

Carsim-Based Modelling and Analysis of Exit Ramp Safety

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Abstract: The exit ramps of highway interchanges are the easy and high incidence points of highway traffic accidents. According to a large number of domestic and international statistics, the number of traffic accidents at freeway interchange ramps accounts for more than 30% of all freeway traffic accidents, and the accident rate at exit ramps is about twice as high as that at import ramps. At present, the research on the safety of exit ramps of freeway interchanges is mostly focused on the individual discussion of each traffic safety influencing factor, but the multiple factors affecting the safety of exit ramps cannot be considered in a comprehensive and coordinated manner. Therefore, in order to improve the safety of highway exit ramps and reduce the probability of accidents, this paper takes the highway exit ramp section as the research object, establishes a simulation model using Carsim software, combines several influencing factors, studies the driving stability of small cars in the exit ramp section, and establishes the relationship between the critical value of safe driving of vehicles in the highway exit ramp section and the radius of circular curve, super high, and friction coefficient. The relationship model between the vehicle's safe driving in the exit ramp section of the highway and the radius of the circular curve, super high, friction coefficient.

Keywords: Traffic Safety, Freeway, Exit Ramp, Driving Stability, Simulation

1. Introduction

The highway is an important lifeline for the country's economic operation, and the economic flow and travel of people in all regions of the country are inseparable from it, followed by an increasing rate of traffic accidents, especially serious ones in the exit area of the highway. Referring to the data of highway accidents in China, it is clear that many driving behaviors such as violation of traffic signs, rollover, lane change, tailgating, etc. are more common at the exit and import locations of highways, the most serious of which is the exit location. More than 30% of highway accidents occur in the highway exit area, referring to the exit ramp, the corresponding distance upstream and downstream of the diversion area and the diversion area. Therefore ramp safety becomes an urgent traffic safety issue for improvement.

2. Introduction of Carsim Software Features

Carsim is a software of the Mechanical Simulation

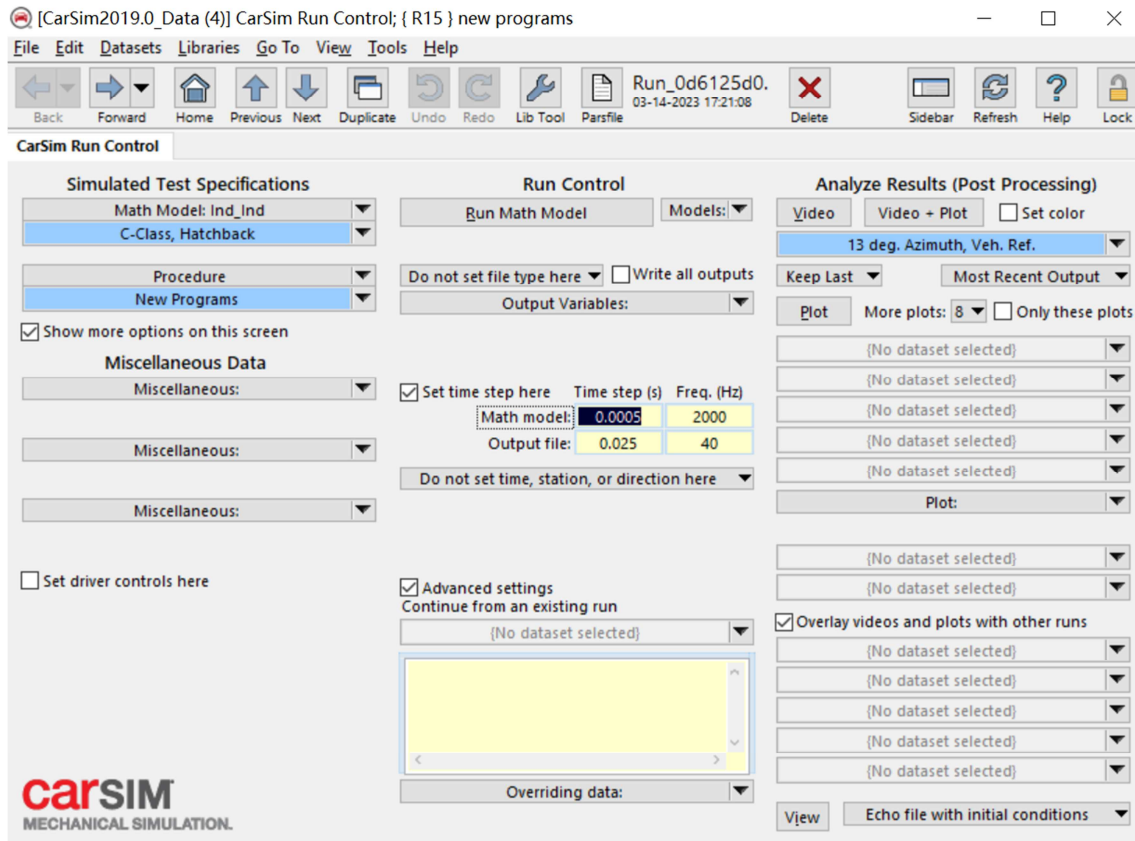
Corporation of the United States, which carries out simulation for dynamics and has a wealth of models, and is commonly used in traffic simulation and other applications [1].

