Journal of KONES Powertrain and Transport, Vol. 17, No. 2 2010

SIMULATION TESTS ON SHAPING THE WORKING WIDTH OF THE CONCRETE PROTECTIVE SYSTEMS

Wacław Borkowski, Zdzisław Hryciów, Piotr Rybak, Józef Wysocki

Military University of Technology
Kaliskiego Street 2, 00-908 Warszawa, Poland
tel.: +48 22 6837403, fax.: +48 22 6837370
e-mail: zhryciow@wat.edu.pl

Abstract

The work addresses the road traffic safety issue related to the use of road safety barriers. It describes the tasks that have to be fulfilled by the protective system. It presents the barrier assessment conditions according to the requirements of the existing standards as far as the working barrier width is concerned. The objective of the work is to evaluate the possibilities of shaping the working width of the concrete protective systems. They have been executed on the basis of a concrete barrier equipped with a prototype joint linking individual barrier segments. It allowed defining the maximum angle of relative angle displacement of the adjacent segments. The model tests have been performed with a 900kg passenger car which allows performing TB11 test according to EN 1317-2 standard. The modelling has been performed with LS-DYNA software, which uses the finite element method.

The work presents the numerical test results, vehicle motion trajectory and barrier displacement. It also includes examples of speed and acceleration courses of selected vehicle elements and the ASI index calculated on that basis which is used to assess the danger level for the vehicle passengers. Obtained results indicate that there is a possibility of shaping the dynamic bending and the working barrier width depending on assumed joint (boundary angle) parameters. Further areas of the analysis have been also defined.

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

1. Introduction

Increasing road traffic intensity related to a growing number of road users forces a continuous development of the road network. In order to increase the safety level for vehicle passengers, the road designers introduce additional elements of the infrastructure preventing the vehicles and pedestrians from entering danger zones and areas. The most common solutions include the road protective barriers. The road protective barrier is a device designed to physically prevent vehicles from going out of the road in danger zones, to prevent vehicles from leaving the road crown, to prevent vehicles from entering the road lane intended for the opposite traffic direction or to prevent vehicle collisions with objects or fixed obstacles located near the road. Types of barriers available on the market, offered in many versions, allow designers to adjust the protection level to the existing road conditions. However, no matter the barrier type, all barriers used on the roads in the European Union have to meet the resolutions of EN 1317 standard [5, 6]. This standard defines the requirements for the protective barriers within a scope of their ability to restrain vehicles and simultaneous limitation of the area required to stop a vehicle or properly lead out a vehicle. One of the most significant parameters used to assess the protective barriers include the working width.

The objective of this work is to define possibilities of shaping the working barrier width during collision. It has been done on the basis of a change of the parameters characterizing the joint which links the adjacent barrier segments. This work makes the elaboration of the issues presented in the work on the concrete protective barriers that disperse the vehicle collision energy designed for high traffic and high accident risk roads prepared within a scope of the research project.

2. Working width

According to the tasks that need to be fulfilled by the protective barrier systems, the structure of those systems has to make a compromise between the resistance and deformability. On one hand, the restraining system should be able to deform during a vehicle collisions and it should be able to absorb the kinetic energy of the impact, resulting in reduction of accelerations affecting the passengers. On the other hand, it should be resistant enough to prevent from breaking the barrier and prevent excessive barrier displacement (characterized by the working width value). In case of the steel barriers, deformation of successive posts and fragments of guides made of profiled bands located between them takes place during collision. On the contrary, in case of the concrete barriers the vehicle kinetic energy is mostly reduced by shifting linked barrier segments and dispersing the energy due to friction forces.

Protective barrier deformation, according to [5, 6], is characterized by: dynamic deflection (D) and working width (W). The working width is a distance between the front surface from the motion side before collision and the maximum dynamic side position of any part of the system (barrier or vehicle in case it deflects outside the barrier outline). The EN 1317-2 standard defines eight working width levels. They are presented in Tab. 1.

