

## Analysis of Shear Failure of Asphalt Pavement under Horizontal Force

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**Abstract.** The finite element method is used to analyze the shear stress distribution of the pavement structure under vertical load and both vertical and horizontal load. The results show that the distribution coefficient of transverse force affects the distribution of shear stress with depth; The maximum shear stress increases with the increase of the lateral force coefficient, and the two have a linear relationship. When the horizontal force is considered, the shear stress of the asphalt surface layer increases and the peak value moves upward, which may cause rutting, displacement and swelling of the asphalt pavement. It is necessary to incorporate the horizontal force into the structural design index system.

### Introduction

With the increasing of highway traffic volume and the development of heavy transportation, especially the operation of channelized traffic in high-grade highways, the rutting of asphalt pavement has become the main disease type <sup>[1]</sup>, and the main type of rutting is the fluidity rutting caused by the shear deformation of asphalt mixture <sup>[2,3]</sup>. In the summer high temperature season, the shear strength of the asphalt mixture gradually decreases with the increase of temperature. When the shear strength decreases to less than the shear stress, the asphalt mixture will produce shear deformation. Under the repeated action of the load, the wheel track will sag and both sides will rise, forming a W-shaped rut with a cross section. At the same time, displacement and swelling and washboard is also caused by the insufficient shear strength under the action of horizontal load at high temperature. Therefore, it is of great significance to optimize the design of pavement structure and reduce the occurrence of ruts to analyze the mechanics of multibrake sections such as steep road sections and toll stations considering the horizontal force and to explore the distribution law of shear stress.

### The Selection of Pavement Structure Parameters and the Establishment of Finite Element Model

#### Pavement Structure Parameters

Select the commonly used semi-rigid base asphalt pavement structure in China, and the material thickness and parameters are shown in Table 1.

Table 1. Calculation parameters of pavement structure.

Horizon	Material	Thickness[cm]	Modulus of compressive resilience[MPa]	Poiss0n ratio
Above layer	Fine grain asphalt concrete	4	1200	0.30
Middle surface layer	Medium grain asphalt concrete	6	1000	0.30
Lower layer	Coarse grained asphalt concrete	8	800	0.30
Base course	Cement stabilized macadam	30	1500	0.25
Subbase	Ash stabilized soil	20	400	0.30
	Soil base	—	40	0.35

## Establishment of Finite Element Model

The size of the geometric model is 4.5m×4.5m of plane size. The depth of the soil foundation is 5.0m. The thickness of each layer above the soil foundation is set according to the actual conditions. The hexahedron 8-node structural analysis unit Brick 8node in Structural Solid is selected as the unit type, and the number is SOLID45. The international system of units is used in the analysis.

The origin is located in the center of the road surface cube, the positive direction of Z axis is perpendicular to the road surface, the positive direction of X axis is the same as the driving direction, and the positive direction of Y axis is perpendicular to the driving direction. In order to adapt to the equivalent node stress, the minimum element mesh size on the road surface is 1/2 of the wheel load radius. The unit division of each structural layer is as follows: the upper layer, the middle surface layer and the lower layer are divided into 4 layers with thickness of 1cm, 1.5cm and 2.0cm respectively; the base course is divided into 6 layers with thickness of 5cm; the subbase layer is divided into 4 layers with thickness of 5cm, and the soil base is divided into 5 layers with thickness of 100cm. See Figure 1 for grid division.

The boundary constraint conditions are as follows: the soil base surface is fixed, that is, the displacement degrees of freedom of X, Y and Z are limited; A horizontal constraint perpendicular to the section is applied to the two sides perpendicular to the X-axis (running direction), that is, the Y-direction displacement is limited; A horizontal constraint perpendicular to the section is applied to the two sides perpendicular to the Y-axis (vertical running direction), that is, the displacement in the X-direction is limited; The contact condition between layers of each structure is set as completely continuous contact state.

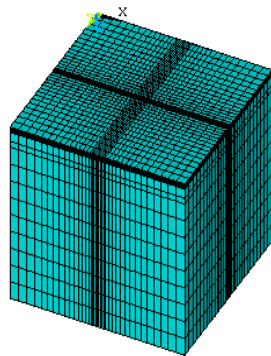


Figure 1. Finite element mesh division diagram.

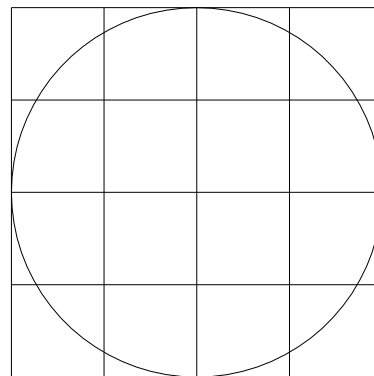


Figure 2. Circular evenly distributed load and cell grid.

## Analysis of Calculation Results

Two cases are considered in the mechanical calculation: (1) vertical load; (2) the combination of vertical load and horizontal load. The vertical load adopts standard axle load BZZ-100, double wheel set, axle weight  $P=100\text{KN}$ , tire grounding pressure  $P=0.7\text{MPa}$ , equivalent circle diameter of single wheel pressure transfer surface  $2\delta=21.3\text{cm}$ , center distance between two wheels is 1.5d.

