TESTING THE RESULTS OF A PASSENGER VEHICLE COLLISION WITH A RIGID BARRIER

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Abstract

High accident index in Poland, including one of the highest death rates in EU, forces undertaking the intense works in order to improve traffic safety. Published road accident statistics indicate that the most dangerous accidents include a vehicle collision with a tree, post or other road object. The road safety barriers make the road infrastructure elements that can significantly protect against that type of accidents. The work presents basic tasks and requirements imposed on the barriers. Problems related to a proper selection of the barriers have been also highlighted. The tools facilitating the barrier design include numerical modelling. The modelling has been done by means of the LS-DYNA software, using the finite element method. A general structure and a developed barrier model as well as vehicle model have been presented. The conditions of the numerical tests have been also specified.

The work presents the results of influence of car impact angle with a rigid safety barrier. Presented results refer to a car of mass of 900 kg, making a basis for the tests of the limiting systems for several limiting levels: including normal limit N2 (according to EN 1317-2). Compared to standard requirements, the scope of numerical tests has been extended by other car impact angle values. The work presents vehicle trajectories and deformations of their bodies. It also includes examples of velocities and acceleration courses and acceleration severity indexes (ASI) calculated on their basis. Obtained results indicate that the barrier location angle has a high influence on the safety level of the car passengers as well as on the car motion trajectory after collision.

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

1. Introduction

Published statistics unequivocally indicate that Poland holds the second disgraceful position (Lithuania is the first) in the traffic accident death rate ranking in the European Union. 5437 people died on Polish roads in 2008, making 143 people per one million inhabitants. Constant grow of a number of motor vehicles as well as improper development of road infrastructure result in a high unacceptable level of accident victims including death toll on the Polish roads since many years. Paradoxically, the highest number of tragic accidents with killed passengers occurs on good straight roads during good weather conditions. Even an empty road is not totally safe. Violation of traffic regulations, a lack of speed and driving style adjustment to current traffic conditions can lead to losing the control over a vehicle and as a consequence it leads to a serious accident. Tab. 1 presents a specification of road accident types in Poland in 2007. The highest number of killed people resulted from a vehicle collision with a pedestrian and the highest death rate occurs in case of a collision with a tree, post, road sign or other road object. 1032 people died in 4906 accidents and it amounts to 21 people per 100 accidents. Therefore there is a need to introduce technical equipment on the roads that can reduce the risk of accident in highly dangerous locations. That kind of equipment includes road safety barriers. Their basic tasks, regardless of their type, are to reduce the risk of driver and passenger injuries and death as much as possible in case of collisions.

Tab. 1. Types of road accidents in Poland in 2007 [7]

Accident type		Number of accidents		Number of killed		Death rate	Number of injured	
		Total	%	Total	%	Killed/100 accidents	Total	%
Collision of two vehicles	frontal	5 595	11.3	1 020	18.3	18.2	9 717	15.4
	side	11 929	24.1	792	14.2	6.6	16 270	25.7
	rear	5 205	10.5	300	5.4	5.8	7 003	11.1
Run into	pedestrian	15 563	31.4	1 924	34.5	12.4	14 708	23.3
	motionless vehicle	525	1.1	42	0.8	8.0	724	1.1
	tree, post, road sign, other road object	**4 906**	**9.9**	**1 032**	**18.5**	**21.0**	**6 830**	**10.8**
	railway barrier	6	0.0	-	-	0.0	9	0.0
	hole, bump	64	0.1	2	0.0	3.1	74	0.1
	animal	128	0.3	5	0.1	3.9	166	0.3
Rolled-over		3 218	6.5	285	5.1	8.9	4 582	7.2
Accident with passenger		878	1.8	63	1.1	7.2	1 190	1.9
Other		1 519	3.1	118	2.1	7.8	1 951	3.1

The safety barrier is used in order to prevent a vehicle going to the side of the road in dangerous locations, vehicle going away from the road crown, vehicle crossing the road and entering the road intended for the traffic going in the opposite direction or to prevent vehicle collision with object or fixed obstacles located near the road. They are used on fly-over, embankments as well as in locations where objects and fixed barriers (posts, buildings etc.) are located near the roads. A safety barrier properly designed and made should also keep a vehicle hitting the barrier on a track parallel or close to parallel to the barrier, reducing the danger for other traffic participants as much as possible. Especially, a vehicle reflection or skidding should be avoided. The results presented in this article make a fragment of the work oriented towards design of concrete safety barriers that meet the above requirements.