Tab. 1. Working width levels according to EN 1317-2 [6]

Working width level	Displacement
W1	$W \leq 0.6$ m
W2	$W \leq 0.8$ m
W3	$W \leq 1.0$ m
W4	$W \leq 1.3$ m
W5	$W \leq 1.7$ m
W6	$W \leq 2.1$ m
W7	$W \leq 2.5$ m
W8	$W \leq 3.5$ m

From the point of view of this work, it was important to define possibilities of shaping the working width by introducing changes to the structure of the joint linking adjacent barrier segments. The main tasks of the joint include a transfer of forces between individual segments as well as providing a possibility of relative segment motion. A prototype joint has been designed within a scope of the research project being executed and its diagram is presented on Fig. 1.

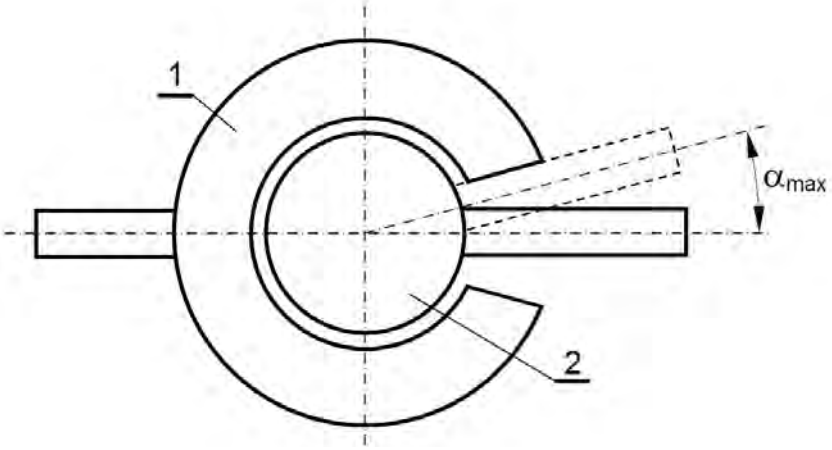

Fig. 1. Joint diagram: 1 –sleeve, 2 –bolt

It consists of two parts linked with cooperating barrier segments. By adjusting the sleeve gap size, it is possible to define the maximum bolt turn angle (limiting angle) towards the sleeve (including the segments connected with them). Applying a gap between the sleeve and the bolt provides easy installation and a relative motion of segments in two remaining planes.

Such joint structure, apart from its impact on the course of accident, also defines the minimum radius of the road curve where the barrier system can be installed (Fig. 2). Tab. 2 presents the minimum road curve radius values for assumed limiting angle values.

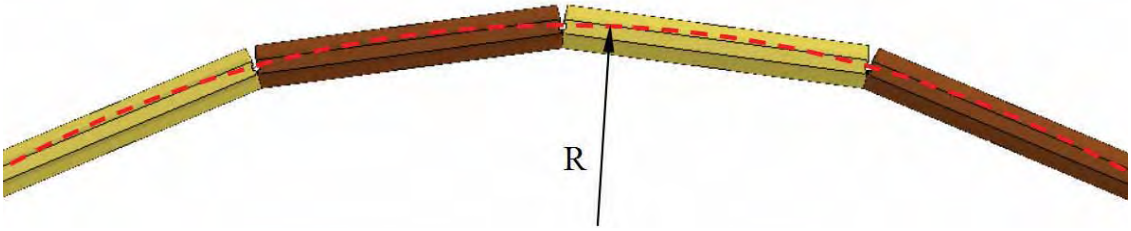

Fig. 2. Minimum road curve radius definition diagram

Tab. 2. Minimum road curve radii

α_{max} [°]	**R_{min} [m]**
5	45.85
10	22.95
15	15.32

3. Test subject model

In order to assess the influence of the maximum value of the angle of a relative displacement of adjacent barrier segments on the working width and the consequences of a passenger car collision with the barrier, a discrete test subject model has been prepared. It includes the concrete barrier system, a car and the ground it moves on. The tests have been performed with a model of Geo Metro designed and provided by the National Crash Analysis Center [9]. A detailed description of the model is included in [7, 8]. Fragments of verification of that model based on the experimental tests are also presented there [7] as well as the influence of the ground type on the course and consequences of collision [8]. A discrete vehicle model including the barriers is presented on Fig. 3.

