Experimental investigation of the motorcycle braking properties when riding on different road surfaces

Dalibor Barta, Ján Dižo¹, Miroslav Blatnický and Jozef Vaňko

University of Žilina, Department of transport and handling machines, Univerzitná 8215/1, 01026 Žilina, Slovak Republic

¹ E-mail: jan.dizo@fstroj.uniza.sk

Abstract. The presence of motorcycles on the roads significantly affects road traffic and its safety. Avoidance manoeuvres requiring braking and acceleration are closely linked to motorcycle riding. This paper points out the influence of the type of motorcycle and the type of its tyres on the braking distance and the stability of the motorcycle. Two types of motorcycles are compared - road and off-road when riding on two different surfaces and also three ways of braking - only with the front brake, only with the rear brake and with both brakes. The work analyses the problem of braking and stability of a motorcycle. When a brake lever is suddenly pushed, the stability of the motorcycle can be lost. Authors have analysed, compared and evaluated braking distances of motorcycles. Results of investigation activities have shown, that reaching of maximal safe and the shortest braking distance on the certain road surface needs to choose a proper type of motorcycle and a tyre.

1. Introduction

Today’s progress places great emphasis on increasing of performance of all vehicles. It leads to increasing of speed on roads. Therefore, it is necessary to develop elements of safety. The safety of vehicles operation depends on various factors, one hand equipment of transport means, i. e. elements of active and passive safety [1, 2] and on the other hand on operation conditions, i. e. weather conditions [3, 4], quality of infrastructure etc. [5-8] The braking system is the key factor of safety in road transport as well as railway transport [9-11]. The main purpose of brakes is to slow down or to stop a vehicle at any speed. Speed plays a big role in case of traffic accidents. It often decides, whether the participants survive the accident or not. Thus, it is necessary to develop and improve brakes and braking system. The development of these key factors is significantly accelerated by new technologies, new materials and electronic systems. The main aim of braking systems, which we recently know and which are used in vehicles, is to reduce braking distance as well as to ensure steering control and stability of a vehicle.

Braking is aimed at decreasing of driving speed of a vehicle. In case of single-track vehicles, the best braking efficiency is reached on a straight road. For a motorcycle, it is redistributed in rate as following: 60% on a front wheel, 40% on a rear wheel [12-14]. It is typical for motorcycles, that the front and rear brake controls work independently of each other. Hence, distribution of braking force depends on skills of a motorcycle driver. Braking of a motorcycle causes, that the most weight is transferred to the front wheel and the rear wheel is lightened (figure 1). Parameters in this figure are: $G$ – the gravitational force, $G_P$ – the load of the front wheel, $G_Z$ – the load of the rear wheel, $CoG$ – the...
centre of gravity, $\Delta Z$ – change of the wheels load distribution during braking, $l$ – the wheels, $h$ – the height of the CoG, and $F_a$ – the inertial force. Therefore, it is important to distribute properly the braking force between the front and rear wheels. The motorcycle driver motion during braking also plays the significant role [15-17]. The state, when a wheel is locked, is supposed as very dangerous [18-20]. It leads to increasing the braking distance as well as to the possible fall of the motorcycle driver. It means, adhesion of friction surfaces road/tyre is very important [12].

Vlk claims [20], braking closely relates to adhesion. Therefore, it is important to know, whether a road is dry, wet, covered by ice, snow or dirt. There must not be a situation, when the braking effect prevails over the grip of the tyre on the road. Even the strongest brakes will not help, if we are not able to transfer their effects on the road. The best adhesion is reached on a dry road. It is even increased by warming up of the tyre during driving, when a surface softens. Sometimes, the rear wheel locking is not observed until the moment, when it starts to turn on its side. If such a state happened, it is necessary a brake lever to release slowly and carefully [12, 19].

![Figure 1. Wheels load distribution during braking of a motorcycle (the front wheel is loaded due to inertia effects, the rear wheel is unloaded) [12.]](image)

2. Experimental motorcycles and methods

The main goal of the experiment has been to measure and compare the braking distance of two type of motorcycles. These types of motorcycles have been compared:

- enduro motorcycle Yamaha WR450F;
- scooter Keeway ARN 125.