2. Test object

The main purpose of the model tests carried out was to analyze the influence of the rigid barrier location angle towards a vehicle on the collision process and its consequences. In order to do that, a rigid barrier model has been prepared and then it has been connected with a passenger car model. According to the authors' main object of interest, i.e. a road barrier, the tests have been performed with Geo Metro car model developed by National Crash Analysis Centre [8]. Selection of that model resulted from the availability. Development of a complete vehicle model is a very time-consuming task and very difficult due to a limited access to a technical documentation of a vehicle.

A discrete vehicle model with a barrier is presented on Fig. 1. The barrier has been modelled by means of rigid, non-deformable, four-node shell elements, making an external outline of the barrier of the base height of 810 mm and width of 550 mm. In order to specify a nature of cooperation, the conditions of a contact between a car and a barrier as well as between a car and the road surface were defined.

The analysis has been performed by the LS-DYNA software, using a finite element method [3, 6]. That software is commonly used in the car crash simulation tests. As a result of calculations carried out, the courses of displacements, velocities and accelerations for individual model elements. They were used to evaluate the influence of the barrier location on the car structure load and the passenger load. Additionally, according to the dependence (1) the Acceleration Severity Index (ASI) has been calculated and it allows for defining the hazard level for the vehicle passengers during a collision with the safety barrier system.

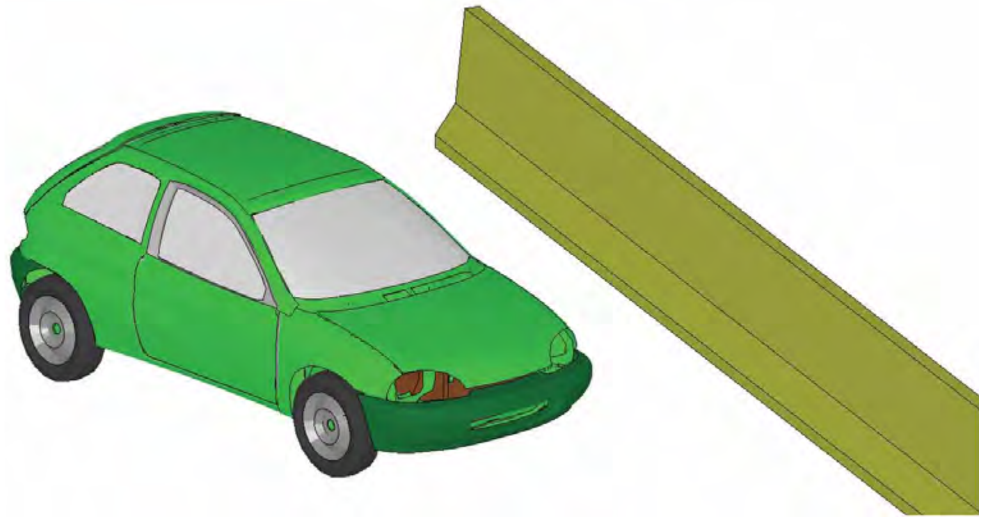

Fig. 1. Model of vehicle

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

where:

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

$a_{x,y,z}$ - 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).

Calculated value should be compared to further crash severity levels. In a desired situation the ASI value should be lower than unity (level A), however higher values are also considered. The ASI value of 1.4 makes a border of the B level and 1.9 makes the C level introduced in 2006.

3. Numerical test results

The main purpose of the tests was to evaluate the quality and quantity of the results of a car collision with a barrier. The numerical tests have been carried out for four crash angles: 10°, 20°, 30° and 40°. A tested vehicle was moving with initial speed of 100 km/h. Therefore calculations carried out for 20° made the TB11 test according to requirements of EN 1317-2 standard at the same time.