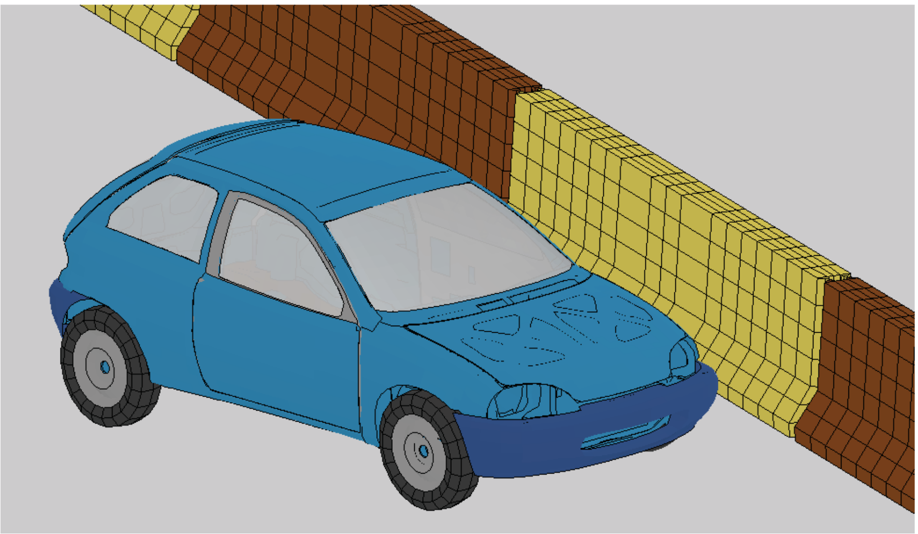

Fig. 3. Model of vehicle

The concrete barrier has been modelled by using rigid non-deformable solid elements and the joints by using four-node shell elements. The joint elements are connected through a cylindrical joint (Constrained Joint Cylindrical) supplemented with a definition of its parameters (Constrained Joint Stiffness). Such attitude allowed defining the joint operation parameters including: limiting turn angles and the friction moment inside the joint. The barrier rested on a non-deformable surface and assumed friction coefficient corresponded to the asphalt surface covered by sand. Calculations were carried out by means of the LS-DYNA software, using the finite element method [1, 4].

4. Numerical test results

The main objective of performed tests is making the qualitative and quantitative assessment of consequences of a car collision with the barrier with various limiting angle values of relative angle segment displacements. Numerical tests have been performed for three angle values: 5° (variant I), 10° (variant II) and 15° (variant III). All simulations have been carried out according to the testing requirements TB11 according to EN 1317-2. Tested 900 kg vehicle was moving at the initial speed of 100 km/h, then it hit the protective barrier system positioned at the angle of 20° towards the vehicle driving direction.

Figure 4 presents selected stages of the vehicle collision with an obstacle for the variant III. During the test, the front part of the car body hit the barrier, the car wheels run over the side barrier surface and then the car was smoothly led out from the crash zone. As a result of the collision, the car body structure underwent small deformations limited just to the front part of the car.