The enduro motorcycle Yamaha WR450F (figure 2) is equipped with a hydraulic braking system. However, it uses a two pistons floating brake caliper on the front wheel and the disc with the diameter of 250 mm and a one piston floating brake caliper on the rear wheel. Tyres pressure has been of 1 bar.

The scooter Keeway ARN 125 (figure 3) has also a hydraulic braking system. The front brake includes a brake disc with a diameter of 220 mm and a fixed brake caliper consisted of two pistons. The rear brake is a drum brake. Tyre pressure has been of 2.3 bar and tyre tread depth of 2.5 mm.

In the preparation phase of experiment realisation, we have chosen a suitable place and conditions for measurement performance. Experiments were performed in the Trebostovo village area (Liptovský Mikuláš district, Slovak Republic). This environment has ensured suitable road and terrain conditions.

The experiment has been realised on two types of road surfaces:

- a dry asphalt road;
- a cart-road.

Motorcycles have been driving on the flat road without road incline. The experiment included three tests, during which behaviour of the motorcycles at heavy braking has been tested. The track length needed for safe acceleration up to the speed of 27 kmh$^{-1}$ has been investigated. This speed has had to be kept until the moment of the braking initiation. After the preparation phase, the measurement of the braking distance followed. Three cases of braking have been investigated:

- braking only by the front brake;
- braking only by the rear brake;
- braking by both front and rear brakes together.
Every type of braking has been performed twelve-times. Both motorcycles has been driven by the same motorcyclist. Braking has been realised at the locking limit. Tests have been realised afternoon about 3 p.m. Tests have been conducted without unexpected circumstances and at weather conditions as following: calm, air temperature of 22°C.

From the safety point of view, grip (adhesion) between a tyre and a road is very important. Therefore, the friction coefficient of the tyre for the given type of a road surface is calculated from measured data.

![Figure 2. The enduro Yamaha WRF450F](image1.png)

![Figure 2. The enduro Yamaha WRF450F](image2.png)

![Figure 3. The scooter Keeway ARN 125](image3.png)

![Figure 3. The scooter Keeway ARN 125](image4.png)

The aim has been to find the adhesion level of motorcycle tyre with the given road surface. Mathematic-statistic methods have been used for further analyses of reached results.

The tyre is a connecting element between a motorcycle and a road. Tyres with the friction coefficient as high as possible are the most suitable for the best transmission of braking forces to the road. The braking distance $s_b$ is given by the known formulation as following:

$$s_b = \frac{v^2}{2g\mu},$$

where $v$ ($\text{ms}^{-1}$) is the motorcycle speed; $g$ ($\text{ms}^{-2}$) is the gravitational acceleration and $\mu$ (-) is the friction coefficient.

Experiments have been focused on comparison of the braking distances of motorcycles. We have aimed at calculation of the friction coefficient $\mu$. The formulation for its calculation is derived from the equation (1). Then, the friction coefficient is calculated as following:

$$\mu = \frac{v^2}{2gs_b}.$$  

3. Measurement of motorcycles braking distances

This section contains results of experimental measurements of motorcycles braking distances. Obtained results of braking distances of the enduro motorcycle Yamaha WRF450 and for the scooter
Keeway ARN 125 driving on an asphalt road and on a cart-road are digestedly arranged in individual subsections containing graphs and tables with measured values.

### 3.1. Braking distances of the enduro motorcycle Yamaha WRF450
Firstly, braking distance of the enduro motorcycle has been measured. Table 1 and figure 4 show results of experiments, when it has been driving on the dry asphalt road.

Example of the calculation of the friction coefficient is given by the equation (3). It is calculated for the dry asphalt, when both brakes are activated. Thus, the friction coefficient is:

\[ \mu = \frac{v^2}{2gs_b} = \frac{\left( \frac{27}{3.6} \right)^2}{2 \cdot 9.81 \cdot 7.23} = 0.396538, \]  

where value of the braking distance \( s_b = 7.23 \) m is taken from table 1 as the average value for the case of braking by both brakes.

