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Study on the maximum longitudinal slope and slope length of construction access roads in mountainous areas

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Abstract

At present, the construction of highways in high mountainous areas is increasing, before the construction of bridges and tunnels in mountainous areas, the construction of right-of-way is an indispensable preparatory work, and the development of engineering construction programmes will rely heavily on the construction of right-of-way. In this paper, for the construction of domestic mountainous highway construction process of construction right-of-way index is low, poor quality of the status quo, this paper focuses on the study of mountainous areas of construction right-of-way maximum longitudinal slope and corresponding to the maximum length of the slope.

Keywords: highway, construction right-of-way, maximum longitudinal slope, maximum slope length, mountainous areas

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1. Introduction

At present, the construction of highways in China's mountainous areas is increasing, and before the construction of bridges and tunnels in mountainous areas, the construction of right-of-way is an indispensable preparatory work, and the development of engineering and construction programmes will rely heavily on the construction of right-of-way. Construction right-of-way index is low, poor quality, can not achieve the expected role, and may even cause engineering accidents endangering the safety of construction workers. In today's design specification system, there is no reasonable design specification for construction right-of-way in high mountainous areas. As a result, the construction of high mountainous area construction right-of-way construction, there will be random layout, poor technical indicators, high accident rate and other phenomena.

In this paper, by analysing the force analysis of dump trucks on the ramp and the actual driving conditions, we draw the speed and distance diagram, and then determine the value of the longitudinal section technical index of the construction roadway through the ‘permissible speed method’.

2. Construction road design vehicle climbing performance calculation

After investigation, most of the construction vehicles in the construction area are heavy-duty vehicles, of which dump trucks are the main models, so the whole thesis takes dump trucks as the design vehicles. This paper proposes to use the fully loaded 25T gross mass of China Heavy Duty Truck Golden Prince Heavy Truck 300 hp 5.6m dump truck as the leading model for the calculation of the flat longitudinal technical indexes of the construction right-of-way.

When calculating and formulating the maximum longitudinal slope, maximum slope length and other longitudinal section technical indexes of the road, the main design vehicle climbing performance is the most important factor affecting these technical indexes. According to the performance of the vehicle as well as the vehicle force analysis and kinematics research theory, calculate the vehicle in different gradient when the immediate running characteristics and draw the speed - distance curve diagram, through the speed - distance curve diagram can clearly see the vehicle in different longitudinal slope under the speed change characteristics. The basic parameters of different design vehicles are very different, and different mass to power ratio has a greater impact on the climbing performance of the vehicle, so the choice of the design vehicle has a great impact on the final longitudinal section technical indicators.

The force analysis of a loaded vehicle on a ramp is shown in Figure.1.

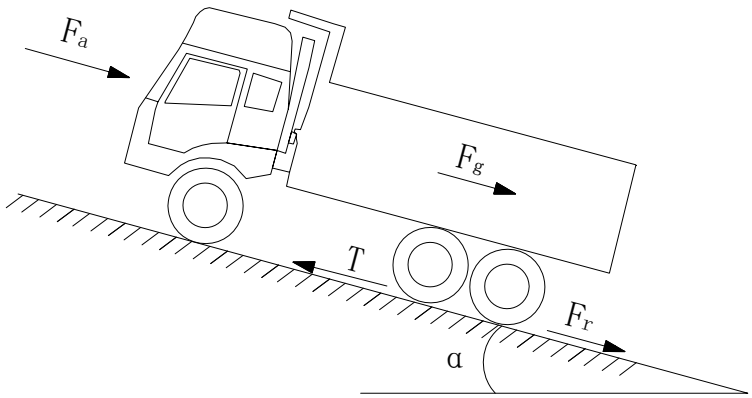

Fig. 1 Forces on a lorry on a longitudinal slope

According to Newton's theory of mechanical equilibrium, the equilibrium equations can be derived when travelling uphill:

$$F_v = \frac{W_v}{g} a_v = T - F_r - F_a - F_g \quad (1)$$

In the formula: F_v —The force required to drive a vehicle at speed v （N）；

W_v —Vehicle weight（N）；

g —The acceleration of gravity, taken as9.8m/s2；

a_v —Acceleration of vehicles（m/s2）；

T —Motive force（N）；

F_r —Rolling resistance（N）；

F_a —Air resistance（N）；

F_g —Slope resistance（N）。

The calculation of each parameter is as follows:

Rolling resistance F_r ,the relationship with vehicle speed is linear. The construction right-of-way is generally a newly constructed cement concrete pavement, so the pavement is in good condition. Slope resistance F_g ，After field investigation, many longitudinal slopes of the right-of-way at the construction site are higher than 20%, so the range of longitudinal slopes in this paper is 4% to 22%.