Figure 2. presents selected stages of car collision with a barrier placed at angle of 10° towards the vehicle motion direction. During a test, there was a small contact of the front part of the car body with a barrier, car wheels ran into the side plane of the barrier and then the car changed its direction (value of angle between car's direction and barrier amounted 3°). Due to a small crash angle value, the body structure deformations are quite small. During the crash, the suspension of car was not damaged.

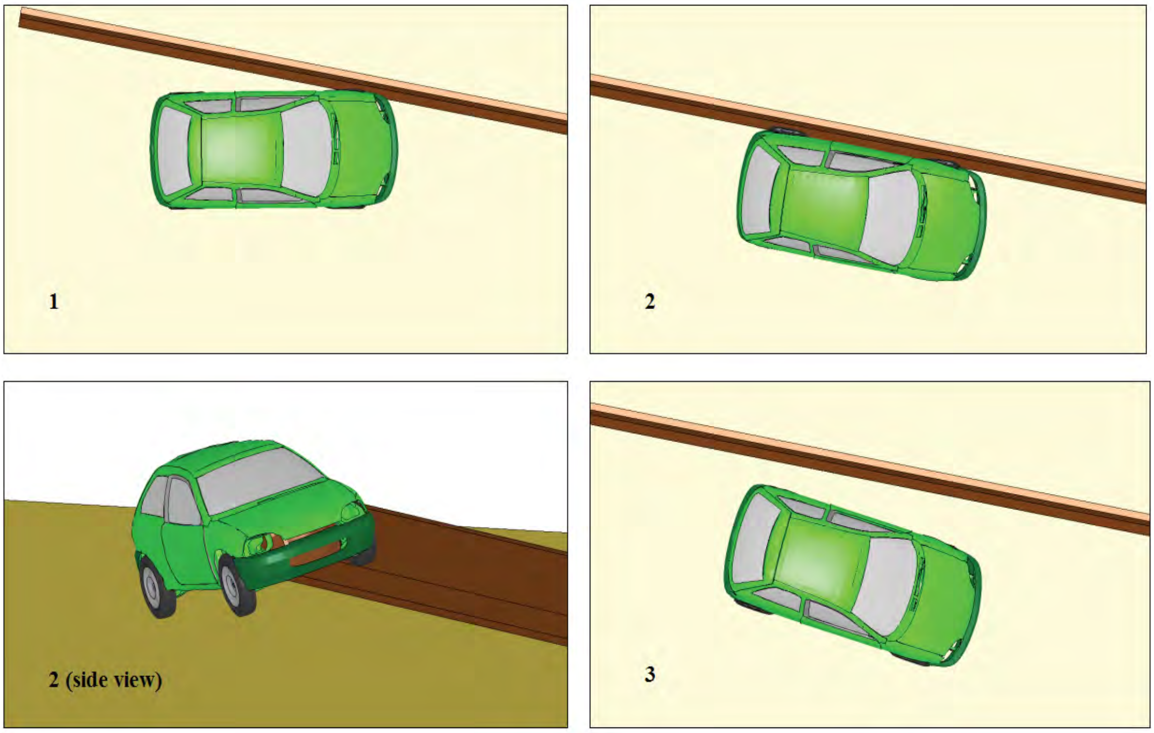

Fig. 2. Stages of car collision with a barrier at 10° impact angle

Figure 3 presents analogical results obtained for the maximum analyzed angle of car collision with a barrier. Compared to a previous accident, very big car body deformations occurred. The left side of the engine compartment was damaged and big deformations of the passenger compartment occurred. Deformed left door and door sill would make the driver removal from a crashed vehicle significantly more difficult. The suspension of the front left wheel was damaged and the wheel was blocked by deformed elements of the car body.