**Table 1.** Measured braking distance of the enduro motorcycle Yamaha WRF450 on the dry asphalt road.

| Experiment No. | Front brake (m) | Rear brake (m) | Both brakes (m) |
|----------------|-----------------|----------------|-----------------|
| 1\(^{st}\)      | 8.17            | 11.88          | 7.50            |
| 2\(^{nd}\)      | 8.84            | 11.20          | 7.20            |
| 3\(^{rd}\)      | 8.07            | 11.30          | 7.15            |
| 4\(^{th}\)      | 8.81            | 11.38          | 7.17            |
| 5\(^{th}\)      | 8.53            | 11.60          | 7.44            |
| 6\(^{th}\)      | 8.31            | 11.55          | 7.16            |
| 7\(^{th}\)      | 8.20            | 11.33          | 7.20            |
| 8\(^{th}\)      | 8.33            | 11.29          | 7.15            |
| 9\(^{th}\)      | 8.15            | 11.39          | 7.11            |
| 10\(^{th}\)     | 8.41            | 11.28          | 7.35            |
| 11\(^{th}\)     | 8.22            | 11.43          | 7.20            |
| 12\(^{th}\)     | 8.19            | 11.26          | 7.09            |
| Average         | 8.35            | 11.41          | 7.23            |

Measured values of the braking distances of the enduro motorcycle on the dry asphalt road are negatively affected by the fact, that this motorcycle is designed mainly for driving in a rough terrain and cart-road. These results are likely caused due to tyre tread, which are intended to be used mostly on unpaved roads.
Figure 4. Braking distances of the enduro motorcycle Yamaha WRF450F on the dry asphalt road.

Only in the case of braking by the rear brake, a wheel was locked. When the enduro motorcycle has been braked by the front brake or by both brakes, wheels were not locked. After the test we observed excessive wear of both tyres with naked eye.

As the second test we have performed measurement of the braking distance for the enduro motorcycle driving on the cart-road. Results of this test are listed in table 2 and graphical outputs are shown in figure 5.

Table 2. Measured braking distance of the enduro motorcycle Yamaha WRF450 on the cart-road.

| Experiment No. | Front brake (m) | Rear brake (m) | Both brakes (m) |
|----------------|-----------------|----------------|-----------------|
| 1st            | 5.62            | 17.76          | 5.49            |
| 2nd            | 5.86            | 17.26          | 5.50            |
| 3rd            | 6.00            | 17.16          | 5.34            |
| 4th            | 5.91            | 17.20          | 5.10            |
| 5th            | 5.95            | 17.33          | 5.25            |
| 6th            | 5.80            | 17.25          | 5.45            |
| 7th            | 5.89            | 17.25          | 5.30            |
| 8th            | 5.75            | 17.31          | 5.15            |
| 9th            | 5.86            | 17.50          | 5.27            |
| 10th           | 5.88            | 17.23          | 5.20            |
| 11th           | 5.92            | 17.20          | 5.20            |
| 12th           | 5.79            | 17.29          | 5.22            |
| Average        | 5.85            | 17.31          | 5.29            |

From measured data of the braking distances we can conclude, that the off-road design and properties of the enduro motorcycle Yamaha WRF450F are positively proved during braking on the cart-road. Comparing of the braking distances we have found out this fact: when a motorcyclist has been braking this enduro motorcycle on the cart-road by the front brake or by both brake, the braking distance was shorter in comparison with braking on the dry asphalt road.
Figure 5. Braking distances of the enduro motorcycle Yamaha WRF450F on the cart-road.

Locking of a wheel has been detected just in case of braking by the rear brake and it has hold over during all time of braking. In case of braking by both brakes, the rear wheel was locked and it was detected from braking beginning till stop.

When we substitute the given driving speed (27 kmh⁻¹) and chosen value of the braking distance of 5.28 m (table 2 – average value for braking by both brakes) to the formulation (2), we get the value of the friction coefficient of 0.541961.

3.2. Braking distances of the scooter Keeway ARN 125

Experiments of braking distances measurement proceeded to investigation of braking performance of the scooter Keeway ARN 125 on the dry asphalt road and on the cart-road.