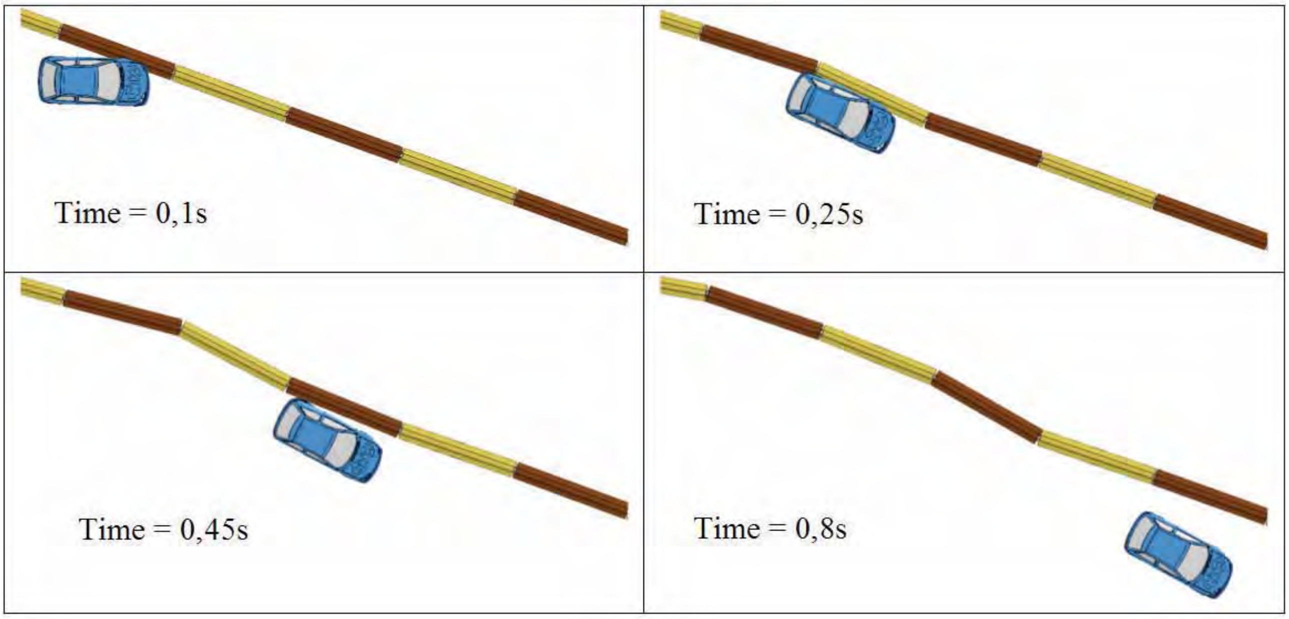

Fig. 4. Stages of collision of Geo Metro car with the movable barrier

Courses of car collisions in the initial fragment for all barrier variants were very similar. However, due to different barrier behaviour the vehicle motion trajectory was different at the next stage of collision (Fig. 5). The limiting angle increase affected the angle of leading out the vehicle from the crash zone. For the limiting angles of the relative barrier motion 5°, 10° and 15° the values amounted to: 2.4°, 4.9° and 7.7° respectively. However, it should be stated that in all analyzed cases the vehicle did not went out of the acceptable area defined by the standard.

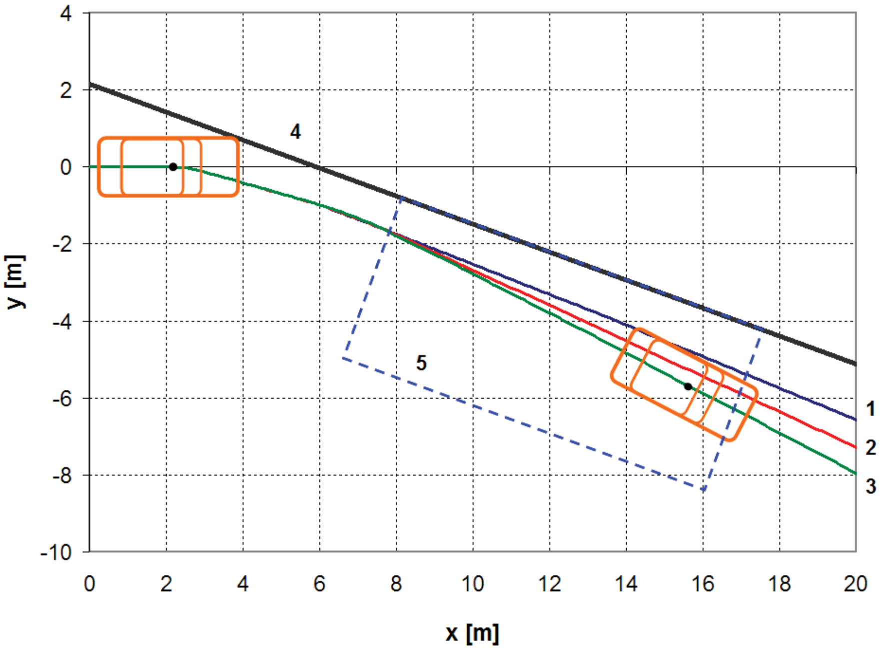

Fig. 5. Car centre of mass trajectory: 1, 2, 3 – variant number, 4 –initial barrier line, 5 – acceptable reflection area

