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Study of the Strain Characteristics of Asphalt Pavement Surfaces Over Long Slopes

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***Abstract*—A structural model of asphalt pavement was developed using Abaqus finite element modeling software to explore variations in shear and tensile stresses caused by vehicle movement loads on long longitudinal slopes. A single factor study was carried out over a variety of slopes, vehicle speeds, temperatures, and braking coefficients. According to the calculation findings, the maximum tensile strain increases as the road slope, driving speed, and braking coefficient increase, but decreases as the temperature increases. Similarly, maximum shear strain rises with temperature, braking coefficient, and driving speed, but decreases as driving speed increases. When the automobile is driving smoothly, the greatest tensile strain and maximum shear strain occur in the intermediate layer, around 5 and 6 cm from the road surface, respectively. Specific improvements to the shear and tensile properties of the intermediate layer may be made during the design phase to improve the road performance of the asphalt surface layer on long and long longitudinal slopes. When the automobile brakes, the road surface will experience significant shear strain due to the high braking coefficient. During the design phase, targeted enhancements to the shear resistance of the top layer of asphalt concrete are needed.**

***Index Terms*—Abaqus FEM, Longitudinal Slope, Tensile Stresses, Strain Characteristic.**

1. INTRODUCTION

The world's transportation infrastructure is increasing at a rapid pace, with more roadways being constructed in high-altitude and plateau areas. Long longitudinal slope portions are inevitable owing to topographical restrictions, and the length and grade of the slope exceed the limits specified in the present regulations [1]. In comparison to the short ramp pavement, the long longitudinal slope portion has much more significant problems, such as rutting and displacement. This is mostly due to the reduced vehicle speed and the frequent accelerating and braking required while driving on the long longitudinal slope portion. Because of the sluggish start uphill and braking downhill, the asphalt concrete in the long longitudinal slope portion would not only generate major ruts but also shear failure while driving. This is because the uphill and downhill parts induce higher horizontal shear strains on the top and interior of the asphalt pavement surface than the level segment. There are various reasons for this disaster. It is dependent on technical elements such as route line type, pavement structure type, and construction quality, as well as traffic volume and vehicle loads.

In recent years, a large number of academics have used the finite element method to investigate the mechanical properties of asphalt pavement with a long longitudinal slope. Shi Tingwei et al. [2] used the finite layer software 3DMove Analysis to generate a three-dimensional finite layer analysis model of an asphalt pavement with a long longitudinal slope. It has been revealed that the maximum shear stress peak in the asphalt pavement increases dramatically as the vehicle accelerates or brakes. Because the highest shear stress peaks occur 0-4 cm below the road surface, it is critical to improve the anti-rutting capabilities of the top section of the long longitudinal slope asphalt surface. Zhou Taohong et al. [3] used Aansys software to construct typical structures after analyzing common illnesses and defining high load conditions. They also calculated and examined the usual structure's surface deflection, tensile stress, compressive stress, and shear stress under different axle loads, as well as pavement structure damage. Yang Zhenzi et al. [4] used ANSYS software to do a quantitative examination of the effects of high temperatures and heavy traffic loads on the structural stress and surface deflection of asphalt pavement. Li Yanchun et al. [5] used Ansys finite element software to develop a three-dimensional finite element model. Using a pulse load, one may determine the strain variation rule of a large longitudinal slope of asphalt pavement under different conditions. Using a three-dimensional finite element model, Jun Fu et al. [6] investigated the relationship between shear stress and load, pavement depth, interlayer contact condition, and modulus. Zhou Yaxin et al. [7] simplified the load distribution model by estimating the equilibrium speed of heavy-duty trucks in the long longitudinal slope segment while they are in equilibrium. A three-dimensional finite element model of asphalt pavement was developed to evaluate and study the mechanical reaction of asphalt pavement under varied slope, temperature, and layer thickness conditions. According to Ruan Luming et al. [8], the typical heavy-duty vehicles and their climbing speed characteristics are identified by first examining the traffic condition in Chongqing. A thorough examination of the contact parameters between the heavy-duty vehicle's tire and the road surface is carried out, and a simplified model of tire grounding for heavy-duty vehicles is presented. Next, the factors that influence the asphalt pavement structure's response indices in the long longitudinal slope section are investigated. Finally, utilizing the Miner fatigue rule as a foundation, the fatigue damage variation rule of the asphalt layer during high temperature months is investigated.

