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Determination of the Main Parameters Ensuring Braking Efficiency of Two-Axle Vehicles with Different Malfunctions in the Braking System

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ABSTRACT

The aim of the current work is to find out the effect of malfunction in the working brake system on the main parameters of the braking process and its performance, and hence, on the accuracy of the expert's conclusion, proposing relevant principles that should guide the experimental research.

The analysis of expert practice in car technical inspection testifies that the majority of questions addressed to the experts are related to the vehicle brake system and its efficiency assessment.

Introduction

The studies of multiple researchers (Balayan, et al., 2008, Bekasov, et al., 1967, Evtyukov and Vasiliev, 2006, Krinitsyn, 1987, Guidelines for Experts, Puchkin, 2010, Suvorov, 2004, Auto-Technical Forensic Examination, 1980) on braking efficiency/performance show that the stopping and braking distances, as well as braking time and movement speed per braking track are determined through the value of maximum deceleration, which the vehicle achieves via emergency braking.

Braking is one of the main quantities for an expert to determine the mechanism of an accident and resolve the issue of the technical feasibility of preventing an accident by braking the vehicle, as well as to create its mathematical model, to analyze various interpretations by the investigator and the court. The amount of deceleration depends on many objective factors, including the road and weather conditions at the time of the accident, the structural features of the vehicle and its technical condition.

The amount of deceleration of a specific vehicle (J, m/s^2) is determined by conducting an investigative experiment in the road conditions of the accident site. If the latter is not possible it can be determined according to informational data, according to the norms established by GOST R 51709-2001 Road traffic rules, or by calculation method.

According to expert practice, the determination of vehicles deceleration amount through calculation method is conducted with the formulae developed by V.A. Bekasov and N.M. Christie (Bekasov, et al., Krinitsyn, 1987). Formulae for determining the amount of deceleration of two-axle vehicles with a faulty brake system are given in the form of a table (Bazikyan and Balayan, 2003, Balayan, et al., Evtyukov and Vasiliev, 2006, Auto-Technical Forensic Examination, 1980).

Materials and methods

Upon the conducted brief overview it becomes clear that in the expert practice, especially when determining the brake parameters of a vehicle with a faulty brake system, it is necessary to take into account a number of principles that can have a significant impact on the results, not excluding possible errors in the expert's conclusion. The foregoing can be shown in detail with examples, using both the technical device and the values of deceleration, braking and stopping distance of a car with faulty brake systems.

Results and discussions

Let's take the passenger car VAZ 2109, M1 category, empty and fully loaded, as the study object. The road surface is asphalt-concrete, dry, flat with horizontal site. The car speed is V_c=40 km/h (11 m/s). The driver's reaction time is $t_1=0.8$ s.

The technical parameters are as follows: t_2 and t_3, coefficient of longitudinal adhesion between tire and road surface is φ according to guidelines for experts.

The car base is $L=2.460$ m, coordinates of gravity center are as follows: without load – $a=0.580$ m; $h_{g.c.}=0.560$ m, fully loaded – $a=1.260$ m; $h_{g.c.}=1.050$ m (Suvorov, 2004).

The amount of deceleration during the movement of a VAZ-2109 car braked on a flat horizontal road, with the wheels locked, is determined by the following formula:

$$J = g \cdot \varphi = 9.81 \cdot (0.7 \div 0.8) \approx (6.8 \div 7.8) \text{ m/s}^2. \quad (1)$$

Table. Analytical calculation of deceleration, braking distance and stopping distance of a two-axle vehicle (VAZ-2109 without load/with load) with a working brake system with different types of malfunctions*

Type of malfunction of the working brake system in a two-axle vehicle	Deceleration calculation formula	Calculated value of J, m/s²	Braking distance formula	Calculated value of S_b, m	Stopping distance formula	Calculated value of S_s, m
$b = L - a = \frac{2.46-0.58}{2.46-1.26} = \frac{1.88m}{1.2m}$, $\varphi_a = \frac{0.7 \div 0.8}{1.2} = 0.58 \div 0.67$, $t_1=0.8$ s $t_1=0.1$ s, $t_1=0.35$ s						
Braking system of the technical device	$J = g \cdot \frac{\varphi}{k_e}$	5.7÷6.5	$S_b=(t_2+0.5t_3)\cdot V_b+V_b^2/2J$	13.9÷12.5	$S_s=(t_1+t_2+0.5t_3)\cdot V_b+V_b^2/2J$	22.5÷21.1
A front wheel fails to brake	$J = \frac{(L+a)\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	3.3÷3.8 3.8÷4.3		21.8÷19.3 19.3÷17.4		30.4÷27.9 27.9÷26.0
A rear wheel fails to brake	$J = \frac{(L+b)\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	5.4÷6.3 4.8÷5.7		14.5÷12.8 15.9÷13.9		23.1÷21.5 24.5÷22.5
A front wheel brakes	$J = \frac{b\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	2.3÷2.7 1.6÷1.9		29.9÷25.9 41.6÷35.5		38.5÷34.5 50.2÷44.1
A rear wheel brakes	$J = \frac{a\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	0.6÷0.7 1.3÷1.5		105.9÷91.2 50.5÷44.2		114.5÷99.8 59.1÷52.8
Only front wheels brake	$J = \frac{b\cdot\varphi_a\cdot g}{L-h_{g.c.}\cdot\varphi_a}$	5÷5.9 3.7÷4.5		15.4÷13.5 19.7÷16.8		24.0÷22.1 28.3÷25.4
Only rear wheels brake	$J = \frac{a\cdot\varphi_a\cdot g}{L+h_{g.c.}\cdot\varphi_a}$	1.2÷1.3 2.3÷2.6		54.5÷50.5 29.9÷26.8		63.1÷59.1 38.5÷35.4
The wheels of only one side brake	$J = g \cdot \frac{\varphi_a}{2}$	2.8÷3.3		25.1÷21.7		33.73÷30.4

