RESEARCH IN PARAMETERS OF BRAKING FOR AUTOMOBILES

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Abstract. The process of braking is important in automotive performance, which impacts the safety of traffic. Several parameters of braking can be determined on stationary test stands, however, more accurate data that can be used in a more simple way in practise are gained by doing tests on the road. Based on EU legal documents on determining parameters of braking, a research methodology has been elaborated and approbated for determining parameters of braking for automobiles in road tests. To determine the parameters of braking, scientific radar Stalker ATS transferring data to a computer were used. Road tests were done for automobiles of various age groups and constructions, determining the period, distance, and deceleration rate of braking. According to the research data, the parameters of braking of the used automobiles comply with the standard for parameters of braking set by the EU. The effectiveness of parameters of braking does not mostly depend on the age of automobiles, but on the technical condition of the brake system.

Key words: distance of braking, deceleration of braking, period of braking, speed regime.

Introduction

One of the causes of traffic accidents is the technical condition of automobiles. The key characteristic of an automobile's technical condition, which impacts the safety of traffic, is the brake system and the effectiveness of its performance which the period and the distance needed to stop an automobile depend on. One of the ways to reduce a number of traffic accidents is to improve the methods and ways of controlling the parameters of braking for automobiles.

Forces of braking are tested in Latvia during annual technical check-ups. Yet several factors like tyre wear, road surface quality, a driver's readiness to start braking and the period of reaction, as well as other parameters that are especially important when doing sudden braking are not taken into account during stand tests.

The research aim is to elaborate and approbate a methodology for determining the main parameters of braking, which are appropriate for Latvian conditions and to compare the parameters of braking for various automobiles.

When certifying new automobiles, braking tests are done in compliance with the European Commission directive 71/320/EEC and its amendments. So far no method has been elaborated and approbated for determining the parameters of braking for automobiles under working conditions in Latvia. In the present research, a method having speed regimes is elaborated and approbated for determining the deceleration rate, distance, and period of braking of automobiles in road tests.

Materials and Methods

1. Standardising and setting parameters of braking

For automobiles produced by automobile plants or companies, the standard for brake systems and the parameters of braking are set by EU regulations. According to these regulations, the key parameters for an effective brake system are as follows:

- for main and reserve brake systems – a distance of braking and a stabilised deceleration rate;
- for parking and extra brake systems –total force of braking produced by brake mechanisms of these systems.

The brake tests are carried out in compliance with the EU directive 71/320/EEC. The performance of a brake system can be evaluated by the distance of braking or the average maximum deceleration rate $j_{\tau,max}$. According to the directive, the distance of braking is defined as a distance covered by a vehicle from the moment when the driver starts pushing the brake pedal until the moment the vehicle comes to a stop. The initial speed of a vehicle v_1 is a speed in the moment when the driver starts pushing the brake pedal. The initial speed of a vehicle shall not be less than 98 % of the speed set for a particular type of automobile and test [1].

The speed and distance of braking are determined by using measuring instruments, the accuracy of which is ± 1 %. The value $j_{\tau,max}$ can be determined by other methods that are not related to measuring speed and distances. In this case, accuracy in determining deceleration rates has to be within a range of ± 3 %. If the maximum speed of the automobile set by its producer is below the speed set for a test, the test is done at the maximum speed of the automobile.

The brake tests are carried out on asphalt surface having good adhesion. During the tests, the force applied to the brake pedal does not have to exceed the force set in the technical data of a respective category of automobile. The tests are done at wind speed of less than 1 m s^{-1}. The tests are started with cold tyres and their pressure is set by the vehicle producer. Any braking is done suddenly without blocking the wheels and with the automobile moving the same direction [1].

1.1. Control tests for automobile brakes

0 type test (usual cold brake performance test). During the test, the brake is cold. The brake is regarded as cold if the temperature measured on the surface of brake discs or drums is below 100 °C. During the experiments, one passenger who registers test results is allowed to sit next to the driver on the front seat. As to towing vehicles, tests without load are performed only for the towing vehicle when it is decoupled from a semi-trailer. It is added weight equal to the weight of its trailer.

0 type test with the engine disengaged. The test is performed at a speed set for a category of vehicles which the particular vehicle belongs to [2].