Carsim can set up a variety of models, confirm specific road indicators, visually confirm 3D animations and specific curves of various indicators, obtain various data such as smoothness, and build supporting mechanical characteristics and road operation and other related links, which can achieve quantitative effects [2].

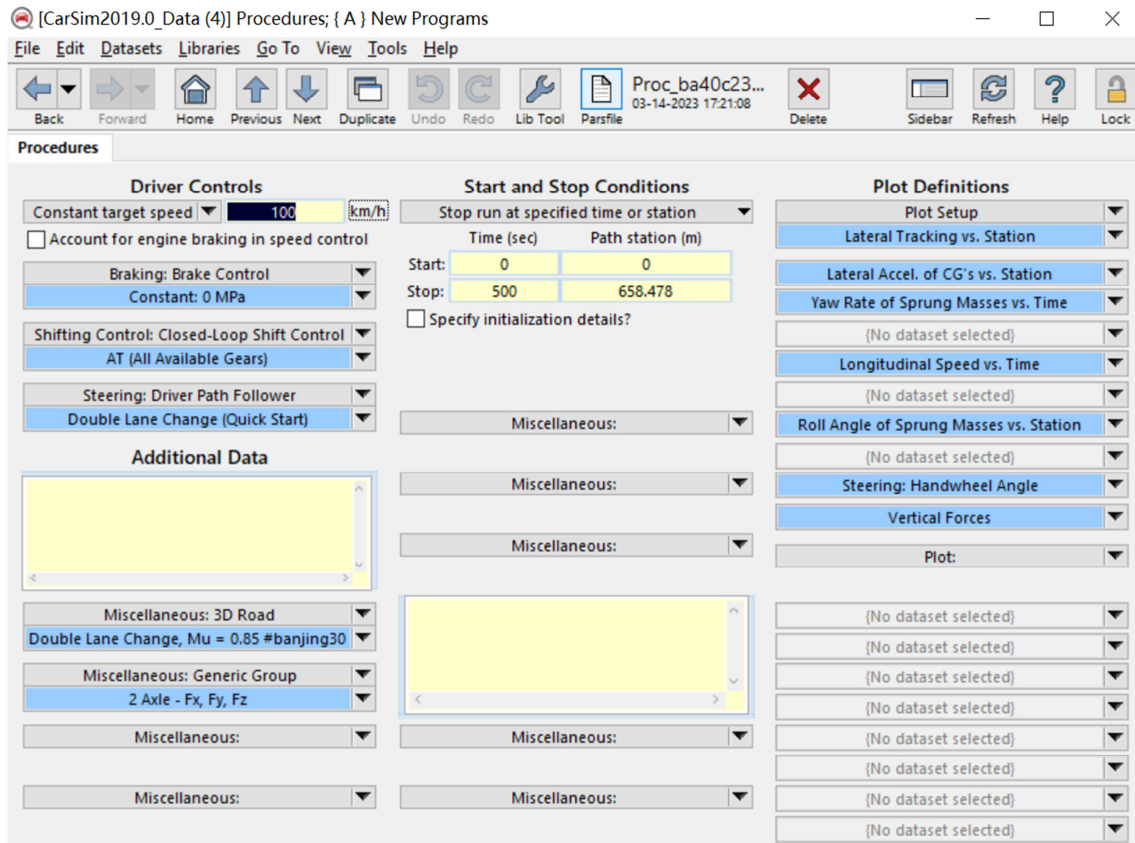
Carsim interface has three major components.

