https://doi.org/10.14669/AM/172911

THE SAFETY OF MOTORCYCLE USERS

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Abstract

There are more and more motorcycles on the roads. This can be seen, for example, on the basis of statistical data from the Central Statistical Office, where newly registered two-wheelers are presented. Based on the data, it can be seen that there are more and more newly registered motorcycles every year and that there are many road accidents involving two-wheelers. According to data provided by the WHO, as many as 28% of fatalities in road accidents are motorcycle riders [11]. The article below reviews the literature on crash tests of motorcycles and test dummies. Unfortunately, it should be noted that this topic is not widely discussed in scientific research. Most of the works related to motorcycle crash tests concern safety tests of cash registers. On the other hand, usually in the literature on the subject you can find publications presenting simulations of mapping a specific accident involving a motorcyclist. The paper presents the most important standard regulating the manner of conducting crash tests of motorcycles. The main purpose of the article is assessment of the problem of motorcycle safety and an analysis of the state of knowledge in the area of motorcycle safety research in crash tests. The paper presents types of two-wheelers crash tests and stands used to test motorcycles. In addition, the authors in the work drew attention to the type of dummies used for crash tests involving motorcycles. Differences between these dummy and other dummies used in crash tests are also described. The article discusses the literature and describes research related to crash tests.

Keywords: motorcycles; crash tests; safety

1. Introduction

Motorcyclists are 28 times more likely to die in a road accident than passengers in passenger cars. According to WHO, 14% of all road fatalities are motorcyclists. It should be noted that improving these statistics is possible by training and educating motorcyclists, improving motorcycle safety, and improving infrastructure. It should be noted that every motorcycle allowed on the road must be approved [21, 22, 34]. Motorcycles are classified as category L vehicles and require homologation. This group includes all motor vehicles with two or three wheels, as well as selected four-wheeled vehicles and mopeds. For a motorcycle to be

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approved, it must meet several important safety requirements regulated by Regulation (EU) No. 168/2013. These are [31, 37, 38]:

- anti-lock braking system – applies to new motorcycles with a capacity exceeding 125 cm^3,
- anti-lock systems, combined braking systems or the presence of both types of systems – applies to two-wheeled motorcycles with an engine capacity of less than 125 cm^3, but the decision to install them rests with the manufacturer,
- a mechanism that automatically turns on the lighting – the installation obligation applies to all new types of L category vehicles,
- differentials – the installation obligation applies to all four- and three-wheeled vehicles belonging to the L category.

No motorcycle will be approved if it does not meet environmental requirements. Pursuant to the applicable regulation, it is necessary to meet the requirements of as many as 8 different tests, including: fuel vapor emissions, devices responsible for controlling pollutant emissions, energy efficiency and noise [30, 37, 38].

Unfortunately, it should be noted that the requirements for introducing a motorcycle to the market are much smaller than in the case of a passenger car. It should undoubtedly be noted that, although motorcycles do not have almost any additional active and passive systems that increase safety, the last decade has seen an increase in the popularity of motorcycle users. Motorcycles are becoming an increasingly common means of transport. This trend is clearly visible in Poland, where in the last decade there has been a 60% increase in the number of motorcycles, and now over 1.8 million such vehicles are registered. The growing popularity of motorcycles is visible in the statistics of road accidents. Between 2017 and 2019, around 3500 motorcyclists died on European roads every year. It should be noted that the number of motorcyclist fatalities still accounts for around 16% of all fatalities on European roads [11, 39, 40].

Motorcycles are becoming an increasingly popular means of transport in European countries, especially in cities. In Asian countries, they constitute a large number of vehicles on the streets. An increase in the number of motorcycles can also be observed in Poland [40]. This can be seen on the basis of the increase in the number of registered two-wheelers in Poland, and the change in the size of registered motorcycles is shown in Figure 1 [40].