0 type test with the engine engaged. Additional automobile tests are performed at various speed with the engine connected to the transmission. The lowest speed is equal to 30 % of maximum speed of the automobile and the highest speed is equal to 80 % of the mentioned speed. Semi-trailer trucks when they are specially loaded for simulating a loaded semi-trailer are tested at speed not exceeding 80 km h^{-1}.

I type test (brake effectiveness reduction test). The experiments are performed for a fully loaded automobile by repeatedly putting on the brake *n*-times. The tests are performed by sequentially engaging and disengaging the brake.

II type test (brake performance test when driving downhill). This is a test for loaded automobiles. The brake is supplied with an amount of energy needed for a vehicle driving *downhill on a* 6 % *slope at an average speed of* 30 km h^{-1} and covering a distance of 6 km with a proper gear and decelerator engaged (in case the automobile is equipped with a decelerator). There has a gear to be engaged ensuring that revolutions of the engine crankshaft do not exceed the nominal rate set by the producer.

1.2. Brake performance indicators

The test parameters for vehicles of various categories, for instance, the initial driving speed, the minimum deceleration rate a.o. can be found in tables of the EU directives.

In our experimental research, M_1 type passenger cars were used – the number of passengers together with the driver does not exceed 9 people. For comparison, Table 1 data include also M_2 automobiles the gross vehicle weight of which can reach 5 t.

Table 1

Test conditions for automobiles of categories M_1 and M_2

Test type		**M_1, 0-I**	**M_2, 0-I**
0 type tests with engine engaged	v, km h^{-1}	80	60
	$s \leq$, m	$0.1v + \frac{v^2}{150} = 50.67$	$0.15v + \frac{v^2}{130} = 36.69$
	$j_{\tau,max}$, m s^{-2}	5.8	5.0
0 type tests with engine engaged	v, km h^{-1}	160	100
	$s \leq$, m	$0.1v + \frac{v^2}{130} = 212.92$	$0.15v + \frac{v^2}{103.5} = 105.62$
	$j_{\tau,max}$, m s^{-2}	5.0	4.0
	Force on pedal F, N	500	700

2. Parameters characterising qualities of braking

The speed of an automobile and the safety of traffic significantly depend on the qualities of braking. Qualities of braking are the ability of the automobile to reduce its speed fast and to come to a stop within a short distance of road, to keep the necessary speed when driving downhill, and to stay immobile under the impact of external forces.

It is assumed in calculations that the automobile brakes with all its wheels under equal conditions of adherence, and the maximum force of braking is gained as follows:

$$P_{\tau,\max} = \varphi \sum Z_{k,\tau} = \varphi G_a \cos\alpha ,$$

where φ – adherence coefficient;

G_a – automobile weight, N;

α – upslope or downslope angle, degrees [2].

The force of braking P_τ arises on wheels after engaging the main brake. The force of braking can be applied to the driving wheels if the engine is not disengaged from the transmission, thus using the engine force of braking P_m or by using special decelerators that can increase the resistance of transmission P_z or the resistance of the engine P_m. When driving uphill, the resistance of the slope P_α will act as force of braking. At high speeds, the resistance of air P_w can be used as force of braking, thus artificially increasing the automobile aerodynamic resistance.

When braking, the resistance of inertia is pointed towards the automobile direction of movement, and taking into account that $j=j_\tau$, it can be calculated:

$$j_\tau = \frac{\varphi G_a \cos\alpha + \psi G_a + \dfrac{kF(v_1^{\,2} - v_2^{\,2})}{2}}{m_a \delta'} \tag{2}$$

where ψ – road resistance coefficient;

k – air resistance coefficient;

F – automobile frontal area, m^2;

v_1 – initial speed of braking, m s^{-1};

v_2 – final speed of braking, m s^{-1};

m_a – automobile weight;

δ' – coefficient of rotating masses if the engine is disconnected from the transmission; it can be assumed 1.05.

If the resistance of air is not taken into account, the minimum period of braking is calculated as follows:

$$t_{\tau,\min} = \int_{v_1}^{v_2} \frac{-\delta' dv}{g(\varphi\cos\alpha + \psi)} = \frac{\delta'(v_1 - v_2)}{g(\varphi\cos\alpha + \psi)} \tag{3}$$

If the automobile is braked until it comes to a stop, then v_2=0.

