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Measurement of the braking distance in dependence on the momentary vehicle weight

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Abstract The braking distance is one of the most important features of the braking system of a vehicle during its operation. The distance depends on many factors related to technical part of the vehicle, road surface or the driver. This paper focuses on the examination of the impact of the momentary weight of the vehicle on its braking distance. It aims at explaining the issue through practical tests and drawing conclusions for further research and practical application in expert activities.

Keywords Braking distance, Vehicle weight, Driving tests

JEL L91 - Transportation: General

1. Introduction

When analysing a traffic accident and determining the cause of the same, one of the crucial factors can be the length of the braking distance or the determination of the braking retardation of the vehicle. The following text implies in part 2 that the weight of the vehicle does not have any impact on the length of the braking distance in the mathematical calculation based on basic physical principles. We, therefore, attempted in our paper to specify values obtained by practical measurement of the braking distance and braking retardation of passenger vehicle and values of the braking distance and braking retardation of cargo vehicle as obtained from the diploma thesis of Bc. Jakub Motl: "Impact of the momentary speed of vehicles on their braking distance“, supervised by doc. Ing. Aleš Vémola, PhD, USI Brno 2010; due to the difficulties we encountered in providing cargo vehicles for our own measurements we wanted to perform.

2. Basic physical relationships.

We are to begin with the known information that kinetic energy of a moving vehicle changes during braking to resistance; it holds that:

$$E_k = A_e \tag{1}$$

$$\frac{m.v^2}{2} = F.s_e \tag{2}$$

$$\frac{m.v^2}{2} = G.\mu.s_e \tag{3}$$

$$\frac{m.v^2}{2} = m.g.\mu.s_e \tag{4}$$

As already said, basic mathematical rules imply that m (vehicle weight) reduces itself as can be seen on both sides of the equation, then:

$$\frac{v^2}{2} = g.\mu.s_{v_e} \tag{5}$$

We used the symbol s_v as the length of the own braking distance, thus, the above relationship results in:

$$s_v = \frac{v^2}{2.g.\mu_e} \tag{5}$$

The said relationship therefore implies that the length of the braking distance does not depend on the vehicle weight. Based on our experience we can ask whether it is really true that the length of the braking distance does not depend on the total vehicle weight; our intention is to clarify this issue in the paper.

3. Methods for testing brakes of road vehicles

Braking systems of vehicles have, with regard to the road traffic safety, one of the foremost places in order of functional parts directly impacting safety of driving.

Basic requirements for vehicle brakes can be summarised as follows:

- brakes should ensure prompt and reliable stopping or slowing down at speed, status of vehicle load and inclination of driving line occurring during traffic. The braking system shall be, therefore, capable of inducing the required braking power on the perimeter of all wheels,
- the braking effect of individual vehicle wheels shall be divided to wheels so as not to disturb directional stability of the vehicle during braking,
- the braking effect shall be created also in case of increased temperature of brake components, for instance during repeated intensive braking,
- achievement of the suitable amount of controlling powers on the breaking pedal,
- achievement of the minimum delay in the start of the pressure of the braking system.

The basic division of methods of testing brakes of road vehicles is the following:

- method of outdoor driving testing,
- rolling brake test room.

Outdoor driving testing of road vehicles aimed at brakes is performed especially for the purpose of practical measurement of required values including:

- braking distance,
- braking retardation,
- braking time,
- initial braking speed,
- other (such as controlling power on the braking pedal).

We currently use under conditions of laboratory equipment of the Department of Road and Urban Transport two devices: a measuring device Correvit with evaluating unit EEP-2 and decelerometer with commercial designation XL Meter (Figure 1).

Figure 1. XL Meter.

We used the decelerometer XL Meter for driving test measurement of braking distances in dependence on the momentary vehicle weight. This is a universal accelero- or decelero-meter with alphanumeric LCD display serving for the measurement and evaluation of vehicle acceleration and condition of operational brakes, with simple operation. This decelerometer enables measurement of basic values such as braking distance, braking retardation, braking time and initial speed of braking. The capacity of performed records is 8 measurements with max. duration of recording 80 seconds with frequency of data storage 200 Hz. The time of start and end of braking is determined on the grounds of measured characteristics. The time of braking (Tbr) is calculated by the difference of the initial and final time of braking. The value of the initial vehicle speed is calculated by integration of acceleration data in the braking interval. The braking distance So is then calculated as the double integral of acceleration in the braking interval.

4. Practical measurements on a passenger vehicle

We performed measurements on a passenger vehicle on the grounds of facts as stated in part 3 of the paper. The Department of Road and Urban Transport uses the vehicle Citroen C6 (Fig. 2) for outdoor driving testing. Measurements were made on the test road, which is the landing field of the former agricultural airport in the village Rosina near Žilina. The test road surface is dry rough asphalt.

