Safety Adaptability of Engine Retarder (Jacobs) on Long Downhill of Expressways

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Abstract. In order to solve the problem that the truck should spray water to cool its brake during run the long downhill on mountain highway in winter, which can lead to icy road and cause traffic accidents. We specially selected the straight truck (6 × 4) which installs the engine brake (Jacobs), carrying out safety tests on Yaxi highway downhill sections in winter. The tests showed that 30% of vehicle overloading conditions, without the engine brake (Jacobs), relying on the service brake to control downhill speed, when the elevation drop of about 300m, the truck’s highest brake drum temperature will rise to a hot recession critical failure temperature (260 ℃) above. If you continue driving, it will lead to break failure and loss of control. When the truck going downhill and open the engine brake (Jacobs), due to the brake load is greatly reduced, the brake drum temperature of the truck maintained at 150 ℃ or less to maintain a good braking performance, and the truck can pass the 51km gap between 1500m long downhill safely. The results of field test show that, when a straight truck goes down a long downhill slope and opens the engine braking (Jacobs), the brake maintains a safe speed without spraying water, and keeps good braking performance. So it can solve the straight truck pass the long downhill sections of mountain highway fundamentally and the brake is not tricking.

1. Introduction
Southwest China is basically a karst landform, referring to the surface of limestone areas common stone buds, stone forests, peak forests, karst ditches, funnels, sinkholes, water caves, erosion depressions, slope valleys, blind valleys and underground karst caves, underground rivers and other cave systems and caves stalactites, stalagnites, pillars, stone waterfalls, etc. For the above unique landforms in the limestone area, the academic circles at home and abroad all named the karst landform plateau in the typical limestone landform area of Yugoslavia, namely "karst landform" (the term "karst landform" was also used in China in the past). The rocks are very hard, the terrain is very complex in many areas, and belongs to hilly areas. Towns are mainly distributed in a few plains and valleys. Urban morphology is greatly influenced by terrain factors. Highway construction in China is advancing to the depth of mountainous areas at present, so restricted by natural conditions, the newly built expressways have steep hills, narrow and sharp roads, natural disasters, low basic conditions for vehicle operation safety, and become accident-prone sections. For example, the Iasi expressway, which has been built and opened to traffic, is located in the Sichuan section of the Beijing Kunming Expressway (G5). The topographic and geological conditions along this section are very complex, the whole process through a total of six ridge crossing, forming three super-long continuous longitudinal slope. Among them, the length of continuous longitudinal slope on the north slope of Niba Mountain, the south slope and the north slope of Tuowu Mountain are 33 km, 26 km and 51 km respectively, ranking the highest in China, with the average longitudinal slope of 2.28%, 2.57% and 2.97% respectively. In addition, there are 22 km above the snow
line in the three extra-long longitudinal slope sections, and some sections are also affected by bad weather conditions such as ice, snow, rain and fog at a certain altitude. The operation safety situation is facing severe situation [1].

2. Testing road and vehicle conditions

2.1. Test vehicle parameter configuration

Table 1 configuration parameters of test vehicle

| Vehicle Brand            | Shanxi Auto Delong F2000 | Vehicle Type | SX3255DR434C |
|--------------------------|--------------------------|--------------|--------------|
| Engine Power             | 254KW/1900rpm            | Drive Form   | 6*4          |
| Gearbox                  | China Fast Gear 9JS180A  | Engine Model | ISME345 30   |
| Preparation Quality / Ton| 13                       | Auxiliary Brake Type | Jacobs |
| Vehicle Bridge Speed Ratio| 5.262                   | Standard Load Gross Weight / Ton | 25 |

2.2. Test Equipment. Vehicle performance testing system (Vbox III), infrared temperature measurement system (Optris CT0220), anemometer, stopwatch, etc.

2.3. Test Section

2.3.1. Niba Mountain. 26km on the northern slope of the Niba Mountain is long downhill with 6.7km above the snow line.

2.3.2. Tuowu Mountain. 51km long downhill on the northern slope of Tuowu Mountain, 16.7km above the snow line.

2.3.3. Temperature. The ambient temperature is 10 C.

2.3.4. Wind speed. The maximum wind speed is 8m/s.

3. Engine braking (Jacobs) brake characteristic test

The braking characteristic test is mainly carried out on the flat road. The vehicle is loaded with 19.5 tons (30% overload). It is used to study the deceleration braking ability of the Jacobs engine brake device and determine the engine braking characteristics.

3.1. Test method

3.1.1. Transmission neutral skid test. The vehicle is accelerated to 80km/h, then the transmission is hung in neutral gear, the vehicle is free to glide, and the data of the relationship between speed and time are recorded with the test equipment [2]. The test is conducted in an opposite direction.

3.1.2. Gearshift taxiing test. Accelerate the vehicle to the top speed of 5 gears, turn on the engine brake (Jacobs) switch, and the vehicle glides freely. Record the data of the relationship between the speed and time with the test equipment.
The test is conducted in an opposite direction. Followed by 6, 7 and 8 stalls, the test is identical to the 5 slip test.

