Test and Analysis of Characteristics of Safe Driving Speed on Typical Ice-snow Road

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Abstract. When a motor vehicle driver encounters ice-snow road on low-grade road, it is easy to cause traffic incidents or even accidents because it is difficult to autonomously control the safe speed, which is a hot and difficult problem in the cold areas of northern China; At present, there is little research on the characteristics of safe driving speed on different types of ice-snow roads at home and abroad. In this paper, six types of typical ice-snow roads, such as fresh snow, snowboards, semi-melted snowboards, ice boards, semi-melted snowboards, and "black ice" (snow-covered ice), were constructed to test the safe driving speed and its corresponding main factors, and the data was processed to explore the safe driving speed on different types of ice-snow roads and its relationship with the main influencing factors; this study has practical significance for guiding drivers to autonomously control safe vehicle speed on ice-snow road, and also provides reference for the development of intelligent transportation technologies such as speed guidance, dynamic speed limit and autonomous driving.

1. Introduction

The mileage of highway of grade 3 and below accounts for 87% of the total mileage of highway in the cold regions of northern China [1], Low-grade highway plays an important role in promoting regional and even national economic development. However, low-grade highway has been covered with ice and snow for 3 to 4 months due to insufficient ice-snow road removal capacity, when a motor vehicle driver encounters road with ice and snow in low-grade road, it is easy to cause traffic incidents or even accidents because it is difficult to autonomously control the safe speed. It is a hot and difficult problem in the cold areas of northern China.

At present, laws and regulations or even technical standards of domestic and foreign do not yet have provisions for safe speed on different types of ice-snow roads. In related literature, in terms of safe speed on ice-snow road, F y Sun and C l Yan [2] derived the formula for calculating the safe speed of ice-snow road based on formula of stopping sight distance, J p Liu [3] used ADAMS/Car simulation software to build a simulation platform, found out the safe vehicle speed under the extreme conditions of driving on ice and snow; on the aspect of the main influencing factors of safe speed on ice-snow road, Wallman and Åström [4], Tokunaga and et al [5] and J p Liu [3] obtained the range values of the adhesion coefficients of different types of ice-snow roads through real vehicle tests; At present, there is a lack of research on the relationship between the speed of safe driving on different types of ice-snow roads and their main influencing factors.

In summary, existing studies on safe driving speed on ice-snow road were based on road adhesion coefficients, and were studied through theoretical calculations or simulation analysis, and adhesion coefficient measured for the typical ice-snow road is mostly a same range, this made it impossible to...
uniquely determine the safe driving speed value of the same type of ice-snow road. Therefore, this paper is based on the theory of safe driving characteristics of speed on ice-snow road, and will construct six types of typical ice-snow roads to test the data of characteristic of safe driving speed. After numerical fitting and analysis of the characteristics of safe driving speed on ice-snow road, to explore the safe driving speed of different types of ice-snow roads and their relationship with the main influencing factors, and provides theoretical support for solving hot and difficult problems in the cold regions of northern China.

2. Basic Analysis of Characteristics of Safe Driving Speed

Under normal road environment, a driver is able to maintain the maximum speed allowed for safe driving under the influence of factors such as highway grade, vehicle stability, and driver handling capability, which is called Safe speed [6]. Under the conditions of ice-snow road, a driver is able to maintain the maximum speed allowed for safe driving under the influence of factors such as the type of ice-snow roads, vehicle stability, and driver handling capability, which is called the safe driving speed on ice-snow road by this paper. Speeds of safe driving on different types of ice-snow roads and their relationship with the main influencing factors, it is called the characteristics of safe driving speed on ice and snow by this article. The characteristics of speed of safe driving on ice-snow road are used to describe the feasible speed values that the current ice-snow road can provide to vehicles when driving on ice-snow road, and their relationship with the main influencing factors, to reveal the mechanism of safe driving speed for different types of ice-snow roads.

