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Stability Control Research of Tire Blowout Vehicle Simulation Model in Collaboration with Carsim

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Abstract: In order to address the high level of danger posed by vehicles experiencing tire blowouts, this article modifies the tire parameters of the vehicle model in Carsim. By simulating a high-speed blowout scenario, the non-blowout tire cylinder braking pressure is controlled using non-linear control in MATLAB/Simulink. This allows for a comparison of the vehicle's motion before and after a blowout. By adjusting the input curve of hydraulic braking pressure multiple times, it was found that introducing a sixth-order control function effectively stabilizes the vehicle after a blowout, preventing it from deviating from the lane. This is mainly manifested by a stable yaw angular velocity of -1deg/s and a deviation from the lane of ±1.5m. These findings have significant research and engineering value in terms of stability control for vehicles after a blowout.

1. Introduction

With the advancement of the automotive industry, vehicle safety has increasingly become a focal point of public concern. However, due to various factors such as poor road conditions, overloading, or speeding, tire blowouts have become a common cause of traffic accidents. Particularly on highways, tire blowouts can lead to severe consequences and even result in casualties[1].

To enhance vehicle stability in the event of a blowout, many researchers have begun exploring various control strategies. Among them, model-based control methods have gained attention for their precision and effectiveness. By establishing a dynamic model of the vehicle and utilizing this model for real-time prediction and control[2], the impact of a blowout on the vehicle can be significantly reduced, enhancing its stability.

In this paper, we propose a tire blowout vehicle stability control method based on Carsim simulation models. Initially, by modifying tire parameters and vehicle motion parameters, we simulate different scenarios of tire blowouts. Subsequently, using Simulink, we design a nonlinear controller to adjust the vehicle's braking behavior. Finally, through numerical simulations, the effectiveness of the proposed control strategy is verified, and the influence of different control parameters on vehicle stability is analyzed.

In summary, our research offers a novel approach and methodology to address tire blowout issues. Through constructing an accurate dynamic model of the vehicle and employing real-time control with Simulink models, we can effectively improve vehicle stability and safety in situations involving tire blowouts. This not only helps reduce the incidence of traffic accidents but also safeguards drivers' lives and public safety[3].

2. Tire Blowout Model

2.1. Vehicle Model

The selection of vehicle parameters in this paper is based on the fundamental specifications of the current model under development. Basic parameters are shown in Table 1 below:

Table 1: Vehicle Basic Parameters

Basic information		Technical parameter
Vehicle parameter	Length (mm) × width (mm) × height (mm)	4660*1900*1520
	Wheelbase (mm)	2880
	Front/rear wheel base (mm)	1590/1600
Steering system	Steering wheel diameter (mm)	370
	Steering ratio (±180°)	15
tyre	Tire size (front/rear)	235/55 R18
	Tire pressure (front/rear) (kPa)	250/250

In the Carsim model, it is set as shown in Figure 1 below:

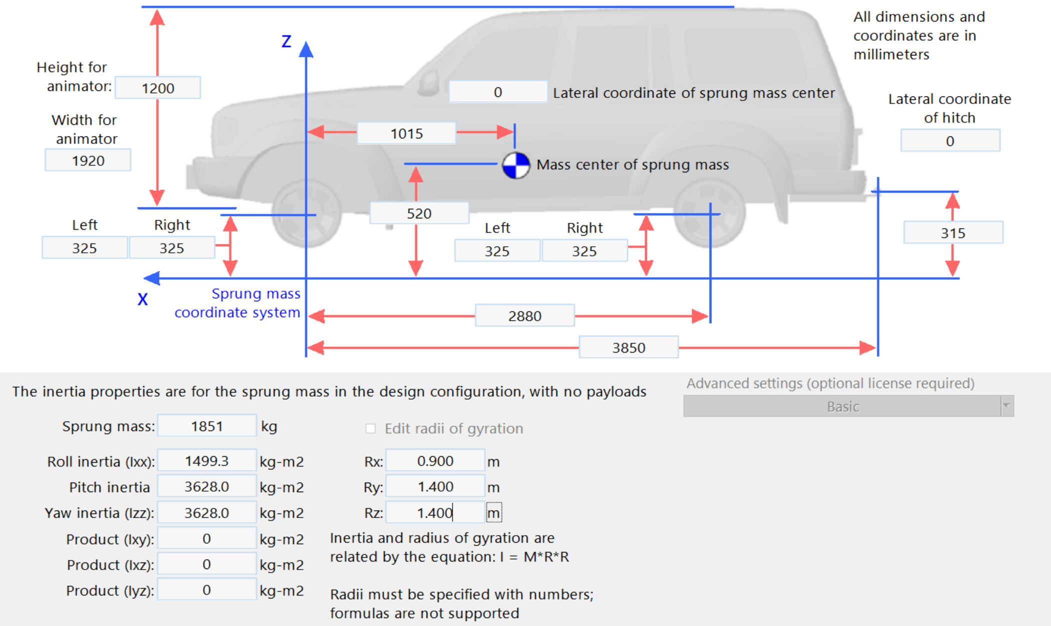

Figure 1: Schematic Diagram of Vehicle Parameters in the CarSim Model

2.2. Tire model

In this paper, the four built-in tires are set to 235/55 R18, and its initial parameters are shown in Figure 2 below:

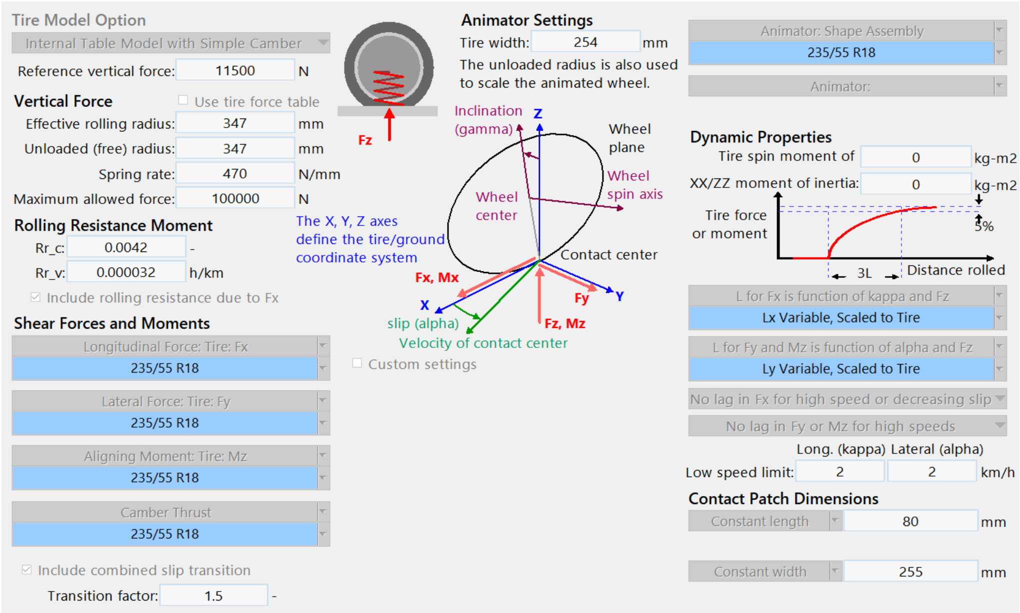

Figure 2: Schematic diagram of tire parameters in carsim model

After a tire burst occurs in a vehicle, the mechanical characteristics of the tire will change greatly, and the changing parameters mainly include: lateral stiffness, roll stiffness, radial stiffness, longitudinal stiffness, rolling resistance coefficient, righting moment, effective rolling radius, etc [4]. Specific changes are shown in Table 2:

Table 2: Tire parameters change table

argument	Degree of change	Experience time /s
Tire rolling resistance coefficient	Increase by 30 times	0.2
Radius of tire rolling resistance	70%	
Radial stiffness of tire	1/15	
Tire longitudinal stiffness	28%	
Tire lateral stiffness	25%	
Tire roll stiffness	66%	
Righting moment	tenfold	

3. Experimental conditions and simulation tests

3.1. Setting of flat tire

The tire burst is a more complex and severe condition. Whether it is simulation experiment or real car test, the conditions should be set accurately to simulate the real tire burst. The following key conditions need to be set before setting the flat tire situation.

(1) Tire parameters: Tire parameters are to ensure that the tire parameters used in the simulation match the tire parameters of the actual vehicle, including tire stiffness, friction coefficient, tire failure characteristics, etc [5].

