Influence of road conditions on the values of longitudinal acceleration during braking of a tourist coach

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Abstract. The paper aims to analyse the longitudinal acceleration of a tourist coach on various road pavements. As part of the experimental research, braking tests were carried out at a speed of 30 km/h and acceleration to a speed of 30 km/h. The tests were carried out on four types of pavement, i.e. dry and wet asphalt and dry and wet concrete. The article describes the impact of road conditions on the braking and acceleration performance on selected road pavement types. To increase the reliability of the test results, ten tests were carried out for each tested pavement. Based on the test results, graphs of braking decelerations and accelerations during accelerating the vehicle as a function of time. This allowed for statistical analysis of the recorded decelerations and accelerations.

Keywords - acceleration, braking tests, automotive safety, road conditions

1. Introduction

The braking system is one of the most important active safety systems in motor vehicles. The system is designed to reduce the driving speed and immobilise the vehicle in the place specified by the driver [1-3]. Under emergency braking conditions, the type of pavement and the vehicle cargo have a significant impact on the deceleration value and the braking distance [4]. Moreover, technical condition of the braking system and the type and condition of tyres [5,6] also affect braking efficiency. The maximum value of deceleration during emergency braking is limited by the force of adhesion of the vehicle tyres to the ground. There are many methods used to test the performance of braking systems. One of them is the measurement of braking deceleration.

Two methods can be distinguished to determine the maximum value of braking deceleration [3, 7]:

– braking test with direct or indirect braking deceleration measurement,
– braking test with measurement of the stopping/braking distance.

To use the first method, it is necessary to install the equipment that records the course of braking deceleration, distance or speed [8,9]. The significant advantage of this method is that there is no need to determine the initial braking speed in a precise way.

As reported in the specialised literature, the simplest available devices for recording the speed or deceleration of the vehicle during the braking test can provide satisfactory results, allowing to determine the mean fully developed deceleration index (MFDD) or braking efficiency. These devices include acceleration sensors or speed recorders using the GPS signal [3]. Another parameter that allows assessing the braking performance is the value of the mean fully developed deceleration $a_{\mu}$. 
Braking deceleration can also be determined by analysis of the braking marks left on the pavement but such analysis may lead to significant errors. This is due to difficulties in determining the actual length of the braking marks and the speed of the vehicle at the beginning of the braking marks [10, 11]. In addition, it should be taken into account that testing vehicles equipped with ABS system may be difficult in this case, as the lack of skidding may make it impossible to find braking traces [12-14].

A more accurate method of determining the braking deceleration is the registration of the vehicle speed during harsh braking [15-18]. By recording the course of speed as a function of time, it is possible to determine the mean value of deceleration of the vehicle braking by linearising the course of speed.

2. Object of research

An Apollo 970.28 coach was used to carry out the measurements. The coach was manufactured by Automet company from Sanok based on MB Atego 1222L. The coach is equipped with a Mercedes OM 904 LA (BlueTec 4) engine with a maximum power of 130 kW (177 HP). Basic technical data of the coach are presented in Table 1 [19].

| Table 1. Technical data of the Apollo 970.28 coach [19] |
|---------------------------------------------------|
| Length | 9,760 mm |
| Width  | 2,440 mm |
| Height | 3,130 – 3,380 mm |
| Gross vehicle weight (GVW) | 11,990 kg |
| Number of seats | 36 |
| Wheelbase | 4,220 mm |
| Gearbox | 6 - speed, manual |
| Maximum speed | 130 km/h |
| Type of the engine | Mercedes OM 904 LA |
| Engine power | 75-130kW at 2,200 rpm |
| Torque | 400-670Nm at 1,200-1,600 rpm |
| Engine displacement | 4,249 cm³ |

The coach is equipped with a dual-circuit brake system with disc brakes on the front and rear axles, ABS system and parking brake. In addition, the vehicle is equipped with an electromagnetic retarder coupled with the gearbox. The photo of the coach is shown in Figure 1.
3. Experimental research and their analysis
An Apollo coach equipped with ABS system was used for the tests. The wheels of the vehicle were fitted with 245/70 R17.5 91H (Fulda Regioforce) tyres with a tread depth of approx. 8 mm and the nominal pressure recommended by the vehicle manufacturer. Road tests and the measurement of the maximum longitudinal acceleration values were carried out on dry and wet asphalt pavement and the dry and wet concrete pavement during harsh braking. The braking testing procedure was carried out at a speed of 30 km/h. There were three people on the coach during the measurements. For measuring and recording the results, research equipment was used, including S-350 Aqua Datron® optoelectronic sensor for measuring longitudinal speed and Datron uEEP-12® data acquisition station with ARMS® data acquisition and analysis software. In addition, TAA™ Datron and TANS™ Datron triaxial linear acceleration sensors were used to measure linear and angular accelerations.