By assuming that the road resistance coefficient ψ and the adherence coefficient φ do not depend on the speed v, the minimum distance of braking is gained [1, 3]:

$$s_{\tau,\min} = -\frac{\delta'}{g(\varphi\cos\alpha + \psi)} \int_{v_1}^{v_2} v dv = \frac{\delta'(v_1^2 - v_2^2)}{2g(\varphi\cos\alpha + \psi)} . \tag{4}$$

3. Experimental research of parameters of braking

The research object is cars the parameters of braking of which are determined in road tests. The research was done for 8 cars on two types of road surface – asphalt and gravel. The gross weight of the cars was within a range of 1430 – 2800 kg. Front disc brakes were used on all cars. Rear disc brakes were used on four cars and drum brakes – on the others. Three cars were equipped with ABS. The depth of the tread was not less than 5 mm on all cars.

In the experiments, distances of braking, periods of braking, changes in the speed of braking, and rates of deceleration were determined. For every car, 5 measurements were repeated. In total, 80 measurements were carried out. The tests were performed in Ogre district, Ogresgala parish on 26 April, 2008. The weather conditions were good (+8 ... + 10 °C). It was sunny, the wind speed did not exceed 3 m s^{-1}. The road surface was dry.

An „ATS Stalker" radar and a laptop computer with „ATS Stalker" software were used in the research. The „ATS Stalker" equipment measures the speed at a precise interval and sends the data to the computer [4]. The radar parameters are as follows:

- accuracy: +/- 0.1609 km h^{-1};
- range of speed measurements: 1.6 – 480 km h^{-1};
- data obtaining period: 0.01 s;
- weight: 1.45 kg;
- maximum detection distance for automobiles 1.82 km [4].

3.1. Research technology

1. The „ATS Stalker" radar is installed on a stand and connected to the laptop computer; the „ATS Stalker" software is activated. The necessary settings are made for performing the brake tests.
2. The first operator starts driving the car, the second one controls the radar. The car moves along the trajectory shown in Fig.1. The test car starts moving around 150 m before the radar in Point "8". After Point "6" is reached, the radar operator switches on the radar. In Stage „S_{main}", the car changes the lane. The car has reached the necessary speed regime and performs intensive braking in Stage „S_{brem}". After the car cames to a stop, the radar operator switches off the device registering the data.

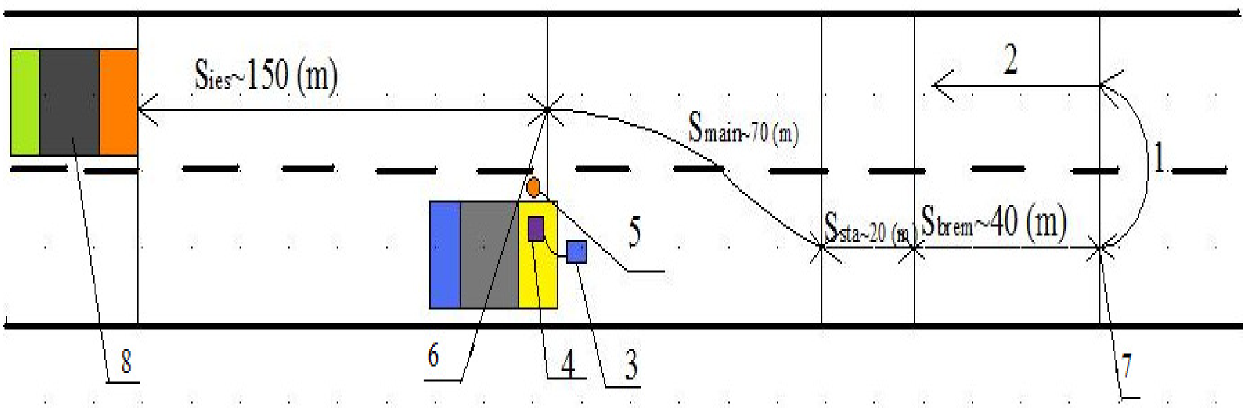

Fig. 1. **Scheme for conducting experiments:** 1 – change of automobile direction of movement; 2 – automobile way back for conducting the next measurement; 3 – „Stalker ATS" radar; 4 – laptop computer; 5 – radar operator; 6 – moment of switching on the radar; 7 – moment of switching off the radar; 8 – test automobile; S_{ies} – automobile distance before starting a test; S_{main} – change of lane; S_{sta} – automobile stabilisation for rectilinear movement; S_{brem} – automobile distance of braking

After the data were selected and the unnecessary data were omitted, 5 curves useful for constructing a curve of average data were obtained. The data registered by the radar from the graphs $v=f(t)$ and $s=f(v)$ are used for further processing.

