NUMERICAL SIMULATION OF THE STANDARD TB11 AND TB32 TESTS FOR A CONCRETE SAFETY BARRIER

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Abstract

The work presents the traffic safety issue related to a use of the road protective barriers. It describes a purpose and tasks that should be fulfilled by the safety system. Conditions of crash tests and their evaluation according to the requirements of the existing standard documents are also presented. The purpose of the work was to evaluate the influence of applied barrier type on the car collision process. A barrier composed of the segments that can move on the ground due to the impact force and a barrier fixed to the road surface were assumed for the model tests. The modelling was carried out by means of the LS-DYNA software, using the finite element method. The tests were performed for two types of cars, mass of 900 kg and 1500 kg.

The work includes the numerical test results, deformations of car bodies and barrier displacement. Examples of velocities and acceleration courses of selected vehicle elements and the ASI index, calculated on their basis, used for evaluation of the passenger danger level were also presented. Obtained results indicate a significant influence of the barrier installation method (joint with the road) on the collision process course and dynamic loads affecting the car passengers. They also indicate directions of safety improvement.

Keywords: *road safety barrier, crash tests, computer simulation, LS-DYNA*

1. Introduction

Providing safety for all road users makes the basic road traffic problem. It refers to vehicle drivers, vehicle passengers as well as other people located in direct proximity to the roads – especially pedestrians and cyclists. Safety assurance and improvement is often related to a need of installing additional elements of the road infrastructure preventing the vehicles and pedestrians from entering the danger zones and areas. Installation of road safety barriers is a common solution. There are three basic types of road safety barriers: steel, concrete and cable, but mostly the first two barriers are used. However, regardless of the barrier type, all barriers used on the roads of the European Union have to meet the resolutions of the EN 1317 [2, 3] standard. This standard defines the requirements. The standard defines the requirements for the safety barriers within a scope of abilities to prevent the vehicles with simultaneous limitation of the area necessary to stop or properly drive away a car.

The introduction of the programme in order to improve the road infrastructure and especially the development of motorways and expressways in recent years resulted in development of works leading to the improvement of safety on the Polish roads. The work [1] presents a detailed analysis of effects of a car collision with a rigid road barrier. This work makes a development of the problem and includes a new type of safety barriers characterized by a possibility of moving on the ground. Selected results of that work have been quoted for comparison purposes.

2. Road safety barriers

The road safety barrier is equipment used for physical prevention from vehicle getting out of the road in dangerous locations, vehicle getting out of the road crown, vehicle crossing the road and entering the lane for the traffic in opposite direction or to prevention a vehicle collision with objects or fixed obstacles located near the road. Types of barriers available on the market, offered in many variants, allow designers adjust the protection level to the current conditions on the road. When selecting the barriers, the following factors are taken into account: type of the road, road location, shape, structure exposure and possible dangerous areas and objects near the road. Designed barriers make a compromise between their strength and deformability. During a car collision, the restraining system should have an ability to deform, thus ability to absorb the kinetic energy of the impact. Therefore, it would result in reduction of accelerations affecting the people. From the other hand, it should be resistant enough to prevent from breaking of the barrier and prevent from too big displacement (characterized by the working width value).

All installed barriers need to meet the requirements of the EN 1317-2 standard within a scope of car restrain level during a crash, expected passenger deceleration values and barrier system deformations. The standard defines 11 variations of the crash tests (Tab. 1) for various types of passenger cars, trucks and buses. Apart from the vehicle type and weight, their barrier impact speed and angle are different.

Tab. 1. EN 1317-2 crash tests definition [2]

Test	Impact velocity [km/h]	Impact angle [°]	Vehicle mass [kg]	Vehicle type
TB11	100	20	900	Car
TB21	80	8	1 300	Car
TB22	80	15	1 300	Car
TB31	80	20	1 500	Car
TB32	110	20	1 500	Car
TB41	70	8	10 000	Rigid HGV
TB42	70	15	10 000	Rigid HGV
TB51	70	20	13 000	Bus
TB61	80	20	16 000	Rigid HGV
TB71	65	20	30 000	Rigid HGV
TB81	65	20	38 000	Articulated HGV

From the point of view of the executed work, two tests are significant: TB11 and TB32. They make a basis of the crash test with assumed restrain level N2 (Tab. 2). This level complies the majority of road safety barriers used on the roads. Due to a higher car speed and mass in the TB32 test, the impact energy is twice higher compared to the TB11 test.

