ANALYSIS OF THE INFLUENCE OF CONCRETE SAFETY BARRIER SEGMENT LENGTH ON ROAD SAFETY

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Summary

The paper presents problems related to road safety in terms of the development of the concrete barriers system, dispersing energy of car collision on the roads with high traffic and high accident risk. Particular attention was paid to barriers' basic parameters - weight and length of the segment. The main objective of the numeric researches was to assess the qualitative and quantitative effects of the car collision with a concrete road barrier in accordance with the standard EN 1317. To the model tests a 900 kg passenger car has been used which allowed to perform TB11 test according to EN 1317-2 standard (initial velocity – 100 km/h). Numerical studies were carried out for concrete segments lengths: 2, 4, 6, 8 m for two selected impact points. Detailed comparisons of simulation test results obtained for individual variants were made on the basis of the acceleration courses of selected car bodywork points, calculated indicators, the trajectory of vehicle movement after collision as well as on the basis of the behaviour of the concrete barriers.

Key words: passive safety, crash tests, concrete safety barrier, computer simulation, LS-DYNA

1. Introduction

Dynamic development of the road infrastructure, construction of the new sections of express motorways and increase of the number of users and the means of transport result in the higher intensity of the road traffic and as a consequence it results in higher number of threats and road collisions. Various types of vehicles of diverse technical conditions,

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driven by drivers of diverse experience take part in that traffic. Young impulsive, sometimes arrogant, drivers with little experience, who violate traffic regulations and often drive the cars under influence of drugs, make a significant problem. In order to improve safety conditions and minimize the effects of the road accidents, many scientific centres carry out intense experimental research [9, 10] and simulations [3-8] that will allow reducing the effects of the road collisions. This paper makes a development of the road traffic safety issue in the aspect of development of the concrete safety barrier system, dispersing the car impact energy on the roads of high traffic intensity and high accident threat and particularly including its basic structure parameters (segment weight and length). Two discrete models, described in the papers [4, 5, 6, 7, 8, 11] were used for numerical tests:

- model of concrete barrier system, including the ground [4, 8], fig.1;
- model of Suzuki Swift car [11], fig. 3.

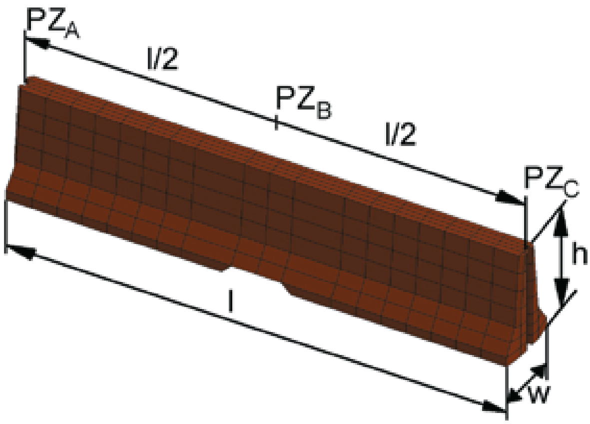

Fig. 1. Segment of the concrete safety barrier: PZA, B, C – impact point, the beginning, the middle, the end of the segment; l (l/2) – segment length (segment half); h= 810 mm – segment height; w= 550 mm – segment width

The concrete safety system consists of the segments making a barrier of the length of about 60 m (fig. 2). Each segment (fig. 1) makes a fragment of the concrete barrier of a constant base height of 810 mm and width of 550 mm and various segment lengths (2, 4, 6, 8 m). A single barrier segment is composed of 524 non-deformable SOLID type elements [12]. Individual barrier segments are connected by a coupler which is designed to transfer the force between the segments and assure their mutual turn at the same time [7].

A discrete vehicle model and a concrete safety barrier are presented on fig. 2.

