Factors affecting the formation of the established deceleration of two-wheeled vehicles

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Abstract. The purpose of this study is to assess the factors that influence the formation of braking parameters for two-wheeled vehicles, specially bicycles, on dry and wet asphalt. Braking tests were carried out to determine deceleration using a decelerometer model "LWS-2MC" on dry and wet asphalt. Depending on the type of braking system, the method of braking, the mass of the two-wheeled vehicle and the cyclist, as well as the suspension design, graphs were built and regression equations were obtained. A quantitative assessment is given to the factors influencing the formation of the established deceleration and the deceleration rise time of a two-wheeled vehicle during emergency braking.

1. Introduction
In Two-wheeled vehicles (TWV), in particular bicycles, are active participants in road traffic, as well as in many road accidents. An important aspect of the reconstruction of road accidents with their participation is the assessment of the ability of the vehicle to brake.

Currently, there are very few published sources that include data on acceleration, braking and rolling resistance for bicycles. In the work of VA Puchkin [1], a table with the parameters of the steady-state deceleration of bicycles and motorbikes is presented, however, due to the active development of the design of the suspension, braking system and types of bicycles, updating and a more detailed consideration of the factors affecting the braking parameters are required, with the purpose of updating the databases and existing techniques for the reconstruction of road accidents. In the monograph Trofimenko Y.V., Shelmakova S.V., Zege S.O., Shashina E.V. [2] considered the advantages and disadvantages of cycling and the level of its development in different countries but did not provide data on road accidents involving cyclists.

2. Justification of the problem
Six cyclists took part in the tests on six bicycles with different frame materials, types of braking systems, suspensions, road vehicle geometry and its purpose. Also were collected the height and weight of cyclists, the weight of the bicycle and the total weight of the subjects (bicycle + cyclist) (Table 1). The road vehicle deceleration was measured using the LWS-2MC model decelerometer, which is designed for any vehicle category [3]. Braking tests were carried out on two sites: on smooth wet asphalt and on smooth dry asphalt. The technique consists in the fact that the drivers of road...
vehicle applied emergency braking at a speed of 20-30 km/h, with the wheels locked, experiencing a certain type of braking: front, rear brakes and a combined method (front and rear brakes)[4]. According to the statistics of "New-retail" [5], at the moment the mountain bike is the most popular type of two-wheeled transport in Russia. Many road accidents involve mountain biking. According to the statistics of the official website of the State Traffic Inspectorate [6] for the period 2017 - 2020. the dynamics of road traffic accidents involving two-wheeled vehicles is traced (Figure 1).

![Figure 1. The dynamics of road traffic accidents involving TWV with the dead and wounded in 2017-2020 in RF (people)](image)

Establishing the true causes of traffic violations that led to the accident, and the circumstances contributing to them, is one of the important tasks of ensuring traffic safety and the operation of bicycles [4].

3. Method for assessing factors affecting the braking of two-wheeled vehicles

Reasoning An important aspect of road accident reconstruction is the ability of the vehicle to brake. There are 3 methods for braking TWV. The first method - front brake only - involved pulsating or intermittent locking of the front wheel during braking. The safer method is not to lock completely, but to quickly and repeatedly lock and unlock the front wheel, especially on uneven surfaces. By keeping the front wheel from locking, the driver can maintain control [7]. As in the case of cars not equipped with anti-lock brakes, after locking the front wheels, the driver loses significant control over the steering [8]. The second method involves locking the rear wheel and opposing the steering to maintain balance. The second method differs from the first by blocking the brake wheel. [9] The third method, in which both brakes are used (combined braking), is the most effective method of speed reduction, therefore, this article will consider the combined braking of the TWV [10,3].
### Table 1. Characteristics of bicycles and cyclists

| Bicycle      | Bicycle weight (kg) | Brake-type | Purpose     | Tire width front-r (mm) | Tread depth front-r (mm) | Driver's weight (kg) | Gross weight (kg) | Height (sm) |
|--------------|---------------------|------------|-------------|-------------------------|--------------------------|----------------------|------------------|-------------|
| Diamondback  | 13.6                | Shimano 105| Mountain    | 52                      | 2.5                      | 90.1                 | 103.7            | 189         |
| Mongoose     | 12.1                | Shimano BR-M400| Mountain    | 52                      | 1.7                      | 69.1                 | 81.2             | 172         |
| Cannondale   | 7.9                 | Shimano 105| Mountain    | 24                      | <0.9                     | 68.3                 | 73.2             | 173         |
| GT           | 12                  | SRAM Level TL| Mountain    | 55                      | 2.4                      | 75                   | 87               | 171         |
| Merida       | 11.4                | TRP SpyreFlatmount| Mountain    | 29                      | 0.9                      | 71.2                 | 82.6             | 175         |
| Specialized  | 9.4                 | Shimano BR-MT200| Mountain    | 47                      | 3.2                      | 96.6                 | 106              | 191         |