Tab. 2. Containment levels according to EN 1317-2 [2]

Containment capacity	Containment levels	Acceptance test
Low angle containment	T1	TB21
	T2	TB22
	T3	TB41 and TB21
Normal	N1	TB31
	N2	TB32 and TB11
Higher	H1	TB42 and TB11
	H2	TB51 and TB11
	H3	TB61 and TB11
Very high	H4a	TB71 and TB11
	H4b	TB81 and TB11

Apart from the test conditions, the standard also defines the criteria of barrier system evaluation. Apart from the mentioned working width, the severity of the impact influence on the car passengers is also analyzed (Tab. 3). It is characterized by the values of the acceleration severity index (ASI), theoretical head impact velocity (THIV) and post-impact head deceleration (PHD). When the conditions of the THIV and PHD index values are met, the ASI index value makes a factor, which decides of classification to one of three levels. It is calculated according to the dependence (1):

$$ASI = \max\left(\sqrt{\left(\frac{\bar{a}_x(t)}{\hat{a}_x}\right)^2 + \left(\frac{\bar{a}_y(t)}{\hat{a}_y}\right)^2 + \left(\frac{\bar{a}_z(t)}{\hat{a}_z}\right)^2}\right), \qquad (1)$$

where:

$$\bar{a}_{x,y,z}(t) = \frac{1}{\delta}\int_{t}^{t+\delta} a_{x,y,z}\,dt\,, \qquad (2)$$

$a_{x,y,z}$ - components of the Centre of Gravity acceleration [g],
$\hat{a}_{x,y,z}$ - threshold accelerations for each component direction, the threshold accelerations are 12 g, 9 g, and 10 g for the longitudinal (x), lateral (y), and vertical (z) directions,
δ - moving time interval (δ = 0.05 s).

Tab. 3. Impact severity levels according to EN 1317-2 [2]

Impact severity level	Characteristic values		
A	ASI ≤ 1.0	and	THIV < 33 km/h PHD < 20g
B	1.0 < ASI ≤ 1.4		
C	1.4 < ASI ≤ 1.9		

3. Test object model

In order to evaluate the effects of a passenger car collision with a barrier, a discrete model of the test object has been developed. It includes a concrete barrier system, a car and the ground. From the point of view of the executed work, due to a complex and time-consuming car model development process, the attention was focused on the barrier model development and defining the conditions of interaction between individual elements. The tests were performed with a model of Geo Metro and Dodge Neon cars developed and provided by National Crash Analysis Centre [8]. The car discrete models and the barriers are presented on Fig. 1. The model tests assumed the safety system composed of 16 segments. Each segment makes a concrete barrier of height of 810 mm, base width of 550 mm and length of 4000 mm. Each segment includes flexible steel connectors with tear force amounting to 350 kN. The flexible connector ends are connected to the coupling elements allowing for connection of individual segments with a possibility of turning individual segments towards each other.

The concrete barrier was modelled by means of rigid, non-deformable solid elements and the flexible connectors and couplers were modelled by means of four-node shell elements. The material characteristics include their reinforcement as well as a possibility of destruction. In order to define the nature of cooperation, the contact conditions were defined including friction between the barrier and the ground, the car and the barrier, the car and the road surface. Assumed factor of friction between the barrier and the ground corresponds to a value for the concrete surface. The calculations were executed by means of the LS-DYNA software, using the finite element method [4, 7]. This software is commonly used in the analysis of quick-changing non-linear processes, including the tests of simulation car crash.