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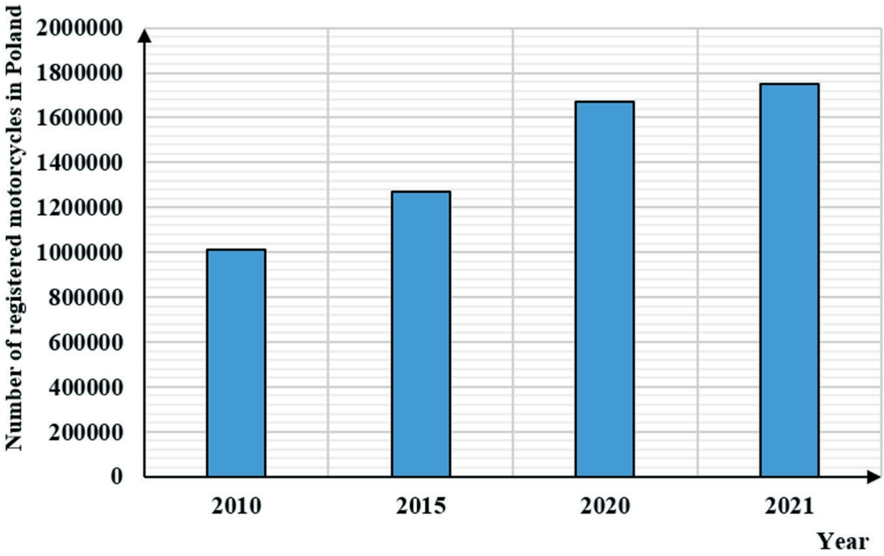

Fig. 1. The change in the size of registered motorcycles in Poland in selected years [40]

In Poland, in 2010, 1,013,000 motorcycles were registered, while in 2020 there were 1,669,000 and in 2021, 1,750,000. It can be seen that in 2020 and 2021, almost 70% more motorcycles were registered than in 2010 [40].

Due to the increasing number of motorcycles, scientific research units have begun to study and analyse road accidents involving motorcycles, because motorcycles do not have as many safety systems as vehicles, and the driver and passenger are not protected to the same extent as vehicle users. Of all road accidents victims, 28% are motorcyclists. In Asian countries, there is a higher percentage of motorcyclists among the victims in Thailand and India – as much as 76% [11]. Every year in Poland there are a large number of accidents involving motorcyclists. Data on the number of accidents are presented in Figure 2. According to police reports, in 2021 there were 2,050 accidents involving motorcyclists.

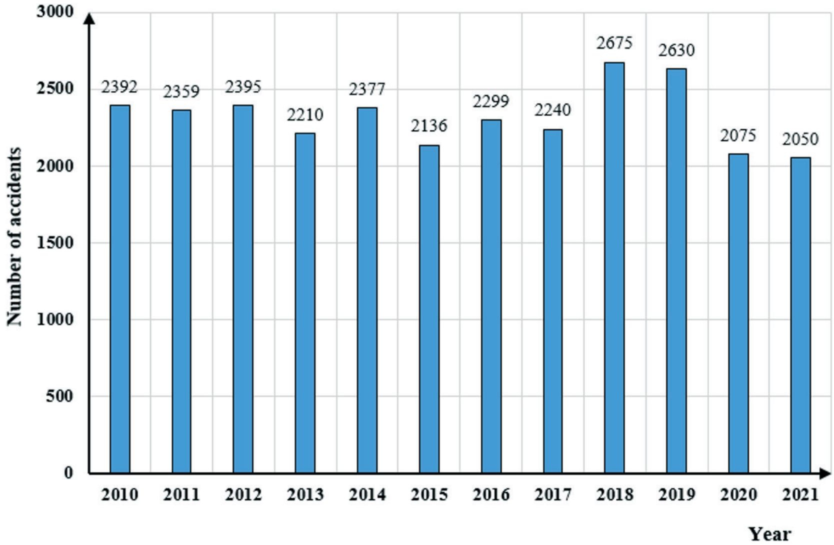

Fig. 2. Number of motorcycle accidents in Poland in 2010–2021 [40]

In 2021, 215 people, 207 drivers and 8 passengers, lost their lives in accidents. Between 2010 and 2021, there were 2,887 fatalities in Poland of people on motorcycles. Data on the number of fatalities is presented in Figure 3. A total of 1,706 motorcyclists and 178 passengers were injured in accidents. Other road users contributed to 50.9% of these motorcycle accidents. The largest number of accidents in years 2010–2021with motorcycles was caused by drivers of passenger vehicles. The characteristics of road accidents caused by other road users, in which the motorcyclist was injured, are presented in Table 1 [36].