- 1) Graphical database: It contains the database related to the whole vehicle, working conditions, etc.
- 2) The main runtime program: it can simulate with software, etc., and can also support solution.
- 3) Output and post-processing: the simulation curves and other solutions are used to confirm the specific results.

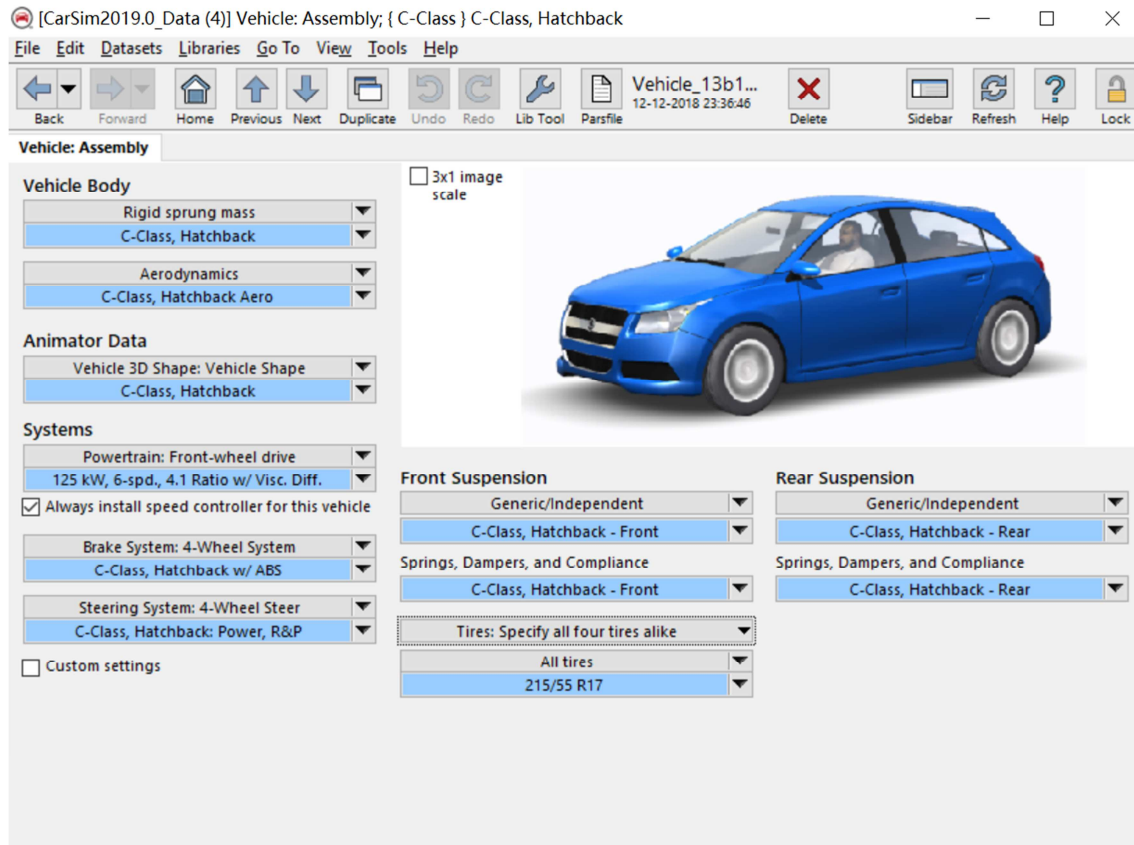
Carsim can combine model parameters in addition to the built-in model, as detailed in Figure 1 to confirm the specific main interface, and can also support the setting of data [3].