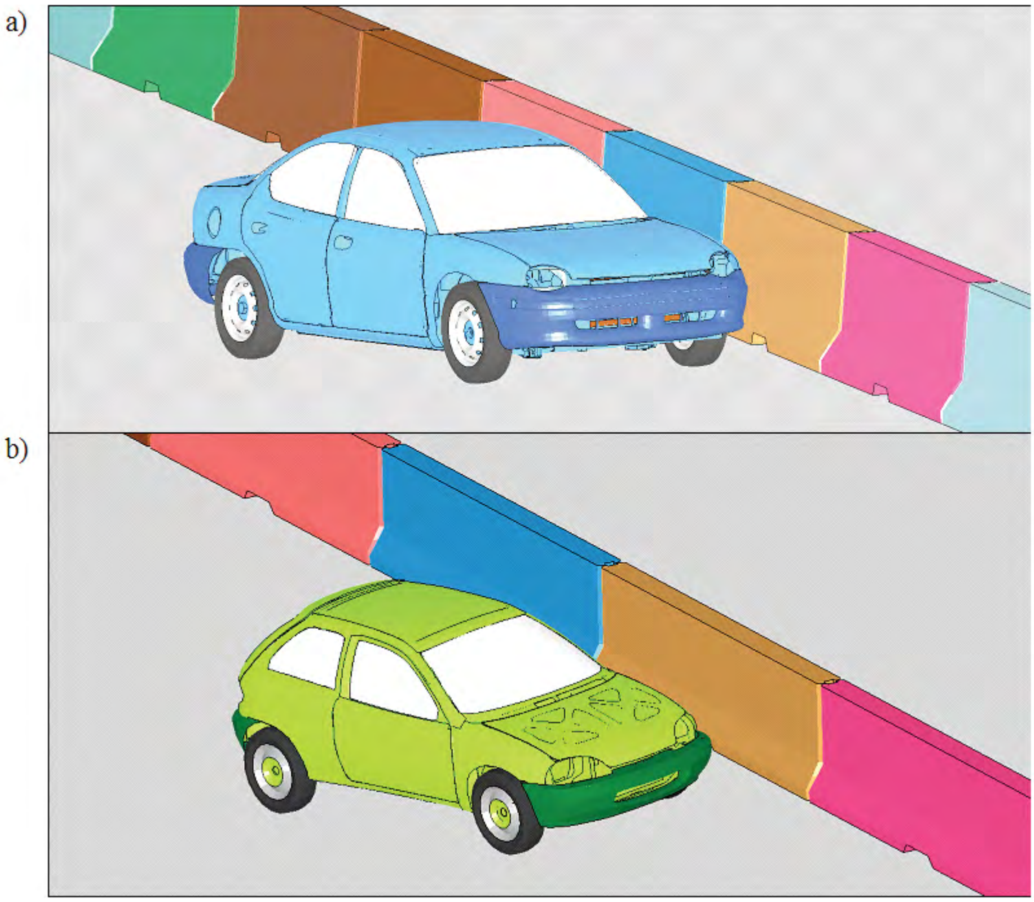

Fig. 1. Model of vehicle: a) Dodge Neon, b) Geo Metro

4. Numerical tests results

The purpose of the tests was to evaluate the behaviour of the concrete safety barriers during collision with a passenger car. The tests were performed with Geo Metro of mass of 900 kg and Dodge Neon of mass of 1500 kg. The use of these vehicles allowed for performing to crash tests TB11 and TB32 (according to EN 1317-2). In the first test, the initial car speed amounted to 100 km/h and it hit the barrier at the angle of 20°. The impact point was located on 1/3 of a distance from the end of the safety barrier. In case of the second test, only the initial speed was increased to 110 km/h. During the calculations, the behaviour of the barrier and the hitting car were recorded. Thus, the courses of displacements, speeds and accelerations of individual elements were obtained. They were used to define the working width of the barrier and the impact severity indexes at the next stage of the test.

Additional purpose of the tests was to compare the behaviour of the portable and fixed barriers (used, among others, on the bridge structures). Therefore, additional calculations were made using the rigid barrier model, represented by RIGIDWALL type elements. All parameters of the test remained unchanged.

Figure 2 presents selected stages of the crash of the 900 kg car with a portable barrier placed at the angle of 20° towards the direction of the vehicle motion. Due to a low mass of the car, the barrier movement is quite small. It was limited to two segments located in direct vicinity of the impact point. The car partially ran into the barrier and then the direction of its motion changed. The car was lead along the barrier wall and at the final stage, it was taken away at a low angle towards the barrier axis. During the test, the car did not get out of the acceptable area defined in the standard. No significant body structure deformations and driving system element destruction were observed.