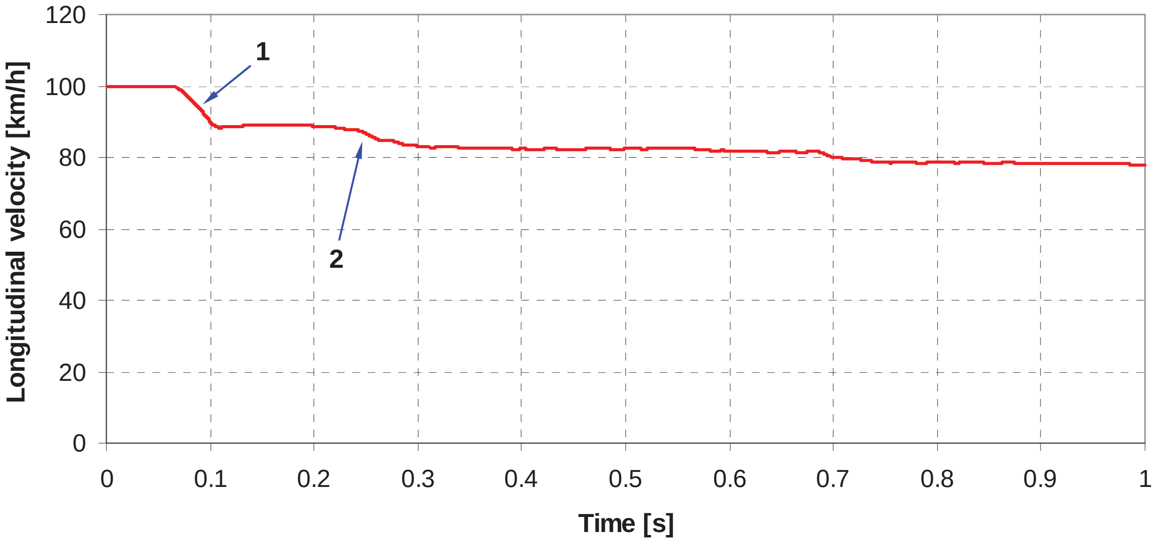

Fig. 6. Longitudinal velocity of the car centre of mass for the variant III: 1 - impact of the front car section, 2 - impact of the rear car section

Figure 6 presents courses of longitudinal car velocity for the variant III. However, it should be highlighted that those courses were formed in a very similar way for the remaining variants. At the first stage of collision (up to app. 0.1s – car front impact) the speed is reduced by about 12 km/h and the direction of the motion is changed. As a result, the rear part of the car hits the barrier for about 0.25s.

Figure 7 presents courses of accelerations of the car centre of mass corresponding to the above variant. Assuming the limiting acceleration value for longitudinal direction amounting to 12 g (g = 9.81 m/s2), assumed in order to calculate the ASI index, it can be stated that this value is not exceeded during the collision with the barrier (10.6 g). Calculated on the basis of courses of accelerations in three directions, the ASI index values amounted to about 1.33 for the analyzed cases. So the performed tests should be classified to level B as far as the acceleration severity index is concerned (according to EN 1317-2).

