Research on numerical simulation and intelligent computing of vehicle wading driving by smooth particle hydrodynamics method

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Abstract. The method based on Smooth Particle Hydrodynamics (SPH) is a meshless method which is widely used at present. Its advantage is that it can effectively improve the mesh distortion when finite element is used to deal with large deformation, and its particle characteristics are suitable to deal with the simulation problem of fluid. Based on the actual vehicle wading test site and the actual parameters of the vehicle, combined with the actual situation and theoretical basis, the SPH method is used for numerical simulation analysis of the vehicle wading problem. By comparing the simulation process with the actual water changes during wading, the feasibility of using SPH method in vehicle wading application is proved. In the simulation process of vehicle wading driving, under the condition of constant water level, by setting different wading speeds of vehicle, the flow law and change mechanism of water free surface are analyzed, which are of great significance in theoretical research and engineering application research.

Keywords: Vehicle wading, SPH method, Flow simulation.

1. Introduction

With the rapid development of economy, the number of private vehicles is rising rapidly. The safety of vehicle operation has been paid more and more attention. When the vehicle is driving on the surface gathered water Road, the droplets carried by the wheel splashing will not only pollute the vehicle surface, but also affect the driver's vision and the exterior rear-view mirror [1]. When the water level reaches a certain height, the engine will be flooded and damaged [2]. Especially for self-driving vehicles and Battery electric vehicles that will occupy a place in the automobile market in the future, some accessories such as sensors and batteries carried on the vehicle are more vulnerable to the influence of water level when driving in water [3]. Therefore, it is of great significance to study the movement trend of free surface and the height of water level when the vehicle wades. Vehicle wading process is an important research orientation of vehicle safety driving [4].

In recent years, with the rapid development of computer technology, computer simulation has some advantages such as low cost, high design freedom and strong flexibility, which makes fluid simulation gradually become a hot research direction. In 2014, Adrian of JLR and Jonathan of EXA successfully simulated the formation process of droplets and the dynamic distribution of surface water layer based
on lattice Boltzmann method and Lagrange particle tracking method of commercial software [5]. In 2015, Hu Xingjun, Lei Liao, Lei Yulong et al. from Jilin University conducted numerical simulation with the improved MIRA model as the simulation object based on the finite volume method, and analyzed and revealed the influence of vehicle outflow field on wheel wading and its surface pollution [6]. In 2016, Yang Hanbo and Liu Haipeng of Jilin University combined the traditional computational fluid dynamics method with the multiphase flow theory to explore a numerical simulation method to study the area of the water droplets splashed by wheels on the surface of the vehicle when welling in water [7,8].

The traditional finite element method for fluid simulation requires the establishment of geometric structure, meshing, setting of parameters, solving calculation and obtaining results [9]. However, the finite element method has some limitations when the vehicle is wading. The mesh moves with the motion of the water and vehicle, when a large area of water deforms and splashes, the mesh will undergo large deformation, which will lead to problems such as grid distortion, mesh distorted and mesh entanglement [10]. The distortion of these mesh will lead to low accuracy or failure of calculation. The SPH method uses arbitrarily distributed particles to solve an integral or partial differential equation, resulting in an accurate solution. Particles do not need to be connected through the mesh, which has a certain advantage in dealing with the large-area deformation of water when the vehicle wades.

2. SPH method

Smoothed particle hydrodynamics is a new pure Lagrangian meshless particle method developed in recent decades [11]. Proposed by Lucy, Gingold and Monaghan in 1977, it was initially applied to three-dimensional open space astrophysics [12, 13], in 1882, Monaghan et al. made an outstanding contribution to the research and application of this method [14, 15], applying the smooth particle dynamics method to the mechanics of continuous solids and fluids. In 1995, SPH method was applied to the numerical simulation of underwater explosion [16]. In 2008, SPH method was applied to the problem of pipeline pneumatic transportation [17]. In 2019, SPH method was applied to simulation analysis of liquid sloshing in liquid storage tanks [18]. In this paper, vehicle wading model is established based on the SPH method. The flow law and change mechanism of free surface of water at different speeds are analyzed and studied. The image processing software is used to calculate the computational domain, and the curves of the height and velocity of water particles with time are obtained. By comparing with the actual vehicle wading situation, the feasibility of SPH method in the process of vehicle wading is proved, which provides some theoretical reference for the subsequent application research of related vehicle wading problems.