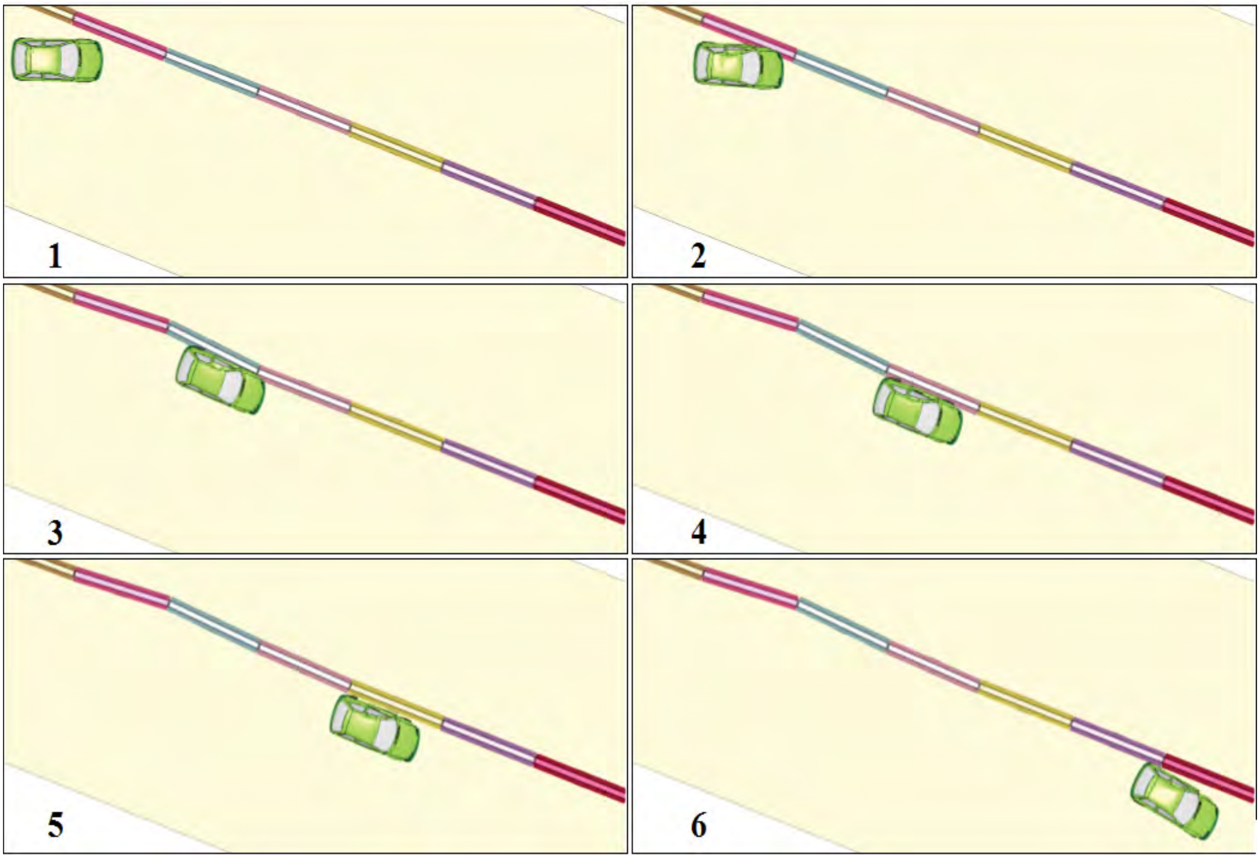

Fig. 2. Stage of collision of Geo Metro with a portable barrier

The course of collision of Geo Metro car with a rigid barrier does not significantly differ from the collision with a portable barrier. There were no significant deformations of the car and the angle between the barrier axis and direction of the car motion amounted to app. 5° after the crash. The vehicle did not get out of the acceptable area.

Figure 3 presents analogical results obtained for the 1500 kg car. Due to a higher impact energy compared to the previous case, there were high deformations of the front part of the car body and significant displacement of the barrier elements. The impact of the front and then the rear part of the car resulted in characteristic barrier line shape. During the crash, the suspension of the front left wheel was partially damaged and the wheel was blocked by deformed elements of the car body. At the final stage of the analysis, it resulted in the change of the car motion direction and car skidding towards the barrier.

During the crash of Neon with a fixed barrier, the front and then the rear wheels were torn away. It resulted in a sudden car braking, skidding and stoppage in a perpendicular position towards the line of the barrier. Such situation is particularly dangerous as it leads to a complete loss of control over the vehicle and it could result in a secondary accident.

Figure 5 present the force courses in the flexible connectors of the barrier hit by the cars. In case of the 900 kg car the maximum force amounted to app. 100 kN. Due to a higher car mass and speed, the forces were about 2.5 times higher during the Dodge Neon crash. However, in none of the cases the value of tearing force of the connectors was not exceeded – amounting to 350 kN in case of the analyzed barrier.

Figure 6 presents courses of longitudinal velocity of the car. The smallest velocity variations can be observed for Geo Metro hitting a portable concrete barrier (curve 3). In the first impact phase (until app. 0.1 s), the velocity is reduced by app. 11 km/h, and then after reflection from the barrier a slow velocity decrease takes place. A course of collision with a rigid barrier is similar (curve 4), however there is a higher velocity decrease in the first phase (by app. 20 km/h). Due to