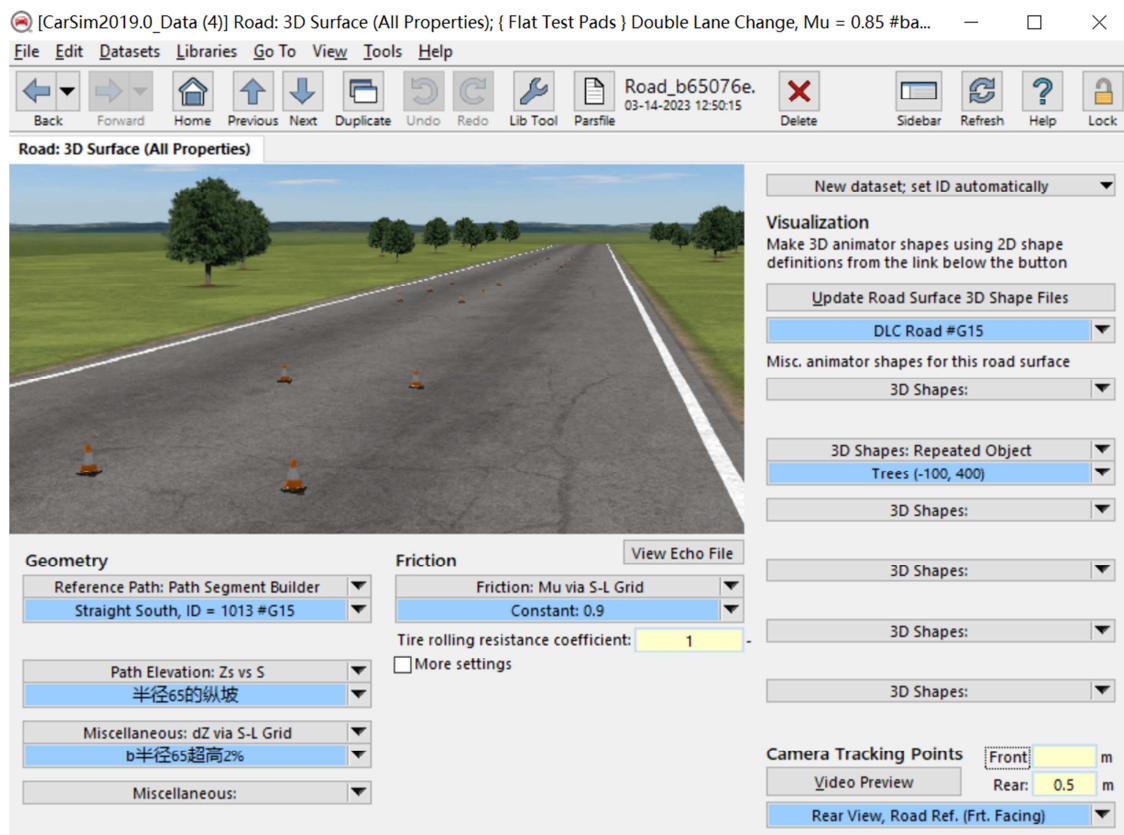
(a) Main Interface



(b) Driver model



(c) Vehicle model



(d) Road model

Figure 1. CarSim Simulation Interface.

3. Carsim Simulation Solution Design

3.1. Road Simulation Model

Carsim software can build a 3D model of the road based on the actual research needs and the obtained parameter information, in addition, it has a high consistency between the constructed model and the actual situation, and can also choose different road friction coefficients according to the different experimental needs. In the Additional Data module of Carsim software, 3D Road is selected to build the road simulation model [4-6].

The simulation in this paper is mainly for a specific highway exit ramp section, according to the relevant specifications of road linear setting, the basic components of the curve are straight section, upstream gentle curve section, circular curve section, downstream gentle curve section and straight section, and the length ratio of upstream gentle curve section: circular curve section: downstream gentle curve section is between 1 : 1: 1 and 1: 2: 1, and the ratio selected for this test is 1: 1.5: 1 The circular curve section is 45°, and the road simulation model is constructed, as shown in Figure 2.