The distance travelled by the vehicle and the corresponding speed equation are calculated by the following equation:

$$s_n = \frac{V_n t}{3.6} + 0.5 a_v t \quad (2)$$

$$V_n = V_{n-1} + a_v t \quad (3)$$

In the formula: s_n —Distance travelled by vehicles（m）；

t —Time interval, which is assumed in the calculations in this paper to be1s；

V_{n-1} —This article refers to the speed of the first 1s（km/h）；

V_n —Speed at the current moment（km/h）。

Based on the above equation, the formula for the acceleration a_v can be derived as:

$$a_v = \frac{3600 \beta_1 P_e \eta_t}{m_v V_{n-1}} - \frac{g \beta_2 (c_1 + c_2 V_{n-1})}{1000} - \frac{K A V_{n-1}^2}{21.15 m_v} - g \sin\alpha \quad (4)$$

In the formula: m_v —Vehicle full load mass（kg）。

The formula for calculating the gradient climb of a vehicle has been listed above, and a graph of the vehicle's travelling characteristics can be drawn from the above formula. The chart can be used to study the maximum longitudinal slope that the vehicle can climb and the corresponding slope length under the premise of ensuring safety when the vehicle is travelling on a slope.

3. Allowable speed method to determine the maximum longitudinal slope

This paper develops the maximum longitudinal slope without limiting the length of the slope mainly to consider the climbing ability of the vehicle. Construction right-of-way has a fixed design vehicles, climbing performance can be based on the design of the vehicle climbing performance chart.

3.1 Allowable speed method research basis

Reference [1] can be obtained, in determining the speed of the vehicle entering the ramp, the average travelling speed in relation to the design speed, can be used as an approximate speed of the vehicle to start climbing.

In determining the maximum length of the slope, the method of determining the grade road is based on a study of the relationship between the accident rate and the average speed, which leads to the determination of an appropriate speed reduction factor. According to an American study [2], which investigated the relationship between road accident rates and speed distributions within a single state in the United States, speed discounts of 10km/h, 15km/h, 20km/h, and 30km/h were obtained, and the results are shown in the figure:

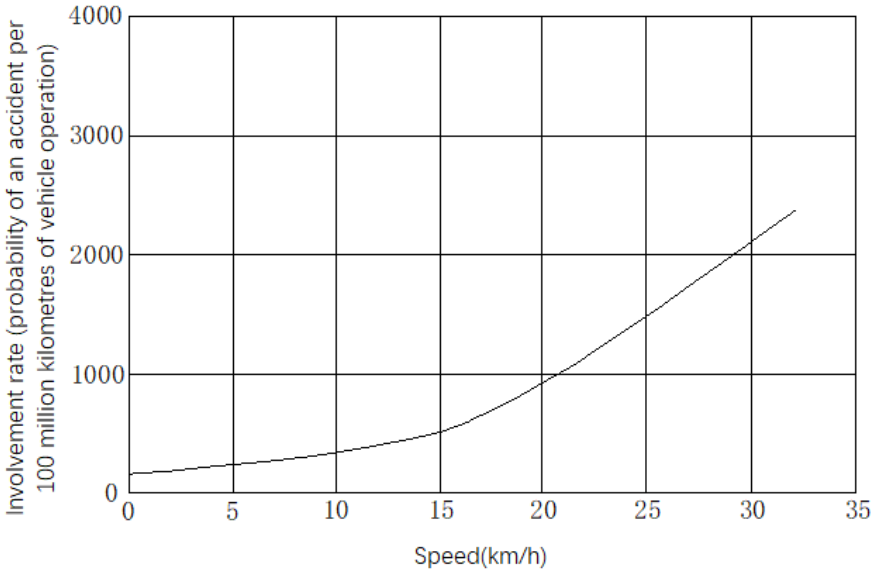

Figure 2 Accident rates for lorries travelling at speeds below the average speed of all vehicles