Measurement conditions:

- the vehicle has the pressure in tires in compliance with the manufacturer's recommendations,
- alternatives to measurement of a full and empty vehicle,
- marking the place of the braking start,
- initial speed of braking provided with the vehicle CC.

Figure 2. Outdoor driving test of the passenger vehicle.

The fully occupied vehicle was the condition when there were 4 more persons in addition to the driver present in the vehicle with total weight of 270kg and cargo in the baggage compartment with weight of 30 kg, i.e. the momentary vehicle weight was increased by 300 kg. The braking of the vehicle took place from the speed of 60 $km.h^{-1}$ and we performed 20 measurements for both conditions (full and empty vehicle). Detailed results of measurements are shown in Tab. 1.

Table 1. Measurement results of the passenger vehicle

n. of m.	Unloaded			
	s (m)	v (km.h^{-1})	t (s)	b (m.s^{-2})
1	19.06	60.93	2.12	8.76
2	20	61.7	2.15	9.39
3	18.8	60.83	2.11	8.49
4	17.07	59.82	1.96	9.4
5	17.61	60.24	1.99	9.31
6	17.34	59.58	1.97	9.14
7	17.01	59.8	1.98	9.35
8	18.32	61.65	2.01	9.16
9	19.56	61.1	2.17	7.79
10	17.97	60.64	2.05	8.7
11	18.48	60.38	2.08	8.62
12	18.64	60.84	2.04	9.43
13	18.73	60.69	2.18	8.65
14	19.38	61.53	2.11	9.04
15	18.56	60.89	2.11	8.94
16	17.69	60.2	1.99	9.2
17	22.3	61.33	2.41	8.14
18	17.8	59.19	2.04	8.63
19	19.28	61.34	2.14	8.26
20	16.97	58.78	1.99	8.92
average	18.53	60.57	2.08	8.87
n. of m.	Loaded			
	s (m)	v (km.h^{-1})	t (s)	b (m.s^{-2})
1	18.82	61.8	2.1	8.21
2	18	59.75	2.07	8.78
3	17.84	59.47	2.08	8.92
4	17.71	58.48	2.06	8.83
5	17.57	58.84	2.05	9.28
6	17.86	60.21	2	9.21
7	18.6	59.5	2.11	9.18
8	18.65	59.56	2.09	9.57
9	19.48	59.81	2.18	8.87
10	18.08	59.34	2.07	9.05
11	18.13	59.57	2.15	8.83
12	18	59.28	2.09	9.14
13	18.14	58.61	2.1	8.86
14	17.06	59.07	2	9.19
15	17.83	59.43	2.03	9.3
16	17.46	59.36	1.99	9.2
17	16.91	58.34	1.97	9.34
18	19.67	60.37	2.13	9.11
19	18.42	60.91	2.04	9.36
20	20.47	60.04	2.22	8.88
average	18.24	59.59	2.08	9.06

Measurement results of the loaded and unloaded passenger vehicle can be considered almost identical. Differences in the value of the braking distance are minimal.

In order to better understand the results of outdoor driving tests, braking power measurements in the rolling brake test room at the Technical Control Station /STK/ Žilina Šibenice were subsequently performed. Again, two measurements were performed, with the loaded and unloaded vehicle. The purpose of the measurement was to determine differences between braking powers. Measured values of braking powers are shown in Tab. 2.

Table 2. Measurement results of the passenger vehicle

	Unloaded		
	left (kN)	right (kN)	together (kN)
Front brake	4.1	4.49	8.59
Rear brake	2.66	2.51	5.17
Axle	6.76	7	13.76
	Loaded		
	left (kN)	right (kN)	together (kN)
Front brake	4.9	5.12	10.02
Rear brake	3.59	3.55	7.14
Axle	8.49	8.67	17.16

The passenger vehicle not loaded during the measurements in the rolling brake test room achieved the total value of braking powers on the front and rear axle 13.76 kN. This value increased after loading the vehicle to 17.16 kN. The result of this test shows that the loaded vehicle is able to induce higher braking power until the wheels are blocked. This fact can be considered the main reason why comparable results of the vehicle braking distance for both the loaded and unloaded vehicle were obtained during outdoor driving tests.

Figure 3. Passenger vehicle in the rolling brake test room

5. Practical measurements of a cargo vehicle

There is an assumption that a significantly differing situation during practical measurements of braking distances will occur upon usage of various types of road vehicles, especially if we consider the size of useful weight. It can be logically assumed that cargo vehicles with high value of usability of the useful weight will reach more significant differences in braking distances before and after loading than the passenger vehicle the useful weight of which is incomparable. The majority of useful weight of passenger vehicles is formed by passengers in the vehicle or other small cargo in the baggage compartment.