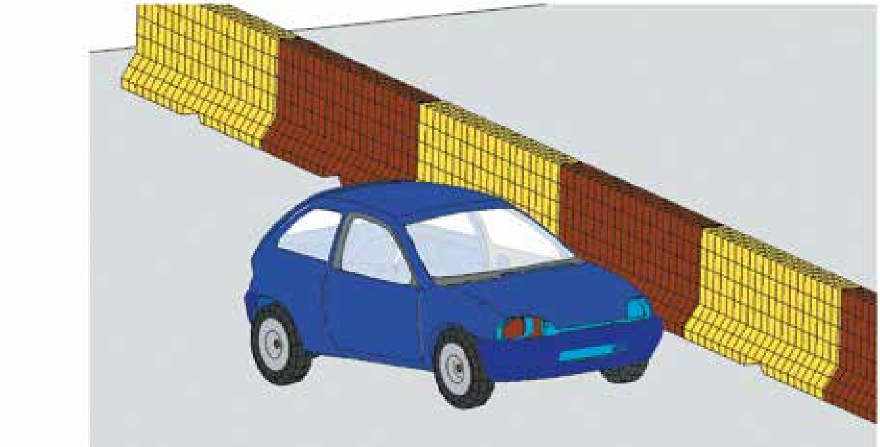

Fig. 2. Suzuki Swift car model with a concrete barrier [4]

1. Purpose and scope of research

The main purpose of the performed numerical tests was to provide quality and quantity evaluation of the effects of the collision of the car and a concrete road barrier with modified segment length (table 1) and impact point (table 2).

Table 1. Selected impact points (PZ) oriented on the safety barrier segment

Impact point PZ	Segment length [m]			
	2	4	6	8
Beginning of the segment - PZ_A	✓			✓
The middle of the segment - PZ_B	✓	✓	✓	✓
The end of the segment - PZ_C	✓			✓

Table 2. Selected calculation parameters of the segment and safety barrier applied in the simulation tests

Segment		Safety barrier			
Length [m]	Weight [kg]	Length [m]	Impact point location PZ [m]		
			PZ_A	PZ_B	PZ_C
2	1140	60	20,4	21,1	22,2
4	2335	60	-	22,3	-
6	3540	60	-	20,9	-
8	4740	64	24,6	28,3	31,6

Crash test conditions for a test car model are presented in table 3. It was assumed that the front and the left side of the car hit the barrier in each test.

Table 3. Crash test conditions for a test car model according to PN-EN 1317-2

Test car	Weight [kg]	Crash parameters		Test type	Restraint level
		speed [km/h]	angle [^{0}]		
Suzuki Swift	900	100	20	TB11	N2

2. Simulation test

The simulation tests were carried out in the LS - DYNA system [3-8, 12] according to the requirements included in the valid standard EN 1317 [1, 2]. As a result of the performed crash tests, time courses of accelerations and speeds of the centre of mass of the car, used for evaluation of behaviour of the test car and the concrete barrier, were obtained. The following indexes were used for evaluation [2]: Acceleration Severity Index (ASI) calculated according to dependence (1) and dynamic deflection (D) working width (W) of the barrier. Specified dependences are defined in [1].

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

where:

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

$\bar{a}_{x,y,z}(t)$ – components of accelerations of the centre of mass of the car [g],
$\hat{a}_{x,y,z}$ – limit values of accelerations for individual directions amount to respectively: 12, 9, 10 g for longitudinal (x), transverse (y) and vertical (z) directions,
δ – floating time section (δ = 0,05 s).

Fig. 3 presents a selected course of longitudinal accelerations of the centre of mass of the car in the time function, for a concrete barrier composed of 4-metre segments with three highlighted time zones:

- **the first one,** including the time of the car approach to the barrier impact point;
- **the second one,** from the moment of the impact with the barrier, frontal impact to the rear impact of the car;
- **the third one,** it includes the lack of contact between the car and the barrier – the car is moving within an expected reflection area.

Depending on the considered length of the barrier and impact point, duration of individual stages differ from one another. In case of shorter segments, the car rotates quicker (the angle is also bigger) and as a consequence the moment when the back of the car hits the barrier comes sooner. Moreover, in case of 2-metre segments, that section of the car hits the barrier twice. In case of longer segments, that stage is not so clear anymore. After the first impact, there is a slower rotation of the car and barrier segments. As a result, the left side of the car hits the barrier and it goes along the external surface of the segments. In that case, the loss of contact between the car and the barrier occurs later. It is also visible on the longitudinal acceleration courses of the car (fig. 4). Contrary to the shorter segments, the increase of delay in that area is not so clear for the long segments.