Tab. 1. Characteristics of road accidents caused by other road users, in which a motorcyclist was injured in 2021 [36]

Vehicle type	Number of Accidents, n	Number of Fatalities, n	Number of Injured, n
Passenger vehicle	898	64	873
A truck with a DMC up to 3.5 t	60	9	54
A truck with a DMC over 3.5 t	20	4	16
Agricultural tractor	15	1	14
Bicycle	21	–	9
Undetermined vehicle	20	–	21
Bus	2	–	2
Moped	3	–	3
A quad bike'	1	–	1
Another vehicle	3	–	4

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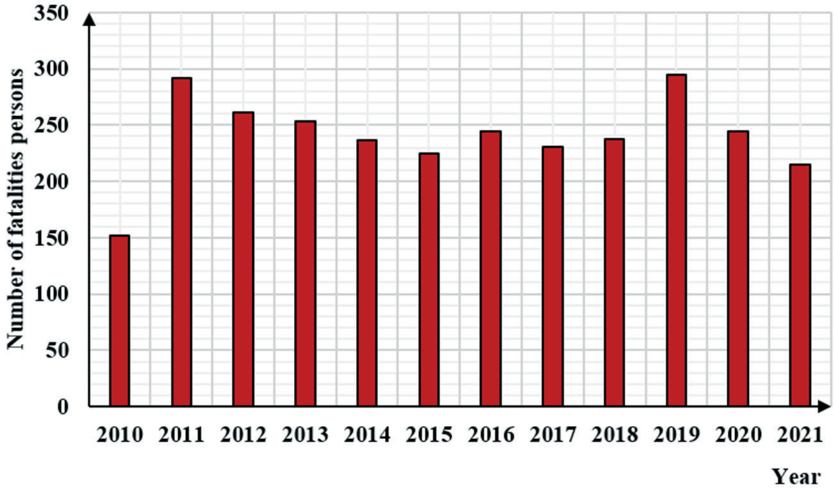

Fig. 3. Fatalities of motorcycle accidents in 2010-2021 [36]

2. Dummies used for motorcycle crash tests

For safety reasons, motorcycle crash tests do not use volunteers, only anthropometric dummies. Anthropometric dummies from the Hybrid III dummy family were mainly used for the study [31]. People involved in crash testing motorcycles decided to develop an anthropometric dummy adapted to testing two-wheelers. As a result of this idea, the MATD 1 dummy (Motorcyclist Anthropometric Test Device) was developed and created [29]. The dummy is presented in Figure 4. The dummy was made as a result of the modification of the Hybrid III dummy [20].

The dummy has built-in sensors that enable wireless data collection [4, 28]. The Hybrid III dummy's standard femurs and tibias have been replaced with brittle bones equivalent to human bones, and knee joints have been created to simulate the possibility of ruptured ligaments. This is in order to observe the injuries that occur during the events and to better represent the movement of the limbs during the collision. Figure 5 shows the fractured femur of the MATD dummy.

Fig. 4. Dummy MATD 1 [26]

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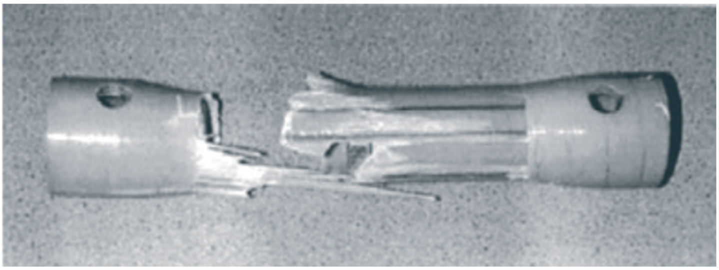

Fig. 5. Broken femur of the MATD dummy during the crash test [7]

The modifications to the Hybrid III dummy also included the hands. The MATD 1 dummy allowed for better hand positioning on the handlebars of the vehicle. Although a motorcycle crash dummy has been specially designed, Hybrid III dummies are often used for testing. On the basis of tests with the use of dummies, it is checked what injuries occur in the limbs, head and spine [1, 2, 8]. The use of dummies and crash tests can increase safety.

