light luggage trailer, brake deceleration, modeling of traffic accidents

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BRAKE DECELERATION OF CARS WITH LIGHT LUGGAGE TRAILERS

Summary. This paper presents some aspects of employing measurements of deceleration for the technical analysis of the brake process of cars with light luggage trailers. The analysis of the deceleration enables to assess the technical state regarding traffic safety and it can also be used for analysing the course of traffic accidents. The measurements of deceleration enables to determine the influence of load on the brake process for different kinds of cars. This method can be employed as the only way of examining during the periodical inspections and services for some kinds of trailers.

OPÓŹNIENIE HAMOWANIA SAMOCHODÓW OSOBOWYCH Z LEKKIMI PRZYCZEPAMI TOWAROWYMI

Streszczenie. W artykule przedstawiono niektóre aspekty wykorzystania pomiaru opóźnienia hamownia do analizy procesu hamowania samochodu osobowego z lekką przyczepą bagażową. Analiza przebiegu opóźnienia hamowania umożliwia ocenę stanu technicznego w aspekcie bezpieczeństwa w ruchu drogowym oraz może być wykorzystywana w analizie przyczyn kolizji drogowych. Pomiar opóźnienia hamowania umożliwia określenie wpływu ładunku na przebieg procesu hamownia dla różnych typów pojazdów. W przypadku niektórych typów przyczep jest jedyną metodą, którą można zastosować zarówno podczas obsługi pojazdu, jak i okresowego badania technicznego.

1. INTRODUCTION

Braking is one of the frequent manoeuvres in road traffic. The effectiveness of braking depends on psychophysical state of drivers as well as technical state of vehicles, state of road surface, etc. [3, 4]. One of the ways to evaluate the braking process is the analysis of the course of brake deceleration. Examining the course of braking deceleration is the only way of assessing brake manoeuvres in the set of vehicles consisting of a car (tractor unit) and a trailer. The analysis of the course of deceleration is extremely important for reconstructing of car accidents.

Taking into account mean values of brake deceleration presented in literature, without considering the courses of changes of values of brake deceleration, can lead to considerable diversities between the results of calculations of parameters which characterise the course of braking process, such as the brake distance and car's velocity after a particular period of brake time. Some parameters such as maximum brake force on wheels, the dependence of the value of brake force on the wheels from the value of pressure on the brake pedal for individual cars, can be defined on the basis of measurements performed at diagnostic workstations which are equipped with control units for measuring brake forces on the wheels. Determining the parameters of brake course for sets of vehicles (car – trailer) is only possible during road tests.

2. ANALYSIS OF BRAKING PROCESS OF A CAR WITH TRAILER

Schematic diagram of forces acting on a car with single axle trailer has been presented in Fig. 1 [5, 6, 7].

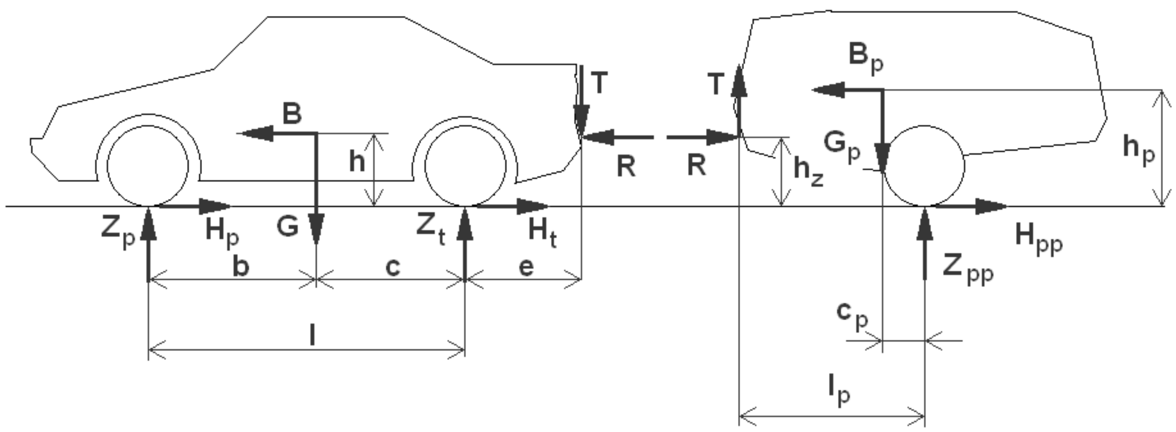

Fig. 1. Diagram of acting forces during brake process
Rys. 1. Schemat sił działających podczas procesu hamowania

