Anti-sliding Risk Model of Wet Surface for Asphalt Pavement and Test Verification

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Abstract. A layer of water film will form on the road surface in rainy weather. Due to the lubrication effect of water film, the anti-skid ability of driving vehicles decreases, which will lead to road traffic accidents. The contact between water film, tread rubber and pavement surface texture is the most direct and concrete when a vehicle travels on wet sliding road surface. Their respective characteristics and coupling effects provide the basis and essential source of tire-road friction. Based on this, in this paper a tire-road anti-skid safety risk model under rainy weather with friction coefficient as evaluation criterion was established by analyzing the fractal characteristics of asphalt pavement surface texture and the viscoelastic properties of rubber tire. Then the correctness of the model was verified by DF test. The test results show that the trend of friction curve calculated by the model is similar to that measured by DF test, which verifies that the model can be used to calculate and characterize the anti-sliding performance of road surface in rainy weather.

1. Introduction

With the rapid development of the highway industry, transportation demand has increased significantly, and traffic volume has increased year by year. At the same time, the speed of modern cars continues to increase, resulting in frequent traffic accidents. Traffic safety is closely related to the anti-skid performance of asphalt pavement. Defects of anti-skid performance of asphalt pavement can lead to slippage of vehicles on the pavement or traffic accidents caused by too long emergency braking distance. How to accurately evaluate the anti-skid performance of pavement is particularly critical. In order to accurately evaluate the anti-sliding performance of the road, the researchers used theoretical calculations, experimental research and finite element modeling to evaluate the anti-sliding performance evaluation methods and indicators, anti-sliding mechanism, anti-sliding performance factors and anti-sliding performance decay laws. Establish a systematic, objective and scientific evaluation system to ensure the anti-sliding performance of asphalt pavement and maximize the anti-sliding performance of vehicles on asphalt pavement. Muarat Ergun [1] comparatively
analyzed the measured data and the friction-related characterization values obtained from the surface texture data of the pavement, quantitatively described the relationship between the friction coefficient of the road surface and the macro-texture and micro-texture, and established the quantitative relationship suitable for the commonly used graded mixture. Marsac [2] uses the tire-pavement finite element model to study the effect of road texture on friction coefficient and gives the curve of friction coefficient varying with speed. Persson [3-4] put forward the theory of friction contact between rubber and self-affine fractal hard cushion. According to this theory, the rough property of hard cushion, the viscoelasticity and the interaction of rubber are the friction source in this particular case. Based on this theory, the theoretical model of friction coefficient has been put forward, which shows that pavement texture has fractal characteristics. Fractal dimension can be used to describe the complexity and similarity of pavement texture [5-6]. It provides a new idea for describing the relationship between pavement texture characteristics and anti-skid performance. When there is water film on the pavement, Ji Tianjian studied the thickness of pavement water film under rainfall conditions by simulation test method. The relationship between pavement water film thickness and rainfall intensity, slope length, slope and rough surface roughness was studied through experimental data [7]. Cong Ling et al. combined with fluid dynamics theory and finite element method to propose a method to determine the braking distance when considering the friction characteristics of the road surface [8]. Fwa et al. simulated the tire friction effect on the wet slip surface by three-dimensional finite element model, and analyzed the influence of water film thickness on the friction coefficient by numerical method [9-10].

At present, the models describing road friction coefficients are regression models or finite element models based on measured data for analysis. There are great differences in measuring conditions, regression methods and model building conditions, which limit their generality. Tread rubber and pavement surface texture are the most direct and specific contact parts in the tire-road friction system. Their respective characteristics and their coupling are the material basis and essential source of the friction system. In this paper, by exploring the characteristics of tire viscoelasticity and road surface texture morphology and their interaction mechanism, a safety risk model for wet slip asphalt surface is established based on friction coefficient. Finally, the friction coefficient curve of asphalt pavement samples was obtained by DF test to verify the correctness of the anti-sliding safety risk model of wet asphalt surface.