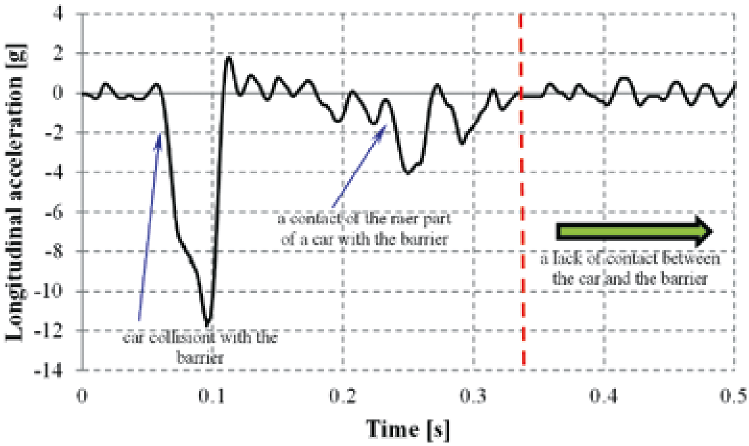

Fig. 3. A course of longitudinal accelerations of the centre of mass of the car in the time function for a concrete barrier composed of 4 m segments with marked out time zones

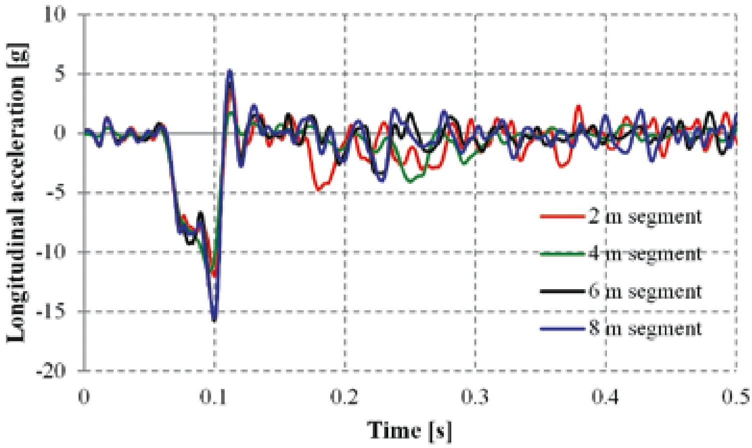

Fig. 3. A course of longitudinal accelerations of the centre of mass of the car in the time function for a concrete barrier composed of 4 m segments with marked out time zones

Similar course nature, with marked three time zones, was obtained for the remaining barrier configurations. Noticed changes referred to the second and the third zones. The nature of these changes is illustrated on fig. 4.

Examples of the ASI index values, calculated on the basis of acceleration time courses (x, y, z) of the centre of mass of the car according to dependence (1 and 2) are presented in table 4 and in a form of a histogram (fig. 5). For performed crash tests (table 4) the obtained values of ASI index amounted to 1.24 – 1.45. For the barriers composed of 2 and 4 m segments, the impact severity level amounted to the scope of normative B level ($1<ASI\leq 1{,}4$), while for the barriers composed of 4 and 8 m segments, the impact severity amounts to level C ($1{,}4<ASI\leq 1{,}9$) in its lower limits [2].

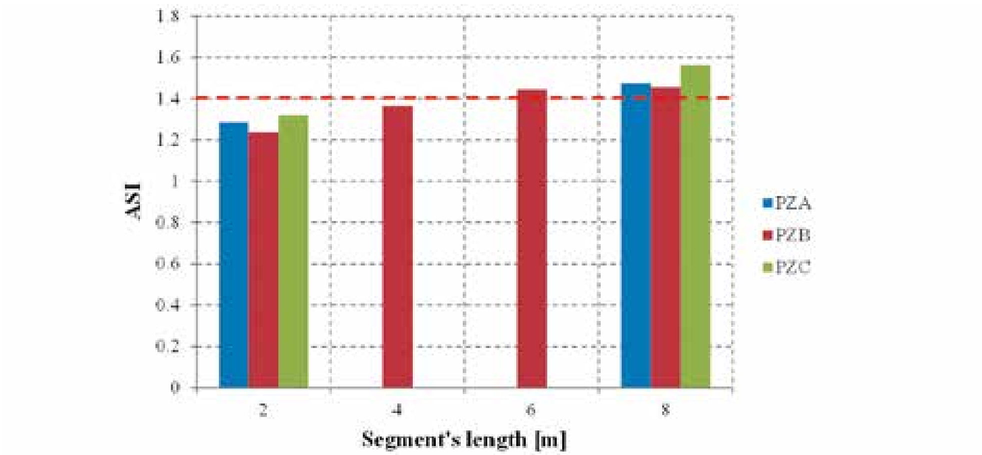

Fig. 5. The histogram of the ASI index for the barriers composed of segments of various lengths and selected points of impact (PZ)