It can be known from the concept of safe driving speed on ice-snow road, safe driving speed on ice-snow road is related to ice-snow road types, vehicle stability, and driver handling capability. The different types of ice-snow roads will directly affect the stability of the vehicle and the driver handling capability, which will make the speed values of safe driving on ice-snow roads different in turn. Therefore, the magnitude of safe driving speed on ice-snow road is mainly determined by the state of ice-snow roads. The road adhesion coefficient can directly reflect the anti-sliding performance of ice-snow road, it can be known that the adhesion coefficient corresponding to an ice-snow road in one state is unique, and also determines that an ice-snow road state will generate a safe driving speed value. This article uses a positive integer $i$ to represent different types of ice-snow roads, Assumes safe driving speed on ice and snow is $v_i$, Adhesion coefficient is $\mu_i$, The following relationship exists between the safe driving speed and the adhesion coefficient:

$$v_i = f(\mu_i) \quad (1)$$

Through the above analysis, speed values of different types of ice-snow roads for safe driving, their main influencing factors (adhesion coefficient), and the relationship between them can directly reflect the characteristics of speed of ice-snow road for safe driving. This characteristic study can effectively guide the driver to autonomously control the safe speed on the ice-snow road, and avoid or reduce the occurrence of traffic incidents or even traffic accidents. This article will test and analyse the safe driving characteristics of speed of six types of typical ice-snow roads, such as fresh snow, snowboard, semi-melted snowboard, ice board, semi-melted snowboard, and "black ice", to explore the safe driving speed and its relationship with the main influencing factors.

3. Test of Characteristic Data of Safe Driving Speed

3.1. Principles of Test Design

Six types of typical ice-snow roads safe driving speed values and adhesion coefficients need to be obtained. In this research, the above typical ice-snow roads will be construct and the characteristics of safe driving speed be tested. In the process of testing, the driver controls the vehicle to perform emergency braking on ice-snow road at the initial speeds increased by equal steps, the safe driving speed on ice-snow road are determined when the wheel lock time exceeds the threshold, and the adhesion coefficient of the ice-snow road are determined by the deceleration of the vehicle obtained during braking. In the cold area of northern China, the winter is cold and dry. Therefore, the
construction of a typical ice-snow road can ignore the slight influence of external temperature and humidity on the road state. During each test process, artificial repair of fresh snow and "black ice" roads required, artificial watering of semi-melted snow board and semi-melted ice board road is performed in time to ensure the repeatability of the same type of road test; During the entire test process, the vehicle and driver are required to be the same at all times, so the effects of different types of tires, quality, and driver's physiology and psychology on the test can be ignored to ensure the accuracy of the test results.

3.2. Method for Testing Characteristics of Safe Driving Speed

3.2.1 Test method for safe driving speed

Driver encounters a dangerous situation on the road ahead when the vehicle is driving at a certain speed on the ice-snow road, the emergency braking measures are generally taken. The vehicle equipped with ABS system will still slip or side slip due to the small road adhesion coefficient, or even lose control of the vehicle such as tail-flick when the driving speed exceeds the safe driving speed, it is likely to cause a traffic incident or even a traffic accident, because the current vehicle is in danger. According to the principle that the front wheels must be locked before the rear wheels during the design process, when the front wheels are locked, the vehicle is considered to be in a dangerous state. FMVSS 135 believes that when the wheel is continuously locked for more than 0.1s, the wheel is locked, and the ISO and standards set by the United Kingdom, the Netherlands, Germany, and Japan all use 0.5s as the threshold. when the wheel lock duration exceeds 0.5s, the vehicle is considered to be in the lock state during the emergency braking process of the vehicle by analyzing the above wheel lock criteria, therefore, in this paper, the safe driving speed on ice-snow roads is detected by this principle.

Through analysis, it can be known that when the time of wheel lock during the emergency braking process of the vehicle exceeds 0.5s, the wheel is locked at this time, that is, the vehicle is in a dangerous state. Therefore, the safe driving speed of all types of ice-snow roads will be detected by this principle.