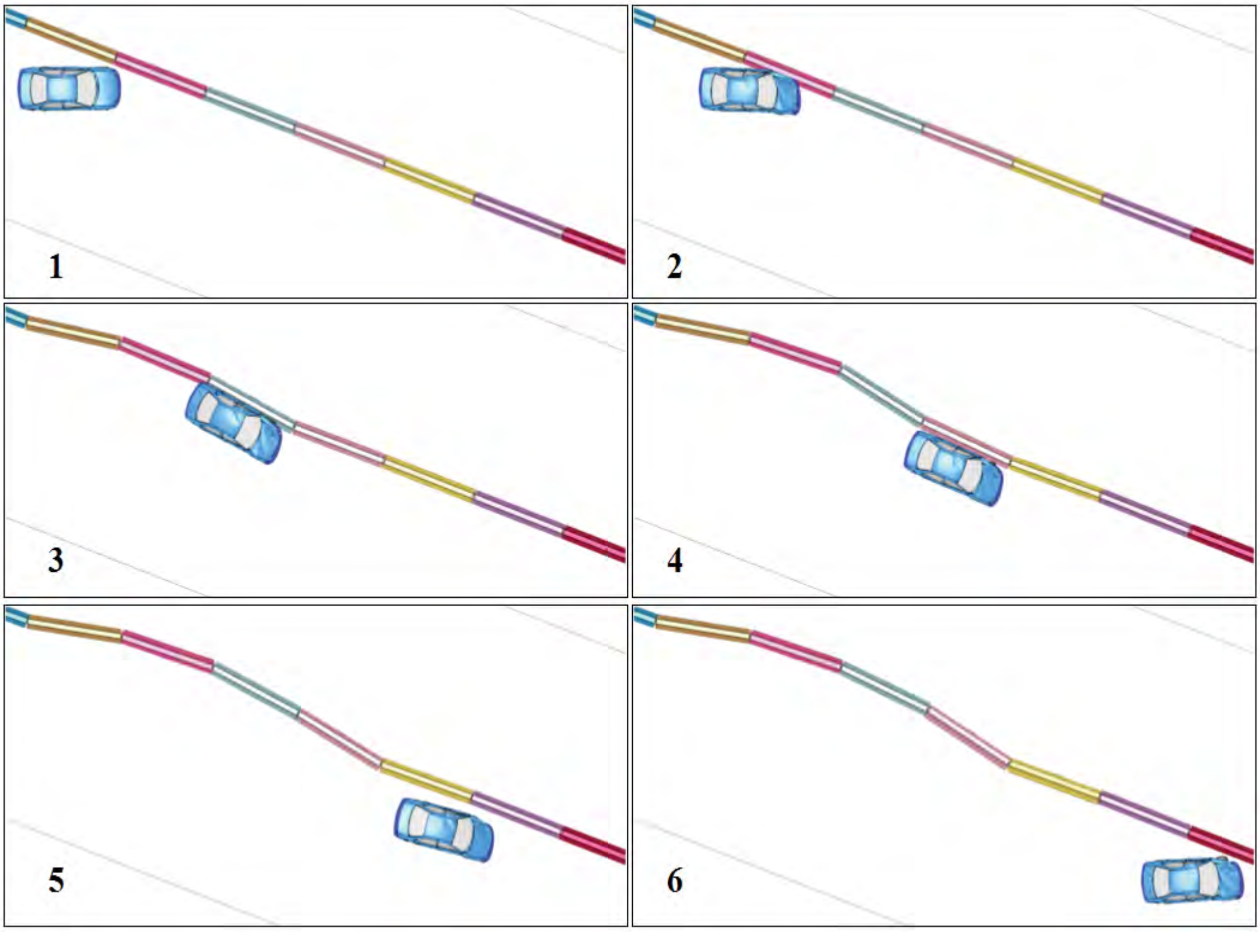

Fig. 3. Stages of collision of Dodge Neon with a portable barrier

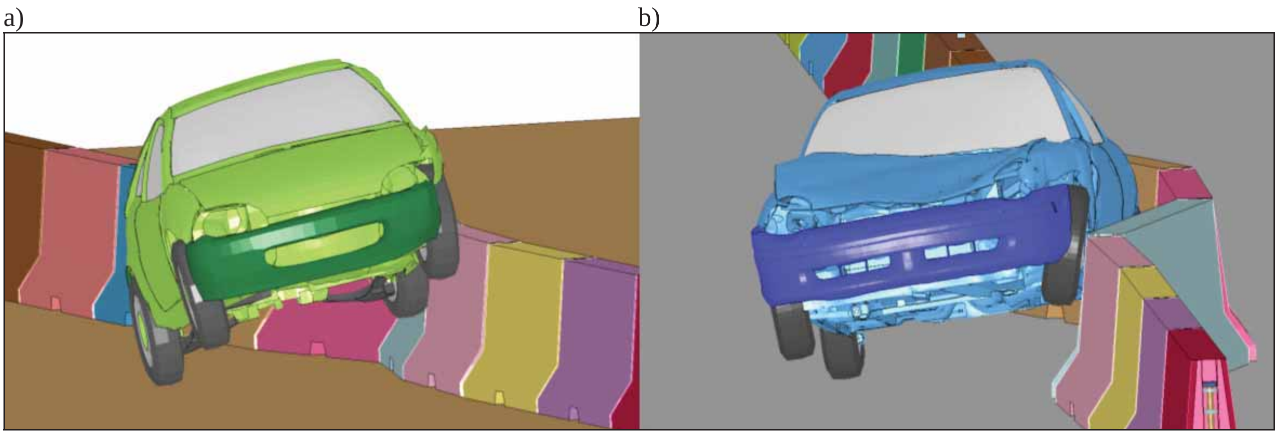

Fig. 4. Collision of a car with a portable barrier: a) Geo Metro, b) Dodge Neon

higher impact energy, Dodge Neon suffers from bigger deformations (curve 1). Compared to the previous case, the bigger part of the kinetic energy turns into the deformation work and there is a higher velocity decrease (by app. 16 km/h).