During the finite element analysis, it is necessary to convert the standard axis load into equivalent nodal forces<sup>[4]</sup>. The contact area between the tire and the road surface is approximate to the elliptic surface, which is generally simplified to the circular surface, and the wheel load is simplified to the equivalent circular uniform load. When ANSYS is used for three-dimensional structure analysis, hexahedral solid elements are generally selected to be regarded as rectangular grids in the road table, so the uniform distributed load and other effects of circular forces are independent and unequal concentrated forces applied to the rectangular boundary surrounding the circle and each node inside the rectangle. In the case of accuracy is not high, generally 4 element surfaces (9 nodes) or 9 element surfaces (16 nodes) are selected to surround the circular surface, but the density of the elements in the stress concentration area directly affects the accuracy of ANSYS. In order to improve the accuracy and approximate the reality, 16 element surfaces (25 nodes) are adopted in this paper to surround the load circular surface, as shown in figure 2 and table 2, table 3 and table 4.

When considering the horizontal force, the horizontal force is determined according to the formula  $F=P \times f$ , where  $f$  is the horizontal force coefficient and  $P$  is the vertical load. When braking slowly, the horizontal force coefficient  $f$  is 0.2; when braking urgently,  $f$  is 0.5.

Table 2.  $f=0$  Equivalent nodal force [N].

30	481	884	481	30
481	1817	2032	1817	481
884	2032	2040	2032	884
481	1817	2032	1817	481
30	481	884	481	30

Table 3.  $f=0.2$  Equivalent nodal force [N].

36	577	1061	577	36
577	2180	2438	2180	577
1061	2438	2448	2438	1061
577	2180	2438	2180	577
36	577	1061	577	36

Table 4.  $f=0.5$  Equivalent nodal force [N].

45	722	1326	722	45
722	2726	3048	2726	722
1326	3048	3060	3048	1326
722	2726	3048	2726	722
45	722	1326	722	45

After calculation, the maximum shear stress at different depths of  $f=0$ ,  $f=0.2$  and  $f=0.5$  is obtained, as shown in table 5 and figure 3. It can be seen from the calculation results that:

(1) When the effect of horizontal force ( $f = 0$ ) is not considered, the shear stress increases first and then decreases with the increase of depth, and the maximum value appears at 3cm away from the road surface;

(2) When the horizontal force is considered, the shear stress changes with the change trend of depth and gradually decreases with the increase of depth. The maximum value appears in the road table.

(3) When the horizontal force is considered, the maximum shear stress increases. When  $f=0.5$ ,  $f=0.2$ , the maximum shear stress increases by 26.6% and 92.8%, respectively, compared with  $f=0$ . Further analysis shows that the maximum shear stress has a linear relationship with the transverse force  $f$ :  $\tau = 0.5034f + 0.2559$  ( $R^2 = 0.984$ );

(4) When the horizontal force is taken into account, the average shear stress of asphalt pavement increases, and the asphalt pavement is prone to ruts. The peak value gradually moved up, and the layer most prone to rutting moved from the middle layer to the upper layer. the road surface shear stress increases, easy to appear the failure of jostle, piling up.

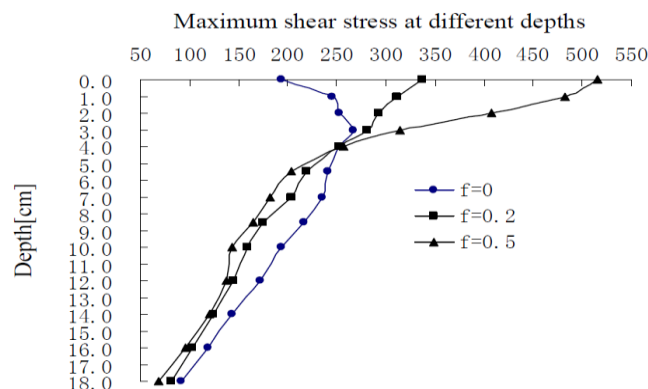


Figure 3. Shear stress distribution of different transverse force coefficients.

Table 5. Shear stresses with different coefficients of transverse forces.

Depth[cm]	f		
	0	0.2	0.5
0	193	338	515
1	246	312	483
2	253	278	408
3	267	269	315
4	253	233	257
5.5	241	219	204
7	235	204	182
8.5	217	175	165
10	193	159	144
12	172	145	137
14	143	124	121
16	119	103	96
18	91	81	69

## Conclusion

The distribution coefficient of transverse force affects the distribution law of shear stress with depth. Regardless of the horizontal force, the shear stress first increases and then decreases with the increase of depth, and the maximum value appears at table 3 of the distance to the depth. When the horizontal force is taken into account, the shear stress changes with the change trend of depth, gradually decreases with the increase of depth, and the maximum value appears in the road table.

The maximum shear stress increases with the increase of transverse force coefficient, and the relationship between them is linear.

When considering the horizontal force, the shear stress of asphalt pavement increases and the peak value moves up, easily causing rutting, pushing and hugging damage of asphalt pavement. Therefore, it is necessary to consider the effect of horizontal force when designing pavement structure.

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