The aforementioned academics' study shows that the mechanical response of asphalt pavement with a long longitudinal slope and its influencing components may be evaluated using the finite element method. As a consequence, this research will create a finite element model of long longitudinal slope asphalt pavement using Abaqus computation software and investigate the effects of temperature, braking coefficient, driving speed, and longitudinal slope on the pavement's tensile and shear stresses.

2. EXAMINING THE FACTORS AFFECTING THE MECHANICAL MODEL OF THE LONGITUDINAL SLOPE SECTION

When driving on asphalt, the automobile experiences several resistances. Examples of such resistances are rolling resistance F_1, slope resistance F_2, air resistance F_3, and acceleration or deceleration resistance F_4. To achieve a steady functioning state, the car's traction must equal the overall resistance encountered when driving.

$$F = F_1 + F_2 + F_3 + F_4 \quad (1)$$

When a vehicle is on a longitudinal slope, it may either gradually accelerate to a stable speed and remain there after entering the hill, or it can gradually slow to a steady speed and stay there.

3. LONG LONGITUDINAL SLOPE SECTION ASPHALT PAVEMENT MECHANICS MODEL AND CALCULATION PARAMETERS

3.1 Establishment of Finite Element Models

This study employs a three-dimensional model for mechanical reaction analysis to optimize accuracy and computing economy. The model size consists of eight node hexahedral pieces. The model's bottom surface is totally limited, 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 completely continuous. These boundary conditions are assumed. Double circular loads are calculated, using the standard load of 0.7 MPa for the tire ground pressure, a load circle radius of 106.5 mm, and a center distance of 319.5 mm between the two wheels. X stands for the road's lateral direction, Y for its driving direction, and Z for its vertical direction. The model is 5 m × 10 m × 5 m in size, and Figure 1 shows how it was put together. The vertical moving load and the horizontal moving load are applied via the ABAQUS subroutines DLOAD and UTRACLOAD, respectively.

