt mixture parameters under different temperature conditions.



Mixture type	Temperature/°C	Elastic parameter		Density/(kg/m^3)
		Modulus of resilience E/MPa	Poisson ratio μ	
Fine-grained bituminous concrete	20	870	0.25	2430
	30	620	0.30	
	40	554	0.35	
	50	530	0.40	
	60	526	0.45	
Medium grain bituminous concrete	20	910	0.25	2440
	30	752	0.30	
	40	600	0.35	
	50	440	0.40	
	60	380	0.45	
Coarse graded bituminous concrete	20	1031	0.25	2450
	30	900	0.30	
	40	710	0.35	
	50	500	0.40	
	60	390	0.45	

Table 2. Elastic parameters of base and soil materials.

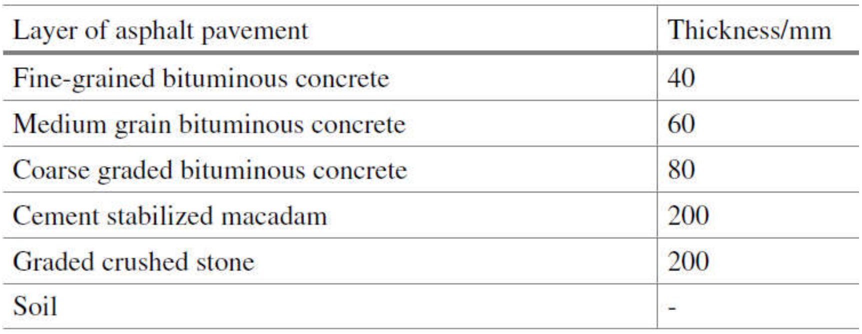


Material	Compressive modulus of resilience E/MPa	Poisson ratio μ	Density/(kg/m^3)
Cement stabilized macadam CTB	15000	0.225	2700
Graded crushed stone GAB	400	0.35	2500
Soil SG	80	0.40	2000

3.3 Pavement Computational Structural

Table 3 displays the composition and thickness of the pavement structural layer from top to bottom.

Table 3. Asphalt pavement structure.



Layer of asphalt pavement	Thickness/mm
Fine-grained bituminous concrete	40
Medium grain bituminous concrete	60
Coarse graded bituminous concrete	80
Cement stabilized macadam	200
Graded crushed stone	200
Soil	-

4. Results and Discussions

The shear stress on the driving direction of the vertical road table location of the wheel load center is calculated and evaluated in the mechanical calculation and analysis. The study and computation of uniform speed just take into account the road surface's 0.7MPa vertical tension, ignoring the impact of friction force acting parallel to the surface.

4.1 Analysis of Mechanical Response Changes with Depth

The variation of the pavement structure's shear stress with depth is computed at a running speed of 60 km/h and a temperature of 60^0 C. The findings are displayed in Figs. 2 and 3.

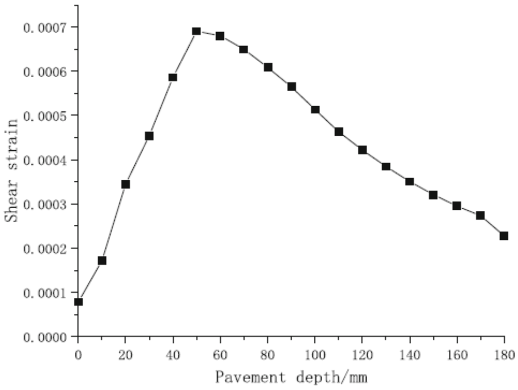


Fig. 2. Variation of shear strain with pavement depth.

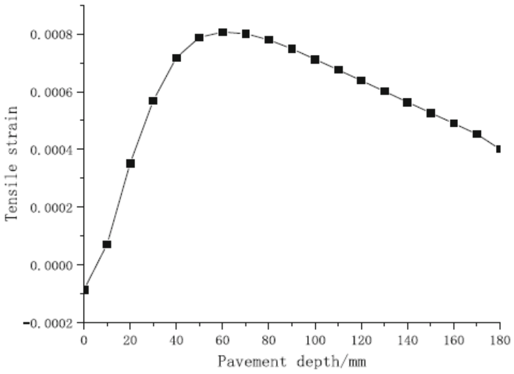


Fig. 3. Variation of tensile strain with pavement depth.

The maximum tensile strain and maximum shear strain are both found in the middle surface layer, and the depth of the maximum tensile strain is greater than the depth of the maximum shear strain. These findings are consistent with the shear and tensile strain of the asphalt surface increasing and then decreasing with depth.