3.2. Research results

The measurements obtained for the car BMW 525 that was tested on asphalt road are compiled in Fig. 2 after being filtrated; the car was braked at the speed of 80 km h^{-1} till it came to a stop.

The car period of braking varies from 2.94 s to 3.43 s. The distance of braking varies from 33.4 m to 38.87 m for this car. All the experiments were repeated for 8 various car types on gravel road, too.

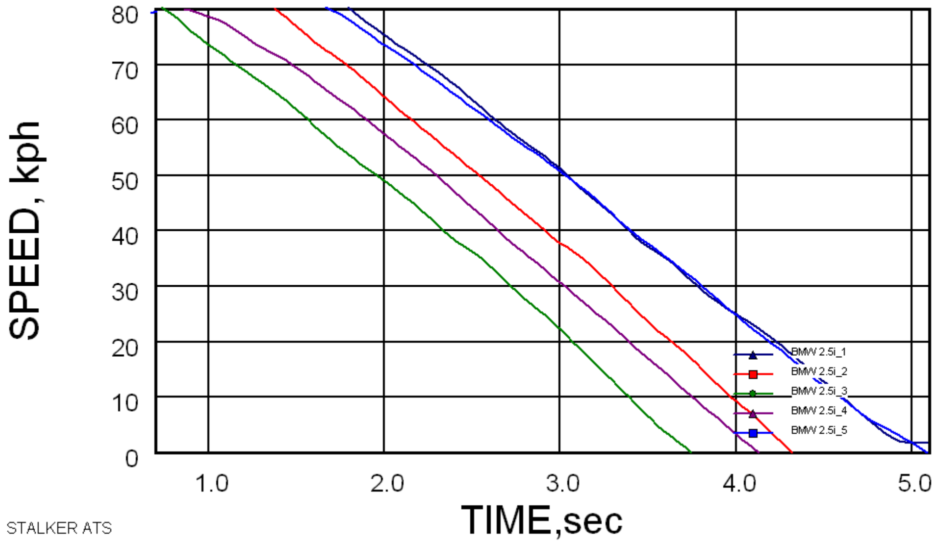

Fig. 2. **Period of braking for a car BMW 525, starting braking at 80 km h^{-1} (Stalker ATS software window screen shot)**

In Fig. 3 the data on the distances of braking on dry asphalt and gravel roads are compiled.