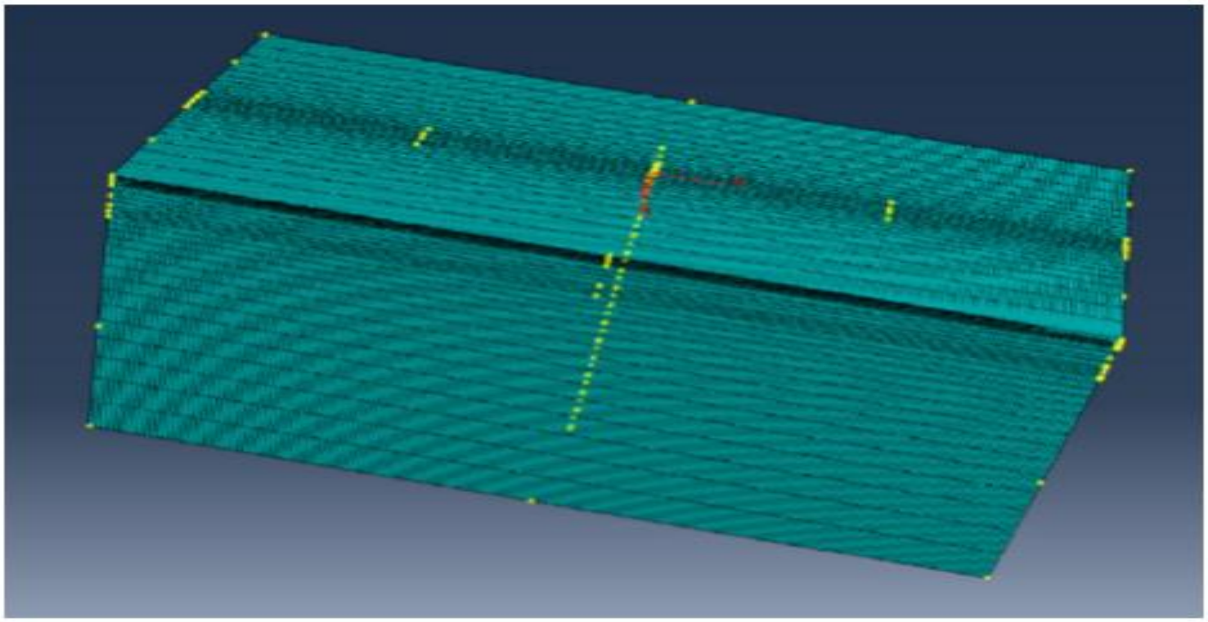

Fig. 1. Finite element model of pavement structure.

3.2 Finding of Asphalt Pavement Surface Material Invariant

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

In the mechanical calculation and analysis, the shear stress on the driving direction of the vertical road table position of the wheel load center is computed and assessed. The influence of friction force operating parallel to the road surface is ignored in the analysis and calculation of uniform speed, which only considers the 0.7MPa vertical tension of the road surface.

4.1 Examination of Changes in Mechanical Response with Depth

The shear stress fluctuation of the pavement structure with depth is calculated at a temperature of 60^0 C and a running speed of 60 km/h. Figures 2 and 3 show the results.

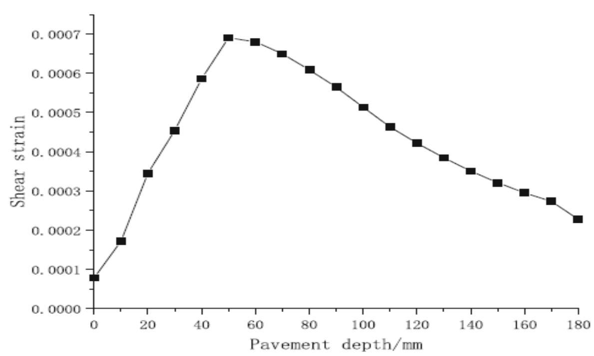

Fig. 2. Variation of shear strain with pavement depth.

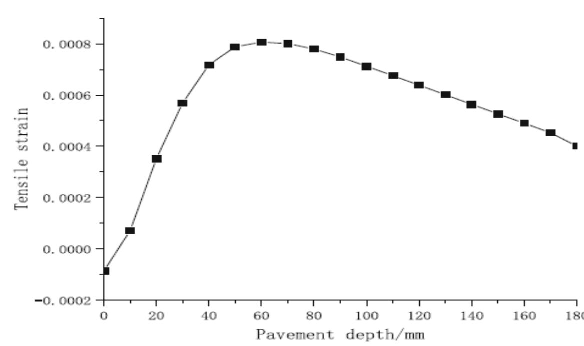

Fig. 3. Variation of tensile strain with pavement depth.

The intermediate layer of the surface contains both the maximum tensile and maximum shear strains, and the depth of the former is higher than that of the latter. These results are in line with the idea that the asphalt surface's shear and tensile strain increases with depth before subsequently reducing.

4.2 Longitudinal Slope Degree's Effect on Mechanical Response

When the temperature is 60^0 C, the driving speed is 60 km/h, and the slope is 0%, 2%, 4%, 6%, and 8%, respectively, the maximum mechanical response and the change law of the position are examined.

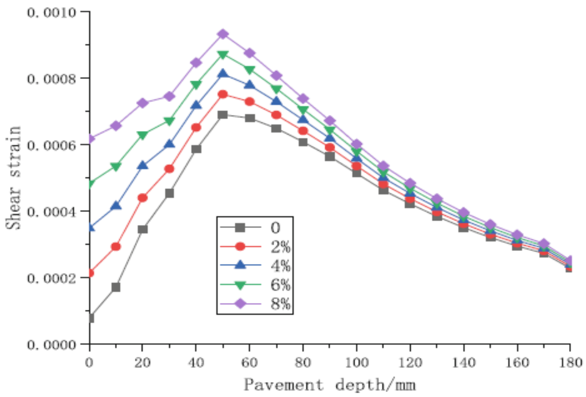

Fig. 4. Variation of shear strain under different slope conditions.