H_H brake force, as well as driver force is tangent to wheel circumference. Its value can be expressed by the following formula:

$$F_H = \frac{M_H}{r_d} \tag{1}$$

where: M_H – moment of braking, r_d – dynamic radius of the wheel

This dependence applies only to one wheel, one axle or the entire vehicle, in the case when M_H is the moment of braking of one wheel, one axle or the entire vehicle. However most frequently braking force at front axle F_{HP} and rear axle F_{HT}, is taken into consideration, where total brake force in such case is:

$$F_H = F_{HP} + F_{HT} = \frac{M_{HP}}{r_d} + \frac{M_{HT}}{r_d} = \frac{M_H}{r_d} \tag{2}$$

where: M_{HP} – moment of braking of front axle, M_{HT} – moment of braking of rear axle.

F_H brake force results in tangent reaction H which counteracts the movement opposite to the direction of car's movement, and it can be expressed by the following formula:

$$H = H_P + H_T \tag{3}$$

where: H – tangent reaction counteracting the movement of car, H_P – tangent reaction of front axle counteracting the movement of car, H_T – tangent reaction of rear axle counteracting the movement of car.

In the case, where all wheels of a car and trailer are locked, the brake deceleration can be expressed by the formula:

$$a = \mu_s \cdot g \tag{4}$$

where: μ_s – value of the sliding coefficient of adhesion at the locked wheels.

When the trailer is not braking and all wheel of a car are locked, equation 4 can be expressed by the formula:

$$a = \mu_s \cdot g \cdot \frac{1}{1+q} \tag{5}$$

where: $q = \frac{m_p}{m_s}$ is the ratio of weight (mass) of a trailer to the weight (mass) of a car (tractor).

Including the load of a car by the trailer (by force acting one the hook) equation 5 can be expressed by the formula:

$$a = g \cdot \mu_s \frac{1 + q \cdot \frac{c_p}{l_p}}{1 + q \cdot \left(1 - \frac{h_p - h_z}{l_p} \cdot \mu_s\right)} \tag{6}$$

When the trailer is not braking and the car uses a full tractive adhesion on the wheel of one axle, the value of the limited adhesion factor can be expressed by the formula:

$$\mu = \frac{\varphi - \frac{c}{l}}{\frac{h}{l} + q \cdot \left[1 - \frac{h_p - h_z}{l_p} \cdot \left(\frac{e}{l} + \varphi\right)\right]} \tag{7}$$

where: φ – brake-force distribution coefficient.

For locked wheels of front axe, the brake deceleration can be expressed by the formula:

$$a = g \cdot \frac{\mu_p \cdot \left(\frac{c}{l} - q \cdot \frac{c_p}{l_p} \cdot \frac{e}{l}\right)}{(1+q) \cdot \varphi - \mu_p \cdot \left[\frac{h}{l} + q \cdot \left(\frac{h_z}{l} - \frac{h_p - h_z}{l_p} \cdot \frac{e}{l}\right)\right]} \tag{8}$$

For locked wheels of rear axle, deceleration of the set (car with trailer) can be expressed by the formula:

$$a = g \cdot \frac{\mu_p \cdot \left[\frac{b}{l} + q \cdot \frac{c_p}{l_p} \cdot \left(1 + \frac{e}{l}\right)\right]}{(1+q) \cdot (1-\varphi) + \mu_p \cdot \left\{\frac{h}{l} + q \cdot \left[\frac{h_z}{l} - \frac{h_p - h_z}{l_p} \cdot \varphi \cdot \left(1 + \frac{e}{l}\right)\right]\right\}} \tag{9}$$

If a trailer is equipped with overrunning brake, and all wheels of car are locked, assuming a linear relation between braking force of the trailer to the force on the tow bar *R*,

$$H_{pp} = k \cdot R \tag{10}$$

the deceleration of a set can be expressed by formula:

$$a = g \cdot \frac{\mu_s \cdot \left(1 + q \cdot \frac{c_p}{l_p}\right)}{1 - q\left[\frac{h_p}{l_p} \cdot \mu_s + \frac{1}{1+k} \cdot \left(1 - \frac{h_z}{l_p}\right) \cdot \mu_s\right]} \tag{11}$$