Table 3 contains values of braking distances of the scooter, when it has been driving on the dry asphalt road. Graphical comparison of measured data is shown in figure 6.

Table 3. Measured braking distance of the scooter Keeway ARN 125 on the dry asphalt road.

| Experiment No. | Front brake (m) | Locking of the front wheel, sliding (m) | Rear brake (m) | Both brakes (m) |
|---------------|----------------|----------------------------------------|----------------|-----------------|
| 1st           | 4.48           | -                                      | 8.82           | 3.48            |
| 2nd           | 6.40           | 3.00                                   | 7.43           | 3.23            |
| 3rd           | 5.84           | 1.00                                   | 8.08           | 2.75            |
| 4th           | 5.10           | 0.75                                   | 8.34           | 2.94            |
| 5th           | 4.70           | -                                      | 7.93           | 3.39            |
| 6th           | 4.70           | -                                      | 7.98           | 2.77            |
| 7th           | 4.99           | 0.75                                   | 8.16           | 3.09            |
| 8th           | 4.16           | -                                      | 7.50           | 3.30            |
| 9th           | 4.00           | -                                      | 8.00           | 3.30            |
| 10th          | 4.09           | -                                      | 7.96           | 2.93            |
| 11th          | 4.04           | -                                      | 8.03           | 2.69            |
| 12th          | 4.03           | -                                      | 7.90           | 2.86            |
| Average       | 4.71           | -                                      | 8.01           | 3.06            |
From measured values, which are indicated in table 3 and figure 6 we can see, that on the dry asphalt road in some cases the front wheel was locked. It was in the case of braking only by the front brake. It happened, when the front brake lever was pushed stronger and more intensive. In this case, stability of the scooter was disrupted and the risk of a motorcycle driver fall was higher as well. When the scooter has been braking by the rear brake or both brakes, no wheel was locked. When we were braking by both brakes, we were sensed more stable behaviour of the scooter.

Substituting of driving speed value as well as the average braking distance for braking by both brakes, i.e. 3.06 m we can calculate the friction coefficient. Its value is relatively high, i.e. of 0.936919. It means, this value is on the great level.

Finally, we have performed experiments, when the scooter Keeway ARN 125 was driving on the cart-road. Obtained braking distances are written in Table 4 and comparison of these values is depicted in figure 7.

Table 4. Measured braking distance of the scooter Keeway ARN 125 on a cart-road.

| Experiment No. | Front brake (m) | Rear brake (m) | Both brakes (m) |
|---------------|----------------|---------------|----------------|
| 1st           | 5.67           | 7.84          | 3.47           |
| 2nd           | 5.60           | 6.83          | 3.67           |
| 3rd           | 5.46           | 7.19          | 3.47           |
| 4th           | 5.47           | 6.50          | 2.93           |
| 5th           | 5.92           | 6.54          | 3.47           |
| 6th           | 5.61           | 6.80          | 3.50           |
| 7th           | 5.80           | 6.61          | 3.45           |
| 8th           | 5.71           | 6.94          | 3.48           |
| 9th           | 5.49           | 6.84          | 3.70           |
| 10th          | 5.46           | 6.55          | 3.52           |
| 11th          | 5.50           | 6.58          | 3.48           |
| 12th          | 5.46           | 6.55          | 3.45           |
| Average       | 5.60           | 6.81          | 3.47           |

From detected data of braking distances for the cart-road we can see, that wheels were locked during the whole braking process. Locking occurred in case of using both the front brake and the rear brake.
When the scooter was braked by both brakes, only the rear wheel was locked. The scooter behaved stable on the dry asphalt road as well as on the cart-road in case of braking by both brakes.

The friction coefficient calculated using equation (2) for the driving speed of 27 kmh\(^{-1}\) and for the average braking distance of 3.47 m (both brakes) is of 0.826217. Difference of the friction coefficient value for the braking on the cart-road and on the dry asphalt road is minimal.