According to the study [3], the determination of the maximum slope length is generally based on the speed discount for a loaded vehicle speed below the average travelling speed. In determining the final speed discount, the initial speed discount is 25km/h, but according to the number of accidents statistics, but according to the statistics of the speed discount of 25km/h accident rate is the speed discount of 15km/h accident rate 2. 4 times, so nowadays to determine the critical slope length is recommended to use the speed discount of 15km/h[4]. This is the general design principle of determining the critical slope length using the speed reduction as a standard.

According to domestic and international experience, the permissible speed is related to the design speed of the road. When the design speed of the road is less than 60km/h, the allowable speed is 50% to 66% of the design speed[5]. The speed of construction right-of-way in high mountainous areas is lower, so the speed discount amount cannot refer to 15km/h of other grades of roads. Reference to the theoretical provisions in the 'Road Survey'[6]: Japan in determining the maximum longitudinal slope of the design of the vehicle's driving status has the following provisions: ordinary laden vehicles can be roughly half of the design speed at a constant speed uphill corresponding to the slope is set as the maximum longitudinal slope of the road.

Maximum longitudinal slope of the slope, ordinary load vehicles at the bottom of the slope with the highest speed to start uphill, to reach the top of the slope to maintain half of the design speed, the longitudinal slope at this time for the maximum longitudinal slope. So for the requirements of the permissible speed method, the design speed of the construction right-of-way is calculated corresponding to the permissible speed table:

Table 1
Allowable speed for right-of-way

Design speed（km/h）	20	15	10
Permissible speeds（km/h）	10	7	5

3.2 0km/h uphill characteristic diagrams

When a vehicle is travelling uphill at 0km/h, there is a limit to the permissible speed of a vehicle on a construction right-of-way with different design speeds, so the 0km/h speed distance diagram can also be used as a basis for determining the maximum longitudinal slope. According to the field investigation, there is a part of the vehicle, at the intersection of the local road and the construction right-of-way will stop or reduce the vehicle to a very low speed, and then make a turn into the construction right-of-way.

(1) Setting the control of parameters: dump truck is the design vehicle, the maximum power is taken 221kw, the value of longitudinal slope ranges from 8% to 18%, the rolling friction coefficient of the vehicle is taken 1.5, the coefficient of air resistance is taken 0.65, the windward area is taken 6.99m2, the vehicle travelling on the road is not subjected to any other conditions, the weather condition is good, there is no silt, precipitation and so on the road surface, and the drivers' field of vision is good.

(2) Calculate the data according to the formula (2), formula (3) and formula (4) derived from 1, and then draw a speed-distance graph with a starting speed of 0km/h through the EXCEL table drawing function.

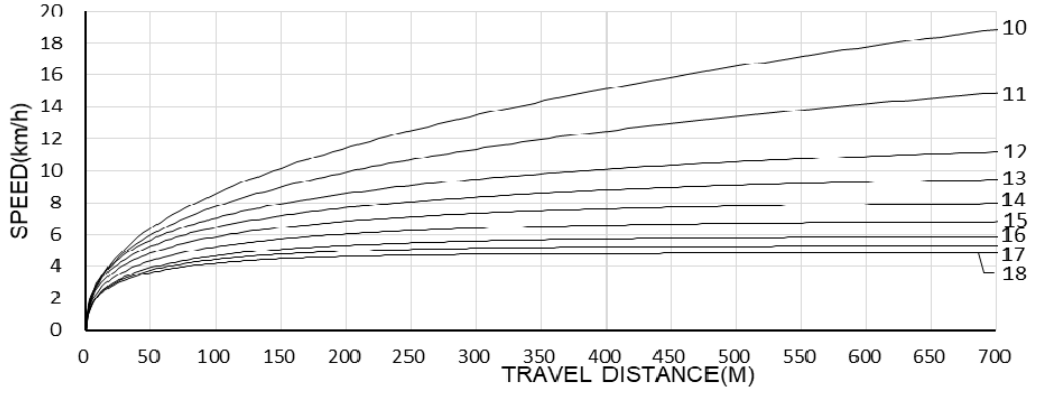

Fig. 3 Velocity-distance plot for a loaded vehicle travelling up a slope at a starting speed of 0km/h