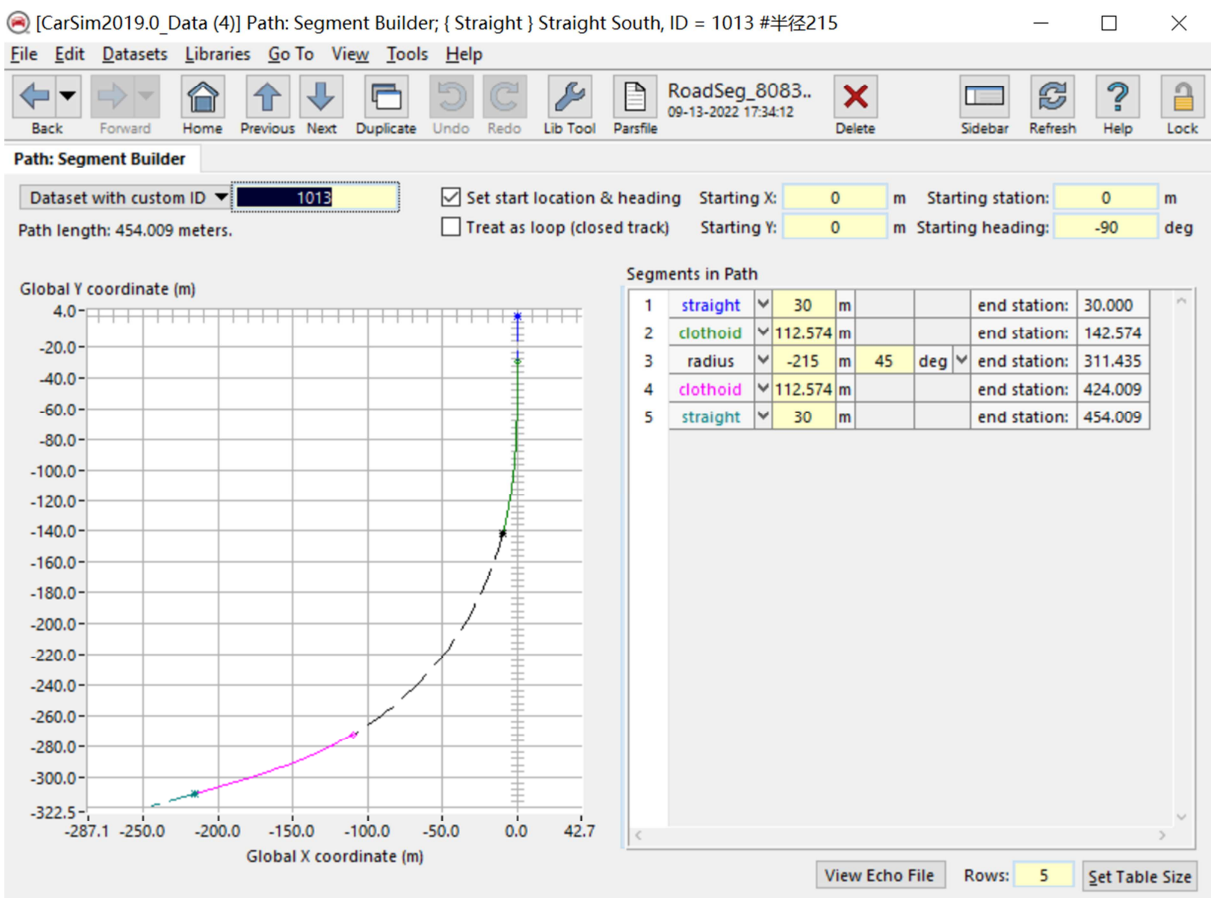


Figure 2. Carsim road simulation model (for a road section with a circular curve radius of 215m).

3.1.1. Planar Line

In the Path Segment Builder module, enter the corresponding alignment and parameter values to obtain the road plane alignment, the road length according to the corresponding radius length of the circle curve, the simulation test selected circle curve radius of 15m, 65m, 115m, 165m, 215m.

3.1.2. Longitudinal Section Alignment

After completing the calculation of the longitudinal slope data, the road elevation is input into the Path Elevation module to obtain the longitudinal section alignment of the road model, and the longitudinal slope selected for this simulation test is a

fixed value of 2%, as shown in Figure 3.

3.1.3. Cross-Sectional Alignment

The relative height difference of each feature point of the pavement width is input into the Off-Path Elevation module [7]. In this paper, the pavement width of the highway exit ramp is set to 3.75m when the study is conducted, and three pavement width points, 1.875m on the left side of the road median, the center of the road and 1.875m on the right side of the road median, are used to determine the cross-sectional alignment to complete the superelevation setting. Work, super high for 2%, 4%, 6%, 8%, 10%, such as Figure 4.