### 3.3 Summary of findings

Calculated values of average data of braking distances of the enduro motorcycle Yamaha WRF450F have shown, that differences have been wide. When motorcycle driver has been braked by the front brake, average values have been higher of 2.5 m and in case of using both brakes, the difference has been of 1.94 m. Both values were on the behoof of the braking on the cart-road. Using of the rear brake was critical, because the difference of average values of braking distances was of 5.9 m on the behoof of braking on the dry asphalt road.

The scooter Keeway ARN 125 has not shown such a wide difference of braking distance depending on road surface quality. Nevertheless, braking on the dry asphalt road is safer than braking on the cart-road. Based on obtained data we can see, that the difference of average values of braking distances for braking on the dry asphalt road for the front brake is of 0.89 m and for the both brakes of 0.41 m lower than braking on the cart-road. Wider difference is found out in case of braking just by the rear brake, which is of 1.2 m lower for the cart-road.

From average values listed in table 5 and in figure 8 we can see small difference for the scooter Keeway depending on the road surface quality. The enduro motorcycle Yamaha shows wider differences. We can notice a significantly longer braking distance, when it is braked just by the rear brake on the cart-road than on the dry asphalt road.

### Table 5. Comparison of average values of braking distances of the tested motorcycles.

| Motorcycle      | The dry asphalt road | The cart-road |
|-----------------|----------------------|---------------|
|                 | Front brake (m)      | Rear brake (m)| Both brakes (m) | Front brake (m) | Rear brake (m) | Both brakes (m) |
| Yamaha (enduro) | 8.35                 | 11.41         | 7.23            | 5.85            | 17.31          | 5.29             |
| Keeway (scooter)| 4.71                 | 8.01          | 3.06            | 5.60            | 6.81           | 3.47             |
Figure 8. Average values of the braking distances of the tested motorcycles.

Comparing the values of the friction coefficients (table 6) we have observed, that the level of tyre friction is greater for the scooter Keeway on the dry asphalt road. After all, this tested scooter Keeway has good friction level on both road surfaces. The tested enduro motorcycle Yamaha has better tyre friction on the cart-road and the tyre friction is significantly lower on the dry asphalt road. We suppose, that such a low value of friction coefficient could be caused because of the different type of the tire tread, which is primary given for heavy off-road conditions. Nipples of tires reduce friction surface and it can lead to lower friction coefficient on the rigid road surface.

Table 6. Comparison of the calculated values of the friction coefficient $\mu$ depending of the type of a road surface for tested motorcycles.

| Motorcycle     | The dry asphalt road ($\mu$) | The cart-road ($\mu$) |
|----------------|------------------------------|-----------------------|
| Yamaha (enduro) | 0.396538                     | 0.541961              |
| Keeway (scooter)| 0.936919                     | 0.826217              |

Generally, we can state, that the best braking performance has been reached, when motorcycles have been braking by both brakes. On the contrary, the worst braking performance has been achieved in the case of braking only using the rear brake.

4. Conclusion

The main goal of the experimental measurement was to determine and to compare the braking distances of two types of motorcycles, when they are driving on two different types of road surface qualities as well as to find out the tyre/road friction level. Moreover, we have wanted to justify the fact, that the proper tyre type is very important element for the safe driving on a motorcycle.

From measured data and calculated average values of braking distances of motorcycles we have determine, that the scooter Keeway ARN 125 has similar braking performance on both types of road surfaces. For the dry asphalt road, the braking distance has been shorter for the front brake and for both brakes in comparison with braking only by the rear brake. On the contrary, using of the rear brake has been more efficient on the cart-road. Achieved differences of braking distances on both road surfaces for the enduro motorcycle Yamaha WRF450F have been very wide. The braking distance on the cart-road has been shorter for the front brake and for both brakes. The rear brake has been more
efficient on the dry asphalt road. From investigated data results, that the tyre friction depends not only on the tyre tread and on climatic conditions, but also on the road surface quality.

Acknowledgments
This work was supported by the Cultural and Educational Grant Agency of the Ministry of Education of the Slovak Republic in the project No. KEGA 044ŽU-4/2019: Implementation of innovative elements in the education process within the study program Maintenance of Means of Transport.

