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EVALUATION OF THE BRAKING PERFORMANCE OF VAN TRUCKS WHEN DESCENDING HILLS USING AUXILIARY BRAKES

ĐÁNH GIÁ HIỆU QUẢ PHANH CỦA XE TẢI VAN KHI XUỐNG DỐC KHI SỬ DỤNG PHANH BỔ TRỢ

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ABSTRACT

The development of the economy in recent years has led to a rapid increase in the number of trucks for transporting goods in recent years. Van trucks are quite popular in Vietnam thanks to their small size and maneuverability, which allows them to transport goods in cities, and even in mountainous areas with complex terrain with long slopes. When operating in such conditions, the braking system may have to operate for a long time and there is a risk of overheating, which can reduce braking efficiency. This paper presents a study to evaluate the effectiveness of auxiliary braking systems that are necessary when designing improvements for van trucks when descending hills. The results of the study show the clear effectiveness of auxiliary braking systems in different operating conditions, which provides a basis for the development and improvement of braking systems in the future.

Keywords: *Braking system; brake assistance; braking efficiency; longitudinal dynamics.*

TÓM TẮT

Sự phát triển của nền kinh tế trong những năm gần đây kéo theo sự phát triển của số lượng xe tải nhằm vận chuyển hàng hóa tăng lên nhanh chóng trong những năm gần đây. Xe tải kiểu van được sử dụng khá phổ biến ở Việt Nam nhờ ưu điểm nhỏ gọn và cơ động cho phép vận chuyển hàng hóa trong thành phố và cả ở những khu vực đồi núi có địa hình phức tạp với những con dốc dài. Khi vận hành trong những điều kiện như vậy, hệ thống phanh có thể phải tác động trong thời gian dài và có nguy cơ bị nóng làm giảm hiệu quả phanh. Bài báo này trình bày nghiên cứu đánh giá hiệu quả của hệ thống phanh bổ trợ cần thiết khi thiết kế cải tiến cho xe tải van khi xuống dốc. Kết quả nghiên cứu cho thấy hiệu quả rõ rệt của hệ thống phanh bổ trợ trong các điều kiện vận hành khác nhau, làm cơ sở cho việc phát triển, cải tiến hệ thống phanh trong tương lai.

Từ khóa: *Hệ thống phanh; phanh bổ trợ; hiệu quả phanh; động lực học phương dọc.*

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1. INTRODUCTION

With the advantage of being compact, van trucks are widely used for transporting small and medium-sized goods in cities and even inter-provincial transportation. In Vietnam, provincial roads and rural areas in the North are often mountainous with large slopes, which makes it difficult and dangerous for vehicles to descend [1]. According to TCVN 4054:2005 Road - Design requirements [2], mountains in Vietnam have slopes from 5 to 11%, when designing, the requirement that the length of the slope should not be too long with the maximum length specified at the design speed must be ensured. For roads with a slope of 10 or 11%, the design speed is 20km/h and the minimum slope length is 300m.

Currently, most trucks use a traditional friction-type braking system, with braking mechanisms located at the wheels. When the vehicle needs to reduce speed when going downhill, especially on long slopes, the braking system is used continuously, generating a lot of heat in the braking mechanism, reducing braking efficiency, and even losing brakes [3]. Therefore, a number of options with auxiliary braking systems have been designed and installed on trucks to assist the main braking system. Auxiliary brakes do not completely replace the main brakes in stopping and parking, but only serve to assist the main braking system in certain situations [4]. Some common options for auxiliary brakes are engine braking, braking on the transmission system, and electromagnetic braking. One of the recently proposed options is to use new materials technologies such as magnetic fluid [5, 6]. However, it is necessary to have research surveys to evaluate the dynamics of the braking process and braking efficiency in a more comprehensive and comprehensive way as a basis for determining the structural parameters and effective working areas of these auxiliary braking mechanisms.

This paper presents the following: In Section 1, a brief overview of the research is provided. In Section 2, a dynamic model of a van truck descending a slope is introduced. In

Section 3, the results of a numerical simulation study are presented to evaluate the braking distance of a van truck descending a slope with auxiliary braking in various conditions according to standard [2]. The degree of assistance is also determined through the braking torque generated by the auxiliary braking system. In Section 4, the effectiveness of the braking torque is evaluated, which provides a basis for selecting suitable design parameters for the auxiliary braking system.