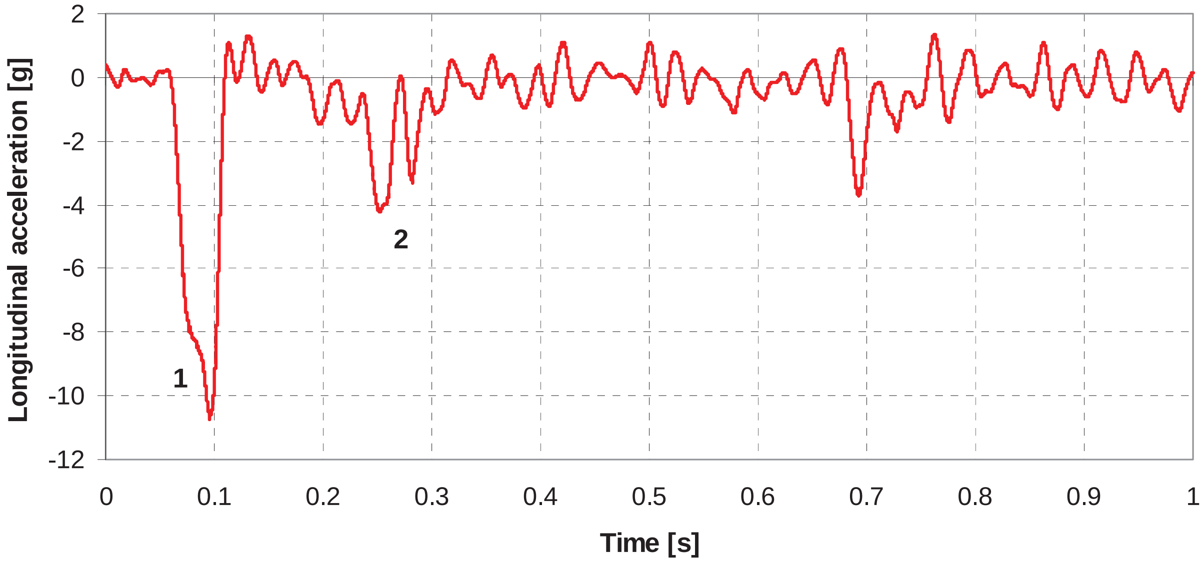

Fig. 7. Longitudinal accelerations of the car centre of mass for the variant III

Figure 8 presents the variation of the relative position angle of 6th and 7th barrier segments. The segment no 6 is hit as the first one during the test. This figure clearly shows the moments when the assumed limiting angles are obtained for analyzed variants (app. 0.22 s, 0.3 s and 0.4 s respectively). They are of high significance for the barrier behaviour later on. The course of collision was the same in all variants until the moment of 0.22 s, therefore no significant differences on the course of the car velocity and accelerations have been observed.

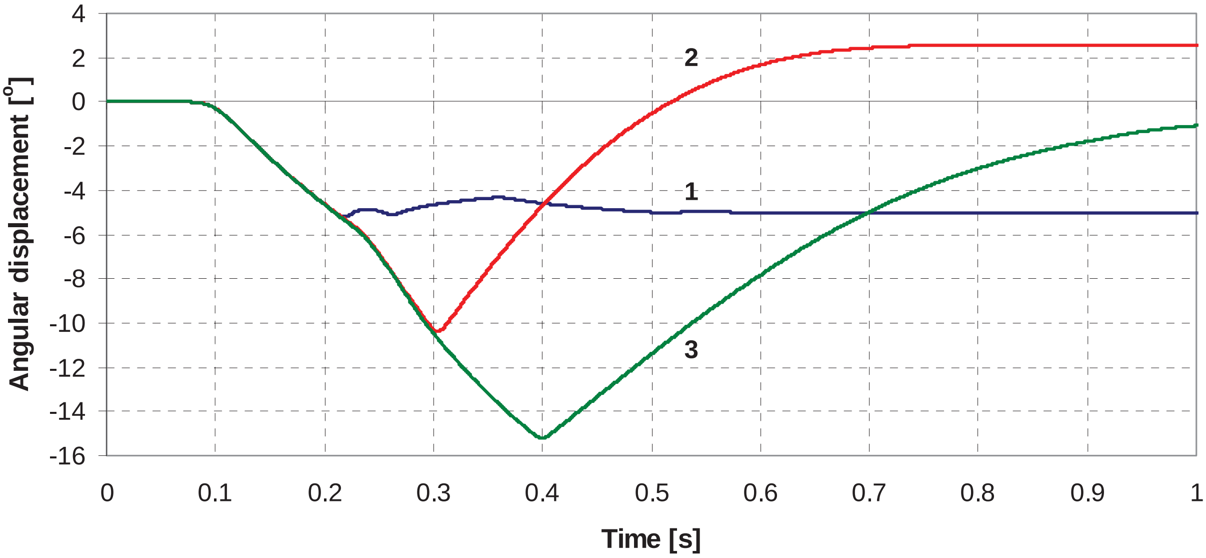

Fig. 8. Relative position angle variation for segments 6 and 7: 1 – variant I, 2 – variant II, 3 – variant III

Figure 9 presents a view of the barrier deformed due to collision at the final simulation stage. It shows that increased limiting angle resulted in higher number of damaged segments as higher segment displacement values. Moreover, Fig. 9c presents the way of defining the working width.