3. Crash tests of motorcycles

In order to analyse road incidents, either crash tests are performed according to strictly defined standards or computer simulations are performed to simulate a collision between a motorcycle and a vehicle. The Commission of the European Community in a white paper set the target of reducing the number of road users killed by 50% compared to 2010. This target was not achieved in 2020, but was postponed to 2030 in accordance with the European Transport Directive Policy [13, 15, 20]. Achieving this requires exploring all options and putting in place protection measures with proven potential. The secondary safety of motorcycles is also important in this respect. The ISO 13232 standard describes the form of impacts, crash tests and the possibility of calculating the risk and benefit of the motorcyclist in relation to real conditions. The literature on the subject also includes studies and crash tests of motorcycles with protective barriers and concrete barriers. Research centres also conduct research into the potential of protective motorcycle clothing.

3.1 Crash tests for motorcycles and vehicles

For safety reasons, motorcycle tests are usually carried out in controlled safety conditions, but sometimes road tests are carried out in normal traffic, during such tests, for example, the effectiveness of the ABS system in motorcycles can be tested [29, 30]. Crash tests of motorcycles are carried out on special stands. Usually, these are special tracks on which the motorcycle moves on a trolley [32, 33, 34]. An example stand is shown in Figure 6. The figure shows a motorcycle placed on a special rack that moves along a prepared track.

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Fig. 6. Motorcycle crash test bench [18]

In the case of crash testing, each test must be thought out by crash experts down to the smallest detail, which requires extensive preparation. In addition, crash tests are not only an effective way of tracking accident processes, but also provide a number of important pieces of information contributing to the improvement of road safety. During the crash test shown in Figures 6 and 7, the anthropometric dummy was placed on a motorcycle, which was traveling at a speed of 50 km/h, and collided at a 90-degree angle with a passenger vehicle (convertible). The motorcyclist's helmet first touched the head of a passenger vehicle and then hit the driver. Had this been a real case, serious injury would be inevitable for all those involved. The motorcyclist would most likely not have survived the collision.

Fig. 7. Motorcycle crash test frame [18]

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Motorcycle crash tests are usually carried out according to the ISO 13232 standard. The standard applies to two-wheeled motorcycles. The standard outlines test and analysis procedures, specifies the type of vehicle the motorcycle collides with, determines whether both vehicles are in motion, specifies the type of motion the motorcycle has before the impact, and specifies whether the motorcycle is to move at a constant speed. The standard also defines which dummies should be used for testing and how they should be placed on the vehicle. The standard describes the injuries that may potentially occur and their division into individual areas of the body.

The standard also specifies what protective clothing the dummy should wear and what conditions it should meet. Based on the analyses, the standard defines various types of collisions between a motorcycle and a passenger vehicle, because it has been noticed that the most frequent accidents occur with these vehicles. The angle at which the vehicles collide was also determined. The collision configurations of a motorcycle and a vehicle are shown in Figure 8. The most frequently performed crash tests are shown in Figure 9. According to the guidelines of the ISO 13232 standard, the motorcycle should move at a speed of 48 km/h [4, 7].

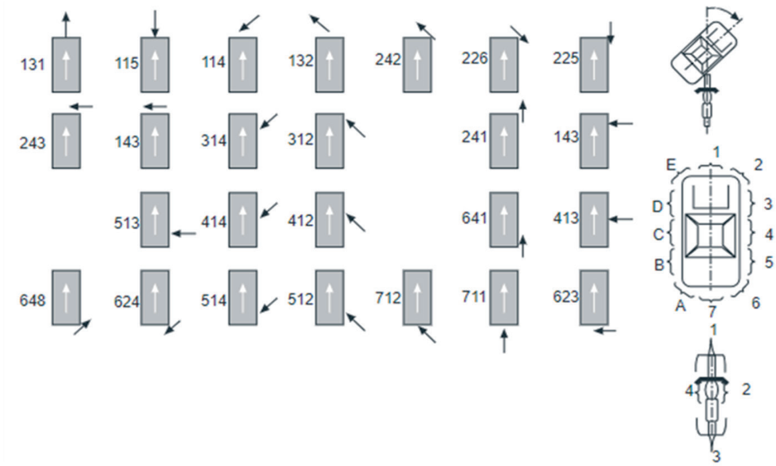

Fig. 8. Various collision options according to ISO 13232 [7]