2. DYNAMICS OF LONGITUDINAL MOTION OF VAN TRUCK WHEN DESCENDING A SLOPE

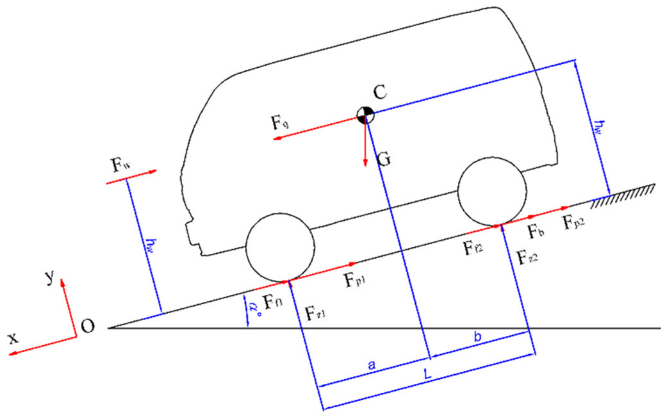

Figure 1. Forces and moments acting on van truck when descending a slope and braking

Figure 1 depicts a schematic representation of the forces acting on a van-type truck when descending a hill and applying brakes. In this figure: G - Vehicle's loaded weight (N); F_q - Inertial force when the vehicle brakes downhill (N); F_w - Aerodynamic drag force (N); F_{zi} - Road surface reaction force (N); F_{pi} - Braking force generated by the primary brake system (N); F_b - Braking force generated by the supplementary brake system (N); F_{fi} - Rolling resistance force (N); h - Vehicle's center of gravity height (m); h_w - Height at which the aerodynamic drag force is applied (m) ($h_w = h$); α - Road gradient angle (0); a, b - Distance from the vehicle's center of gravity to the front and rear axles (m); L - Vehicle's wheelbase length (m). The subscripts i = 1, 2 correspond to the forces and moments at the front and rear axle wheels.

In this study, it is assumed that the auxiliary braking system is installed after the axles and before the driving axle. In this case, the braking force F_b generated by the auxiliary braking torque M_b to the rear wheel will be:

$$F_b = M_b * i_0 / r_b \tag{1}$$

Where i_0 is the transmission ratio of the primary powertrain, and r_b is the average working radius of the rear wheels (m).

Let F_p be the sum of all braking forces acting on the vehicle, including the braking forces from the main braking system at the front and rear wheels, as well as the auxiliary braking force converted to the rear wheel:

$$F_p = F_{p1} + F_{p2} + F_b \tag{2}$$

The force equilibrium equation in the x-direction (Figure 1) is determined as follows:

$$\Rightarrow m\ddot{x} = -F_p - \frac{1}{2}\rho C_D A\dot{x}^2 - G(f\cos\alpha - \sin\alpha) \tag{4}$$

Where: f - Rolling resistance coefficient; ρ - Air density (kg/m^3); C_D - Drag coefficient of the vehicle; A - Frontal area of the vehicle (m^2).

Represents the displacement, velocity, and acceleration of the vehicle in the longitudinal direction x.

When designing a braking system, the structure of the main brake mechanism is typically determined in the case of a vehicle running on a level road with a coefficient of friction of φ. When this is done, the maximum total braking force generated by the main brake mechanism is determined as follows:

$$F_{p1max} = F_{z1}\varphi;\ F_{p2max} = F_{z2}\varphi \tag{5}$$

The normal reaction forces at the front axle (F_{z1}) and the rear axle (F_{z2}) are determined as follows:

$$F_{z1} = \frac{-\frac{1}{2}\rho C_D A\dot{x}^2 + m\ddot{x}h + hG\sin\alpha + bG\cos\alpha - fGr_{bx}\cos\alpha}{L} \tag{6}$$

$$F_{z2} = \frac{\frac{1}{2}\rho C_D A\dot{x}^2 - m\ddot{x}h - hG\sin\alpha + aG\cos\alpha + fGr_{bx}\cos\alpha}{L} \tag{7}$$

Let k be the ratio of the brake pedal travel (in percentage, compared to the maximum travel). If we consider the driver's braking law to be ignored, then the actual braking force generated at the front and rear wheel of the main braking system is:

$$F_{p1} = kF_{p1max};\ F_{p2} = kF_{p2max} \tag{8}$$

The maximum braking force that can be achieved at each front and rear wheel must not exceed the adhesion force at the corresponding wheel. Therefore, the total braking force at the wheels is calculated as follows:

$$\begin{aligned} F_p &= \min\left(F_{p1} + F_{p2} + F_b, G\varphi\cos(\alpha)\right) \\ &= \min\left(kG\varphi + \frac{M_b i_0}{r_b}, G\varphi\cos(\alpha)\right) \end{aligned} \tag{9}$$

A longitudinal dynamic model of a van truck when descending a slope and braking is used to calculate and evaluate the braking efficiency and to investigate the effects of parameters on the braking efficiency of the vehicle during operation. The evaluation parameters include auxiliary braking moment M_b, braking level (through the coefficient k is the ratio of the brake pedal travel), slope and road adhesion coefficient.