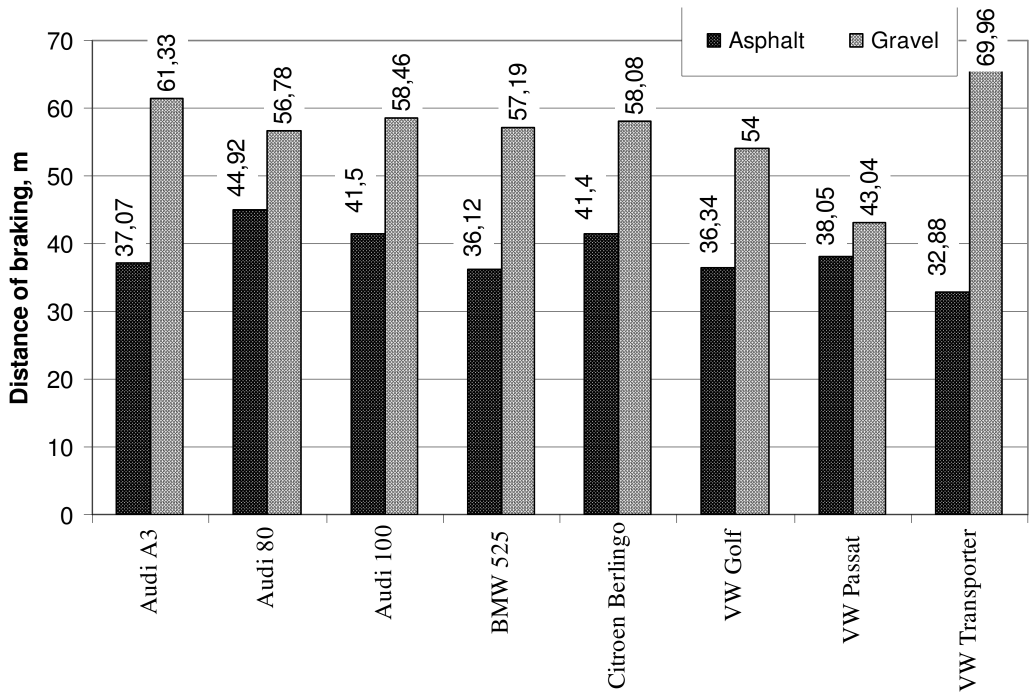

Fig. 3. **Distances of braking for test cars on asphalt and gravel roads**

The car VW Transporter has the shortest distance of braking on asphalt – 32.88 m, whereas the car Audi 80 has the longest distance of braking – 44.92 m. The distance of braking on asphalt for the car Audi 80 is 20 % longer than for all the other cars, which can be explained by the ineffective performance of its brake system [5].

On gravel road, the shortest distance of braking is registered for the car VW Passat – 43.04 m, while the longest – for the car VW Transporter – 69.96 m. The distances of braking on gravel road for the cars is on average 38 % longer than on asphalt road. The average periods of braking for the cars are compiled in Fig. 4.

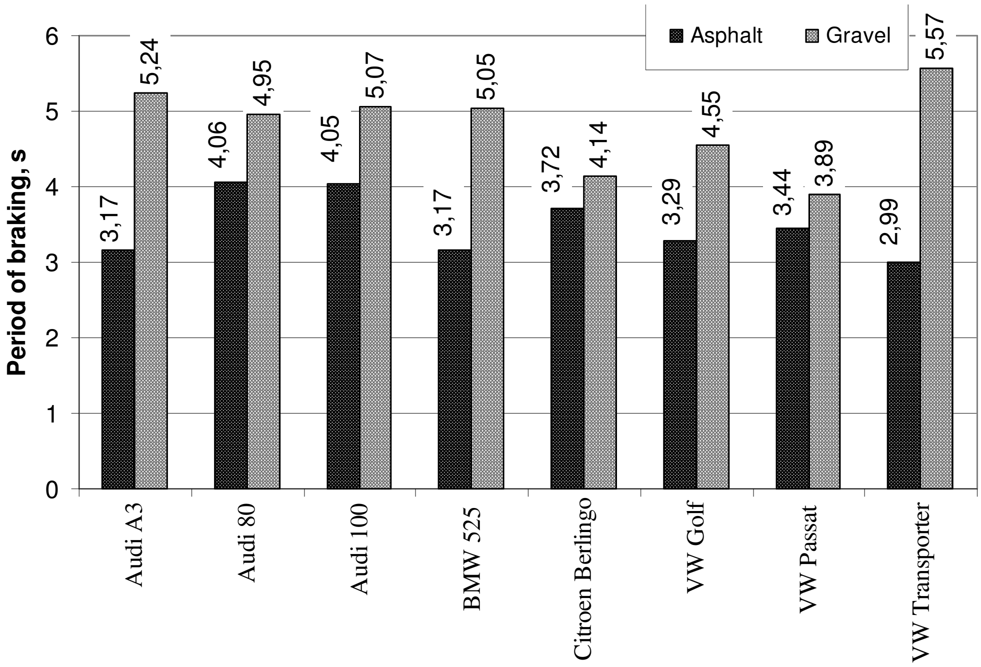

Fig. 4. **Periods of braking for cars on asphalt and gravel roads**

VW Transporter has the shortest period of braking on asphalt road – 2.99 s. The longest periods of braking on asphalt are registered for the cars Audi 80 – 4.06 s and Audi 100 – 4.05 s.