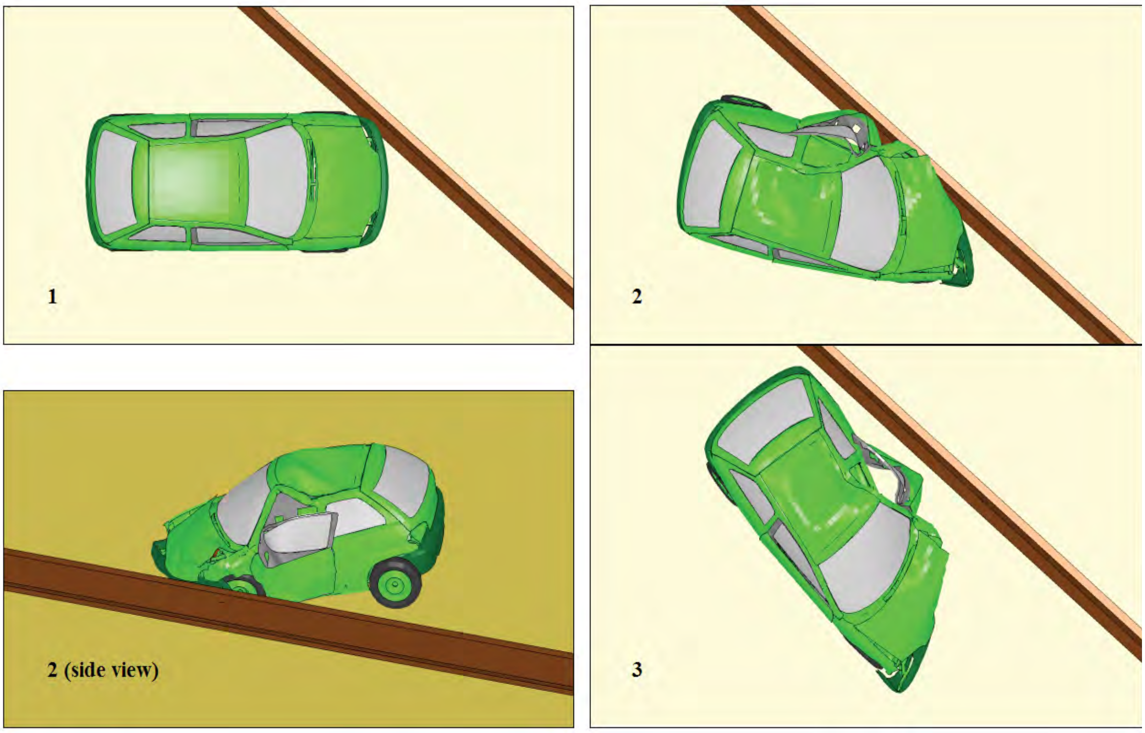

Fig. 3. Stages of car collision with a barrier at 40° impact angle

Figure 4 presents time and speed courses along the longitudinal centre of a vehicle mass for analyzed car-barrier impact angles. Having analyzed obtained results in direct surroundings of the crash moment, it can be stated that the speed dropped during approximately 0.1 s relatively by 6.7%, 17.5%, 30.6% and 42.9%. It means that increasing the impact angle value four times (from 10° to 40°) resulted in the car speed reduction by app. six times (6.4).