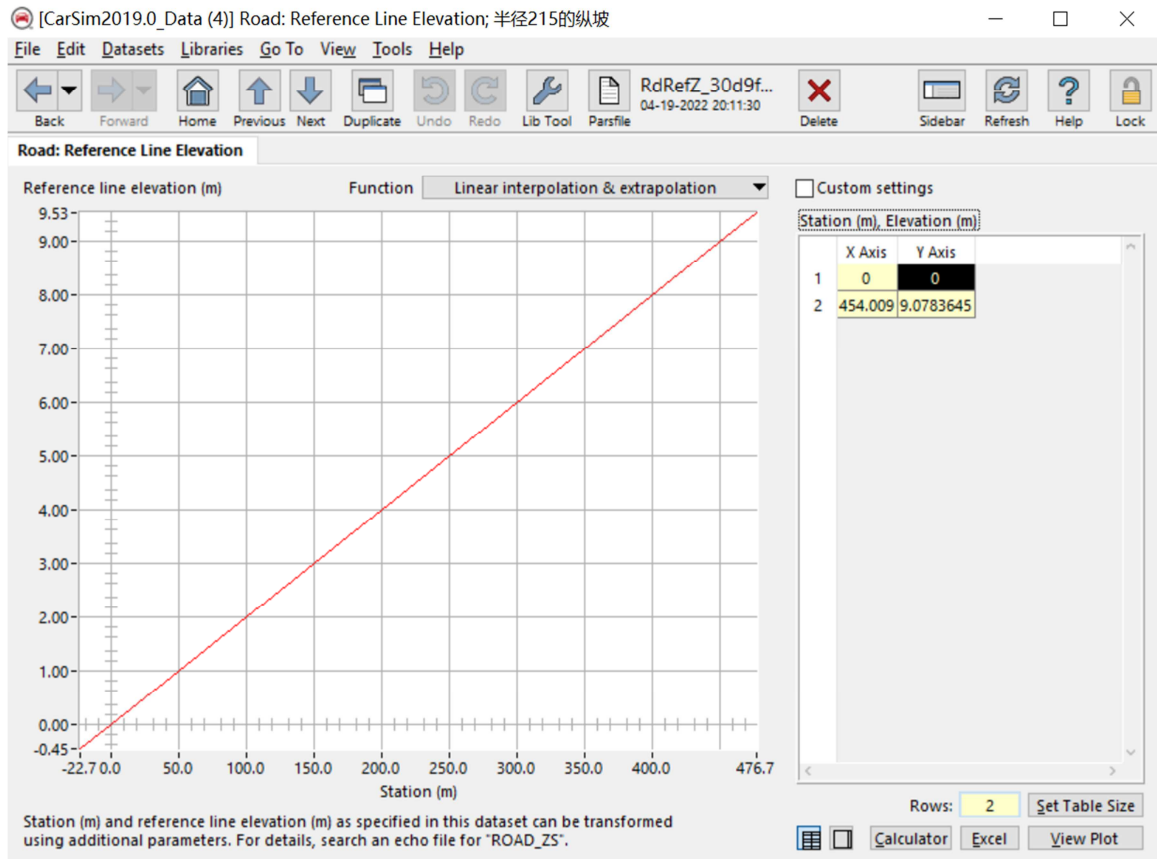


Figure 3. Carsim longitudinal section alignment (for example, the longitudinal slope of a section with a circular curve radius of 215m).