3.2.2 Measurement method of road adhesion coefficient

The vehicle always maintains the maximum deceleration during braking, so the vehicle's maximum braking deceleration can intuitively reflect the anti-skid performance of the road surface. Therefore, the adhesion coefficient can be obtained by combining Newton's second law and the balance equation between the vehicle braking force and the frictional the road surface and the tire:

$$\mu = \frac{a}{g}$$

3.3. Construction of The Test Site

The characteristics of safe driving speed on ice-snow road would be tested on campus. Considering the total length of the road section is 100m, the test site is designed as follows. This test limited the maximum vehicle speed to 40km/h [7], the theoretical acceleration of the test vehicle is 2.35m / s², and the distance required for the vehicle to accelerate to 40km/h on a dry road is 26.27m, and the length of the vehicle and the actual situation were considered, so the acceleration distance would be set to 40m; The speed of the vehicle would change due to the vibration of the vehicle body when the vehicle is driving on an ice-snow road, so the length of the buffer section is set to 10m to ensure the vehicle can maintain the predetermined speed value when it reaches the braking position; The braking distance is 42m when the initial braking speed of the vehicle is 40km/h and the road adhesion coefficient is 0.15; the safe driving speed is far less than 40km/h under the condition of low adhesion coefficient road surface in the actual test process, so the braking distance is set to 50m. The test site and test point locations are selected as shown in Figure 1.
3.4. Test Steps
As the figure 1 shows, the test vehicle is equipped with one driver and one recorder, the driver controls the vehicle to accelerate on the acceleration road and reach a predetermined speed value, and maintains the vehicle speed on the buffer section until the brake point is reached. The instantaneous speed value of the vehicle passing the point would be measured by the person at point B with a radar speedometer, to as the initial speed of the vehicle brake Value, at this moment ,the driver takes emergency braking measures and feels the vehicle ABS start situation; The person at point A follows the vehicle closely, and observes the front wheel lock status and records the wheel lock time; The recorder uses the computer to save the braking deceleration data collected by the accelerometer after the vehicle is completely stopped. Tests need to be performed intensively around this critical speed value to ensure that an accurate safe driving speed value is found when the vehicle's braking time exceeds 0.5s during the braking process.

3.5. Test Data and Preliminary Processing

3.5.1 Safe driving speed. In this paper, various types of ice-snow roads were tested for safe driving speeds. Relevant test data for various types of ice-snow roads has been obtained after discrete data were discarded and sorted. Taking the data of the fresh snow road as an example, the relevant data of the safe driving speed test of fresh snow road is shown in Table 1.

### Table 1. Test data on fresh snow road

| Number | Speed (km/h) | Situation of ABS | Wheel lock time(s) | Number of brake | Speed (km/h) | Situation of ABS | Wheel lock time(s) | Wheel lock |
|--------|--------------|------------------|-------------------|----------------|--------------|------------------|-------------------|-------------|
| 1      | 12           | ×                | 0.00              | ×              | 14           | 31               | √                 | 0.28        | ×           |
| 2      | 13           | ×                | 0.00              | ×              | 15           | 31               | √                 | 0.31        | ×           |
| 3      | 15           | ×                | 0.00              | ×              | 16           | 32               | √                 | 0.28        | ×           |
| 4      | 17           | ×                | 0.00              | ×              | 17           | 33               | √                 | 0.39        | ×           |
| 5      | 20           | √                | 0.00              | ×              | 18           | 33               | √                 | 0.41        | ×           |
| 6      | 23           | √                | 0.00              | ×              | 19           | 33               | √                 | 0.37        | ×           |
| 7      | 25           | √                | 0.00              | ×              | 20           | 34               | √                 | 0.49        | ×           |
| 8      | 26           | √                | 0.00              | ×              | 21           | 34               | √                 | 0.64        | √           |
| 9      | 27           | √                | 0.00              | ×              | 22           | 34               | √                 | 0.45        | ×           |
| 10     | 28           | √                | 0.00              | ×              | 23           | 34               | √                 | 0.59        | √           |
| 11     | 29           | √                | 0.00              | ×              | 24           | 34               | √                 | 0.62        | √           |
| 12     | 30           | √                | 0.21              | ×              | 25           | 35               | √                 | 0.81        | √           |
| 13     | 30           | √                | 0.19              | ×              | 26           | 35               | √                 | 0.87        | √           |
It can be found that during the speed test of safe driving on the new snow road through analysis. The vehicle ABS system started when the vehicle speed was 20km/h; the lock time of the wheels floats around 0.5s when the vehicle speed was 34km/h. In order to eliminate the interference of adverse factors in the test process, a centralized test is performed near the vehicle speed value. Three emergency braking tests were performed on the vehicle at an initial speed of 33km/h to ensure that the wheels was not locked when the vehicle was emergency braked at this speed value; five emergency braking tests were performed on the vehicle at an initial speed of 34km/h to ensure that the wheels was locked when the vehicle was emergency braked at this speed value; the time of wheel was lock far exceeds the threshold when the vehicle is emergency braking at an initial speed of 35km/h. Finally, the safe driving speed of the fresh snow road is 33km/h. The data of other types of ice-snow road are similarly processed. The obtained safe driving speed values of various types of ice-snow roads are shown in Table 2.