Figure 10 presents the working width variation during collision. Its maximum value makes the classification criterion according to the standard. Results obtained for variant I (0.96 m) classify the barrier to class W2, variant II (1 05 m) to class W3, and variant III (1.32 m) to class W5.

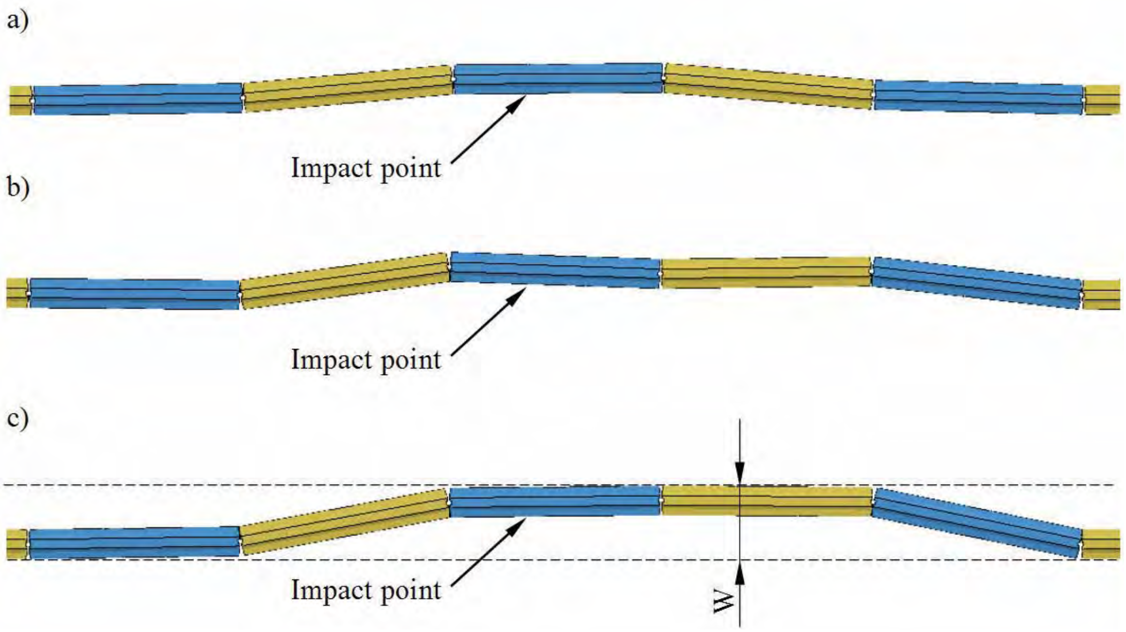

Fig. 9. A view of deformed barriers: a), b), c) – variants I, II and III respectively