(2) The timing of the puncture: it is necessary to determine the timing of the puncture, and the timing of the puncture can be set according to the actual situation, usually at a simulated specific time point or under specific conditions.

(3) Vehicle dynamics model: The vehicle dynamics model is to ensure that the vehicle dynamics model used can accurately describe the vehicle behavior after a tire burst, including the dynamic

characteristics of the suspension system, braking system, etc.

(4) Control algorithm: If the control algorithm needs to be used in the simulation to deal with the tire burst, it is necessary to ensure that the parameters and logic of the control algorithm are consistent with the actual situation, and can effectively control the vehicle after the tire burst.

After the above conditions are set, the tire burst can be simulated through carsim and simulink to evaluate the behavior of the vehicle after the tire burst and possible control strategies.

Tire parameters and vehicle dynamics model have been set in the previous section. As for the design of tire burst time, the author uses the Event event in carsim software. The main Settings are as follows: Event 1 is defined as normal motion, the speed is set to 120km/h, and the road is set to straight. Event 2 is defined as when time t≥2, the left front wheel is switched to the burst tire model to simulate the burst tire condition. The end event is defined as the end of vehicle movement when t≥8. As shown in Figure 3 below.

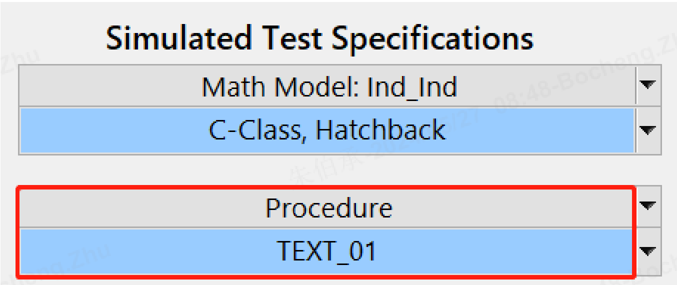

Figure 3: Schematic diagram of event model

3.2. Output parameter setting

In order to better analyze the vehicle movement after the tire burst, it is necessary to set the output parameters of the post-processing. The parameters used to characterize the instability factors of a vehicle after a tire burst are mainly reflected in the yaw speed of the vehicle and the trajectory of the vehicle [6]. This parameter can be output in carsim, and can be compared with the change of control. As shown in Figure 4 below.

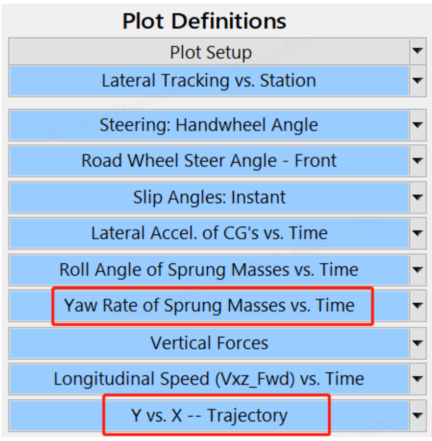

Figure 4: Output parameter characterization diagram

3.3. Experimental results without control

After setting vehicle parameters, tire parameters and tire burst time, it can be simulated. The 3D driving situation of the vehicle after operation is shown in Figure 5 below:

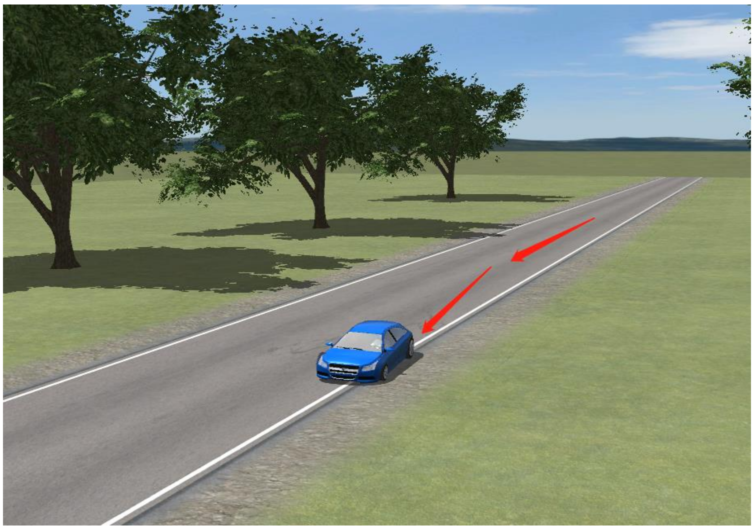

Figure 5: Schematic diagram of vehicle 3D driving condition

The arrow points to represent the initial driving trajectory of the vehicle and the driving trajectory after the tire burst. Since the author originally set the left front tire burst, when the left front tire burst, the vehicle will shift to the left. This is because the left front wheel of the vehicle is usually used for steering, so when the left front wheel blows out, it loses effective steering support, causing the vehicle to shift to the left. The simulation results are consistent with the theoretical analysis.

The yaw velocity change of the vehicle after the tire burst is shown in Figure 6 below:

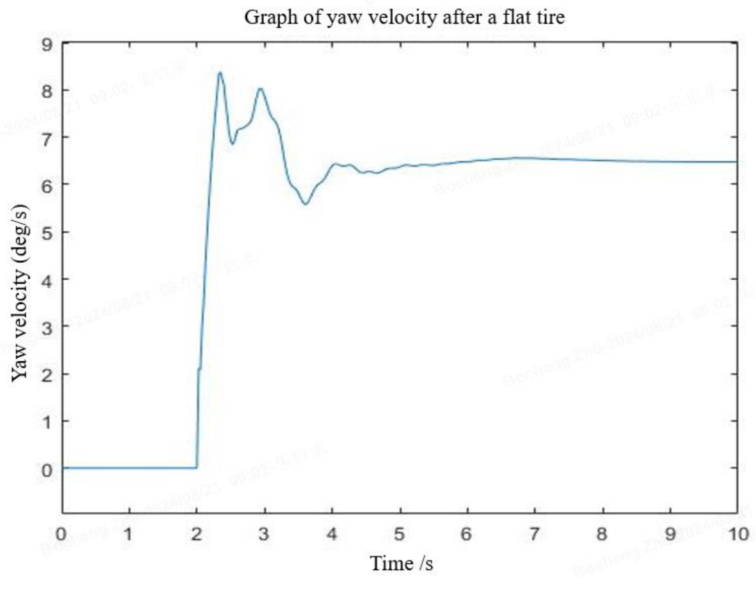

Figure 6: Schematic diagram of yaw speed of a vehicle with a flat tire

As can be seen from the figure, when the time is in the second second, the left front tire of the vehicle bursts, and the instantaneous yaw speed of the vehicle changes to 8.37deg/s, and then the vehicle continues to drive, and its yaw speed is stable at 6.5 deg/s.

The changes of the vehicle's driving trajectory and target driving trajectory after the tire burst are shown in Figure 7:

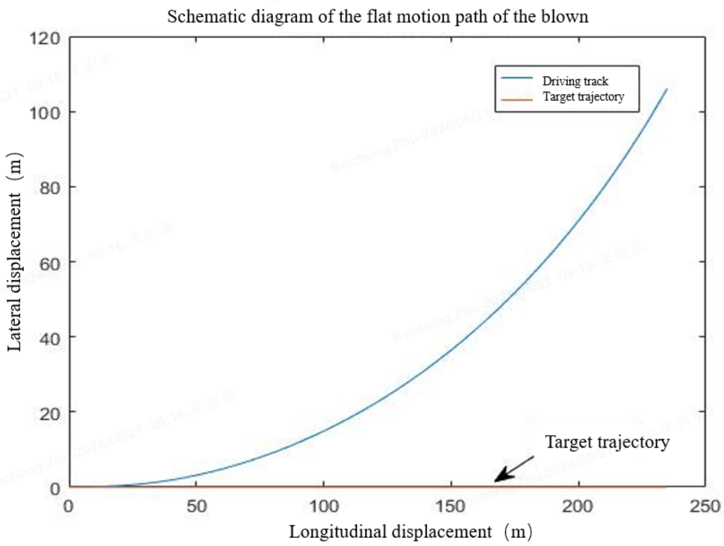

Figure 7: Schematic diagram of plane driving trajectory of the vehicle with a flat tire

According to the figure, it can be seen that the driving track of the vehicle with a flat tire is quite different from the target track in the lateral direction, which also indicates that the vehicle will deviate to the left when the left front wheel blows a tire.