A course of collision of Dodge Neon with a rigid barrier is different from other cases. Apart from the highest velocity drop in the first phase (by app. 40 km/h), there was also a sudden crash of the rear section of the car with the barrier. It results in further velocity decrease during 0.2 to 0.3 s. Due to a damage of the car suspension, at the next stage of the motion, there was a higher reduction of the longitudinal motion and increase of the rotational motion of the car compared to other cases.

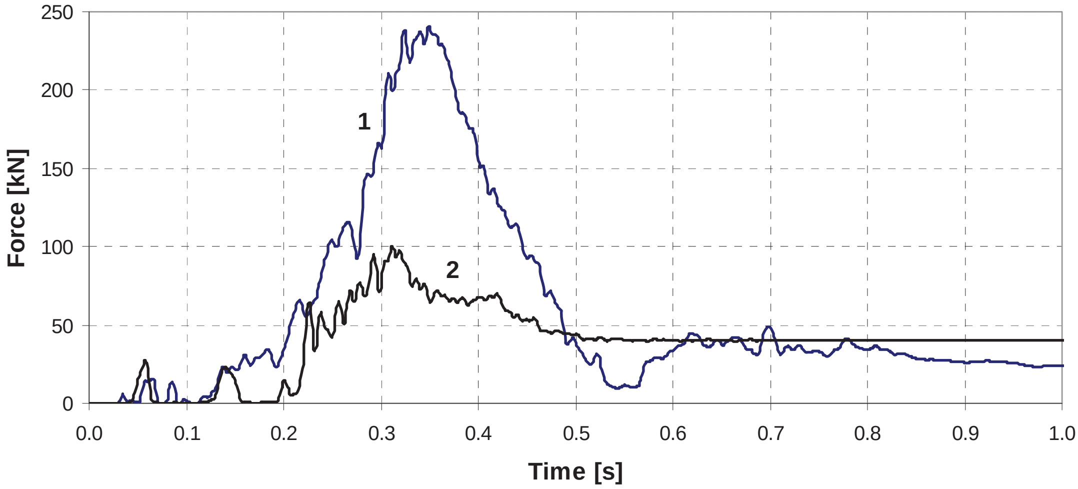

Fig. 5. Forces in the barrier connectors: 1 – Dodge Neon, 2 – Geo Metro

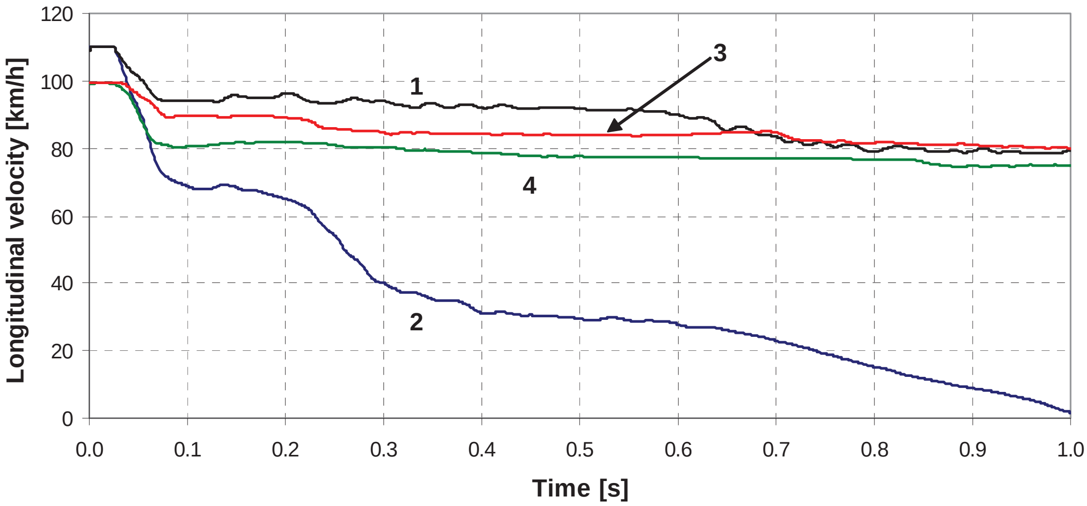

Fig. 6. Longitudinal velocity of the centre of car mass: 1 – Dodge Neon, portable barrier, 2 – Dodge Neon, rigid barrier 3 – Geo Metro, portable barrier, 4 – Geo Metro rigid barrier