When a trailer in braking by overrunning brake without locking wheels and a car uses a full grip on one axle then,

$$\mu_{gr} = \frac{\varphi - \frac{c}{l} + q \cdot \left(\frac{e}{l_p} + \varphi\right)}{\frac{h}{l} + q \cdot \left[\frac{1}{1+k} - \left(\frac{h_p}{l_p} - \frac{1}{1+k} \cdot \frac{h_z}{l_p}\right) \cdot \left(\frac{e}{l} + \varphi\right)\right]} \tag{12}$$

When the wheels of front axle are locked, the brake deceleration of set can expressed by the formula:

$$a = g \cdot \frac{\mu_p \cdot \left(\frac{c}{l} - q \cdot \frac{c_p}{l_p} \cdot \frac{e}{l}\right)}{\varphi + \frac{1}{1+k} \cdot q \cdot \left[\varphi - \mu_p \cdot \left(\frac{h_z}{l} + \frac{e}{l} \cdot \frac{h_z}{l_p}\right)\right] + \mu_p \cdot \left(q \cdot \frac{e}{l} \cdot \frac{h_p}{l_p} - \frac{h}{l}\right)} \tag{13}$$

When the wheels of rear axle are locked, the brake deceleration of set can expressed by the formula:

$$a = g \cdot \frac{\mu_p \cdot \left[\frac{b}{l} \cdot q\right] + \frac{c_p}{l_p}\left(1 + \frac{e}{l}\right)}{1 - \varphi + \frac{1}{1+k} \cdot q \cdot \left\{1 - q + \mu_p \cdot \left[\frac{h_z}{l} + \left(1 + \frac{e}{l}\right) \cdot \frac{h_z}{l_p}\right]\right\} + \mu_p \cdot \left[\frac{h}{l} - \left(1 + \frac{e}{l}\right) \cdot q \cdot \frac{h_p}{l_p}\right]} \tag{14}$$

3. RESULTS OF MEASUREMENTS

Measurements of brake deceleration during road tests were carried out for two cars M1 category and two light luggage trailers with one axle. The tests have been performed for empty trailers and weighted by 250 kg mass. Types and mass of vehicles have been shown in Tab. 1.

Table 1

Types and mass of vehicles which were used for tests

Type of vehicle	Actual mass, kg
SUV	1580
Car – sedan	1325
Trailer without overrunning brake	150
Trailer with overrunning brake	190

Both cars were equipped with ABS. The types of sets tractor – trailer have been shown in Tab. 2. The road tests were carried out on the flat area with dry asphalt surface. The air temperature was +25^{o}C, wind speed was less than 1 m/s.

Table 2

Types of sets tractor – trailer which were used for tests

No of test (case)	Type of car	Type of trailer	Load of trailer, kg
1	SUV	without brake	250
2	SUV	without brake	0
3	SUV	with overrunning brake	250
4	SUV	with overrunning brake	0
5	sedan	without brake	250
6	sedan	without brake	0
7	sedan	with overrunning brake	250
8	sedan	with overrunning brake	0

Speed of cars was measured by the hand radar device Bushnell Radar Gun. Brake deceleration was measured by two decelerometers - MAHA VZM 300 i Elhos OP1.

Sample results of the tests for the particular cases have been shown in Fig. 2-9. The results concerning emergency braking in order to stop the vehicles have been presented as well.