3. Establishment of Model

Vehicle wading means that the vehicle passes through the wading pool at a certain speed after the assembly is completed. In this paper, SPH method is used to simulate the process of vehicle wading. According to the parameters of the vehicle wading test site, ignoring the compressibility of the water and the driving resistance of the vehicle, the calculation domain size is determined according to the principle of equal scale reduction, which can not only save the calculation time, but also improve the calculation efficiency. In this paper, the ratio of 10:1 is used to establish a wading model.

3.1. Vehicle model establishment

According to the three-dimensional solid model of the vehicle, the wheel and the outer surface of the vehicle are selected to generate the space. Vehicle structure, engine structure and chassis structure are complex [19]. To save time and reduce the number of particles. Ensure the accuracy of simulation results. The bottom and the body of the vehicle are built into a whole, the wheels and the exterior surface remain similar [20]. The vehicle model is established.
3.2. Establishment of geometric model
The first step of modeling is to define the computational domain of the vehicle wading model. 1600mm in length, 600mm in width and 1000mm in height. Then the vehicle model is built and the flow model is set up. The water model is set as 1600mm in length, 600mm in width and 80mm in height. In the model, the longitudinal direction of the vehicle is x-axis, the transverse direction of the vehicle is y-axis, and the height of the vehicle is z-axis. Parameters such as density, surface tension and viscosity of water at 22°C are taken as reference. Model parameters are shown in Table 1. After the setup is complete, the model is created. As shown in Fig. 1, the model outputs 103715 particles.

Table 1. Model parameters

| Parameters                        | Numerical value |
|-----------------------------------|-----------------|
| Density of water (kg/m³)           | 998.2           |
| Acceleration of gravity (m/s²)    | 9.8             |
| Surface tension of water (σ/10⁻³·m⁻¹) | 72.44          |
| Viscosity of water (mpa·s)        | 0.9579          |
| δSPH                              | 0.1             |
| Particle spacing (m)              | 0.01            |
| Simulation time (s)               | 4.5             |
| Vehicle running time (s)          | 2               |

Figure 1. Vehicle wading model.

4. Analysis of simulation result
The water remains stationary at the initial moment. When the car passes through the wading field at a constant speed. The change rule and change mechanism of the free surface of water within 0.5s to 2.0s in the wading process under the interaction of vehicle driving force were selected. As shown in Fig. 2.

Figure 2. Simulation result
Vehicle wading is a complex process, which is affected by water level height, vehicle type and vehicle speed. In the simulation, we choose an important factor of vehicle speed to analyze the flow law and change mechanism of water free surface. Select an important factor in the simulation, vehicle speed analysis. Fig. 3 show the changing shape of the water free surface when the vehicle wades underground in the wading test ground [21]. Fig. 4 show SPH simulation results of water free surface during wading. During the whole simulation, the SPH method can effectively simulate the fluctuation of the free surface of water in the computational domain. Including water waves generated and particle splashing in the process of wading. The complex waveforms formed when the water body moves in a straight line with the car can be simulated, and the simulation results are in good agreement with the actual results.

4.1. Analysis of particle velocity on free surface of water
The red arrow in Fig. 5 indicates the velocity direction of water particles in the unit. Each velocity direction is to sample the uniformly distributed particles in unit space under the condition of ensuring the accuracy in the maximum range. The velocity direction of water particles in the plane determined by x-axis and y-axis is analyzed. 0.5s, The car is moving forward at a constant speed Water bodies are disturbed by the interaction of driving forces. Such disturbance is transmitted in the form of fluctuation under the action of the restoring force of water [22]. The front end of the vehicle forms a unidirectional shallow water wave with fan-shaped diffusion. 0.5s to 1.5s, the water forms a swell around the vehicle that spreads out in all directions. Water waves gradually pass around and attack the walls on both sides of the wading site. Under the action of the wall, the direction of particle velocity changes sharply. Then the water velocity on both sides of the body moves backwards. 1.5s to 2s, the water wave continues under the influence of the vehicle, the direction of particle velocity in the rear of the vehicle shows the tendency of blending and convergence. Water continues to propagate in waves under the influence of surface tension and gravity [23].
Figure 6. Variation of water particle velocities with time under different wading velocities of vehicles