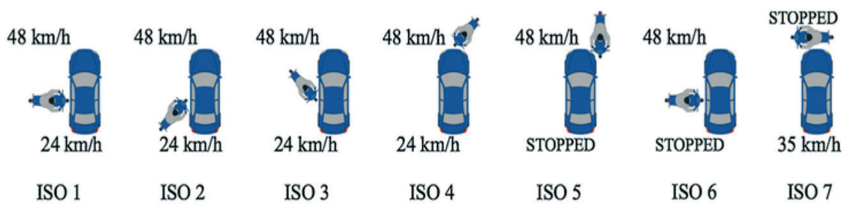

Fig. 9. The most frequently performed crash tests according to ISO 13232 (motorcycle speed is given at the top and the speed of the motor vehicle at the bottom) [35]

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Based on the ISO 13232 standard, simulation tests are first performed in a computer environment. Simulation tests enable thorough analysis of the event without the need to perform a test during which the motorcycle and the other vehicle are damaged. An example of a motorcycle–vehicle collision simulation is shown in Figure 10.

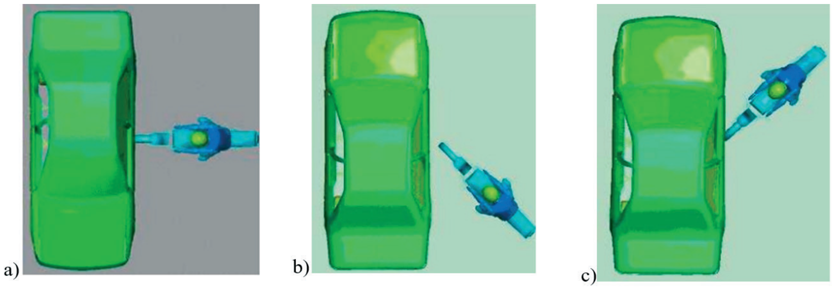

Fig. 10. Simulations of crash tests of a motorcycle with a passenger vehicle in the PAM/CRASHTM simulation program:
a) Case I: The vehicle is stationary, the motorcycle hits at a speed of 13.4 m/s at right angles,
b) Case II: A vehicle moving at a speed of 6.7 m/s, motorcycle traveling at 13.4 m/s at an angle of 45° from the front.
c) Case III: A vehicle moving at a speed of 6.7 m/s, a motorcycle moving at a speed of 13.4 m/s at an angle of 45° from the rear [27]

It should be noted that in order to recreate the dynamics of the collision of the motorcycle and the opposite vehicle, the passenger vehicle, the main parts of the motorcycle and vehicles, which determine their significant behavior during the collision, are modelled as rigid bodies that are connected to each other by kinematic joints. As a result, the model focuses on representing crash-relevant structural elements such as the front wheel, tires and suspension assembly. Parts that are assumed not to deform because they are very stiff or did not deform in a crash, such as driveline components, are modelled as rigid, but their dimensions, weight, and position are taken into account. Figure 11 shows a simulation of a full-scale crash test SH01.01 [5] with a conventional Yamaha FZS 600 Fazer motorcycle with a hybrid III anthropometric dummy representing a 50th percentile man wearing a helmet against a VW Golf II.

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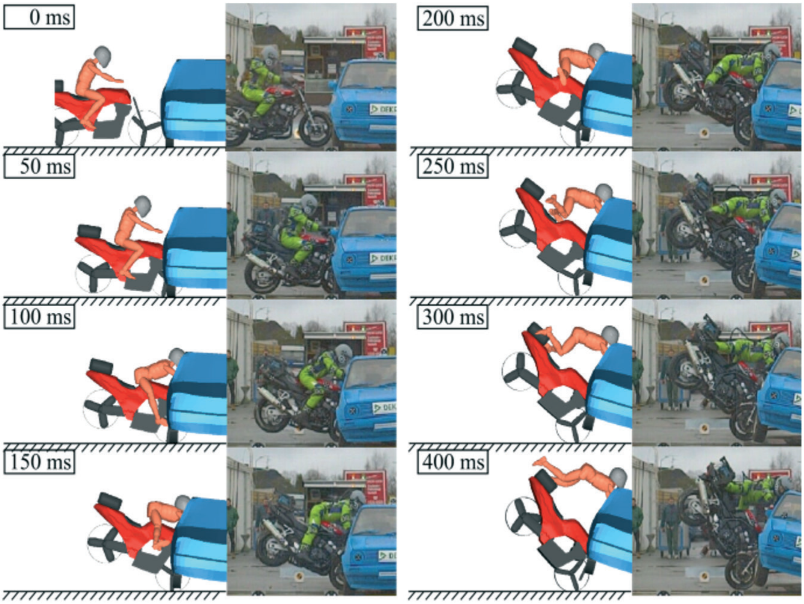