3.3 Determination of maximum longitudinal slope

With reference to the above curve diagrams and tables, as well as the different permissible speeds corresponding to different design speeds, the maximum longitudinal slopes corresponding to different design speeds of the construction right-of-way can be derived:

Table 2
Maximum longitudinal slope of the right-of-way

Design speed（km/h）	20	15	10
Permissible speeds（km/h）	10	7	5
Maximum longitudinal slope（%）	13	15	18

4. Allowable speed method to determine the maximum slope length

The design speed is different, the vehicle starts to climb the slope speed will be different, the design speed were 10km / h, 15km / h, 20km / h. In different design speed on the vehicle speed will be different, but they are close to the construction of the roadway design speed, so this paper construction of the roadway ramp starting

speed selected construction roadway corresponding to the design speed.

4.1 Drawing speed-distance curve

According to the above theoretical provisions, and then through the analysis of 10km / h, 15km / h, 20km / h speed - distance curve that can be derived from the maximum longitudinal slope of the construction right-of-way. The specific drawing process is as follows:

(1) Setting parameter control: the design vehicle is a dump truck, the maximum power of 221kw, longitudinal slope of the value range of 7% to 22% (the initial speed of different corresponding to the longitudinal slope interval will change, discard the significance of the longitudinal slope), the rolling friction coefficient of the vehicle to take 1.5, the coefficient of air resistance to take 0.65, the windward area to take 6.99m2, the vehicle travels on the road is not restricted by other conditions, weather conditions are good, the road surface is good, the vehicle travels on the road without other conditions. restrictions, weather conditions are good, the road surface is free of silt, precipitation, etc., and the driver has a good field of vision.

(2) According to 4.1.2 the conclusion of the formula, and then through the EXCEL table drawing function to draw the starting speed were 10km / h, 15km / h, 20km / h speed distance graph, as follows Figure 4 ~ 6.

(3) The horizontal coordinate in the icon represents the distance travelled by the vehicle, the vertical coordinate represents the speed travelled by the vehicle, and the number marked in the end is the longitudinal slope corresponding to the line.

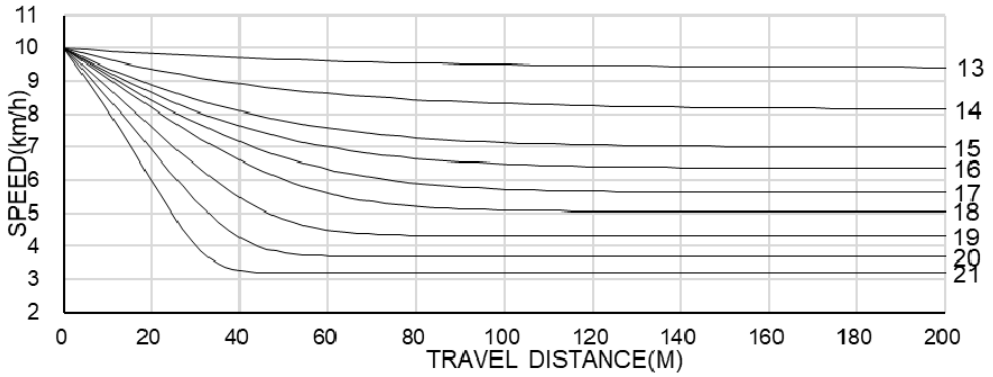

Fig. 4 Velocity-distance plot for a loaded vehicle travelling uphill at a starting speed of 10km/h