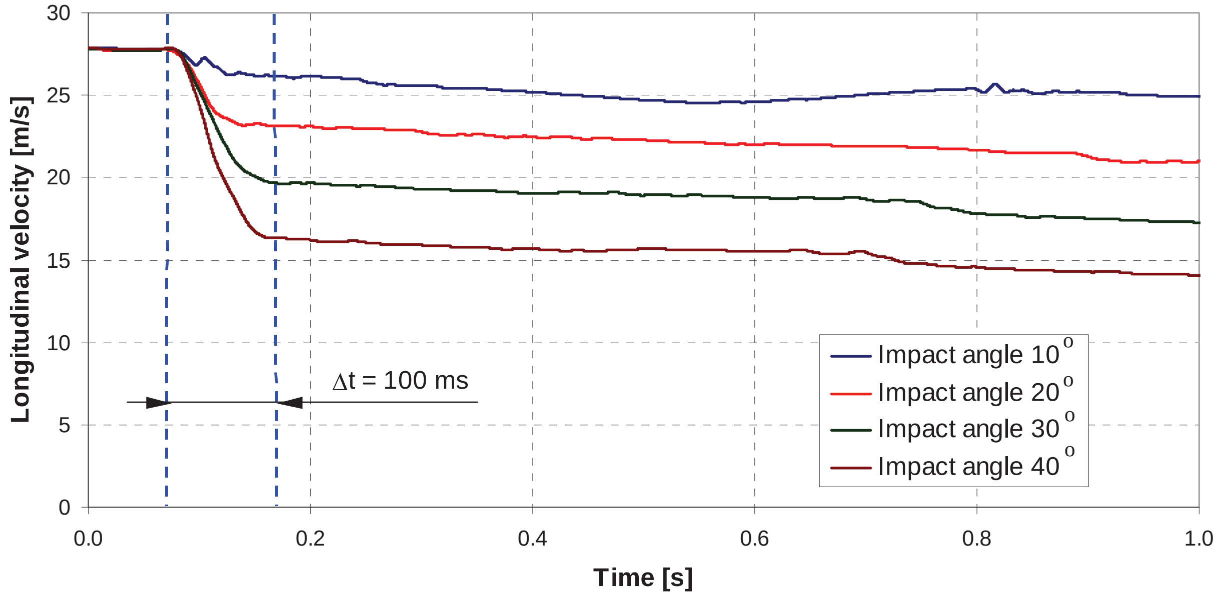

Fig. 4. Longitudinal velocity of the centre of vehicle mass for individual impact angles

Figure 5 presents courses of acceleration of centre of car mass. The increase of the impact angle value results in sudden increase of deceleration. Taking into account assumed boundary acceleration value for a longitudinal direction amounting to 12 g (g = 9.81 m/s2), assumed in order to calculate the ASI index (1), it should be stated that this condition is satisfied for the barrier positioned at angle of 10°. The increase of the impact angle by each further 10° results in the increase of the maximum deceleration value by about 12 g.