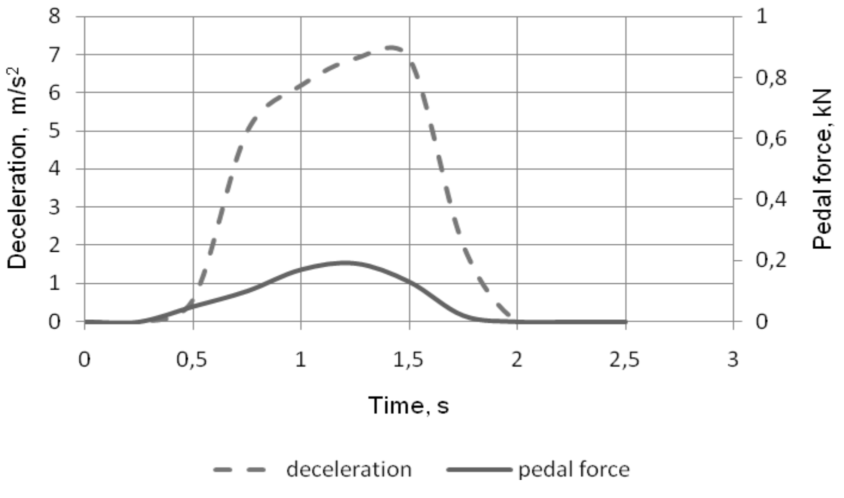

Fig. 2. The course of brake deceleration – case 1

Rys. 2. Przebieg opóźnienia hamowania – przypadek 1

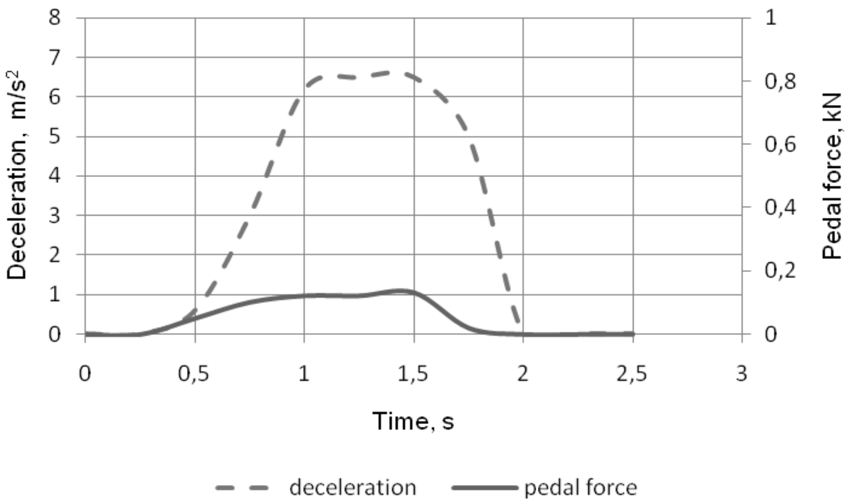

Fig. 3. The course of brake deceleration – case 2
Rys. 3 Przebieg opóźnienia hamowania – przypadek 2

Brake distance for each value of measured deceleration, for a particular test, was calculated. The calculations were carried out for initial speed of 30 km/h. Examples of calculation results have been presented in Tab. 3-6.

Table 3

Measured and calculated braking distance for a set (SUV – trailer) without brake system

Type of test	Initial speed, km/h, (m/s)	Actual braking distance $s_H = \frac{V_0^2}{2 \cdot a_H}$ [m]	Calculated braking distance for initial speed of 30 km/h $s_{H(30)} = \frac{V_{0(30)}^2}{2 \cdot a_H}$ [m]
Braking with load	36 (10,00)	7,37	5,11
Braking without load	39 (10,83)	8,14	4,81

Table 4

Measured and calculated braking distance for a set (SUV – trailer) with brake system

Type of test	Brake deceleration, m/s^2	Initial speed, km/h, (m/s)	Actual braking distance $s_H = \frac{V_0^2}{2 \cdot a_H}$ [m]	Calculated braking distance for initial speed of 30 km/h $s_{H(30)} = \frac{V_{0(30)}^2}{2 \cdot a_H}$ [m]
Braking with load	6,92	39 (10,83)	8,47	5,01
Braking without load	6	29 (8,05)	5,4	5,78