3. RESULTS AND DISCUSSION

In this study, the authors used the numerical simulation method using Matlab-Simulink software to solve differential equations and evaluate the effects of a number of parameters on the braking efficiency (through braking distance). Table 1 presents the basic technical specifications of the Suzuki van truck used in the simulation calculation process.

Table 1. The parameters of a survey vehicle model

Parameters	Symbols	Values
Vehicle total mass (kg)	m	1450
Distance from the vehicle's center of gravity to the front axle (m)	a	1.02
Distance from the vehicle's center of gravity to the rear axle (m)	b	0.84
Wheelbase length (m)	L	1.86
Average working radius of the wheel (m)	r_b	0.284
Transmission ratio of the primary powertrain	i_0	5.125
Center of gravity height (m)	h	0.733
Coefficient of frontal aerodynamic drag ($N.s^2/m^4$)	C_D	0.45
Overall width (m)	B	1.205
Overall height (m)	H	1.78
Air density coefficient	ρ	1.24
Road rolling resistance coefficient	f	0.02

3.1. Evaluating the braking efficiency when the road slope and auxiliary braking moment change

In this study, it is assumed that the pedal brake travel ratio is k = 50% (partial braking state). The vehicle operates under dry and clean road conditions with an adhesion coefficient of φ = 0.7. The initial speed at the start of braking is v_1 = 60km/h, and the desired final speed at the end of the braking process is v_2 = 20km/h. The braking efficiency of the van-type truck is evaluated by varying the values of the supplementary brake torque M_b under hilly road conditions with gradients ranging from 5% to 11%, following the Vietnamese standard TCVN 4054:2005 [6]. According to [6], the length of the downhill section of the road must exceed the minimum length prescribed at the design speed. For roads with a gradient of 10% or 11%, the design speed is 20km/h, and the minimum downhill length is 300m.

Figure 2 illustrates the simulation results investigating braking distance and braking time with different values of supplementary brake torque (M_b = 20 to 80Nm) under varying road gradients ranging from 5% to 11%. The initial speed before braking is v_1 = 60km/h, and the desired speed at the end of the braking process is v_2 = 20km/h, with a road adhesion coefficient of φ = 0.7. In this study, the pedal brake travel ratio is k = 50% (resulting in braking force generated by the primary brake mechanism). The results in Figure 2 align with theoretical expectations. On a road with a constant gradient, as the supplementary brake torque Mb increases, both the braking distance and braking time decrease. Additionally, when the road has a smaller gradient, the braking distance is also reduced.

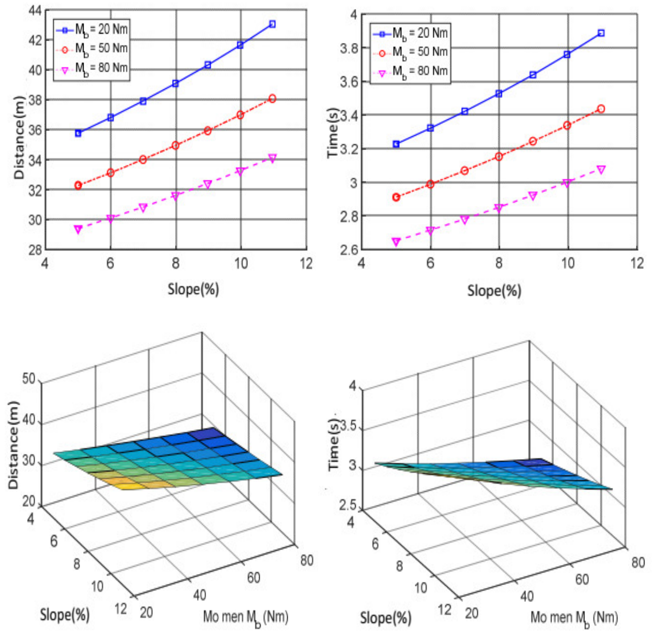

Figure 2. Investigation of braking distance and braking time with road gradients ranging from 5% to 11%, supplementary brake torque M_b varying from 20 to 80Nm (adhesion coefficient φ = 0.7, v_1 = 60km/h, v_2 = 20km/h, pedal brake travel ratio k = 50%)

With the steepest road gradient in the survey being 11%, when M_b = 20Nm, the braking distance is 35.9m, and the braking time is 3.21s. As M_b increases to 80Nm, the braking distance reduces to 29.5m, and the braking time is 2.65s. Within the range of supplementary brake torque values (M_b from 20 to 80Nm) and across all road gradients from 5% to 11%, the braking system with a pedal ratio k = 50% combined with supplementary brakes demonstrates effectiveness as the braking distance does not exceed the prescribed downhill length.