Based on the curves of acceleration recorded in 10 tests during harsh braking on various pavements, the maximum, minimum and mean acceleration values were determined, as well as standard mean deviation SD and quantiles 0.1 and 0.9.

Figure 2 presents examples of recorded acceleration values during the process of harsh braking at a speed of 30 km/h on dry asphalt. The results of the measurements and calculations are presented in Table 2.

![Figure 2. Diagrams of longitudinal acceleration during harsh bus braking at a speed of 30 km/h on a dry asphalt pavement performed during 10 tests](image-url)
Table 2. The acceleration statistics during the harsh braking of the coach at a speed of 30 km/h on different pavements

| Measurement No. | acceleration, a [m/s²] | type of pavement | dry asphalt | wet asphalt | dry concrete | wet concrete |
|-----------------|-------------------------|-----------------|-------------|-------------|--------------|--------------|
| 1               | -8.688                  |                 | -7.926      | -7.44       | -7.497       |              |
| 2               | -8.221                  |                 | -8.742      | -7.284      | -6.232       |              |
| 3               | -8.863                  |                 | -7.88       | -8.018      | -6.543       |              |
| 4               | -8.835                  |                 | -8.577      | -8.119      | -5.755       |              |
| 5               | -8.697                  |                 | -7.825      | -7.788      | -5.947       |              |
| 6               | -8.807                  |                 | -7.944      | -8.018      | -6.213       |              |
| 7               | -8.842                  |                 | -8.724      | -7.954      | -6.241       |              |
| 8               | -8.349                  |                 | -7.633      | -7.77       | -6.094       |              |
| 9               | -8.294                  |                 | -7.923      | -8.247      | -6.617       |              |
| 10              | -8.239                  |                 | -8.036      | -7.724      | -5.755       |              |
| min             | -8.221                  |                 | -7.633      | -7.284      | -5.755       |              |
| max             | -8.863                  |                 | -8.742      | -8.247      | -7.497       |              |
| mean            | -8.564                  |                 | -8.121      | -7.836      | -6.289       |              |
| SD              | 0.259                   |                 | 0.402       | 0.300       | 0.513        |              |
| Q 0.1           | -8.838                  |                 | -8.726      | -8.132      | -6.705       |              |
| Q 0.2           | -8.237                  |                 | -7.806      | -7.424      | -5.755       |              |

Figure 3 shows a graphical view of the average acceleration values for the same initial braking parameters, calculated based on ten tests carried out on different pavements.

**Figure 3.** Average values of longitudinal acceleration during harsh braking of the coach at a speed of 30 km/h on different pavements.
When analysing the values of the maximum accelerations during the braking of the coach at a speed of 30 km/h, it is clearly visible that the greatest acceleration values occurred for most measurements of braking on dry asphalt, which results from the greatest adhesion of tyres to this pavement $a_{\text{max}} = -8.863 \text{ m/s}^2$. The smallest acceleration values were obtained on the wet concrete pavement, which may be related to the structural characteristics of concrete pavement $a_{\text{max}} = -7.497 \text{ m/s}^2$. The average values of the maximum accelerations during braking shown in Figure 3 confirm the nature of the change in acceleration values depending on the type of pavement. Moreover, when braking on the pavement of wet concrete, the highest value of the mean standard deviation $SD = 2.846$ was obtained.

4. Conclusions
Based on the conducted tests, the maximum and average values of braking accelerations were obtained for a tourist coach on various pavements at a speed of 30 km/h. The test results and their analysis showed the dependency between the type of pavement and the braking efficiency, which was determined by the acceleration statistics. As research shows, obtaining a high value of braking acceleration depends not only on weather conditions but also on the condition and the type of road pavement. The acceleration values specified in the paper were obtained on asphalt and concrete in good technical condition. In the case of asphalt and concrete of lower quality and greater wear, the acceleration will be lower, which should be borne in mind in further research and analysis of the influence of the pavement type and weather conditions on the braking efficiency.

The test results, especially the maximum acceleration values, will be used in further work related to the analysis of active safety during extreme braking. To limit the adverse impact of road conditions, as well as the type and condition of the pavement on the braking efficiency, the speed should always be adjusted to the existing road conditions, but also the vehicle load must be taken into account, which may directly affect the aforementioned active safety of the vehicle.

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