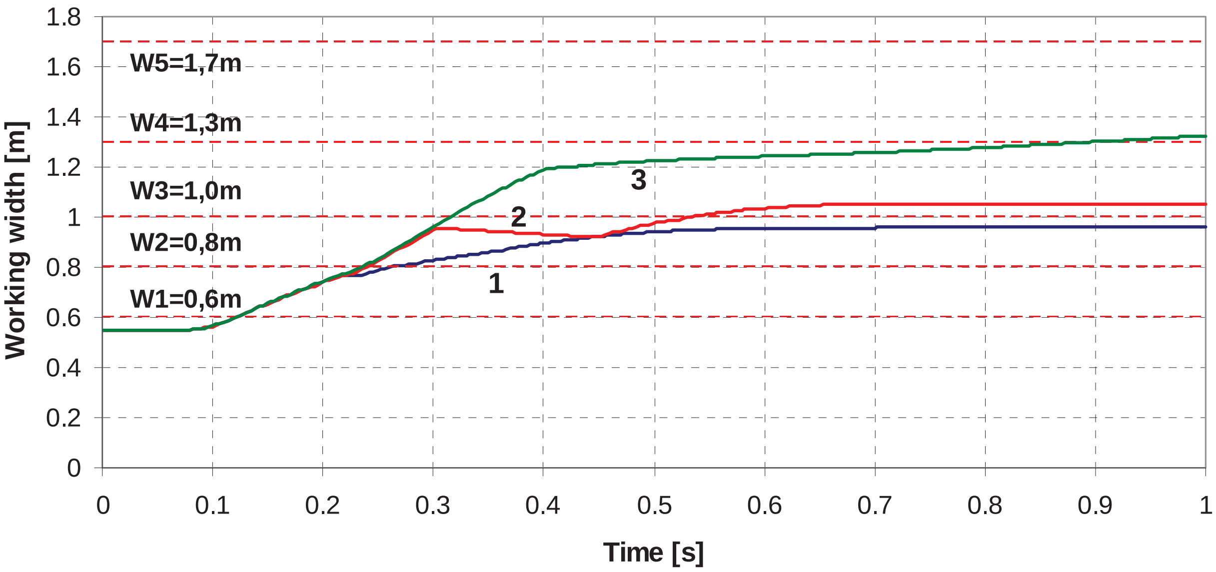

Fig. 10. Working width variation during collision: 1 – variant I, 2 – variant II, 3 – variant III

5. Summary

This work presents the results of the simulation tests performed to assess a possibility of shaping the working width of the concrete protective barriers. The tests and assessment have been carried out according to the requirements included in the standard EN 1317-2. Assumed vehicle allowed performing the TB11 test. The simulation tests have been performed on the basis of successfully verified vehicle and the concrete barrier models.

Results obtained during the tests indicate that there is a possibility of shaping the working width by changing the structure (limiting angle adjustment) of designed barrier joint. Due to a short time of the car collision with the barrier, no significant influence of the limiting angle on the maximum loads affecting the vehicle passengers and calculated acceleration severity index (ASI) has been observed. Differences appear in the later course of collision. Obtaining, in various moments of time, the maximum angles of the relative barrier segment displacement (different for each variant) affected the car motion trajectory. Higher limiting angle resulted in higher angle of car reflection from the barrier. Moreover, it has significantly affected the dynamic deflection value and the working barrier width as well as the barrier shape after the test.

Broadening the analysis to other barrier segments (e.g. 2 m and 6 m distances) seems to be important. Combined with the limiting angle change, it can broad the possibilities of shaping the barrier behaviour during collision.

References

[1] Dacko, M., Borkowski, W., Dobrociński, S., Niezgoda, T., Wieczorek, M., *Metoda elementów skończonych w mechanice konstrukcji*, Arkady, Warszawa 1994.

[2] Hallquist, J. O., *LS-DYNA Keyword User’s Manual. Version 971*, Livemore Software Technology Corporation, Livermore 2007.

[3] Hallquist, J. O., *LS-DYNA Theoretical Manual*, Livemore Software Technology Corporation, Livermore 1998.

[4] Kleiber, M., *Metoda elementów skończonych w nieliniowej mechanice kontinuum*, IPPT PAN, Warszawa-Poznań 1985.

[5] *CEN, EN 1317-1, Road resistant system – Part 1: Terminology and general criteria for test methods*, 1998.

[6] *CEN, EN 1317-2, Road resistant system – Part 2: Performances classes, impact test acceptance criteria and test methods for safety barriers, 1998.*

[7] Borkowski, W., Hryciów, Z., Rybak, P., Wysocki, J., *Badania skuteczności drogowych systemów zabezpieczających*, Journal of KONBiN, No. 1(13), Safety and Reliability Systems, Warsaw 2010.

[8] Borkowski, W., Hryciów, Z., Rybak, P., Wysocki, J., *Ocena wpływu rodzaju podłoża na zachowanie betonowej bariery ochronnej*, Górnictwo Odkrywkowe Nr 4, Wrocław 2010.

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

Acknowledgement

The scientific work financed by the funds assigned for the science during 2007-2010 as a developing project.