Table 2. Speed value of safe driving under different road conditions (km/h)

| Index       | Fresh snow | Snowboard | Semi melted Snowboard | Ice board | Semi melted ice board | "Black Ice" |
|-------------|------------|-----------|-----------------------|-----------|-----------------------|-------------|
| Safe driving speed | 33         | 21        | 27                    | 17        | 16                    | 18          |

3.5.2 Adhesion coefficient. During the determination of the road adhesion coefficient, the data collected by the accelerometer are regarded as valid only when the vehicle does not slip. Modern vehicles have ABS systems, three types of data for ABS started and no slippage were selected for various types of ice-snow road, the adhesion coefficient value obtained of ice-snow road were processed and averaged to ensure the adhesion coefficient of ice-snow road was correct. Taking fresh snow road as an example, the raw data image and smoothed image were drawn as shown in Figures 2 and 3, respectively.

The maximum deceleration duration of the vehicle during braking is short, because the initial speed is small. The stable deceleration value remains at -4m/s² as can be seen from Figure 3. It can be obtained that the adhesion coefficient of the fresh snow road is 0.41 According to formula (1). Similarly. The adhesion coefficients of various types of ice-snow roads can be obtained, as shown in Table 3.

Figure 2. Changes in raw acceleration

Figure 3. Changes in acceleration after filtering
Table 3. Coefficient of adhesion of different ice-snow roads

| Index            | Fresh snow | Snowboard | Semi melted Snowboard | Ice board | Semi melted ice board | "Black Ice" |
|------------------|------------|-----------|-----------------------|-----------|-----------------------|-------------|
| Adhesion coefficient | 0.41       | 0.17      | 0.35                  | 0.12      | 0.11                  | 0.13        |

4. Test Data Fitting and Analysis of Characteristics of Safe Driving Speed on Ice-snow Roads

4.1. Fitting of Test Data
The safe driving speed value and road adhesion coefficient obtained above were fitted, and five common fitting functions were compared. Their correction values ($R^2$) were arranged from large to small: logarithmic function ($R^2=0.963$), linear functions ($R^2=0.962$), power functions ($R^2=0.959$), exponential functions ($R^2=0.952$) and quadratic functions ($R^2=0.950$). As shown in Figure 4. In general, the larger the correction value ($R^2$), the better the curve fitting degree, the logarithmic function is very close to the correction value ($R^2$) of the linear function. The changing law of the speed of the safe driving speed on ice-snow road could be reflected more intuitively by using a simpler linear. Therefore, the data was fitted by a linear function, and the relationship between the them can be obtained:

$$v = 50.38\mu + 11.17$$

(3)

Figure 4. The speed of safe driving is accompanied by changes in the coefficient

4.2. Analysis of Characteristics of Safe Driving Speed on Ice-snow Roads
The data of safe driving characteristics of speed of six types of typical ice-snow roads were fitted, the result shown that there is a linear function relationship between the safe driving speed values on ice-snow road and their main influencing factors (adhesion coefficient), the value of speed decreases with the decrease of the adhesion coefficient. We conducted research on the characteristics of safe driving speed on different types of ice-snow roads, based on the premise that the same vehicle and the same driver have a fixed adhesion coefficient on typical ice-snow roads, so it is necessary to analyse how the road adhesion coefficient and the safe driving speed value are affected by other factors.

