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Research on Hydroplaning Performance of Wet Pavement Tires Based on CEL Method

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Abstract **– When a vehicle is running on the water road surface, the water film will affect the contact between the tire and the road surface, which can easily lead to the tire hydroplaning, reduce the braking performance and operation stability of the car, and seriously threaten the safety of the vehicle. In order to improve the hydroplaning performance of automobile tires, a 205/55R16 longitudinal groove tire model was established in this paper. Based on the ABAQUS/CAE platform, a hydroplaning model of water flow was created by Coupling-Euler-Lagrange (CEL) method. The relationship between tire hydroplaning performance and the water thickness, inflation pressure, driving speed and tire load were obtained by observing the change of contact reverse force between the tire and the road surface. Last, this paper proposes to give some measures to improve tires hydroplaning performance from the perspective of use. The results showed that the hydroplaning performance of the tire can be improved by increasing the inflation pressure and tire load. Meanwhile, reducing the driving velocity and driving on the thinner water flooded surface lead to better contact and hydroplaning performance between the tire and the road.**

Keywords **– Tire Hydroplaning, Finite Element Model, Radial Tires, Contact Reverse Force.**

I. INTRODUCTION

As the only link between the vehicle and the road surface, the tires are closely related to the braking ability, operation stability of the car. When the tire is running on the water flooded road, the tire and water will squeeze each other. Then water will produce the dynamic pressure acting on the tire, and the vertical pressure will offset part of the vehicle load, resulting that the water pressure exceeds the tire load as the speed increases to a certain value. At this time the tire is completely off the road, the contact reverse force is zero and hydroplaning occurs. Now the vehicle is in an extremely dangerous working condition, braking performance and handling stability are greatly reduced because the tire lost ground adhesion. Therefore, the study of tire hydroplaning performance and improvement method of waterlogged pavement tires has great practical significance.

Researchers at home and abroad have explored tire hydroplaning from different perspectives. Based on MSC. With Dytran computer-assisted simulation software, Nakajima et al. performed finite element analysis for the tire, and the Euler formula for the fluid to study the hydroplaning phenomenon of complex pattern tires. Kumar et al. used the finite element software ABAQUS to simulate the optical surface tires in pure sliding and pure rolling conditions, and found that the risk of tire hydroplaning in pure sliding state is much higher than when the tire is in pure rolling conditions. Ls-dyna finite dimensional software was used by Zang Mengyan et al. [13] to establish the three-dimensional structure of the tire, the flow of water flow in the pattern were analyzed through the simulation settlement method. They curved the relationship between the tire and the surface contact force and speed when the tire moved on two different roads. It is concluded that the thicker the water film is, the more likely the tire is to undergo hydroplaning. Zhou Haichao et al. used fluent software to simulate the tire hydroplaning fluid domain model, and elaborated the tire hydroplaning mechanism and interference factors. With the help of the bionic principle, the V-riblet bionic grooves was applied to the bottom of the groove, so as

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to achieve the improvement of hydroplaning performance.

In this paper, ABAQUS/CAE software was used to establish the 205/55R16 tire model and compare the tire sinking amount under different loads through the static loading test to verify the effectiveness of the simulation results. Secondly, the CEL method was used to establish a tire hydroplaning model, define the water flow hitting the fixed tire at a certain speed, and study its hydroplaning performance. Then, the different parameters of the tire hydroplaning model, like the wheel load and inflation pressure, were changed to obtain the road surface contact reaction force and conduct comparative analysis to determine the specific impact of the parameters on the hydroplaning performance. Finally, some measures to improve tires hydroplaning performance from the perspective of use was proposed according to the research results in this paper.

II. THE COUPLING - EULER - LAGRANGE METHOD

In this paper, the 205/55R16 tire model was established by Lagrange method and the water film model was established by Euler element. CEL method is the combination of Lagrange method and Euler method. It has the advantages of solid and fluid algorithm, high simulation accuracy and easy convergence. In the simulation, the Lagrange element is used to describe the solid model, the material is always filled with the element, and the material changes strictly with the movement of the grid, which can accurately track the moving boundary of the solid. In the simulation, the Euler element is used to describe the fluid model, the position and shape of the grid remain unchanged, and the fluid material moves freely in the fixed Euler domain. The boundary of the fluid can be well tracked through the update of the volume fraction, and the grid distortion will not occur.