3.2. Engine braking (Jacobs) force test and calculation
According to the above test method, the starting speed \((v_0)\), the terminal speed \((v_t)\), the running time \((t)\), the running distance \((s)\), the wind speed \((v_w)\) and other parameters can be accurately detected. According to the vehicle driving equation, [3]:

\[
\delta_i \cdot m \cdot \frac{du}{dt} = F_J + F_f + F_w \quad \text{(1)}
\]

\[F_J: \text{Jacobs engine braking force; } F_f: \text{Wheel rolling resistance; }\]

\[F_w: \text{Air resistance; } \delta_i: \text{The conversion coefficient of rotation mass of the corresponding gear; } m: \text{Total vehicle mass; } \frac{du}{dt}: \text{vehicle deceleration.}\]

\[
\frac{du}{dt} = \frac{(v_0 - v_t)}{t} \quad \text{(3)}
\]

\[
F_J = \delta_i \cdot m \cdot \frac{(v_0 - v_t)}{t} - (F_f + F_w) \quad \text{(4)}
\]

\[
F_w = \frac{C_D A U_a^2}{21.15} \quad \text{(5)}
\]

\[
F_f = G \cdot f \quad \text{(6)}
\]

According to the test results, the relationship between the total braking force of each gear and the vehicle speed can be obtained by calculating the data. See Fig. 1.

![Figure 1](image1.png)

Figure 1 the total braking force curve that each block of engine brake with the speed change

3.3. Engine braking (Jacobs) braking power test and calculation
According to the formula of engine power:

\[
P_e = T_u \omega_e = \frac{T_u l_i l_0}{r} u
\]

The braking power of the engine's braking (Jacobs) can be calculated, as shown in Table 2 and Figure 2.

| Rotational speed (r/min) | 1000 | 1200 | 1400 | 1600 | 1800 | 1900 |
|-------------------------|------|------|------|------|------|------|
| Braking power (kW)      | 52   | 73   | 96   | 121  | 147  | 160  |
| Driving power (kW)      | 159  | 214  | 230  | 244  | 251  | 254  |
| Braking power / driving power | 32.7% | 34.1% | 41.7% | 49.6% | 58.6% | 63.0% |
The results show that the driving power of ISM345 30 engine is 254 kW and the braking power is equivalent to 63.0% of the driving power at the rated speed of 1900 r/min. At the maximum speed of 2300 r/min, the braking power is 211kW, equivalent to 83.1% of the rated driving power.

4. Safety test for long downhill of expressways in Yaxi mountainous area

In order to test the safety degree of long longitudinal slope section of mountain expressway after installing engine brake (Jacobs) on single truck, the research group selected two long downhill sections of Niba Mountain (25.6 km) and Tuowu Mountain (51 km) on Yaxi expressway for field test.

During the test, the total weight of the vehicle is 30% overloaded and the total weight is 32.5 tons. When going downhill, the sprinkler is closed, and the engine brake system is closed and the engine brake system is opened. If necessary, the running brake is used to control the speed of the vehicle.

4.1. Safety test for North Slope of Niba Mountain.

4.1.1. Close the sprinkling device, turn off the engine exhaust brake (Jacobs) and drive downhill. The environmental temperature (NA), the right front hub temperature (RF), the right rear front axle hub temperature (RR1) and the speed of the truck are shown in the figure when the truck is downhill in the 7-8 gear (high grade).

The Figure 3 diagram shows that: the whole downhill process takes 27 minutes and 46 seconds, the highest speed is 69.7 km/h, the average speed is 55.6 km/h, the brake use time accounted for 69.2% of
the total travel time; because the front axle load is lighter, so the temperature rise of the right front wheel hub changes less, the range is within 100 degrees Celsius. The latter bridge is relatively large, so the temperature rises faster, and the maximum temperature of the rear axle hub reaches 472.7 degrees.

According to the research conclusion of the western project of the Ministry of Communications, when the brake drum temperature reaches 260 °C, the vehicle will lose the ability of emergency braking. Therefore, in the long downhill section of mountainous expressway, the brake efficiency of heavy-duty truck can easily be reduced to the limit value because of the brake overheating under the condition that the brake is not watering and there is no auxiliary brake device, resulting in traffic accidents [4] [5].

4.1.2 Close the sprinkling device and start the engine braking (Jacobs) downhill driving. Under the same loading and downhill gear conditions as in the first test, the engine brake (Jacobs) is turned on when going downhill, and the parameters of the vehicle in the downhill process are shown in the figure.

![Figure 4 Truck overloaded 30% driving downhill; turn on the water spray and engine brake system, brake drum Temp, speed change curve, north Niba mountain slope](image)

The diagram shows that the whole downhill process takes 26 minutes and 14 seconds, the highest speed is 73.5 km/h, the average speed is 59.4 km/h, and the ratio of brake using time to total driving time is 47.1%. As the use of engine brake, the brake frequency and strength are greatly reduced, so the brake drum temperature also rises very slowly, the right front hub temperature change is small; the range is within 50 degrees Celsius. The maximum temperature of the brake drum of the right rear axle is 149.7 degrees centigrade.

Thus, under the condition of using engine brake (Jacobs), a single truck can ensure the validity of the braking system even if it runs downhill with 30% overload, and make the vehicle safely descend a long slope at a faster speed.

4.2. Safety test on the north slope of Niba Mountain (51km)

In order to further test the reliability of the truck engine brake (Jacobs) on the ultra-long downhill section, the research group conducted a test on the 51 km downhill section of the north slope of Tuowu Mountain on the Yaxi Expressway. During the test, the vehicle is still overloaded by 30%. When going downhill, close the sprinkler, turn on the engine brake (Jacobs) and try not to use the running brake. The test results are as follows:
5. Conclusion

When the truck is loaded standard, the engine brake (Jacobs) can safely pass through the long downhill section of the mountain expressway without watering the brake. It is more suitable to control the speed at about 60 km.

When a single truck is loaded beyond the limit of 30%, the engine brake (Jacobs) can safely pass the long downhill section of the mountain expressway without watering the brake, and the speed of the truck can be controlled at about 50 km.

As there are many manufacturers of engine brake systems in China and the quality of products is different, it is suggested that trucks should walk on mountain expressways by bicycle and store a certain amount of water in the water tank of the sprinkler for occasional use.

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