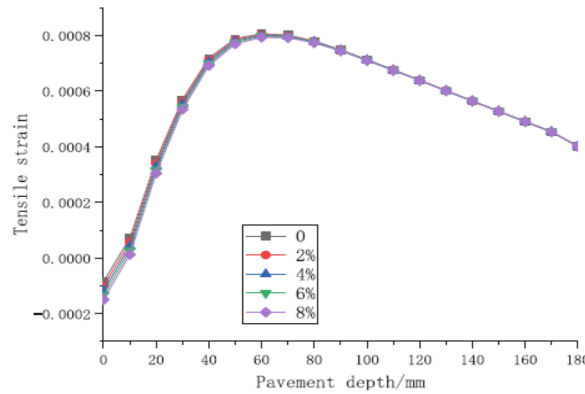

Fig. 5. Variation of tension strain under different slope conditions.

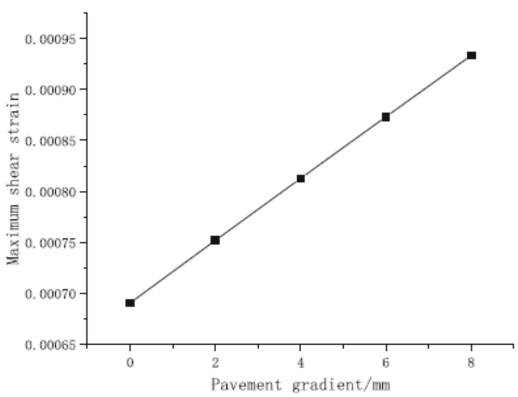

Fig. 6. Variation of maximum shear strain under different slope conditions.

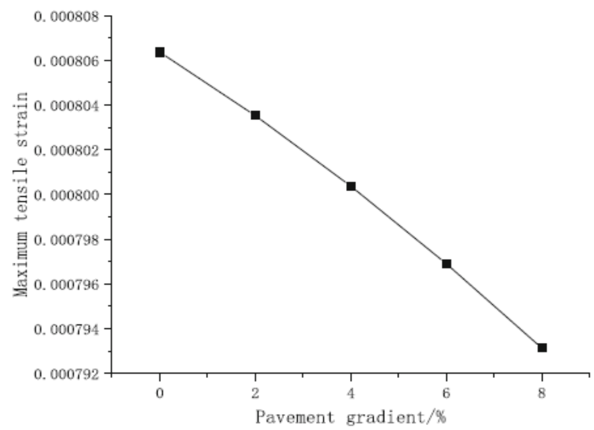

Fig. 7. Variation of maximum tensile strain under different slope conditions.

As the pavement depth rises, the shear and tensile stresses of the asphalt surface layer initially increase for a given slope and then drop, as shown in Figures 4 and 5. The maximum tensile strain decreases and the maximum shear strain increases as the road slope increases, as shown in Figures 6 and 7.

5. CONCLUSIONS

Under various slope circumstances and with varying depths, the shear and tensile strains of the asphalt layer of the asphalt pavement with long longitudinal slopes were examined. Abaqus, a finite element calculation program, was used to create the asphalt pavement calculation model. The following findings are drawn from the research mentioned above:

Vehicles in smooth motion, highest tensile strain, and largest shear strain emerge from the central surface layer. The tensile and shear resistance of the asphalt concrete's intermediate surface layer must be enhanced during the design phase in order to enhance the performance of the long longitudinal slope section of the asphalt surface layer of the road. While tensile strains are mostly unaffected by vehicle braking coefficients, shear stresses are significantly influenced. When the braking coefficient is high, the road surface will experience severe shear strain. The top layer has to be considered during the design phase in order to improve the shear resistance of asphalt concrete.

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