On gravel road, VW Passat has the shortest period of braking – 3.44 s, but VW Transporter – the longest one or 5.57 s. The periods of braking on gravel road are on the average 37.2 % longer than on asphalt road.

Fig. 5 shows the average deceleration rates of braking for the test cars.

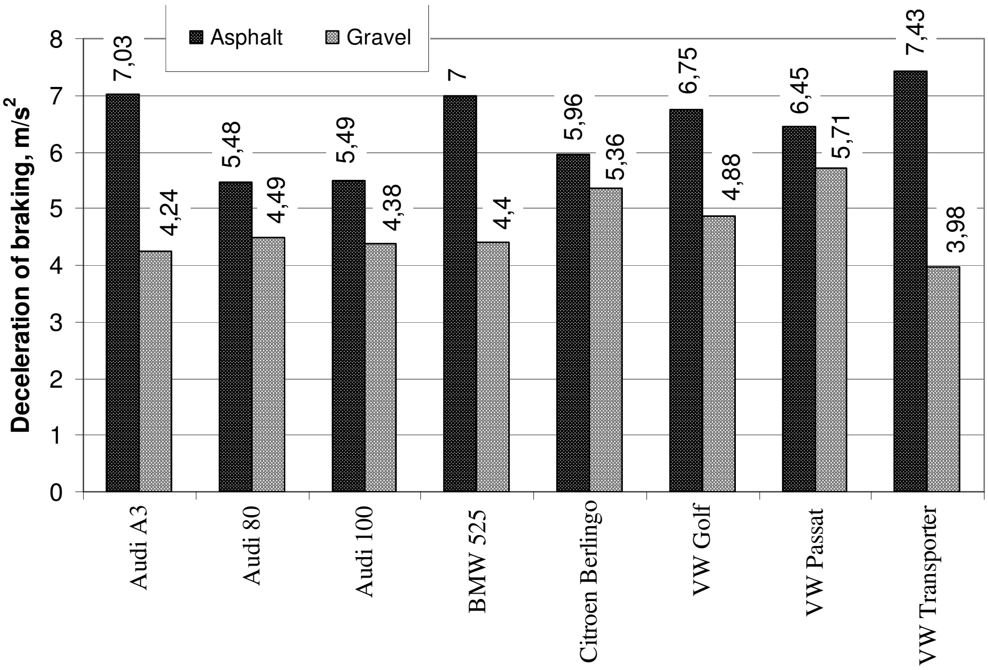

Fig. 5. **Comparison of average deceleration rates of braking for cars**

The largest deceleration rate of braking on asphalt road is registered for VW Transporter – 7.43 m s^{-2}, whereas Audi 80 and Audi 100 have the smallest deceleration rates of braking, respectively 5.48 and 5.49 m s^{-2}.

On gravel road, VW Passat has the largest deceleration rate of braking – 5.71 m s^{-2}, but the smallest one is registered for VW Transporter – 3.98 m s^{-2}.

Conclusions

3. It is useful to conduct comparable tests of braking, which are based on the test principles set by the European Commission directive 71/320/EEC.
4. On asphalt road, the best parameters of braking s_τ=32.88 m, t_τ=2.99 s, j_τ=7.43 m s^{-2} were shown by the car VW Transporter, whereas on gravel road the best parameters belonged to VW Passat with s_τ=43.04 m, t_τ=3.89 s, j_τ=*5.71* m s^{-2}.
5. The lowest parameters of braking s_τ=44.92 m, t_τ=4.06 s, j_τ=*5.48* m s^{-2} on asphalt road belonged to Audi 80, but on gravel road the weakest performance was shown by VW Transporter with s_τ=69.96 m, t_τ=5.57 s, j_τ=3.98 m s^{-2}.
6. None of the test car distance of braking on asphalt with φ=0.75 did not exceed 50.67 m, which proves that cars used in Latvia comply with the standard for the EU tests.
7. The deceleration rates for the cars Audi 80 and Audi 100 were less than $j_{max.}$=5.8 m s^{-2}, which is related to the poor condition of the brake systems of these cars.
8. The use of ABS on a dry asphalt road does not significantly improve the parameters of braking, a better effect is provided by the technical condition of the brake systems and cars as well as the tyres used.

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