In the simulation analysis of the model established in this paper, the solution method of “hidden first and then explicit” was adopted. Firstly, the implicit calculation was carried out, and the implicit solver in ABAQUS was used to inflate the tire and generate the three-dimensional model of radial tire. Then lift the road surface to make the tire contact with the road surface and apply a load to the road surface. At this time, the tire was standing on the model road surface. Then the steady-state rolling was carried out. ABAQUS/standard was applied to solve the inflation, rotation, loading and steady-state rolling of the tire, and the stress-strain field at a specific speed was obtained in the results to prepare for the subsequent calculation. Explicit calculation means that the explicit solver in ABAQUS software was used to simulate tire hydroplaning. Firstly, the stress-strain field of tire during steady-state rolling obtained in ABAQUS implicit solver was imported. As the initial value of tire hydroplaning in the explicit solver, the operation of tire under each transient was calculated in the explicit solver of ABAQUS.

Because this paper aims to study the tire hydroplaning performance, when simulating in the finite element software, it is necessary to add the water film model established by Euler method and set the boundary conditions and initial conditions of tire hydroplaning model. The reliability of tire hydroplaning model needs to be verified. If it is reliable, simulation calculation can be carried out.

III. ESTABLISHMENT OF THE TIRE FINITE ELEMENT MODEL

In this paper, a three-dimensional finite element model of 205/55R16 semi steel radial tire was established. In order to facilitate drawing and calculation, the tire structure was simplified and the following assumptions were made:

(1) All material properties used in the tire model will not change temperature, which is a fixed value;

(2) The materials will not squeeze and interact with each other, and will not affect each other;

(3) During the tire assembly and simulation experiment, there is no mutual movement between the parts.

A. *Establishment of the Tire Model*

Draw the two-dimensional profile of the tire in Auto CAD, import HyperMesh for meshing, and get the two-dimensional mesh, as shown in Figure 3.1.

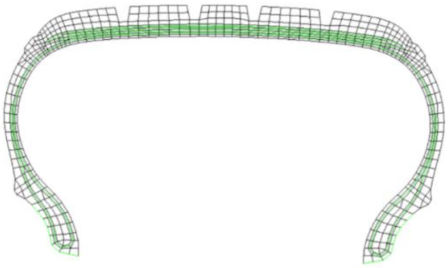

Fig. 3.1. Tire 2-d grid diagram figure.

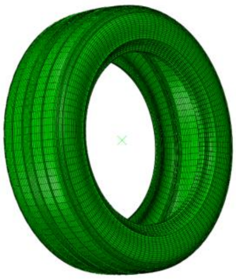

Fig. 3.2. Tire three-dimensional finite element model.

The above two-dimensional meshed diagram was exported in. INP format, and then imported into ABAQUS. Inflate it through implicit calculation, and then rotate it to obtain the three-dimensional model, as shown in Figure 3.2.

B. *Verification of the Model*

The accuracy of the established model and simulation results are affected by many factors: setting accuracy and optimization of grid division, type of selected materials and operation when setting assembly, setting of boundary conditions, equation arrangement and parameters, etc. To ensure the validity of the built model and the accuracy of the results obtained during the simulation experiments, the established finite element model need to be stiffness verified. On the one hand, the test value of the tire radial stiffness was measured by the CSS-88100 electronic universal test machine. On the other hand, the model radial tire was simulated by ABAQUS software. The simulation results were compared with the experimental values. If the two results are very similar and the established tire model is correct, the next simulation analysis can be performed. Otherwise, the model needs to be remodified and validated again.

Electronic universal test machine of model CSS-88100 is selected for loading test, as shown in Figure 3.3. Actual operation is as follows:

(1) To reduce the effect of the temperature change on the air pressure, the room temperature is stabilized at around 20 °;

(2) Selected six evenly distributed test points on the fetal side, and the experimental results were averaged from these six points;

(3) The tire pressure is set to 250 kPa, and set indoors for one day;

(4) Install the static completed tire on the experimental machine, level, and then measure the initial amount of the ground radius;

(5) Load the vertical load on the test tire at 0.5 KN, 1 KN, 2 KN, 3 KN, 4 KN, 5 KN, 6 KN, 7 KN, respectively.

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Hold for 1 minute after loading, and record the experimental value of tire radial deformation under each condition;

(6) Organize the measured experimental data. A maximum and minimum value are rounded separately, and the remaining four numbers are averaged, namely, the amount of tire sinking under different loads.