Figure 7 presents courses of acceleration of the centre of mass of the car. Assuming the boundary value of the longitudinal acceleration amounting to 12 g (g = 9.81 m/s^2), assumed in order to calculate the ASI index, it can be stated that this value is not exceeded during the collision of both 900 kg and 1500 kg cars with a portable barrier (relatively 8.7 and 11.9 g). Higher values were recorded during a crash with a rigid barrier. The maximum deceleration for Geo Metro amounted to 17.8 g, but in case of Dodge Neon, it exceeded 40 g. Additionally, during a crash of the rear part of the car, another impulse was recorded and deceleration amounted to 13.4 g. When comparing maximum deceleration values during the crash tests for portable and rigid barriers, the increase amounted to 105% and 240% relatively for the 900 kg and 1500 kg cars.

Figure 8 presents ASI index values, calculated on basis of dependence (1), for analyzed cases. Based on the obtained results it can be stated that the car collision with a rigid barrier create higher danger for the people inside the vehicle. In case of Dodge Neon the index value exceeded the boundary value amounting to 1,9 twice. When comparing the analyzed crashes, a collision of the small car with a portable barrier created the lowest danger for a man. The ASI index amounted to 1.3 and it classifies this case, in respect of severity of crash influence on the car passengers, as level B. The remaining two were classified as level C.

Figure 9 presents working width variation during the crash. The maximum value makes the criterion for classifying it for a proper class according to the standard. Due to a fact that the working