In the simulation, the wading speed model of the car is set respectively, 0.3 m/s and 0.5 m/s. In order to clearly and intuitively understand the variation relationship between water particle velocity and time, the curves of the maximum velocity, average velocity and minimum velocity of water particle on the free surface under different wading speeds of vehicles within 0.5 s to 2.0 s were calculated. As show in Fig. 6. When the velocity is 0.3 m/s, the maximum velocity of particles fluctuates up and down. The average particle velocity shows a slow rising trend in the period from 0.5 s to 2.0 s, and the maximum particle velocity reaches its peak near 2 s. When the vehicle wading speed is 0.5 m/s, within 0.5 s to 1.5 s, the maximum velocity of particles in water presents a wave-like rising trend, and the average velocity of particles increases gradually. The maximum velocity of the particle rapidly reaches its peak near 2 s, and the particle splatter appears at this time. The higher the vehicle speed when wading, the higher the maximum velocity of water particles.

4.2. Analysis of water body height change

When the vehicle starts running, the water is acted on by the driving force. The velocity of water flow in front of the vehicle and near the tire is relatively high, and the water begins to diffuse and transfer to the surrounding in waves. As show in Fig. 7. Its front end forms a unidirectional fan-shaped shallow water wave and surging forward. As the water level in the front of the vehicle rises, the water diffuses to both sides of the vehicle body. The water is unsteady flow in the whole process of change. As the water level rises, the water gradually diffuses to both sides. As show in Fig. 8. Vel Magnitude is expressed as the value of the particle velocity. The red area is higher velocity, the blue area is lower velocity.

Figure 7. Free surface velocity of water Figure 8. Free surface height of water
Fig. 9 shows the change of water free surface height with time when vehicle wading speed is 0.3m/s and 0.5m/s within 0.5s to 2.0s. The wading speed of the vehicle is 0.3m/s, and the highest water level rises slowly in a wavy way with the advance of the vehicle. When the wading speed of the vehicle is 0.5m/s, the height of the free surface of the water will show a steady trend between 0.5s and 0.8s. Then, as the vehicle waded through the water, the highest water level of the water began to rise rapidly, and the water generated splashes under the action of the vehicle's high speed.

5. Conclusion
Vehicle wading is a complex process, in this paper, an important influencing factor of vehicle speed is selected to study. Based on the SPH method. Combined with the actual situation and theoretical basis, the wading simulation model of automobile is established according to the proportion of vehicle wading test site on the premise of ensuring the calculation accuracy and improving the calculation efficiency. The flow law and change mechanism of water are analyzed, especially the change of height of water free surface and water velocity with time. The following conclusions are drawn:

(1) SPH method is used to calculate the variation of water and the fusion process of water free surface under the influence of vehicle driving force. Combined with the change chart of velocity direction with time, we can analyze and predict the change flow law and change mechanism of water free surface when the vehicle wades.

(2) Through the analysis of the height of water free surface and the velocity of water particles, it can be concluded that the highest water level of water free surface appears near the maximum velocity of water particles.

(3) Through the SPH method results and the actual vehicle wading situation comparison. The shape of free water surface can be captured well by SPH method. The three processes of wave formation, wave propagation and particle surging and splashing are predicted. The feasibility of SPH method in vehicle wading is proved. As a new meshless particle method, SPH method has been widely used in the field of fluid simulation in recent years. Based on SPH method will greatly promote the research and application level of vehicle wading problem.

Acknowledgments
This project is financially supported by Shandong province agricultural machinery equipment research and development innovation plan project (2018YF016); Shandong province Key Research and Development Program (2019GNC106032); A Project of Shandong Province Higher Educational Science and Technology Program (J13LB62).
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