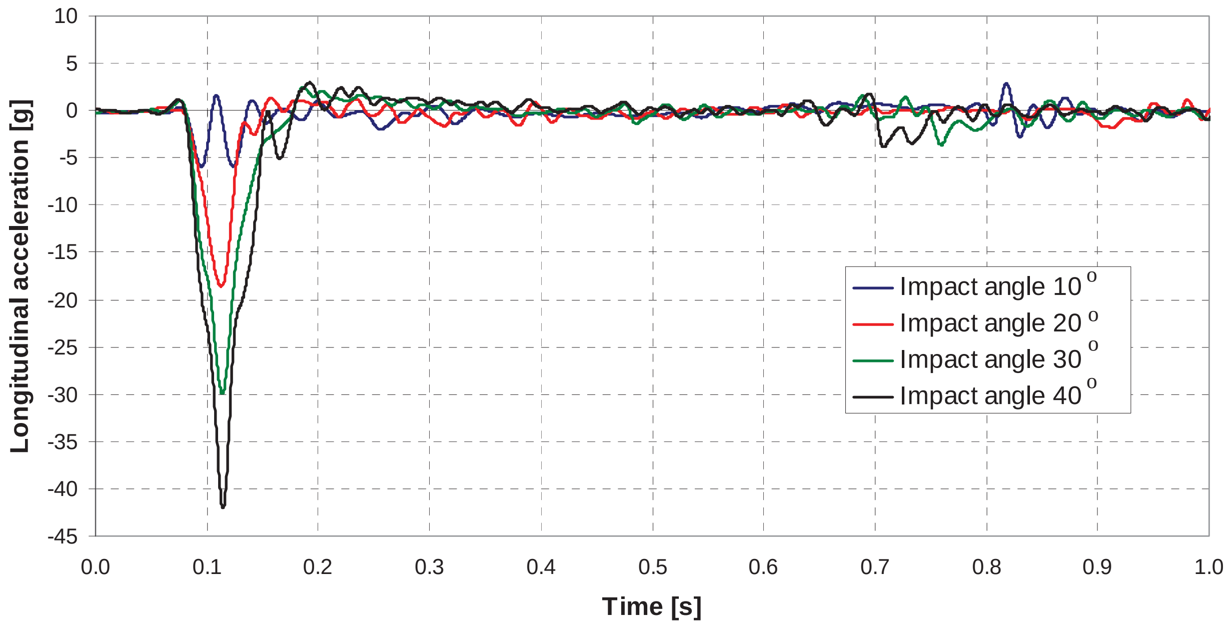

Fig. 5. Longitudinal acceleration of centre of car mass for individual impact angles

Figure 6 Presents car motion trajectories before, during and after the impact.

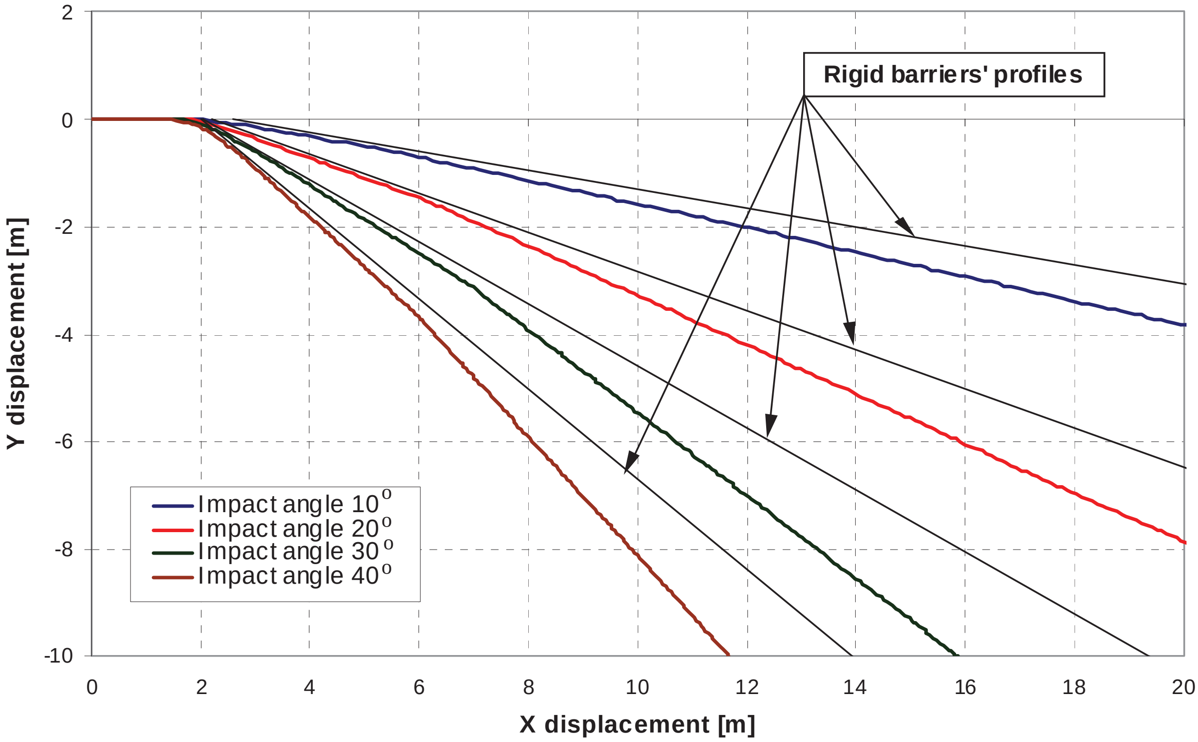

Fig. 6. Car motion trajectories

The barrier side outline is marked with thin lines on the above figure. They facilitate evaluation of the car behaviour after crash. Depending on the barrier position, the angle of the car moving towards the barrier after the crash has changed. For the next barrier positions it amounted respectively to: 3°, 5°, 8° and 8°. The increasing value for small impact angles has stabilized for the big angles. Big angles of a car motion after the collision with the barrier are particularly dangerous as they could lead to running into a road lane of the opposite traffic direction and could result in a secondary accident. In analyzed cases, the car did not cross its acceptable road lane on the section of 10 m defined in the standard [2].