The temperature and humidity of the surface will have a greater impact on the adhesion coefficient of ice-snow road. The ice and snow particles on the surface of ice-snow road will slightly melt when the temperature and humidity increases, especially under the combined effect of vehicle loads, the adhesion coefficient of ice-snow road greatly reduces and the speed of safe driving drops; the stability
of the vehicle is mainly related to the road condition, the type and quality of the vehicle tires when a vehicle is driven on an ice or snow road. The braking performance of the vehicle would decrease when the road adhesion coefficient decreases. The amount of friction between the rubber tire and the ice-snow road surface increases as the contact area increases. Therefore, the fewer the number of tire patterns and grooves, the worse the braking performance of the vehicle. For vehicles of different masses with the same tire pattern and groove, the vertical load of the tire on the ice-snow road surface increases when the vehicle mass increases, and the friction between the two increases non-proportionally, the increase is faster in the early stage and smaller in the later stage. However, it is actually the process of converting the kinetic energy into thermal energy by the friction between the tire and the ice-snow road in the process of braking and stopping the vehicle, obviously, the increase in mass to kinetic energy is much greater than the increase in frictional kinetic energy, therefore the greater the mass of the vehicle, the longer the braking distance required; Driver handling capability is different when the physical and psychological characteristics of different drivers are affected by the same ice-snow road environment. The safe driving speed would be decreased when the driver responds slowly and operates slowly. Therefore, the safe driving speed value would be smaller when the adhesion coefficient of road is lower, the number of tire patterns and grooves is smaller, the mass of the vehicle is greater, the driver handling capability is lower.

5. Epilogues
Based on the safe speed, the concept of safe driving speed on ice-snow road is proposed. Based on above, the theory of safe driving characteristics of speed on ice-snow road is proposed to analyse the safe driving speed of different types of ice-snow roads and the relationship between the main driving factors and the safety characteristics, which provided theoretical guidance for testing the characteristics of safe driving speed on ice-snow road; a method for testing safe driving speed on ice-snow road is proposed, and combined the existing road adhesion coefficient measurement methods, the safety driving speed values and adhesion coefficients on six types of typical ice-snow roads were obtain; The data were fitted and the characteristics of safe driving of speed on ice-snow road were analysed, which shown that the speed value of safe driving on ice-snow road is linearly related to the road adhesion coefficient, the safe driving speed value would be smaller when the road adhesion coefficient is lower, the number of tire patterns and grooves is smaller, the quality of vehicle is greater and the driver handling capability is lower. This study can be used to guide drivers to autonomously drive safe speeds on ice-snow road and also promoted the development of intelligent speed guidance and speed limit and intelligent transportation system technologies and driverless cars on ice-snow road.

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7. References
[1] National Bureau of statistics of the people's Republic of China, statistical yearbook [DB] http://www.stats.gov.cn/
[2] Sun Fengying and Yan Chunli 2010 Analysis of Driving Speed and Safety Hazards on Ice and Snow Road in Winter J. Forest engineering. 03 44-45
[3] Liu Jianping 2016 Study on Traffic Safety of Baihua Section of Beijing-Canada Highway under Conditions of Ice and Snow D. (Harbin City: Northeast Forestry University)
[4] C G Wallman and H Åström 2001 Friction measurement methods and the correlation between road f-riction and traffic safety J. Vti Meddelanden. 3 367-377
[5] R A Tokunaga M Funahashi N Takahashi and et al 2008 A Feasibility Study on Friction for Winter Road Management J. Transportation Research E-Circular. 352
[6] Tu Huizhao , Mou Tao , Bi Yufeng and et al 2015 Freeway Safety Evaluation Method Based on Safety Speed Analysis J. Inner Mongolia Highway and Transportation. 6 1-7
[7] Adila Parhat 2019 Safety Driving Speed Test and Analysis of Semi-melted Road Surface With Snow D. (Urumqi: Xinjiang University)