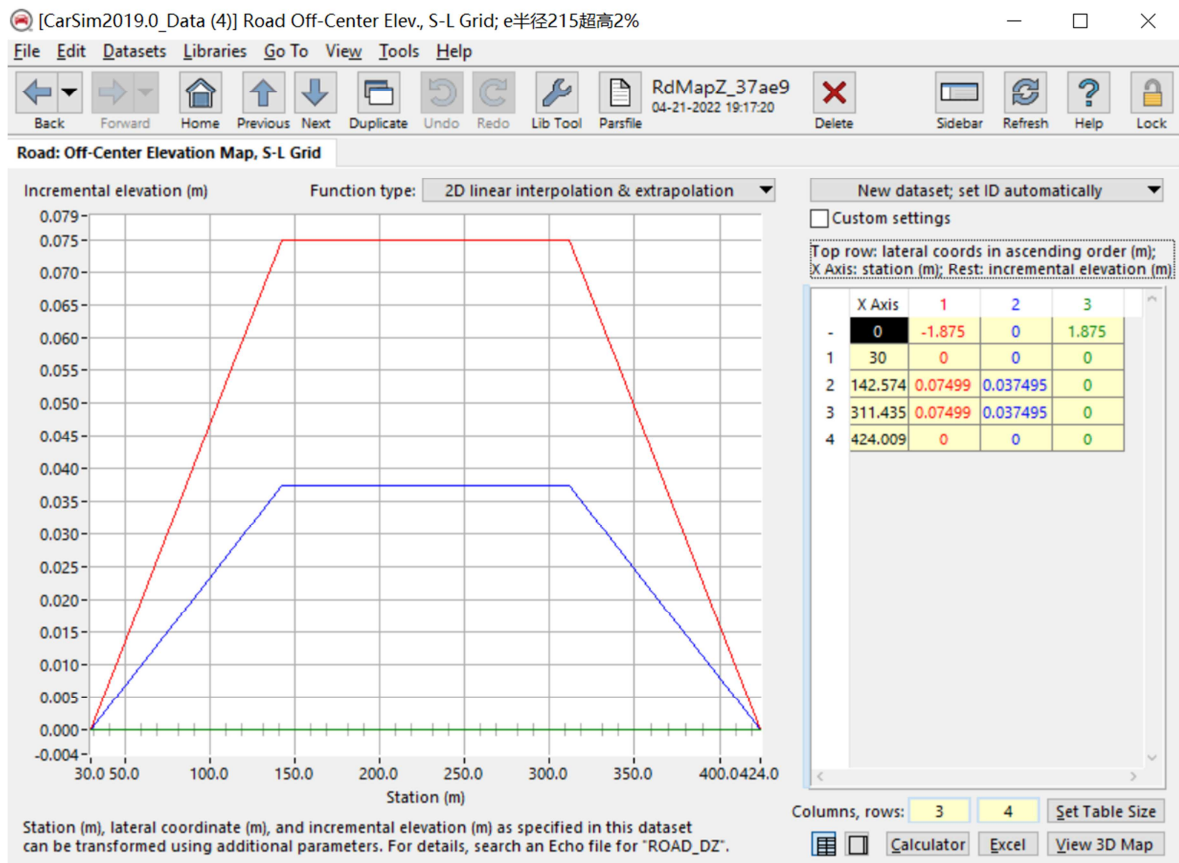


Figure 4. Carsim cross-sectional alignment (for example, a section with a circular curve radius of 215m and 2% superelevation).

3.1.4. Friction Coefficient of Road Surface

In Carsim software, the friction coefficient of pavement is divided into two types [8-9]: variable setting and constant setting, which can be freely selected based on the actual

weather conditions at the time of the accident, and the friction coefficients selected for this simulation test are 0.1, 0.3, 0.5, 0.7 and 0.9.

3.2. Summary of Simulation Solutions

Table 1. Carsim Simulation Solution Statistics.

Radius of circular curve (m)	Friction coefficient	Ultra High (%)	Traveling speed (km/h)	Number of programs (groups)
15	0.1, 0.3, 0.5, 0.7, 0.9	2, 4, 6, 8, 10	10, 25, 40, 55, 70	125
65	0.1, 0.3, 0.5, 0.7, 0.9	2, 4, 6, 8, 10	10, 25, 40, 55, 70	125
115	0.1, 0.3, 0.5, 0.7, 0.9	2, 4, 6, 8, 10	10, 25, 40, 55, 70	125
165	0.1, 0.3, 0.5, 0.7, 0.9	2, 4, 6, 8, 10	10, 25, 40, 55, 70	125
215	0.1, 0.3, 0.5, 0.7, 0.9	2, 4, 6, 8, 10	10, 25, 40, 55, 70	125

Considering the four factors affecting the driving stability of the exit ramp section of the highway: radius of circular curve, friction coefficient, super high and driving speed, there are 625 groups of simulation schemes for small cars, as shown in Table 1, and model simulation runs are established according to the relevant parameters.

4. Test Index Determination

4.1. Sideslip Risk Test Indicators

Vehicle sideslip is a common phenomenon in the exit ramp section of highway, the vehicle is affected by the radius of road circular curve, longitudinal slope change, road friction coefficient, through correlation analysis, the vehicle is influenced by the road friction coefficient. According to the existing research, the lateral offset and lateral acceleration can characterize the driving stability of the vehicle. According to the national standard, usually, the lateral acceleration of ordinary small cars cannot exceed 0.4g (g is the acceleration of gravity) [10]; the lateral acceleration of large trucks cannot exceed 0.3g, and the relevant evaluation index of sideslip can be obtained through simulation. The lateral offset of the vehicle's path, the driving process can be expressed through the trajectory deviation, assuming that in the process of vehicle driving, its driving according to the center line, the deviation between its driving trajectory and the center line trajectory during the turn should be less than 0.3m [11].