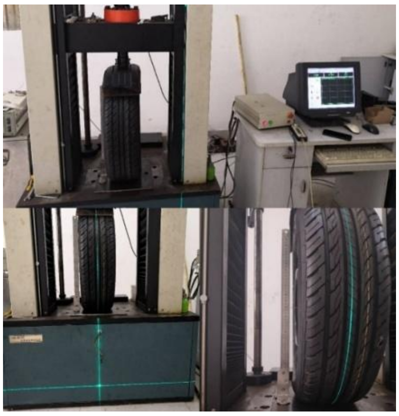

Fig. 3.3. Static loading test.

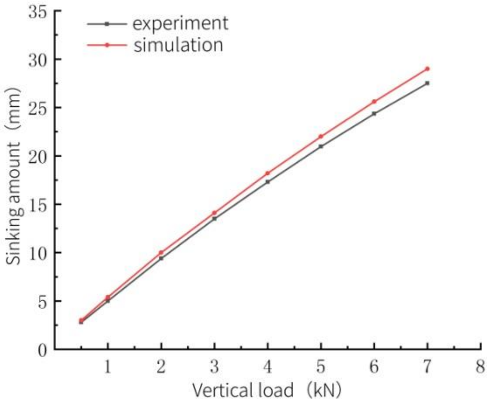

Fig. 3.4. Sinking plot.

The experimental values and the simulation results were plotted in Figure 3.4, and the abscissa was the vertical load of the tire, and the ordinate was the sinking amount. As shown in the figure, the sinking amount under different vertical loads measured by the experimental results basically matched the simulation results, with a very small difference. The effectiveness and reliability of the established finite element model were demonstrated and could be used for the tire hydroplaning analysis in the next step.

IV. ESTABLISHMENT OF THE TIRE WATER SLIP MODEL

A. *Water Film and Pavement Model*

The water membrane model was created using ABAQUS/CAE, including the water flow area, the air area, the tire water membrane contact area, defined the material as water, imported into the tire model and assembled, divided into the grid, etc., to obtain the Euler water membrane model, as shown in Figure 4.1.

The focus of this paper was studying hydroplaning performance of radial tires in water flooded road, the main body were the tire and water film, observe the changes of the two in the simulation process, do not consider the road materials, road condition and other factors. The pavement only supported the water film and the tire in the simulation process. When considering building the pavement model, the shell unit was selected to resolve the rigid body.

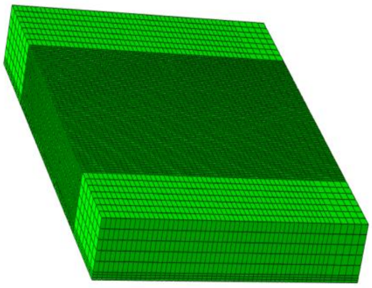

Fig. 4.1. Euler water membrane model.

Fig. 4.2. Tire hydroplaning model.

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B. *Establishment of Tire Hydroplaning Model*

The tire hydroplaning model consisted of radial tire, water film and pavement models, where the water film in turn included the air and water layer, as shown in Figures 4.2. When the tire runs on the wet road, the fluid covers the longitudinal road length over which the tire rolls. If the simulation analysis is carried out according to the motion form of the actual tire, although the motion state of the tire on the wet road can be truly reproduced, the calculation consumption is huge. Therefore, this paper restricted the movement of the tire along the road and applied a certain speed to the water flow to make it move relative to the tire, which can significantly improve the calculation efficiency.

C. *Reliability Validation of the Tire Hydroplaning Model*

To verify the tire hydroplaning model built in the paper, the critical hydroplaning velocity obtained from the simulation was compared with the results obtained by the empirical formula. This paper considered the tire pressure and tire grounding print in 1986:

$$v = 25.01\rho^{0.21} \left(\frac{1.4}{FAR}\right)^{0.5} \tag{1-4}$$

In the above formula, v is the critical hydroplaning speed; ρ is the inflation pressure of the tire; *FAR* is the ratio of the tire ground imprinted width to length. In the model and simulation analysis established here, the model set an inflation pressure of 250kPa, grounding width of 155mm, grounding length of 118mm. The critical hydroplaning velocity of 82.32km/h was calculated in the substitution formula. Simulation results show that the speed of the model was 80km/h, error only 2%, proving that the built model is reliable.

V. ANALYSIS OF INFLUENCING FACTORS OF HYDROPLANING PERFORMANCE AND IMPROVEMENT MEASURES

When the vehicle is running on the water flooded road, the performance of the tire will directly affect the condition of the vehicle and the safety of the drivers and passengers. Therefore, the hydroplaning performance of the tire must be regarded as the top priority of the tire design. This paper mainly explored the influence of hydroplaning performance of water road surface, and studied the influence of four factors of water film thickness, vehicle driving speed, tire load and inflatable pressure, to provide guidance for the safe driving of water road surface from the point of use.