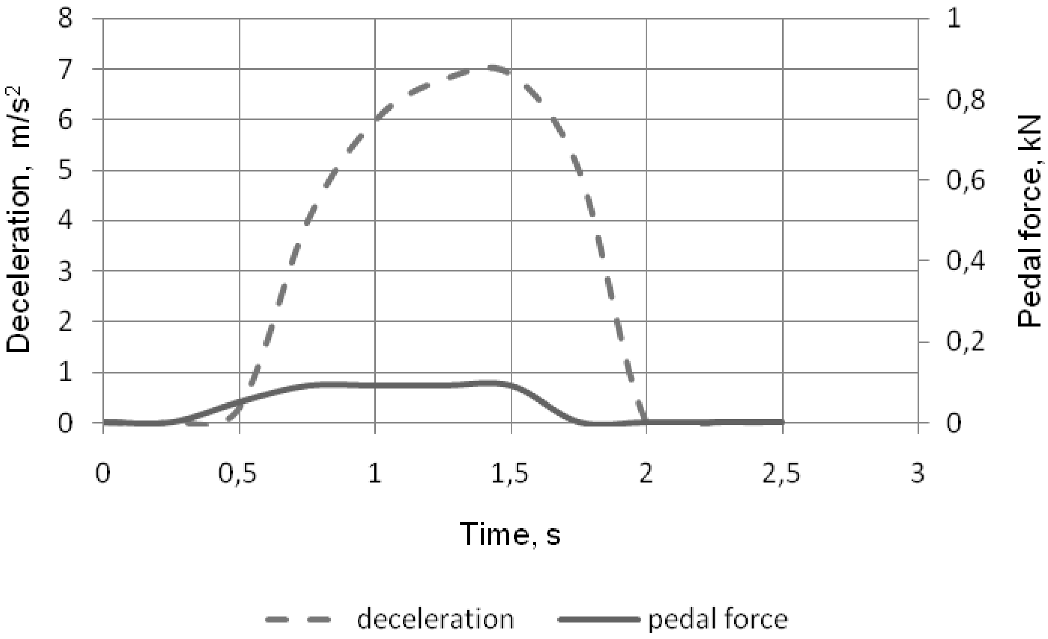

Fig. 4. The course of brake deceleration – case 3
Rys. 4. Przebieg opóźnienia hamowania – przypadek 3

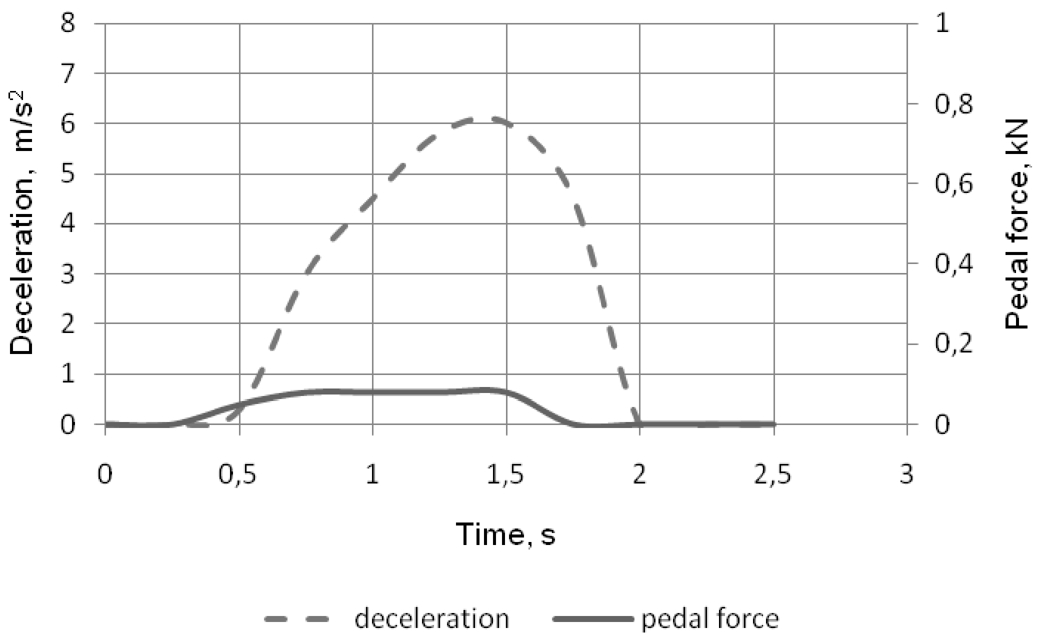

Fig. 5. The course of brake deceleration – case 4
Rys. 5. Przebieg opóźnienia hamowania – przypadek 4