Continuation of the table*

1	2	3	4	5	6	7
$\varphi_a=\frac{0.5\div0.6}{1.1}=0.45\div0.54,\ \varphi_a=\frac{0.5\div0.6}{1.2}=0.42\div0.5$, t_2=0.1 s, t_{31}=0.3 s, t_{32}=0.25 s						
Braking system of the technical device	$J=g\cdot\frac{\varphi}{k_e}$	4.4÷5.3 4.1÷4.9	$S_b=(t_2+0.5t_3)\cdot V_b+V^2_b/2J$	16.8÷14.4 17.5÷15.4 16.5÷14.4 17.5÷15.1	$S_s=(t_1+t_2+0.5t3)\cdot V_b+V^2_b/2J$	25.7÷23.3 26.4÷24.3 25.4÷23.3 26.4÷24.0
A front wheel fails to brake	$J=\frac{(L+a)\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	2.6÷3.1 2.8÷3.3		26.5÷22.7 24.8÷21.5 26.2÷22.4 24.5÷21.2		35.4÷31.6 33.7÷30.4 35.1÷31.3 33.4÷30.1
A rear wheel fails to brake	$J=\frac{(L+b)\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	4.1÷5.0 3.4÷4.1		17.8÷15.1 20.9÷17.8 17.5÷14.8 20.6÷17.5		26.7÷24.0 29.8÷26.7 26.4÷23.7 29.5÷26.4
A front wheel brakes	$J=\frac{b\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	1.8÷2.1 1.1÷1.3		37.1÷32.2 58.9÷50.2 36.8÷31.9 58.6÷49.9		46.0÷41.1 67.8÷59.1 45.7÷40.8 67.5÷58.8
A rear wheel brakes	$J=\frac{a\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	0.5÷0.6 1.0÷1.1		126.2÷105.6 64.5÷58.9 125.9÷105.3 64.2÷58.6		135.1÷114.5 73.4÷67.8 134.8÷114.2 73.1÷67.5
Only front wheels brake	$J=\frac{b\cdot\varphi_a\cdot g}{L-h_{g.c.}\cdot\varphi_a}$	3.8÷4.6 2.4÷3.0		19.0÷16.2 28.9÷23.3 18.7÷15.9 28.2÷23.0		27.9÷25.1 37.4÷32.2 27.6÷24.8 37.1÷31.9
Only rear wheels brake	$J=\frac{a\cdot\varphi_a\cdot g}{L+h_{g.c.}\cdot\varphi_a}$	0.9÷1.1 1.8÷2.1		71.3÷58.9 37.1÷32.2 71.0÷58.6 36.8÷31.9		80.0÷67.8 46.0÷41.1 79.9÷67.5 45.7÷40.8
The wheels of only one side brake	$J=g\cdot\frac{\varphi_a}{2}$	2.2÷2.6 2.1÷2.4		30.8÷26.5 32.2÷28.5 30.5÷26.2 58.6÷28.2		39.7÷35.4 41.1÷37.4 39.4÷35.1 67.5÷37.1
$\varphi_a=\frac{0.3\div0.4}{1.0}=0.3\div0.4$, t_2=0.1s, t_{31}=0.2 s, t_{32}=0.15 s						
Braking system of the technical device	$J=g\cdot\frac{\varphi}{k_e}$	2.9÷3.9	$S_b=(t_2+0.5t_3)\cdot V_b+V^2_b/2J$	23.2÷18.0	$S_c=(t_1+t_2+0.5t_3)\cdot V_b+V^2_b/2J$	32.1÷26.9
A front wheel fails to brake	$J=\frac{(L+a)\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	1.7÷2.3 2.1÷2.7		38.2÷29.0 31.3÷25.1		47.1÷37.9 40.2÷34.0
A rear wheel fails to brake	$J=\frac{(L+b)\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	2.7÷3.5 2.3÷3.2		24.8÷19.8 28.8÷21.5		32.9÷27.9 37.7÷30.4
A front wheel brakes	$J=\frac{b\cdot\varphi_a\cdot g}{2L-h_{g.c.}\cdot\varphi_a}$	1.1÷1.6 0.8÷1.0		58.0÷40.8 125.4÷63.9		66.9÷49.7 134.3÷72.8
A rear wheel brakes	$J=\frac{a\cdot\varphi_a\cdot g}{2L+h_{g.c.}\cdot\varphi_a}$	0.3÷0.4 0.7÷0.8		207.6÷156.5 90.1÷79.4		216.5÷165.4 99.0÷88.3
Only front wheels brake	$J=\frac{b\cdot\varphi_a\cdot g}{L-h_{g.c.}\cdot\varphi_a}$	2.5÷3.3 1.6÷2.3		26.6÷20.9 40.5÷29.0		35.5÷29.8 49.4÷37.9
Only rear wheels brake	$J=\frac{a\cdot\varphi_a\cdot g}{L+h_{g.c.}\cdot\varphi_a}$	0.6÷0.8 1.3÷1.7		104.8÷79.4 49.4÷38.5		113.7÷88.3 58.3÷47.4
The wheels of only one side brake	$J=g\cdot\frac{\varphi_a}{2}$	1.5÷2.0		43.1÷33.1		52.0÷42.0