### Table 2. Braking tests carried out on smooth, wet asphalt. Testing brakes on a flat surface using combined braking

| Bicycle      | Steady-state deceleration (j), m/s² | Rise time deceleration (t), s |
|--------------|-------------------------------------|-------------------------------|
| Diamondback  | 4.0                                 | 0.15                          |
| Mongoose     | 4.2                                 | 0.2                           |
| Cannondale   | 4.2                                 | 0.16                          |
| GT           | 4.4                                 | 0.18                          |
| Merida       | 4.5                                 | 0.19                          |
| Specialized  | 4.4                                 | 0.17                          |
| Mean         | 4.3                                 | 0.18                          |

### Table 3. Braking tests carried out on smooth dry asphalt. Testing Asphalt Brakes Using Combined Braking

| Bicycle      | Steady-state deceleration (j), m/s² | Rise time deceleration (t), s |
|--------------|-------------------------------------|-------------------------------|
| Diamondback  | 4.9                                 | 0.1                           |
| Mongoose     | 5.1                                 | 0.13                          |
| Cannondale   | 5                                   | 0.11                          |
| GT           | 5.4                                 | 0.13                          |
| Merida       | 5.5                                 | 0.13                          |
| Specialized  | 5.6                                 | 0.12                          |
| Mean         | 5.25                                | 0.12                          |
Table 4. Average values of steady-state deceleration and deceleration rise time on smooth dry and wet asphalt

| Act                                                                 | Steady-state deceleration (j), m/s² | Rise time deceleration (t₃), s |
|---------------------------------------------------------------------|-----------------------------------|-------------------------------|
| Braking with isp. both brakes on wet asphalt                       | 4.3                               | 0.18                          |
| Braking with isp. both brakes on dry asphalt                        | 5.25                              | 0.12                          |
| Braking with isp. both brakes on dry asphalt                        | 5.25                              | 0.12                          |

Based on the experimental data, for each investigated two-wheeled vehicles, the nature of the change in the steady-state deceleration and deceleration rise time depending on the total mass was determined (Figures 3 and 4). The processing of the results of experimental studies made it possible to obtain polynomial regression equations.

**Figure 2.** Braking diagram in combined mode braking and coefficient of adhesion $\phi \approx 0.5$

- Maximum steady-state deceleration $(j) = 6.47 \text{ m/s}^2$;
- Average steady-state deceleration $(j) = 5.22 \text{ m/s}^2$;
- Maximum speed $= 22.38 \text{ km/h}$;
- Deceleration rise time $(t₃) = 0.15 \text{ s}$;
**Figure 3.** Plot of steady-state deceleration versus gross weight on dry and wet asphalt using combined braking

**Figure 4.** Rise time plot of deceleration versus gross weight on dry and wet asphalt using combined braking
The obtained regression equations describe polynomial curves (average values), with the help of which it is possible to obtain a unit value of the steady-state deceleration for any TTP braking mode, depending on the state of the road surface, the weight of the bicycle and the cyclist (Table 5).

**Table 5. Equations of the regressions of the steady-state deceleration values and the TTP deceleration rise time**

| № | Measurement parameters | Figure | Regression equations, \( y = f(x) \) |
|---|------------------------|--------|-----------------------------------|
| 1 | J steady-state is on dry asphalt using combined braking | 3 | \( y = 86.053x^2 - 901.3x + 2443.5 \) |
| 2 | J steady-state is on wet asphalt using combined braking | 3 | \( y = 445.22x^2 - 3784.6x + 8119.4 \) |
| 3 | \( t_{\text{is}} \) on dry asphalt using combined braking | 4 | \( y = 41583x^2 - 9515.8x + 625.7 \) |
| 4 | \( t_{\text{is}} \) on wet asphalt using combined braking | 4 | \( y = 11411x^2 - 4047.2x + 444.93 \) |

where \( x \) - is the total mass of the subject, kg, \( y \) - is the steady-state deceleration, m/s\(^2\) (item 1.2), \( y \) - is the deceleration rise time, s (item 3,4)

4. Conclusion

The practical significance of the regression equations lies in the possibility of their use to determine the value of the steady-state deceleration and the deceleration rise time for various combined TTP braking modes, when research or conducting an investigative experiment to determine the steady-state deceleration value and the deceleration rise time is not possible due to the resulting accident damage to two-wheeled vehicles.

Thus, as a result of the research carried out, the following conclusions can be drawn:

1. The mass of the driver and TPA influences the formation of the steady-state deceleration parameter and the deceleration rise time on dry and wet asphalt;
2. The value of the steady-state deceleration during combined braking on dry asphalt pavement is 18\% higher than the combined braking of TPA on wet asphalt pavement;
3. The value of the deceleration rise time during combined braking on dry asphalt pavement is 33\% less than the combined braking of TPA on wet asphalt pavement;

Further research will be devoted to identifying the factors influencing the formation of the value of the steady-state deceleration and the time of its increase in other types of two-wheeled vehicles in other weather conditions with different design features, which will allow updating and expanding the database necessary to improve the methods of reconstruction of road accidents.

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