4.2 Influence of Longitudinal Slope Degree on Mechanical Response

The maximum mechanical reaction and the change law of the position under various slope circumstances are investigated when the driving speed is 60 km/h, the temperature is 60^0 C, and the slope is 0%, 2%, 4%, 6%, and 8%, respectively.

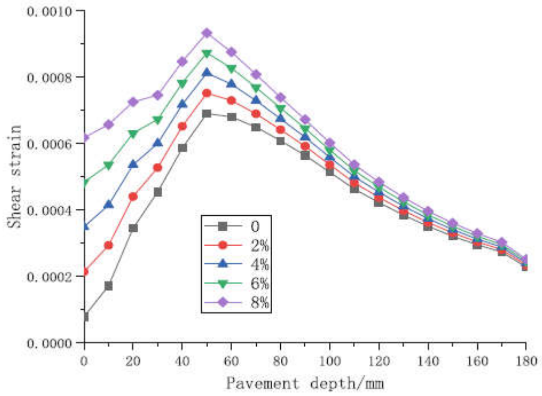


Fig. 4. Variation of shear strain under different slope conditions.

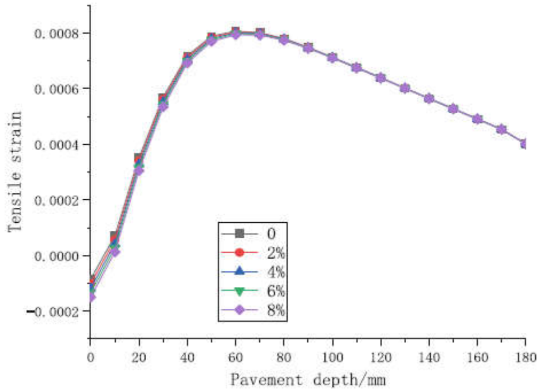


Fig. 5. Variation of tension strain under different slope conditions.

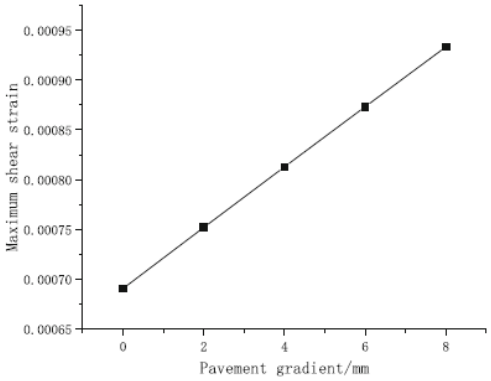


Fig. 6. Variation of maximum shear strain under different slope conditions.

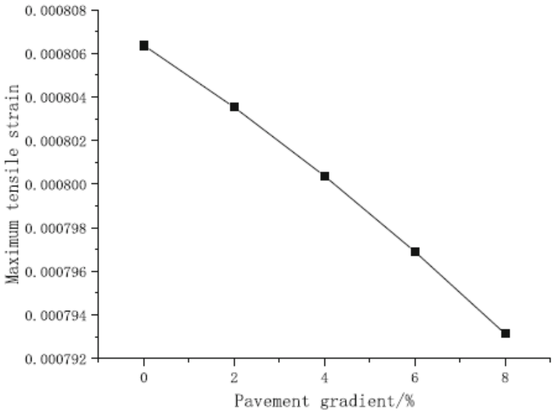


Fig. 7. Variation of maximum tensile strain under different slope conditions.

Figures 4 and 5 show that, for a given slope, the shear and tensile strains of the asphalt surface layer increase first and thereafter decrease as the pavement depth increases. Figures 6 and 7 show that when the road slope increases, the maximum shear strain rises and the maximum tensile strain falls.

5. Conclusions

The shear strain and tensile strain of the asphalt layer of the asphalt pavement with long longitudinal slopes were analyzed under the conditions of different slopes and changes with depth. The asphalt pavement calculation model was established by using the finite element calculation software Abaqus. The study presented above yields the following conclusions:

The middle surface layer is where vehicles in smooth motion, greatest shear strain, and maximum tensile strain emerge. In order to improve the long longitudinal slope section of the asphalt surface layer of road performance, the middle surface layer of asphalt concrete has to have its shear resistance and tensile characteristics improved at the design stage.

Shear stresses are greatly impacted by vehicle braking coefficients, but tensile strains are mostly unaffected. There will be significant shear strain on the road surface when the braking coefficient is high. In order to increase asphalt concrete's shear resistance, attention must be paid to the top layer during the design stage.

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