*Composed by the authors.

According to Evtyukov and Vasiliev $J=\varphi_a \cdot g$, (2) or according to Technical Forensic Expertise $J=g\cdot\frac{\varphi}{k_e}$ m/s^2 (3), where φ_a is the adhesion coefficient, which upon the joint solution of (2 and 3) formulae will be equal to:

$$\varphi_a=\frac{\varphi}{k_e}\ , \quad (4)$$

$g=9.81$ m/s^2 is the acceleration of free fall, k_e is the coefficient of braking efficiency, accounting for the degree of use of the adhesion sum force of the tires of the braked wheels with the surface of the passing part, which according to technical expertise is assumed to be as follows: in case of $\varphi \geq 1.7$ $k_e=1.2$, in case of $\varphi = 0.5 \div 0.6$ $k_e=1.1$, and in case of $\varphi \leq 0.4$ $k_e=1.0$.

As it can be seen from the calculations, the main parameters of the brake system performance, and, therefore, the accuracy of the expert's conclusion, are significantly affected by the following malfunctions of the brake system, respectively: only rear wheels brake, a front wheel brakes, the wheels of only one side brake, a front wheel fails to brake, only the front wheels brake and a rear wheel fails to break. For example, among the mentioned malfunctions, the most significant effect on the parameters is exerted, when a rear wheel brakes. In this case the deceleration declines:

$$J=\frac{(5.7\div0.6)\div(6.5\div0.7)\quad m/s^2}{(5.7\div1.3)\div(6.5\div1.5)\quad m/s^2} \text{ or } \frac{(89.2\div89.5)\quad \%}{(76.9\div77.2)\quad \%},$$

(without load/fully loaded).

The braking distance increases in:

$$S_b=\frac{(13.9\div105.9)\div(12.5\div91.2)\quad m}{(13.9\div50.5)\div(12.5\div44.2)\quad m} \text{ or } S_b=\frac{(6.1\div6.6)}{(2.4\div2.6)}$$

times.

Equally the stopping distance gets increased.

Conclusion

Thus, upon the calculation of the introduced possible options of braking parameters for a two-axle vehicle with the working brake system characterized by different types of malfunctions, a number of principle theses have been derived, which should serve as a guideline when conducting experimental research.

1. It is relevant to perform technical calculations with two values of the starting parameters (in this case, vehicle deceleration, braking and stopping distances): the minimum permissible and the maximum possible, that is, to use the range of individual parameters included in the calculation formulas, in which the obvious exact value of this or that parameter can be found.

2. When formulating a categorical conclusion, only one value of this or that parameter of the braking efficiency of the vehicle (deceleration, braking and stopping distances) can be used in the calculations: the minimum permissible, if the driver of the vehicle had a technical possibility to prevent the accident by reducing the speed of movement in time, or the maximum possible if he had no technical ability to prevent the accident.

It is necessary to note that making such decision is correct only if in cases of any other values (large in the first case and small in the second) of this or that parameter for the braking efficiency of the vehicle (deceleration, braking and stopping distances) the conclusion made by the expert based on the results of the technical calculations stays unchanged.

3. In cases where the research results are not equal, the expert's conclusion should be also the same, with the reasonable clarification of the decision terms for reaching the verdict.

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