Fig. 11. Simulation of a collision between a vehicle and a motorcycle [5]

Crash tests are then performed on full-size test stands to verify the correctness of simulation tests. Figure 12 presents a crash test performed according to configuration 413 of the ISO 13232 standard. The test was performed at a speed of 48 km/h and the effectiveness of the airbag located on the motorcycle's handlebars was checked [4, 40].

Fig. 12. Collision of a motorcycle with a passenger vehicle according to ISO 13232 – configuration 413 [24]

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Works [1, 2, 8] discuss whether the helmet adequately protects the motorcyclist's head during a collision with a vehicle or during a fall. Computer simulations are carried out showing the movement of the head. Head movement simulation is shown in Figure 13.

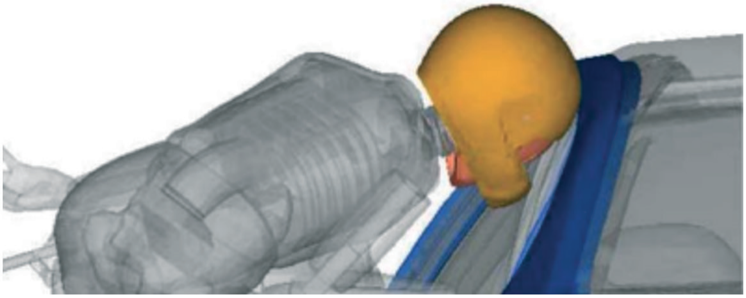

Fig. 13. The simulation of the impact of a motorcyclist's head on the side of the vehicle [25]

It is well known that motorcyclists involved in accidents are at high risk of serious injury. Although injuries in a road accident affect the whole body (mainly the head and chest). Head injuries are still one of the leading causes of death among motorcycle riders [9, 12, 13]. Significant effort has been made in recent decades to reduce the risk of fatal head injuries among motorcyclists, especially through road safety legislation and the compulsory wearing of helmets. Direct investigations collect information on the displacement and acceleration that occur during the event. In addition to crash tests, medical reports are analysed concerning the injuries suffered by the driver of the vehicle. Based on these studies, it can be seen that motorcycle helmets prevent loss of life and reduce the risk of serious skull injuries. The type of helmet that the rider was wearing is also analysed. In addition to crash tests, motorcycle helmets are tested in a simulation environment (Figure 14) and in laboratories (Figure 15) in which the helmet is struck on the ground or a heavy element simulating a collision is dropped on the helmet [9, 11, 12].

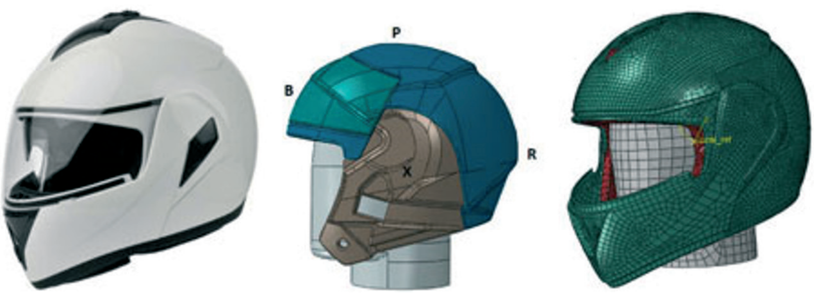

Fig. 14. Example of a rider's helmet reproduction in a simulation program according to ECE R22.05 [28]