The above simulation analysis of the yaw speed and driving trajectory of the vehicle with a flat tire shows that the vehicle will destabilize with a large yaw speed under the condition of a flat tire, thus deviating from its target driving trajectory.

3.4. Experimental results under nonlinear control

According to the results of the simulation experiment of the uncontrolled tire burst, the instability of the vehicle is more serious, so it is necessary to carry out stability control. After experience, we know that after the tire burst, either brake control or steering control can stabilize the vehicle. Considering that it is difficult for the driver to calmly take the corresponding steering measures when the tire is blown, if the vehicle actively steering, it will be contrary to the driver's intention or there will be excessive steering. Therefore, in the aspect of active steering, the author does not consider, and adopts braking measures to carry out stability control. The author adopts the nonlinear control method to brake the three tires except the blown tire wheel. That is, the brake pressure will change with time, if the brake pressure is constant, there will be a situation that the vehicle will rotate in place due to the constant brake pressure after stability. The specific nonlinear function is as follows:

Right front wheel brake pressure polynomial function:

$$y = \frac{7}{100000}x^6 - \frac{21}{10000}x^5 + \frac{11}{400}x^4 - \frac{1473}{10000}x^3 + \frac{1427}{10000}x^2 + \frac{727}{625}x + \frac{207}{25} \tag{1}$$

Rear wheel brake pressure polynomial function:

$$y = -\frac{23}{5000}x^2 - \frac{703}{2500}x + \frac{209}{25} \tag{2}$$

According to the debugging six-order control function, the control effect in each stage is analyzed, and then the above control function is imported into matlab/simulink to carry out the co-simulation test. Its control module is shown in Figure 8 below:

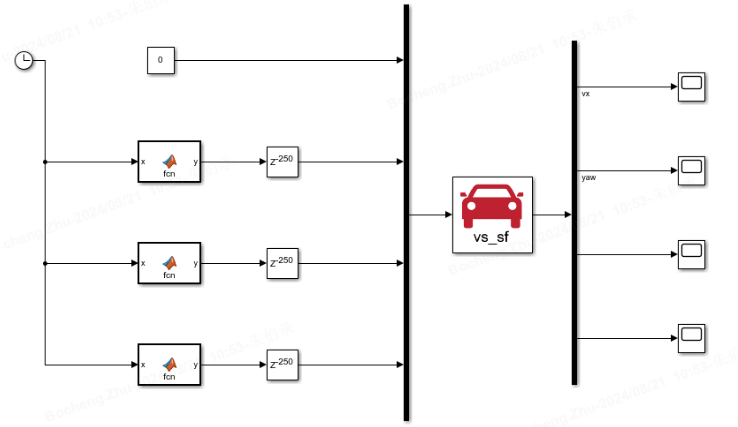

Figure 8: Simulink schematic diagram of control model

The yaw speed change of the controlled vehicle after the tire burst is shown in Figure 9 below:

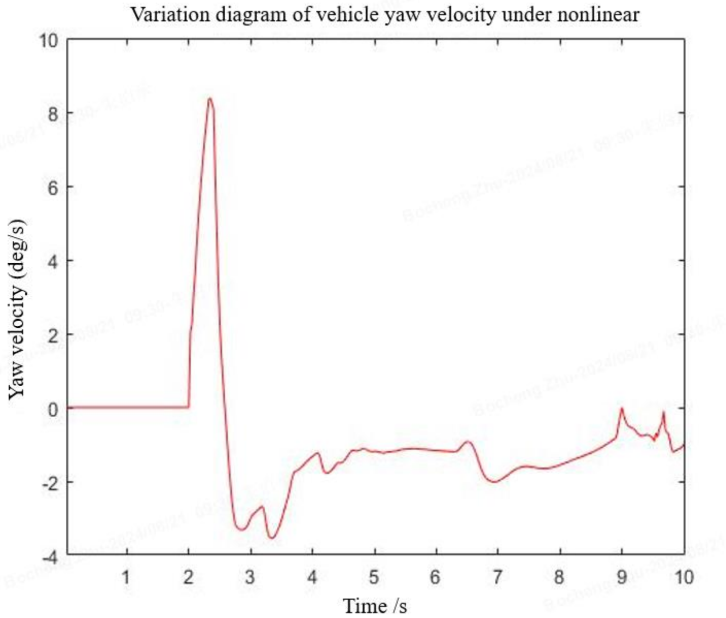

Figure 9: Variation diagram of vehicle yaw velocity under nonlinear control

As can be seen from the figure, when the time is in the second second, the left front wheel of the vehicle blows out the tire, and the instantaneous yaw speed of the vehicle changes to 8.37deg/s, which is consistent with the uncontrolled result. After nonlinear control of the brake pressure, the yaw velocity is stable at -1deg/s, which can be regarded as vehicle stability.