References
[1] Savino G, Lot R, Massare M, Rizzi M, Symeonidis I, Will S and Brown J 2020 Active safety systems for powered two-wheelers: A systematic review Traffic Injury Prevention 21(1) pp 78–86
[2] Chen C P and Chiang M H 2018 Mathematical simulation and analyses of proportional electro-hydraulic brakes and anti-lock braking systems in motorcycles Actuators 7(3)
[3] Luskova M, Dvorak Z and Leitner B 2015 Impact of extreme weather events on land transport infrastructure 19th Int. Sc. Conf. on Transport Means (Kaunas, Lithuania) pp 306–9
[4] Luskova M and Leitner B 2018 Extreme weather impact on transportation and energy infrastructure 22nd Int. Sc. Conf. on Transport Means (Trakai, Lithuania) pp 569–73
[5] Buczaj A, Krzysiak Z, Pecyna A, Caban J and Brumercik F Safety during chemical transport of dangerous goods, Przemysl Chemiczny 98(8) 1276–80
[6] Rybicka I, Caban J, Vrábel J, Šarkan B, Stopka O and Misztal W 2018 Analysis of the safety systems damage on the example of a suburban transport enterprise 11th Int. Science and Technical Conference Automotive Safety (Casta Papiernicka, Slovakia) pp 1–5
[7] Droździel P and Wrona R 2018 Legal and utility problems of accidents on express roads and motorways 11th Int. Sc. and Technical Conference Automotive Safety (Casta Papiernicka, Slovakia) pp 1–5
[8] Madlenak R, Hostakova D, Madlenakova L, Drozdziel P and Torok A 2018 The analysis of the traffic signs visibility during night driving Advances in Science and Technology – Research Journal 12(2) pp 71–6
[9] Kurčík P, Gerlici J, Lack T, Suchánek A and Harušinec J 2019 Innovative solution for test equipment for the experimental investigation of friction properties of brake components of brake systems Transportation Research Procedia 40 pp 759–66
[10] Gerlici J, Gorbunov M, Kravchenko K, Prosivirova O, Lack T and Hauser V 2018 Assessment of innovative methods of the rolling stock brake system efficiency increasing Manufacturing Technology 18(1) pp 35–8
[11] Gerlici J, Gorbunov M, Kravchenko K, Prosivirova O and Lack T 2017 The innovative design of rolling stock brake elements Communications – Scientific Letters of the University of Zilina 19(2) pp 23–8
[12] Vlk F 2003 Dynamics of Engine Vehicles (František Vlk, Brno) p 431 (In Czech)
[13] Kovácsová N, Grottoli M, Caliberti F, Lemmens Y, Happee R, Hagenzieker P M and de Winter J C F 2020 Emergency braking at intersections: A motion-base motorcycle simulator study Applied Ergonomics 82
[14] Ariffin A H, Hamzah A, Solah M S, Paiman N F, Mohd Jawi Z and Md Isa M H 2017 Comparative analysis of motorcycle braking performance in emergency situation J. of the Society of Automotive Engineers Malaysia 1(2) pp 137–45
[15] Lack T and Gerlici J 2017 Integration methods for rail vehicle ride dynamic solution assessment 23rd Conf.: Current problems in Rail Vehicles (Ceska Trebova, Czech Republic) pp 217–34
[16] Gerlici J, Sakhno V, Yefymenko A, Verbitskii V, Kravchenko A and Kravchenko K 2018 The stability analysis of two-wheeled vehicle model MATEC Web of Conferences 157
[17] Rabinovich E et al. 2018 Evaluation of the powertrain condition based on the car acceleration and coasting data SAE Technical Papers 2018
[18] Koetniyom S, Dangchat M, Mongkonlerdmanee S, Carmai J and Chanta S 2018 Identification of handbrake patterns of young motorcycle riders in Thailand using a newly invented force measuring device Engineering Journal – Thailand 22(5) pp 185–97

[19] Huertas-Leyva P, Savino G, Baldanzini N and Pierini M 2020 Loss of control prediction for motorcycles during emergency braking maneuvers using a supervised learning algorithm Applied Science 10(5)

[20] Chindamo D, Gadola M, Armellin D and Marchesin F 2017 Design of a road simulator for motorcycle applications Applied Science 7(2)