3.2. Evaluating braking efficiency when road gradient and pedal brake travel ratio vary

In this study, the road gradient also varies according to the standard (from 5% to 11%), and the pedal brake travel ratio (resulting in braking force generated by the primary brake mechanism) is examined within the range of k = 30% to 70%. Other conditions remain constant: the initial speed before braking is v_1 = 60km/h, and the desired speed at the end of the braking process is v_2 = 20km/h, with a road adhesion coefficient of φ = 0.7.

Figure 3 illustrates the simulation results of braking distance with a supplementary brake torque value of M_b = 20Nm. The results in Figure 3 align with theoretical expectations. On a road with a constant gradient, as the pedal brake travel ratio increases (resulting in increased braking force from the primary brake mechanism), the braking distance decreases. Additionally, when the road has a smaller gradient, the braking distance is also reduced. With the steepest road gradient in the survey being 11%, when k = 30%, the braking distance is 82m. When k increases to 70%, the braking distance reduces to 30m.

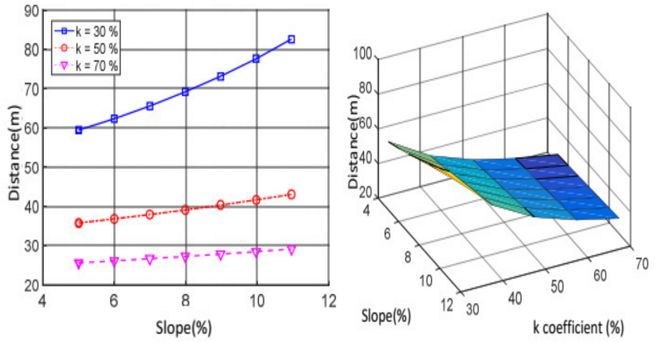

Figure 3. Investigation of braking distance with road gradients ranging from 5% to 11% and pedal brake travel ratio k varying from 30 to 70% (supplementary brake torque $M_b = 20Nm$; adhesion coefficient $\varphi = 0.7$, $v_1 = 60km/h$, $v_2 = 20km/h$).

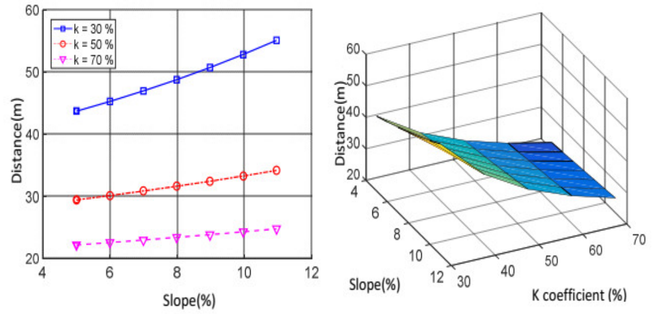

Figure 4. Investigation of braking distance with road gradients ranging from 5% to 11% and pedal brake travel ratio k varying from 30 to 70% (supplementary brake torque $M_b = 80Nm$; adhesion coefficient $\varphi = 0.7$, $v_1 = 60km/h$, $v_2 = 20km/h$)

Figure 4 illustrates the simulation results of braking distance with a high supplementary brake torque value of $M_b = 80Nm$. The results in Figure 4 also align with theoretical expectations, similar to the results in Figure 3. With the steepest road gradient in the survey being 11%, when k = 30%, the braking distance is 55m. When k increases to 70%, the braking distance reduces to 25m.

Within the range of pedal brake travel ratio values (k from 30 to 70%) and across all road gradients from 5% to 11%, the braking system with a pedal ratio k = 50% combined with supplementary brakes demonstrates effectiveness as the braking distance does not exceed the prescribed downhill length.

4. CONCLUSION

The paper presents simulation results of the downhill braking process for van trucks equipped with a supplementary braking system. It includes a study that evaluates the braking effectiveness (measured by braking distance and braking time) when the vehicle descends downhill with varying parameters, including supplementary braking torque, road gradient, and pedal brake travel ratio. The research results show that under changing road conditions (road gradient) and variations in the primary braking system operation conditions (pedal brake travel ratio), the range of supplementary braking torques from 20Nm to 80Nm all demonstrate appropriate braking effectiveness, as evidenced by the braking distance not exceeding the prescribed downhill length according to TCVN (Vietnamese standards). The findings of this study can serve as a basis for selecting the structure and design parameters for supplementary braking systems for van trucks operating under downhill conditions on Vietnamese roads.

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