Figure 7 presents the ASI index values, calculated on the basis of dependencies (1), for analyzed car-barrier collision angles. On the basis of obtained results, it can be stated that only the value of that index is lower than the boundary value of 1 (level A), defining the safe level for a human being, only for the smallest angle. For the higher impact angles, the index values significantly exceed that limit and it is directly related to a high danger for the people taking part in such accident. Considering the highest level of impact severity, for which the ASI index amounts to 1.9, the test results obtained for 20° angle can be also defined as moderately safe.

4. Summary

The work tries to evaluate the influence of car impact angle during collision with a rigid safety barrier. Presented consideration refers to a car of mass of 900 kg, which makes a popular segment of the passenger vehicle market in Europe. Selection of that vehicle also resulted from the standard conditions. That type of a vehicle makes a basis for the safety system tests for several restrain levels: including normal N2 restrain and higher H1, H2 and H3 levels (according to EN 1317-2 [2]). Compared to the standard requirements, the scope of numerical tests was extended by other car impact angle values.

The results of initial numerical tests indicate that the barrier position angle has a high influence on dynamic loads affecting the vehicle. In case of small impact angles, a vehicle suffers from small deformations and it is smoothly driven out from the crash zone. In case of the biggest impact angles, the acceleration values and car body deformations are getting bigger. In such case there is a high possibility of blocking a wheel by deformed body elements or total suspension damage on the impact side, leading to uncontrolled vehicle motion and skidding.

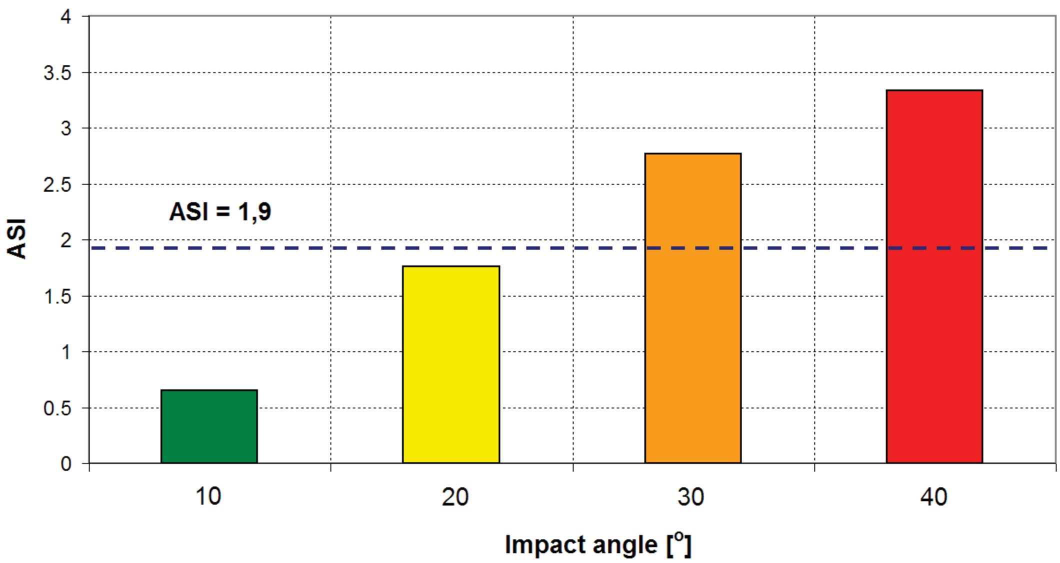

Fig. 7. ASI index for individual impact angles

The Acceleration Severity Indexes, calculated on the basis of accelerations of a centre of car mass, indicate that collisions with a rigid barrier positioned at angle exceeding 20° results in a serious threat for the car passengers' lives and health.

The results presented in this work make the initial stage of the work and further calculations require checking the correctness of the car and barrier calculation models.

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