Table 4. Values of the ASI index and working width W for a concrete safety barrier composed of segments of various lengths at impact in the middle part of the segment (PZ_B)

No.	Concrete barrier composed of segments	Acceleration Severity Index (ASI)	Working width W [m]	Dynamic deflection D [m]
1	2 m	1.24	1.69	1.14
2	4 m	1.37	1.07	0.52
3	6 m	1.44	0.85	0.3
4	8 m	1.45	0.79	0.24

Deformation of the restraint system composed of concrete segments is characterized with a dynamic deflection (D) and working width (W). Test results are presented on fig. 6 and 7 and in table 4.

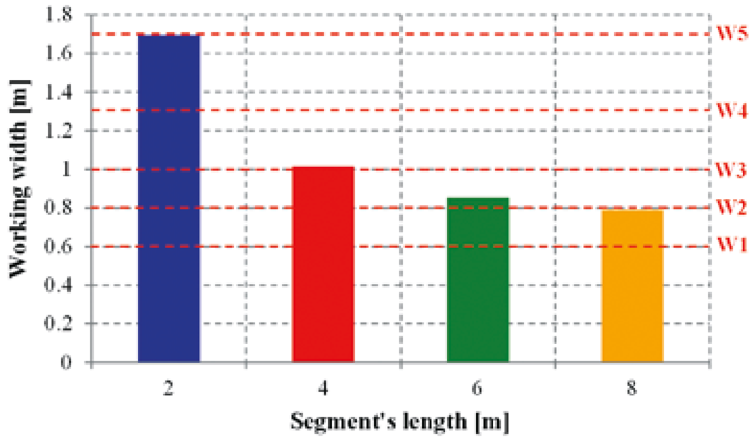

Fig. 6. Working width (W) of the concrete safety barrier for various segment lengths

Observed values of the working width (W) vary between 0,79 – 1,69 m, and it corresponds to the normative classes W2 – W5 [2]. The values of dynamic deflection D, that have significant influence on the tested working width, are worth noting. In the analysed cases, changes between 0,24 – 1,14 m were observed, while the lower limit refers to the barrier composed of 8 m segments and the upper one refers to the barrier with 2-metre segments.

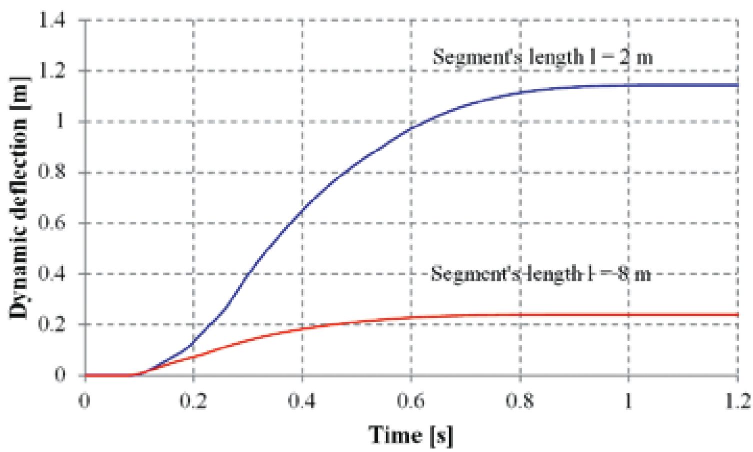

Fig. 7. Dynamic deflection of the concrete safety barrier for two segment lengths