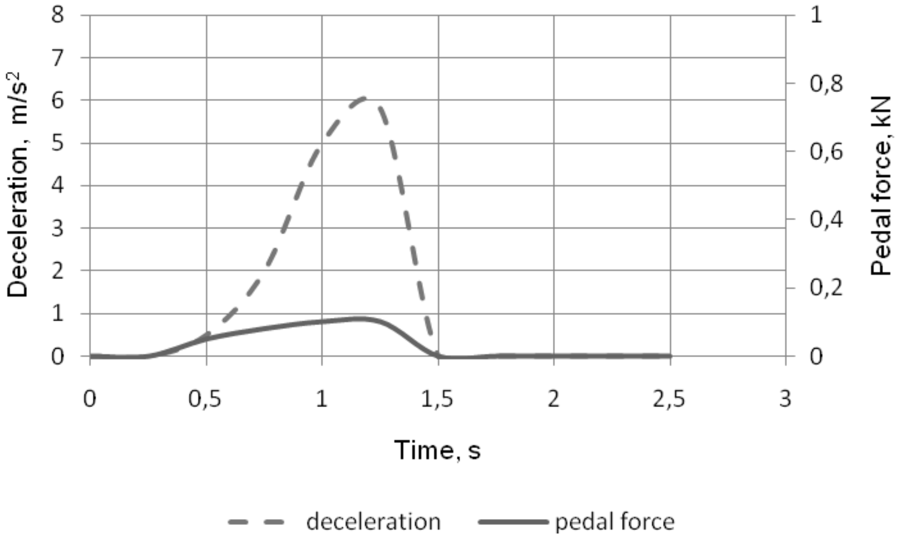

Fig. 6. The course of brake deceleration – case 5
Rys. 6. Przebieg opóźnienia hamowania – przypadek 5

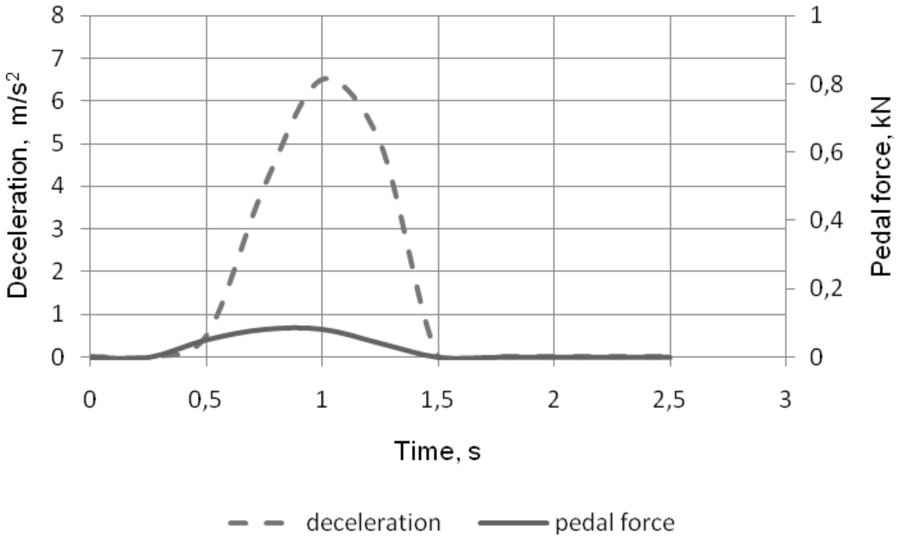

Fig. 7. The course of brake deceleration – case 6
Rys. 7. Przebieg opóźnienia hamowania – przypadek 6

Table 5

Measured and calculated braking distance for a set (sedan – trailer) without brake system

Type of test	Initial speed, km/h, (m/s)	Actual braking distance $s_H = \frac{V_0^2}{2 \cdot a_H}$ [m]	Calculated braking distance for initial speed of 30 km/h $s_{H(30)} = \frac{V_{0(30)}^2}{2 \cdot a_H}$ [m]
Braking with load	30 (8,33	5,91	5,91
Braking without load	34 (9,44)	6,59	5,13