2. Calculation of power spectrum on road surface

The surface of asphalt pavement has fractal characteristics. The size of fractal dimension can reflect the complexity and richness of surface texture comprehensively. Moreover, the asphalt surface texture section elevation data can be regarded as a one-dimensional signal, so the texture characteristics can be studied by means of signal processing. The power spectrum can reflect the energy distribution of the signal in the frequency domain, and the statistical distribution of the surface elevation value is characterized by the power spectrum of the texture. The power spectrum calculation theory of fractal surface is used to represent the texture characteristics of asphalt pavement. The approximate calculation of power spectrum of asphalt pavement is shown in formula (1):

$$C(q) \approx \frac{H}{2\pi} \cdot \left( \frac{h_0}{q_L} \right)^2 \cdot \left( \frac{q}{q_L} \right)^{-2(H+1)}$$  \hspace{1cm} (1)

$h_0$ is the root mean square texture elevation of Asphalt Pavement, $q$ is the wave vector of Asphalt Pavement, $q_L$ is the upper limit wave vector of Asphalt Pavement, $q_L$ is the lower limit wave vector of Asphalt Pavement, $H$ is House index.

3. Tire-road anti-sliding risk model
3.1. Model assumption

The surface of the road will be covered by water film during rainfall. It is found that the hydrodynamic effect on the tire-road coupling can be neglected when there is a thin water film on the road surface. When the tire slides on the road surface, there is enough time to drain the water between the tire and the road. Only part of the water will be left in the crack of the road surface by rubber seal, forming a closed "pool" phenomenon. The rubber particles of the tire can fully contact with the bulge of the asphalt pavement, but can not fully contact with the bottom of the groove. When the tread rubber slides on the asphalt pavement, \( \lambda \) defined as the wavelength, \( A(\lambda) \) is the true contact area, \( A(L) \) is the ideal contact area for sufficient contact and \( L \) is the radial length of the ideal contact area. In order to characterize the case where the roughness of the tread rubber and asphalt pavement is superior, the proportional coefficient \( P(\zeta) = P(\zeta) = A(\lambda)/A(L) \) is introduced to characterize the ratio of the true contact area at the wavelength \( \zeta \) scale and the ideal contact area at the full contact. The proportional coefficient \( P(q) \) is represented by the following formula.

\[
P(q) = \frac{2}{\pi} \int_{0}^{\infty} \frac{\sin x}{x} \exp[-x^2 G(q)] dx
\]

The function \( G(q) \) is represented by the Eq.(3).

\[
G(q) \approx \frac{H}{16\pi} \cdot \frac{1}{h_0^2} \cdot q_1^{2n} \cdot \int_{q_0}^{q} d\zeta \zeta^{-2n+1} \times \int_{0}^{2\pi} d\phi \left| \text{Im} \left( \frac{E(q_\zeta^2\gamma^2\cos\phi)}{(1-\gamma^2)^2}\sigma_0 \right) \right|
\]

![Figure 1. Sealed "pool" phenomenon](image)

3.2. Construction of theoretical model of tire-road friction coefficient

When tread rubber and asphalt pavement are fully in contact with sliding, \( A_0 \) is the ideal contact area, \( \sigma \) is the frictional stress between the tire and the road surface, \( v \) is the sliding speed, \( \gamma \) is the tread rubber Poisson's ratio, \( t_0 \) is the sliding time, \( u \) is the displacement, and \( \sigma \) is the stress distribution function. The energy consumed in the sliding time \( t_0 \) is represented by the Eq.(4).

\[
\Delta E = \sigma_f A_0 v t_0 = \int dx^2 dt u \sigma
\]

The displacement function \( u_z \) of the elevation direction is denoted by \( h \), and the \( \sigma_f \) expression can be derived from the Eq.(4).

\[
\sigma_f = \frac{(2\pi)^3}{w h_0^2} \int dq (-q'_z) [M_{\zeta}(q'_z-w)] \times h(q) h(-q)_z
\]

![Figure 1. Sealed "pool" phenomenon](image)
\[ M_z(q_w) = -\frac{2(1-\gamma)}{Eq} \] is stiffness matrix and \( <h(q)\overline{h(-q)}> = \frac{A_n}{(2\pi)^2} C(q) \) is correlation coefficient.