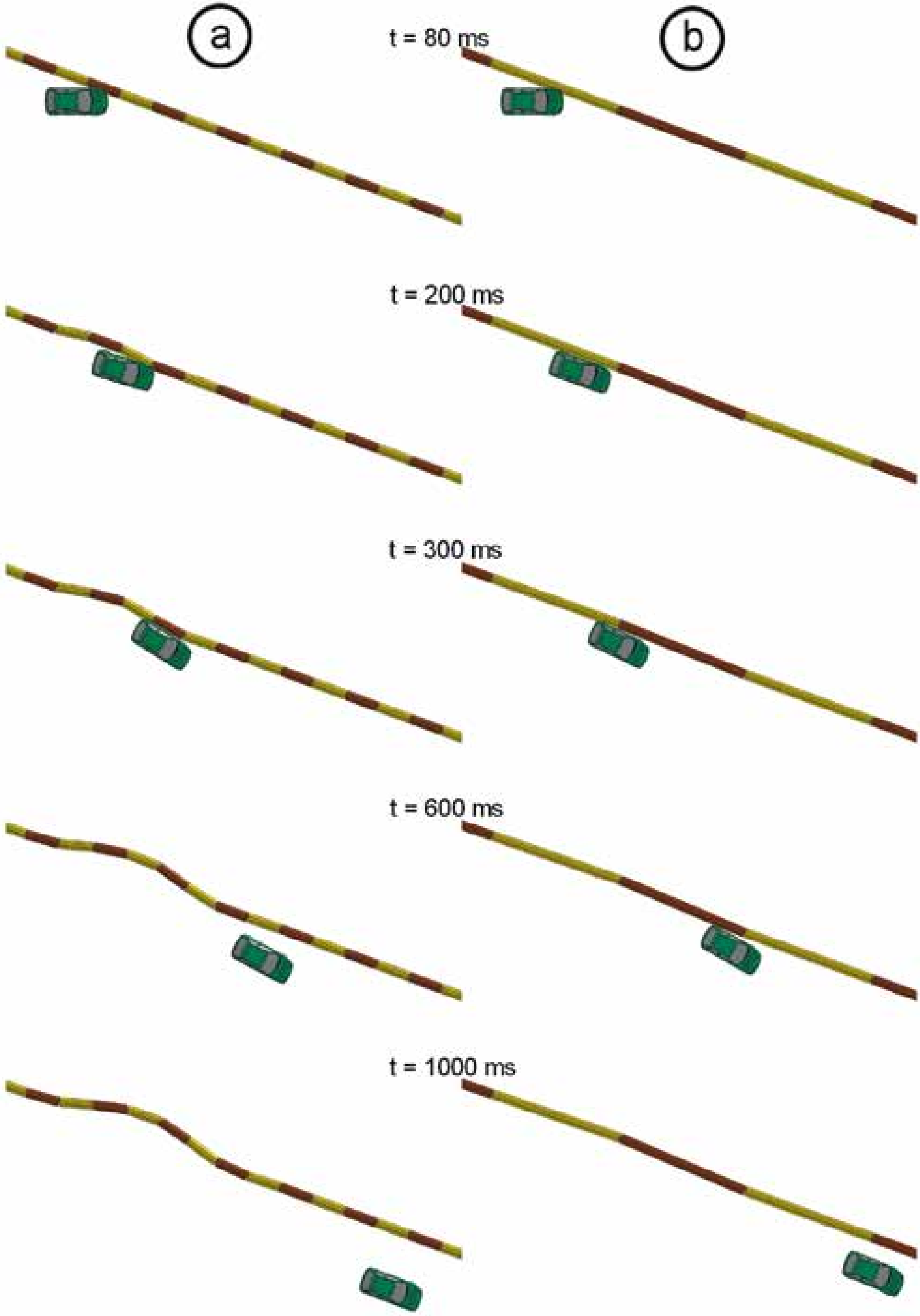

Fig. 8. The course of impact phases (impact point PZB), for t = 80, 200, 300, 600 and 1000 ms, for a Suzuki Swift car with a concrete safety barrier composed of segments of various length: a) – 2m segment, b) – 8m segment

In order to illustrate (fig. 8) the course of a collision of the car the concrete safety barrier (in two variants: with a 2 m segment – fig. 8a and 8 m – fig. 8b), their mutual position for selected stages of motion is presented:

- the beginning of simulation was assumed for t = 0 ms,
- car arrival to the barrier in 0< t <80 ms
- the beginning of the car contact phase (left front) with a barrier for t = 80 ms,
- continuous car body deformation (left front and side of the car) and barrier geometry change for t = 200 ms,
- change of the car contact area (left rear) with a barrier for t = 300 ms,
- car departure from the area of mutual contact with a deformed barrier up to t = 600 ms,
- further car motion in the so-called reflection zone.