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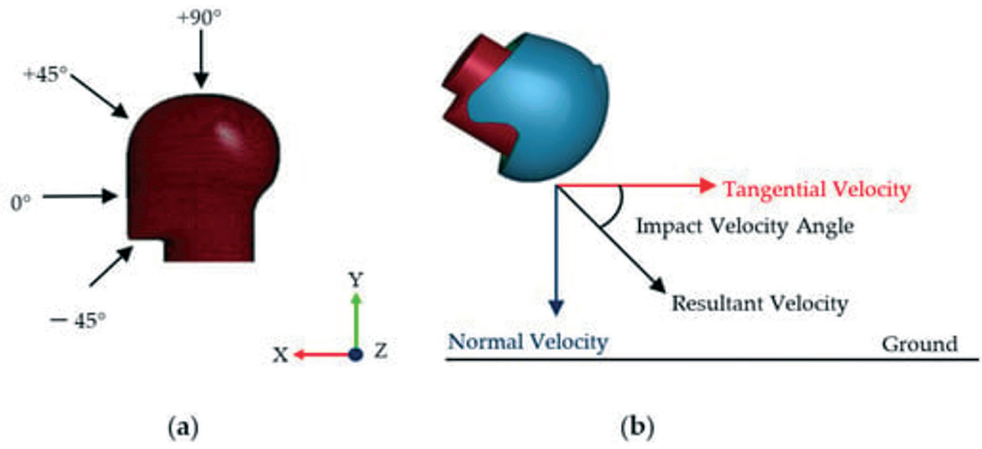

Fig. 15. Angles of impact with the helmet in laboratory conditions [23]

Crash tests of motorcycles enable the development of newer and newer solutions that increase the safety of motorcyclists [3]. The tests allow us to determine the forces acting on the motorcyclist and on the vehicles during the event. The motorcycle hitting the side of the vehicle had a speed of about 50 km/h. During the test, the initial position of the driver's head and its displacement relative to the trunk were determined using a high-speed camera. In addition, during the test, the impact of the padding inside the helmet on the victim was checked. The conducted tests showed what part of the kinetic energy of the motorcyclist's body was dissipated during the collision. The dissipation of energy depended on the course of deformation of the vehicle body at the point of impact of the motorcyclist's head and the helmet, and on the type of helmet lining material.

Motorcycle crashes are based on vehicle crash tests [10]. One of the studies using a motorcycle collision was a study to determine whether the measurements recorded by a high-speed camera would be consistent with data recorded by the acceleration and angular velocity sensors placed in the black box inside the vehicle [16, 17]. The impact of a motorcycle against the side of a passenger vehicle was registered. The crash test is shown in Figure 16.

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Fig. 16. Crash test recorded with a high-speed camera recording 1000 frames per second [14]

The data recorded by the camera was processed using a program adapted to the analysis of films recorded by high-speed cameras. The data recorded by the sensors was analysed through mathematical relationships [7, 43]. Based on the comparison of these two methods of event analysis, the authors concluded that the measurement results are consistent with each other because the position of the silhouette resulting from the mathematical relationships was consistent with what the camera recorded on the film. The results of the analysis are shown in Figure 17.

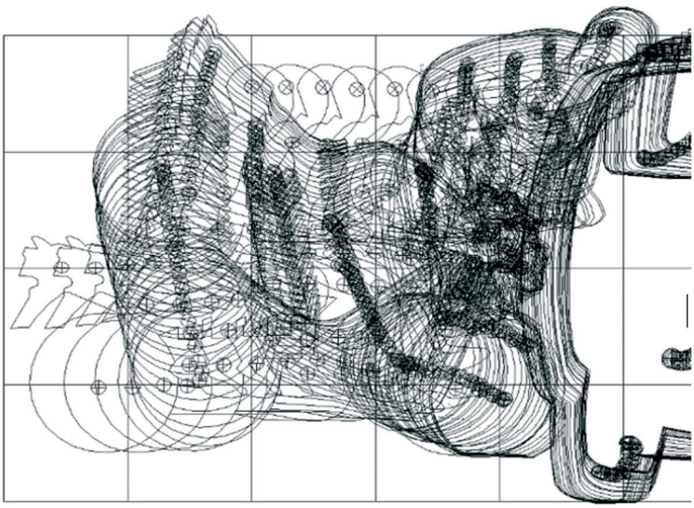

Fig. 17. Time-lapse analysis based on PTZ camera footage [14]