The expressions of stiffness matrix and correlation coefficient are introduced into equation (5) to obtain sufficient expressions for contact sliding:

\[ \sigma_f = \frac{1}{2} \int dq \cdot q^2 \cos\varphi \cdot C(q) \text{Im} \left( E(qv\cos\varphi) \right) \frac{E(qv\cos\varphi)}{1-\gamma^2} \] (6)

The maximum wave vector of the asphalt pavement is \( q_l \), and the minimum value is \( q_L \). The surface topography of the pavement has a sinusoidal function curve on any section. Rotating \( 2\pi \) over the horizontal plane is the corresponding surface, so the angle between the wave vector and the velocity is \( [0,2\pi] \). By the definition of the friction coefficient, the proportional coefficient \( B \) is introduced at the same time to obtain the friction coefficient expression under normal conditions:

\[ \mu = \int_{q_L}^{q_L} dq \cdot q^2 C(q) P(q) \times \int_{0}^{2\pi} d\varphi \cos\varphi \text{Im} \frac{E(qv\cos\varphi)}{(1-\gamma^2)} \sigma_0 \] (7)

Substituting equations (1), (2) and (3) into equation (7) to obtain the anti-sliding calculation model for wet-slip asphalt surface.

\[ \mu = \frac{1}{4\pi} \left( q_i h_i \right)^2 H \int_{0}^{q_i} d\zeta \zeta^{-2H-1} P(q) \times \int_{0}^{2\pi} d\varphi \cos\varphi \text{Im} \frac{E(q\zeta v\cos\varphi)}{(1-\gamma^2)} \sigma_0 \] (8)

Where \( E(q\zeta v\cos\varphi) \) is as expressed in Eq.(8):

\[ E(q\zeta v\cos\varphi) = \frac{E_1(1-i\tau \cdot qv\cos\varphi)}{a_i + 1-i\tau \cdot qv\cos\varphi} \] (9)

4. DF test verification feature model

In order to verify the rationality of the anti-slip risk model, the SMA-13 rutting plate was specially prepared. The most advanced self-focusing three-dimensional surface measuring instrument was used to extract the three-dimensional characteristic parameters of the sample surface. The test piece texture information is shown in Figure 2. Bring the parameters obtained from the test into the equation (8) for simulation calculation, and obtain the theoretical calculation results. The theoretical calculation results and the results of the DF instrument are shown in Figure 3.

![Figure 2. Specimen texture information](image-url)
As can be seen from Figure 3, the final section of the measured curve of the DF meter covers the transition process between the surface of the sample and the rubber slider of the DF instrument, which is separated by contact, starts to contact, and gradually contacts until the contact is fully sufficient. The speed starts to decrease from 80km/h, and the friction coefficient grows rapidly after creeping, which is caused by test methods and conditions. After eliminating the inevitable abnormal factors at the end of the measured curve, the theoretical calculation curve and the measured curve are basically the same in the range of 0km/h to 80km/h.

5. Conclusions

This paper deduces a risk model of anti-slip on wet road surface, which can calculate the friction coefficient of vehicles when they slip on wet road surface. Then, the results of model calculation are analyzed and verified by DF real test pieces. The verification results show that the theoretical calculation results of the anti-slip risk model are basically consistent with the measured results of the DF test. The model provides a scientific and reliable method for anti-slip in the process of running on the wet slide surface, which has important theoretical significance and application value.

6. References

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