Due to the reasons specified in the introduction we used results of this measurement from the mentioned diploma thesis. The author performed practical measurements on the cargo vehicle Scania P 380. The load of the vehicle changed during measurements from the status of fully loaded (24 060 kg), partially loaded (16 980 kg) and empty vehicle (11 660 kg). 8 measurements of the braking distance were performed for each of the said conditions from the speed 35 and 55 $km.h^{-1}$. Measurement results are shown in Tab.3 for the reference speed 35 $km.h^{-1}$ and in Tab.4 for the reference speed 55 $km.h^{-1}$.

Table 3. Measurement at speed 35 $km.h^{-1}$

	Loading		
	Empty	Partial	Full
Average speed ($km.h^{-1}$)	36.61	35.36	36.79
Average braking distance (m)	7.79	8.31	10.24
Average braking time (s)	1.53	1.67	1.97
Average value of MFDD ($m.s^{-2}$)	7.35	6.58	5.7

Table 4. Measurement at speed 55 $km.h^{-1}$

	Loading		
	Empty	Partial	Full
Average speed ($km.h^{-1}$)	58.06	58.54	58.24
Average braking distance (m)	19	20.51	23.93
Average braking time (s)	2.38	2.49	2.93
Average value of MFDD ($m.s^{-2}$)	7.18	7.06	6.09

The results show that the biggest difference of the measured braking distance occurred at the speed 58 $km.h^{-1}$ of full and empty vehicle, namely almost 5 metres and the difference of the achieved braking retardation was app. $1m.s^{-2}$.

Of course, it would be necessary to perform more driving tests and measurements, especially starting from higher initial speeds of vehicles, in order to further explain differences in the length of braking distance and braking retardation. We would probably find even bigger differences in the length of the braking distances and in achieved braking retardation. We intend to perform such measurements in the future.

6. Conclusion

These findings are important for experts from the field of road transport, because it was experimentally found that for solving traffic accidents the momentary weight of a vehicle does not have any impact on the length of the braking distance or on the value of the braking retardation. Regarding the solution of cargo vehicles traffic accidents, the momentary weight of vehicles does have impact on the length of the braking distance and on the value of braking retardation and the expert can thus already base his/her conclusions on specific measured values, for instance, of braking retardation, which are used for certain analytical solving of traffic accidents. However, we would like to repeat that it is necessary to perform further practical measurements for higher speeds of vehicles.

These findings and results make clear that the momentary weight of a vehicle does have an impact on the length of the braking distance and on the value of achieved braking retardation. However, it cannot be derived that basic physical relationships stated in the first part of paper do not apply here. The length of the braking distance and the achieved value of braking retardation depend on the value of the braking power. The value of the braking power depends on the design of brakes and on their dimensioning. The dimensioning of brakes is not a problem for passenger vehicles, but it is a clear problem for cargo vehicles and, therefore, the above said differences of length of braking distances and value of braking retardations were measured for the cargo vehicle upon the change of the momentary weight of the cargo vehicle.

REFERENCES

[1] Anton Hudák, Ján Vrábel, "Faktory ovplyvňujúce bezpečnosť styku pneumatiky a vozovky", ŽU Žilina, Transport and Communication, vol.6, no.1, ISSN 1336-7676, 2010.

[2] Vladimír Rievaj, Ján Vrábel, "Vplyv hustenia pneumatik na brzdovú dráhu vozidla" , in CMDTUR Žilina, ISBN 978-80-554-0512-4, 2012.

[3] Rafal S. Jurecki, Marek. Jaškiewicz, Marek. Guzek, Zbigniew. Lozia, Piotr. Zdanowicz. "Driver's reaction time under emergency braking a car - Research in a driving simulator", Lista Filadelfijska, Eksploatacja i Niezawodnosc, 295-301, ISSN 1507-2711, 2012.

[4] J. Motl, A. Vémola, Š. "Vliv okamžité hmotnosti vozidel na jejich brzdovou dráhu", Vysoké učení technické, Česká republika, 2010.

[5] M. Jaskiewicz , Š. Liščák. "Wprowadzenie do systemów transportowych", Podrecznik Akademicki, Wydawnictwo Politechniki Świetokrzyskiej, Polsko, 2013, PL ISBN 978-83-63792-00-8.

[6] Rafal S. Jurecki, T. L. Stańczyk, Marek Jaśkiewicz, "Research of driver reaction time in accident situations" , in 11-Th International Technical System Degradation Conference, Slovakia, p 25-27, ISBN 978-83-930944-3-1.