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3.2 Crash tests for motorcycles with road barriers

In addition to examining road accidents involving a motorcycle and a motor vehicle, collisions of motorcyclists with energy-intensive barriers are also investigated [3, 6, 14]. Such events usually occur outside of urban areas and are usually caused by excessive speed of the driver, and loss of control of the vehicle during manoeuvres. During the tests, the impact of a motorcyclist against concrete and steel barriers is examined. This type of test is performed at a speed of 60 km/h [32, 42, 44]. The speed is faster than the ISO 13232 crash tests because these events occur in non-urban areas. The Hybrid III dummy representing the 50th percentile male is most often used for crash tests. During the test, the motorcycle hits the guard rails at different inclinations. Figure 18 shows a stand with appropriate sleds to ensure the appropriate angle of impact of the motorcycle against the barrier. During the tests, the displacement and acceleration of individual parts of the body, in particular the head, are measured. During the tests, the forces that affect the driver and the vehicle during the collision with the barriers are measured.

Fig. 18. Crash test bench with road barriers [19]

Based on the analysis of collisions, it was noted which injuries occur most often and what their causes are. Based on the research, it was proposed to modernize the barriers in order to increase the safety of motorcyclists. Further studies have been carried out, which have shown that changes in barriers can increase the safety of drivers [19, 32, 41].

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4. Conclusions

Although motorcycles have many advantages, there are also disadvantages, mainly related to safety. The biggest safety issue with motorcycles is that they are lightweight two-wheeled vehicles with powerful engines that can accelerate faster and top speeds higher than most other vehicles. Moreover, motorcyclists do not have a vehicle cover compared to other vehicles, and the balance of the motorcycle is highly dependent on the skill of the rider. Due to the relatively small contact patch between the road surface and the motorcycle (tyres), any loss of friction between the front or rear tire and the road surface, such as when turning or cornering, can have a significant negative impact on handling. In addition, their relatively small size makes them less detectable and less predictable for car drivers. From the information above, road accidents involving motorcyclists can often have serious consequences. This is confirmed by accident statistics.

More and more motorcycles are on the roads and their riders account for almost one-third of all road fatalities. In addition, there are countries where they account for more than half all the victims. In Poland alone, over 25,000 people have died in road accidents in the last 10 years. On the other hand, almost 3,000 people have died in road accidents involving motorcyclists in the last 10 years. For this reason, it is very important to research issues related to motorcycle safety as much as possible. As a result of such research, it is possible to make changes to vehicles, protective clothing and road infrastructure in order to increase the safety of two-wheelers. The tests allow us to know exactly what forces are acting on the human body and the vehicle. During the research, research teams also develop research dummies in order to conduct the most accurate research. In further works, the authors intend to make a forecast of road accidents and fatalities involving motorcycles until 2035 and will compare road accidents involving motorcycles in Poland and selected EU countries in the years 2010–2022.

The aim of the article has been achieved, the analysis of previous publications and statistical issues confirm the high number of motorcyclist fatalities that has persisted over the last decade and confirm the fact that motorcycle drivers are deprived of active safety systems. The literature review confirms the fact that the subject of motorcycles is ignored, which is why few scientists deal with this topic. The largest part of the articles on motorcycle collisions refers to a computer simulation of a specific road accident involving a motorcyclist. In this type of articles, accelerations and displacements of individual parts of the motorcyclist are most often analyzed in order to reproduce the accident in the environment of simulation programs. There is a lack of research in the literature that contributes to increasing the safety of motorcycle users, including safety systems, e.g. obstacle detection or a system that prevents motorcycles from moving between a column of vehicles in a traffic jam. Moreover, there is a lack of research related to the selection and modification of motorcyclist protective clothing and safety helmets. The type of safety helmet for a specific type of motorcycle should be particularly important. For example, scooter users have a different position than sports motorcycle users. Therefore, frequent collisions in city traffic caused by a vehicle hitting a scooter standing at a traffic light or at an intersection can cause serious injuries to the motorcyclist's cervical section at low collision speeds.

Research on safety helmets should take into account the purpose of the helmet and the possibility of extending it with pads or pads that additionally protect the motorcyclist's cervical section.

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