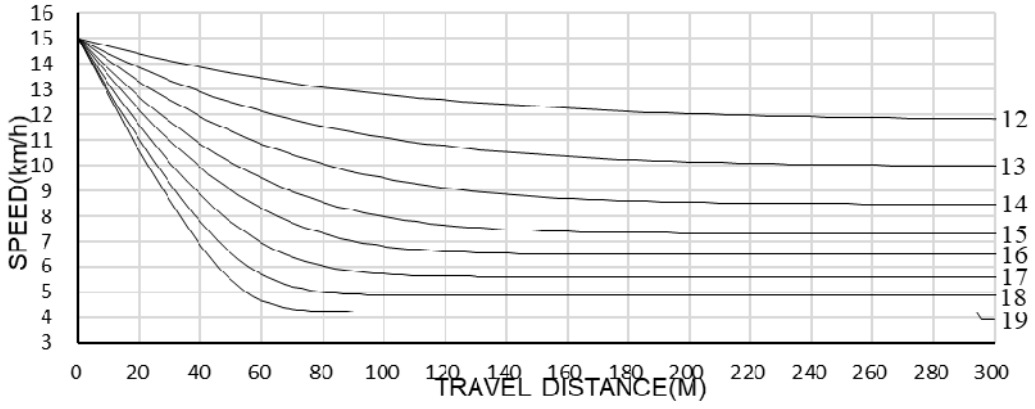

Fig. 5 Velocity-distance plot for a loaded vehicle travelling uphill at a starting speed of 15km/h

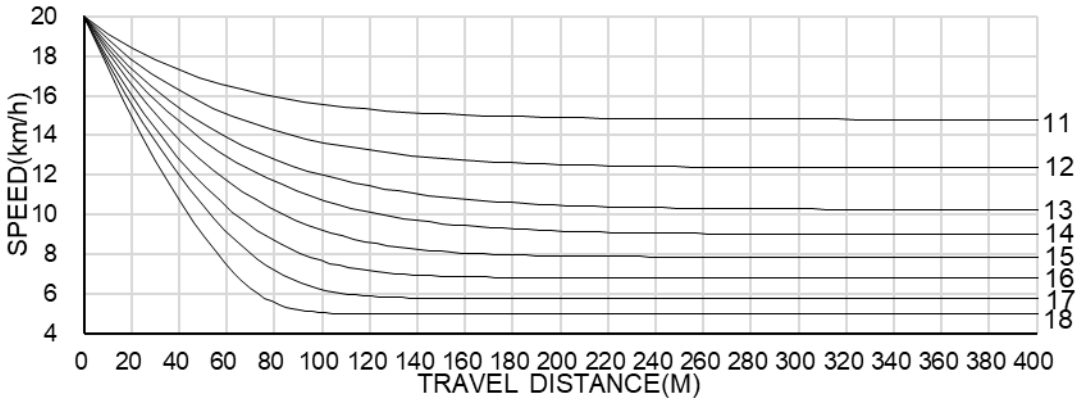

Fig. 6 Velocity-distance plot for a loaded vehicle travelling uphill at a starting speed of 20km/h

4.2 Determination of maximum slope length

The conclusion can be obtained by specifically analysing Figures 4~6:

(1) Under the same slope conditions, the higher the starting speed the faster the construction right-of-way speed decreases;

(2) in the same slope conditions, the higher the starting speed, the higher the final equilibrium speed, but the final equilibrium speed difference is not large, the slope speed between 10km / h ~ 20km / h, the final equilibrium speed will be 1km / h ~ 2km / h between the starting speed from low to high, and ultimately reach the speed of the stability of the distance required to be reduced in order to shorten;

(3) Under the condition of the same longitudinal slope, the larger the starting speed is, the farther the vehicle rushes up the slope, and with the increase of the slope, the distance required to descend to the fixed speed of the speed is getting shorter and shorter.

Combined with the above method and Fig. 4~6 speed distance diagram, we can get the table about the construction right-of-way longitudinal slope length limitation:

Table 3
Maximum slope length

Design speed（km/h）		20	15	10
Longitudinal slope gradient（%）	13	200	/	/
	14		/	/
	15		150	/
	16			/
	17			/
	18			100

Referring to the regulations on local roads and local streets in the U.S. Geometry of Roads[1], the maximum longitudinal slope at the minimum design speed in mountainous areas is 17%, and the design speed as well as the technical grade of the construction right-of-way is lower than that of the local roads, so the maximum longitudinal slope of the construction right-of-way up to 18% is acceptable.

5. Conclusion

This paper studies the climbing performance and force analysis of the design vehicle, the statistical study of the vehicle travelling on the construction road, through the force analysis of the climbing vehicle drawing speed - distance diagram, and then through the permissible speed method of the construction road longitudinal section of the maximum longitudinal slope and the maximum length of the slope to analyse and study.

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