A. *Effect of Vehicle Speed on Tire Hydroplaning Performance*

Driving speed has a great impact on the hydroplaning performance of tires on the wet road. The higher the speed, the more likely hydroplaning occurs. The vehicle speed selected in this paper were 70 km/h, 75 km/h and 80 km/h, the tire inflation pressure was 250 kPa, load and the water film thickness were 3700 N and 10 mm, respectively.

As shown in Figures 5.1, compared with the road contact reaction curve at different speeds in the figure, we can conclude that when the vehicle speed increases from 70km/h to 75km/h, the contact reaction force between the tire and the road surface greatly decreases. When the speed reached 80 km/h, the road contact reverse force basically disappeared over time. At this point, the water film held the tire completely, and a “complete hydroplaning” occurs. Therefore, reducing the speed can make the tire better contact with the ground and produce greater contact force, through the water road can effectively prevent the tire hydroplaning, increase driving safety.

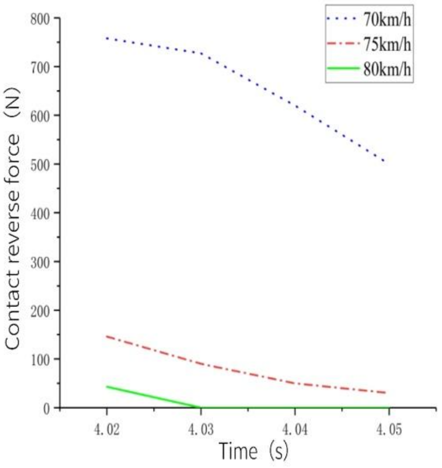

Fig. 5.1. Change of road contact reverse force at different driving speeds.

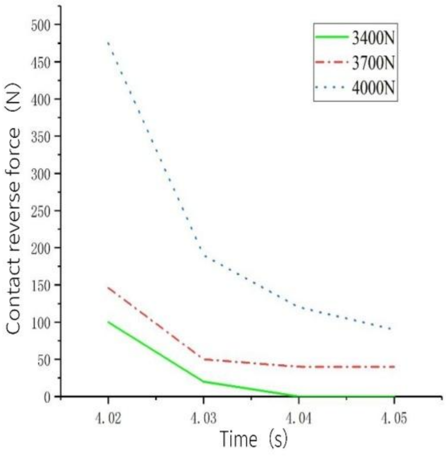

Fig. 5.2. Change of road contact reverse force at different wheel loads.

B. *Effect of Tire Load on Hydroplaning Performance*

In addition to the driving speed, the tire load is also the main factor affecting the tire surface contact condition. In general, the larger the load, the better hydroplaning performance tires owned. The tire pressure was 250 kPa, speed was 75 km/h, and the water film thickness was 10 mm. Respectively, the wheel load was 3400 N, 3700 N, 4000 N to study the change of road contact force over time under different tire loads.

As can be seen in Figures 5.2, the maximum pavement contact resistance at the tire load was 4000 N and the least at 3400 N. When other conditions remain unchanged, the greater the tire load, the greater the contact reaction of the road, the better the performance of the tire hydroplaning. Because when the tire load increases, the vertical force of the tire on the road will also increase accordingly, under the same conditions, the tire can press the ground, so that the tire has a larger contact area with the road. Therefore, increasing the load when passing through the water road surface was conducive to improve the hydroplaning performance of the tire.

C. *Effects of Inflation Pressure on Hydroplaning Performance*

At the inflation pressure of 3700 N, 200KPa, 250KPa, 300KPa, was selected to study the effect of tire inflation pressure on the hydroplaning performance of slippery pavement.

As can be seen from Figures 5.3, as the inflation pressure of the tire increases, the contact reverse force between the tire and the road surface increases. When the inflation pressure was 200kpa, the tire was excessively deformed due to the load, and the tire pattern trench space for drainage decreased, resulting in a large decrease in the pattern trench drainage capacity. At the same time, too low inflatable pressure will reduce the support ability of the tire and the depth of the pattern during driving, was not conducive to the tire pattern cutting through the water film, prone to hydroplaning phenomenon. Instead, when the inflation pressure increased to 300kpa, the tire maintained its shape, and the tire pattern was not squeezed, resulting in decreased drainage capacity, conducive to improving hydroplaning performance. Therefore, rainy days, appropriate increasing the pressure of the tire, can improve the hydroplaning performance of the tire and safety.