The changes of the controlled vehicle driving track and target driving track after the tire burst are shown in Figure 10 below:

As can be seen from the results shown in the figure, after nonlinear control, the lateral movement of the vehicle's plane motion track is within ±1.5m, and most domestic lane widths are set at 3.75m[7]. Therefore, it is possible to stabilize the vehicle with a flat tire within the lane line after adjusting the brake pressure through non-linear control.

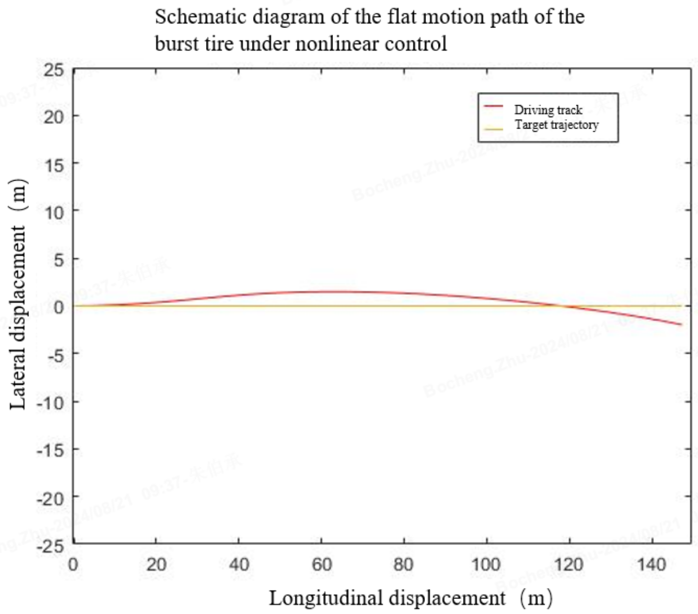

Figure 10: A schematic diagram of the trajectory of a flat burst tire under nonlinear control

4. Conclusion

Based on the complexity and risk of tire burst conditions, this paper designed a polynomial function according to the movement of the vehicle in the process of left front wheel tire burst to carry out nonlinear control of brake pressure. After control, it was found that the yaw speed of the vehicle was significantly reduced, indicating that the vehicle tended to a stable state. From the comparison of vehicle driving track, it is found that after control, the driving track of the vehicle with a flat tire can be kept in one lane, which can greatly avoid the collision between the car and the side car due to the flat tire, and also improve the driving stability of the car.

References

[1] Li Mengen, Zhang Yanhui. Analysis of Research status of Small vehicle Tire blowout [J]. Automotive Parts, 2021, (06): 107-112.

[2] Li Mengen, Zhang Yanhui. Research on Fuzzy PID Control for Stability Control of Vehicle with Flat Tire [J/OL]. Machine Design & Manufacture, 1-6[2024-05-27].

[3] Zhan Weiliang, Dong Hongzhao. Tire Burst Stability Control for four-wheel Steering Vehicles Based on MPC [J]. Times Automobile, 2023,(22):186-188.

[4] Han Zexuan, Lu Yongjie, Zhang Junning, et al. Research on Active Safety Control of Vehicle with Tire blowout with Driver in Loop [J]. Journal of Shijiazhuang Railway University (Natural Science Edition), 2023, 36(02):89-95.

[5] ZHOU Peng. Research on Motion Characteristics and Stability Control of Vehicles with Flat Tires [D]. Shaanxi University of Technology, 2023.

[6] Teng Xingwang, Zhang Xiangwen. Research on Fuzzy Optimization Coordinated Stability Control of Vehicle with Flat Tire [J/OL]. Mechanical Science and Technology for Machinery, 1-12[2024-05-27].

[7] CJJ 37-2012, Urban Road Engineering Design Code [S].