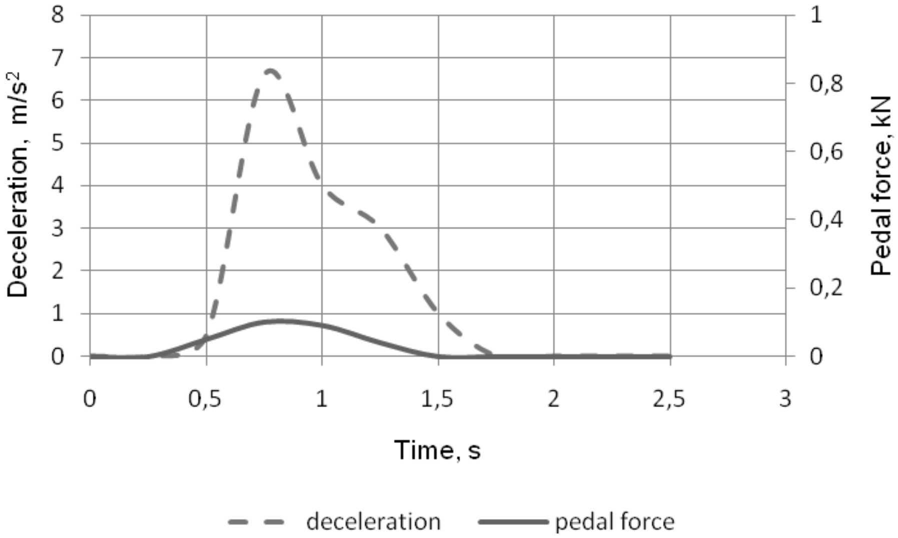

Fig. 8. The course of brake deceleration – case 7
Rys. 8. Przebieg opóźnienia hamowania – przypadek 7

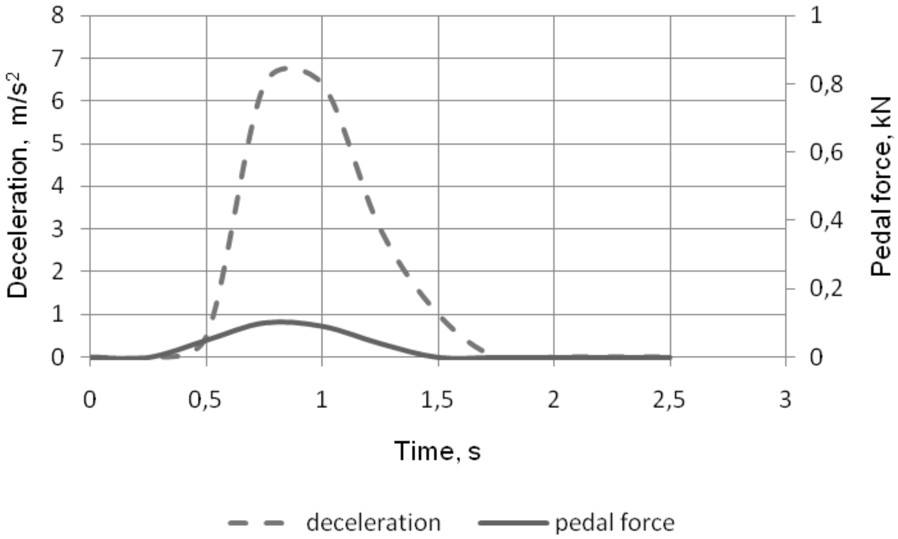

Fig. 9. The course of brake deceleration – case 8
Rys. 9. Przebieg opóźnienia hamowania – przypadek 8

Table 6

Measured and calculated braking distance for a set (sedan – trailer) with brake system

Type of test	Brake deceleration, m/s^2	Initial speed, km/h, (m/s)	Actual braking distance $s_H = \frac{V_0^2}{2 \cdot a_H}$ [m]	Calculated braking distance for initial speed of 30 km/h $s_{H(30)} = \frac{V_{0(30)}^2}{2 \cdot a_H}$ [m]
Braking with load	6,38	34 (9,44)	6,98	5,43
Braking without load	5,88	34 (9,44)	7,57	5,89

4. CONCLUSIONS

The course of brake deceleration of a set tractor – trailer depends largely on the type of trailer and mass of load on the trailer. Brake distance can be shorter for a trailer with load, compared with unloaded trailer when a trailer is equipped with brake system.

The tests have shown that the calculation of brake distance for these type of vehicles (set of vehicles) should be made using the values of deceleration which were obtained during road tests. Recording and analysing of the course of value of deceleration, allows to determine the speed of a vehicle at any point of time during the braking process and any irregularities of courses of brake deceleration as well as faults of brake s systems in trailers can be detected.

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