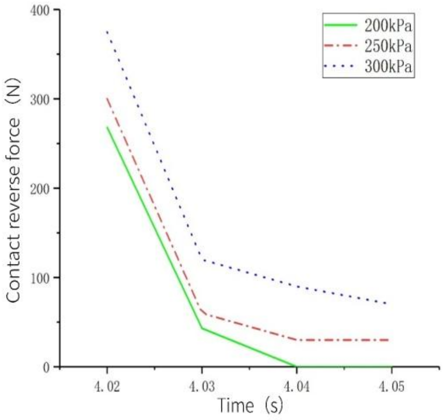

Fig. 5.3. Change of road contact reverse force at different inflation pressures.

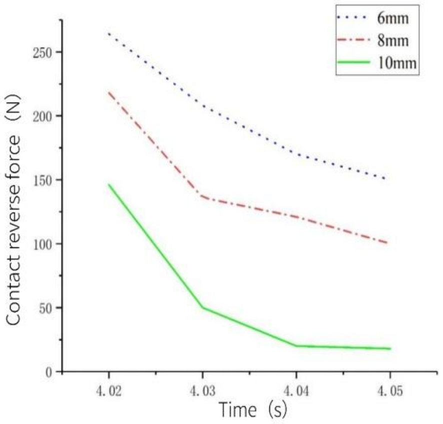

Fig. 5.4. Change of road contact reverse force at different water film thicknesses.

D. *Effect of Water Film Thickness on Hydroplaning Performance*

When the vehicle is driving on the water road, the tire pressure over the water film will produce dynamic water pressure, hold the tire, affect the attachment performance of the tire, resulting in the decline of the tire performance of hydroplaning. According to the research conclusion of literature, when the tire slides over the wet road, when the water film thickness of the road exceeds 10mm, the increase of water film thickness has little effect on the change of dynamic water pressure. Therefore, when considering the influence of water film thickness on the contact reaction force between tire and pavement, the maximum water film thickness was 10mm, and three water films of 6mm, 8mm and 10mm were set respectively to study the influence of different water film thickness on the contact reaction force between tire and pavement.

It can be seen from Figure 5.4 that when other conditions remain unchanged, the greater the water film thickness, the smaller the pavement contact reaction. Because the greater the water film thickness, the greater the force of water flow on the tire, lift the tire upward, reduce the interaction between the tire and the road, and the contact reaction decreases. Secondly, the water film thickness increases to 10mm. When it exceeds the depth of the tire groove, the pattern can not cut the water film smoothly. The contact between the tire and the ground can only be realized after a large amount of water is removed through the pattern groove. Under the condition of the same tire pattern, the thicker the water film, the easier the tire is to ski. Therefore, when passing through the ponding Road, select the area with thin water film or the area with high road surface. There is less ponding in this area compared with other areas, which can ensure the safety of vehicles and drivers to a certain extent.

VI. CONCLUSION

Based on the Coupling-Euler-Lagrange method, a hydroplaning model of 205/55R16 longitudinal groove tire was established and the hydroplaning analysis process was completed in this paper. To further explore the relationship between tire hydroplaning performance and interference factors by observing the change of contact reverse force between the tire and the road surface. Combining with the main work in exploring the tires hydroplaning performance of waterlogged pavement, the following conclusions were obtained in this paper.

(1) The research shows that the two models of tire hydroplaning simulation using CEL method are almost equivalent in using the contact reaction force between tire and ground to evaluate the tire hydroplaning

performance. However, the grid scale of the fluid region is much larger than that of the flow model, which seriously affects the computational efficiency. Therefore, the water flow model for hydroplaning simulation was selected in this paper.

(2) Taking the contact reaction force between tire and road surface as the evaluation index, the effects of main parameters such as water film thickness on tire hydroplaning performance were studied. The result showed that tire load and inflation pressure are positively correlated with tire hydroplaning performance, that is, in a certain range, the larger the values of these two influencing factors, the smaller the contact reaction force between road surface and tire, and the tire has better drainage capacity. The water film thickness and driving speed are negatively correlated with the hydroplaning performance. When other conditions are consistent, the greater the water film thickness and the higher the driving speed, the greater the probability of tire water skiing.

(3) In view of the above laws, their respective reasons was explained in this paper, and some measures was proposed to improve tire hydroplaning performance and reduce accident rate from the perspective of use.

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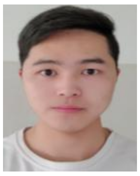

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