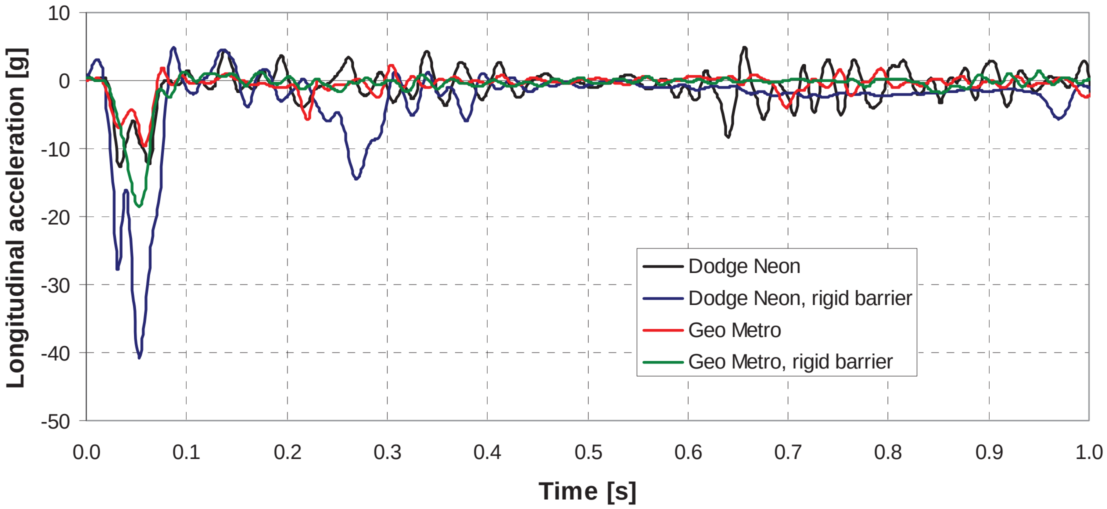

Fig. 7. Longitudinal acceleration of the centre of mass for individual variants

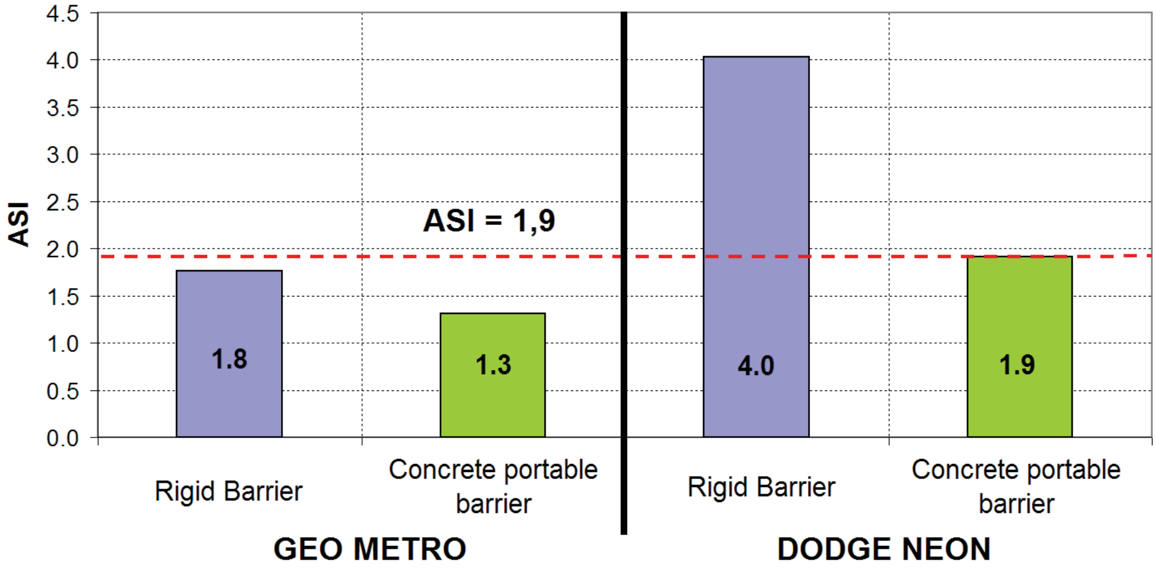

Fig. 8. ASI index for individual variants

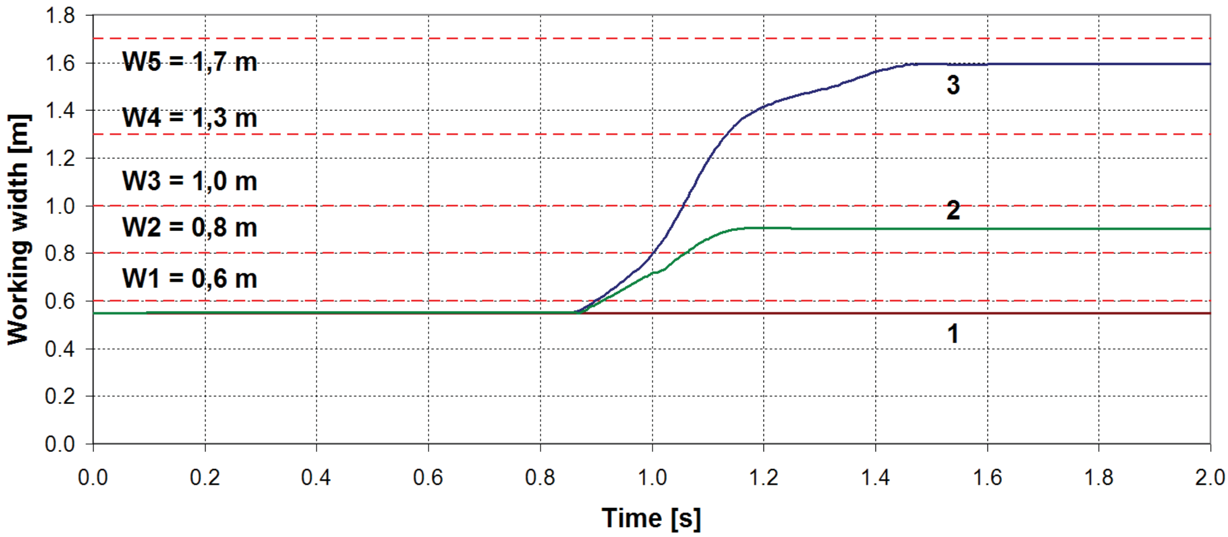

Fig. 9. Working width variation during a crash: 1 – rigid barrier, 2 – Geo Metro, portable barrier, 3 – Dodge Neon, portable barrier

width also includes the initial barrier width, the results obtained for the fixed barrier do not assume the value, which equals zero. Results obtained for Geo Metro classify the portable barrier for class W3, and the results for Dodge Neon classify it for class W5.

5. Summary

The work presents the simulation test results for a collision of 900 kg and 1500 kg cars with two types of safety barriers. The tests and evaluation were carried out according to the requirements included in the EN 1317-2 standard. Assumed vehicles allowed for performing the TB11 and TB32 tests, making the basis of the limiting system tests for normal restrain level N2.

The basic variant included the concrete barrier system, which can move on the ground when affected by the impact force. Additional variant included a rigid barrier fixed to the road surface. The calculations models assumed in that way allowed for evaluation of both barrier types. The results obtained during the simulation tests, for both vehicle types, indicate that there is a lower threat for the people inside the car during a crash with a portable barrier. In case of these barriers, the kinetic energy of a vehicle turns, apart from the body deformation work, into a work required to move the barriers and it is dispersed by the friction forces.

The test results indicate that the traffic safety can be improved by proper shape of the barrier structure. Barrier dimensions, mass and quantity as well as the nature of their cooperation with the surroundings can have a significant influence on the road accident course. However, it requires further more wide analyses. A verification of applied calculation models is also necessary by means of a crash test. The authors of this work plan to carry out proper experimental tests in the second half of 2009 and publish their results.

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