Depending on such factors as the barrier length (its weight) and the place on the segment where the car hits, moments of occurrence and duration of individual stages vary. The fastest changes occur for the barrier composed of shorter elements. Due to bigger displacements and turns of short segments, the car rotation is higher. As a result it loses the contact with the barrier quicker. Unfortunately, at the same time it is related to the reflection angle (the angle between the car motion direction after the impact with the barrier line). In some situations it can have negative consequences. From the point of view of meeting the normative requirements, it can lead to violation defined in the acceptable reflection field standard (EN 1317). However, in the real conditions it can lead to uncontrolled move to the lane of the traffic in the opposite direction and repeated collision with other vehicle.

Analysing the displacement of the barrier segments, it can be stated that the use of shorter segments favours the creation of the so-called catenary curve. It facilitates the impact energy dispersion and it results in lower delay values recorded during the tests. The use of long segments limits the possibilities of mutual displacement and therefore it also leads to the increase of affecting forces and accelerations.

3. Summary

Results of multivariate simulation tests, using the advanced numerical systems, confirmed the influence of the segment length and the impact point (PZ) on the course and effects of impact, also make the significant supplement to the previous publications [3 – 8]. The choice of the 900 kg car results from its high popularity on the European passenger car market and guidelines included in the normative acts [2], where the test TB11 (including cars of total weight of 900 kg) occurs on the level of normative restraint N2, higher restraint H1, H2 and H3 and very high restraint H4a H4b [2]. Presented methodology of numerical calculations can be successfully used when designing prototypes and analysing the existing solutions of concrete safety systems. The authors are aware of the fact that the prototype safety system has to meet normative requirements [1, 2], that are verified during the experimental tests in the certified European laboratories.

References

[1] PN-EN 1317-1:2001: *Systemy ograniczające drogę - Część 1: Terminologia i ogólne kryteria metod badań*

[2] PN-EN 1317-2:2001: *Systemy ograniczające drogę - Część 2: Klasy działania, kryteria przyjęcia badań zderzeniowych i metody badań barier ochronnych.*

[3] BORKOWSKI W., HRYCIOW Z., RYBAK P., WYSOCKI J.: *The researches of effectiveness of Road restraint Systems,* Journal of KONB i N, No1(13)2010, Safety and Reliability Systems, str.53-64,Warsaw, 2010.

[4] BORKOWSKI W., HRYCIÓW Z., RYBAK P., WYSOCKI J. :*Ocena wpływu rodzaju podłoża na zachowanie betonowej bariery ochronnej.* Górnictwo Odkrywkowe nr 4/2010, str. 226-229, Wrocław, 2010.

[5] BORKOWSKI W., HRYCIÓW Z., RYBAK P., WYSOCKI J.: *Simulation tests on shaping the working width of the concrete protective systems.* Journal of Kones vol. 17, nr 2/2010, str. 43-50, Warszawa 2010.

[6] BORKOWSKI W., HRYCIÓW Z., RYBAK P., WYSOCKI J.: *Numerical simulation of he standard TB11 and TB32 tests for a concrete safety barrier.* Journal of Kones vol. 17, nr 4/2010, str. 63-71, Warszawa 2010.

[7] BORKOWSKI W., HRYCIÓW Z., RYBAK P., WYSOCKI J.: *Prototype articulated joint in connections of the concrete protective barrier.* Journal of KONES vol. 18, no 1, Warsaw 2011, str. 85-92.

[8] BORKOWSKI W., HRYCIÓW Z., RYBAK P., WYSOCKI J.: *Analiza skuteczności betonowych barier ochronnych na łuku drogi.* Przegląd Mechaniczny nr 7-8'12. Warszawa 2012, str. 21-24.

[9] WICHER J.: *Bezpieczeństwo samochodów i ruchu drogowego.* WKŁ, Warszawa 2004.

[10] WICHER J.: *Rozpraszanie energii kinetycznej samochodu przez przesuwną betonową barierę drogową.* Archiwum Motoryzacji 1/2011, Warszawa 2011, s. 97-115.

[11] http://www.ncac.gwu.edu/

[12] HALLQUIST J. O.: *LS-DYNA. Keyword User's Manual,* V971 R4 Beta, LSTC Co., CA, USA 2009.

[13] STURTA R., FELLA C.: *The relationship of injury risk to accident severity in impacts with roadside barriers.* International Journal of Crashworthiness Volume 14, Issue 2, 2009.