4.2. Rollover Risk Test Indicators

In quantifying the evaluation index of vehicle rollover, the vehicle lateral load deflection rate (LTR) is the key index to assess whether the vehicle is in rollover state, in the process of vehicle driving the vertical load on the tires will be transferred in its inner and outer side which can reflect whether the vehicle is balanced, and then determine the safety of vehicle driving [12].

LTR represents the ratio of the force difference between the left and right side wheels of the vehicle, the relevant formula is as follows (1) [13]:

$$LTR = \frac{\left| \sum_{i=1}^n (F_{li} - F_{ri}) \right|}{\sum_{i=1}^n (F_{li} + F_{ri})} \quad (1)$$

Where:

Fli-vertical load on the left wheel of the vehicle, N;

Fri-vertical load on the right-hand wheel of the vehicle, N;

i-position of the axle;

n-Total number of axles.

According to the definition of LTR content when its value is 0 on behalf of the wheel does not exist transfer load, when the vehicle stability is good, if its value is 1, it represents the wheel load completely transfer, when the vehicle is extremely dangerous, so the smaller the value of the indicator, the better the safety of the representative vehicle. But the above two cases are the limit state, in general the indicator takes the value in 0 ~ 1 range, when its value is less than 0.6 when the vehicle security is considered better, based on the above, the final determination of its relevant evaluation criteria as Table 2 [14-15]:

Table 2. Tire load deflection rate evaluation criteria.

Evaluation Standards	Excellent	Good	Medium	bad
Tire load deflection rate	<0.2	0.2~0.4	0.4~0.6	>0.6

5. Carsim Safe Speed Analysis

Use Origin software to find the intersection of the lateral offset of the car and the safety threshold value of 0.3m under various working conditions, which can be called the safety threshold speed with the lateral offset as the standard; find the intersection of the lateral acceleration of the car and the safety threshold value of 0.4g under various working conditions in the same way, which can be called the safety threshold speed with the lateral acceleration as the standard. Under the same working condition, compare the two safety critical speed, the smaller value is the safety critical speed of the car driving under the working condition.

Since there are too few safety situations when the radius of the circular curve is 20m for the analysis of the critical value of the safe speed, only the situations when the radius of the circular curve is greater than 20m are analyzed.

When the friction coefficient is 0.1 and 0.3, the friction coefficient increases and the critical value of car safe speed increases; when the friction coefficient is 0.5, 0.7 and 0.9, the friction coefficient increases and the critical value of car safe

speed tends to be flat, and the car safe speed at this time is less affected by the friction coefficient.

In other conditions, the radius of the circle curve increases, the car safety speed critical value also increases; but super high increase, the car safety speed critical value instead of decreasing.

Since the influence of slope is not obvious, the influence of slope on the critical value of safe speed of car driving is not considered for the time being. The relationship between the critical value of safe speed of car driving v_{csc} and the radius of circular curve r and friction coefficient μ is obtained by MATLAB fitting as equation (2):

$$v_{csc} = a[1 - (1 - br)^c] \quad (2)$$

where:

v -the velocity;

r -the radius of the flat curve;

a , b and c -the fitting parameters, which are related to the friction coefficient as in Table 3:

Table 3. Relationship between a , b , c and friction coefficient.

Friction coefficient μ	a	$b \times 103$	c	R^2
0.1	19.77	1.04	-20.26	0.65
0.3	161.57	13.68	-0.54	0.90
0.5	172.46	7.16	-0.97	0.99
0.7	163.99	6.73	-1.10	0.99
0.9	161.42	6.40	-1.17	0.94

6. Conclusion

Through Carsim simulation software to simulate the exit ramp section of the highway, the driving stability of small cars on the exit ramp section is studied, and the driving lateral offset, lateral acceleration and tire load offset rate of small cars are analyzed under the conditions of different radii of circular curve, super high, and friction coefficient, and the relationship model between the critical value of safe driving of small cars on the exit ramp section of the highway and the radius of circular curve and super high is established.

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