

Numerical studies on the influence of selected construction features and road conditions on the performance of road cable barriers

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Abstract. Cable barriers are commonly used on Polish roads, including motorways and local roads. Their main elements are pre-stressed wire ropes, which are usually anchored at two ends in concrete blocks buried in the soil. In this work numerical studies concerning the influence of selected construction features and parameters of the vehicle motion on the performance of cable barriers were performed. Numerical simulations are a useful tool to conduct such analyses that is now being used more and more. The calculations were carried out by using finite element code of LS-DYNA.

1 Introduction

Safety barriers are one of the safety devices used to increase safety on the roads. The vehicle impacting the barrier has to be redirected by barrier back on the road and should continue its motion approximately parallel to the barrier face before impact [1]. One of the types of safety barriers are cable barriers. Their main elements are pre-stressed wire ropes, which must be easily detachable from the posts during the accident [2] and must correctly contain impacting vehicle.

Current standards EN 1317 [3,4] concerning crash tests, published in 2012, established the requirements that barriers must fulfil to be used on roads. However, these standards include only a limited number of cases of the tests, in which the vehicle type, its weight, angle and velocity of the impact are determined, see table 1. Nevertheless, many other configurations of the vehicle impact into barrier may appear in reality on the roads, which mentioned standards do not consider. A really useful tool that can be used as a supplement to the real full scale crash tests are numerical simulations based on finite element method. They allow for the analysis of any number of cases, including those not described in the standards. Some examples of cases not included in EN 1317 standards (e.g. barrier on road's arc or an obstacle behind the barrier) were studied in the works [5–7]. Other examples of using numerical simulation to perform crash tests considering barriers were presented in the papers [8–10]. This method of analysing barriers significantly reduces the number of expensive real crash tests. Currently, the importance of numerical simulations in

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the process of designing and improving barrier systems increases. Namely, the standard [11] enables, under some conditions, certification of the modified barrier systems based on numerical calculations. In recent time many works about conducting simulations of the crash tests appeared, especially the European standards [12–15].

This paper is concerned with the analysis of the influence of selected construction features and parameters of the vehicle motion on the performance of cable barriers system. Numerical FEM simulations were performed in which the effect of barrier's height and also tension applied on the cable on barrier's efficiency was examined. Moreover, the influence of the change of the velocity and the impact angle was studied.

Table 1. Vehicle impact test descriptions [4].

Test	Impact speed, km/h	Impact angle, °	Total mass, kg	Type of vehicle
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*

* Heavy Goods Vehicle

2 Finite element model

2.1 Vehicle

In the simulations of crash tests a numerical model of Geo Metro (Suzuki Swift) was used (fig. 1). The model was obtained from ROBUST project repository [16] and then subjected to some modifications. The model consist of 20089 nodes and 16291 finite elements. The width of the numerical model of the vehicle is 1,70 m, the length is 3,75 m and its height is 1,43 m. The vehicle is equipped with an accelerometer (placed near to the centre of gravity) for recording accelerations and angular velocities, see fig 1c. Based on the data collected from FEM analysis, severity indices (ASI and THIV) were determined. Table 2 shows the comparison of the actual parameters of the numerical vehicle with the standard requirements. Only lateral distance from centre line (CGY) is slightly exceeded, which should not noticeably affect the results of calculation.

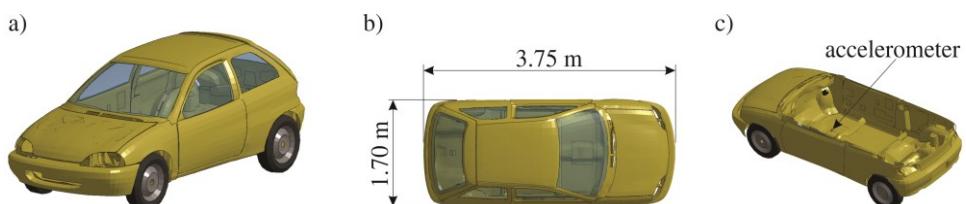


Fig. 1. Numerical model of Geo Metro, a) general view, b) top view, c) accelerometer.

Table 2. Comparison between numerical vehicle's parameters and EN 1317 requirements.

Vehicle specifications	EN 1317 [Błąd! Nie można odnaleźć źródła odwołania.]	Numerical model	Is the requirement met?
Total mass, kg	900 ± 40	928,7	Yes
Dimensions: Front wheel track, m Rear wheel track, m Wheel radius, m Wheel base, m	$1,35 \pm 0,17$ $1,35 \pm 0,17$ Not applicable Not applicable	1,37 1,36 Not applicable Not applicable	Yes Yes Not applicable Not applicable
Centre of mass location: Longitudinal distance from front axle (CGX) Lateral distance from vehicle centre line (CGY) Height above ground (CGZ)	$0,90 \pm 0,09$ $\pm 0,07$ $0,49 \pm 0,05$	0,89 0,10 0,50	Yes No Yes

2.2 Cable barrier

The numerical model of the cable barrier consists of three pre-stressed wire ropes, steel posts and hooks, plastic elements mounted on the top of the posts and soil foundation for each post. The model of the barrier system is 64.124 m long. A shortened description of the implementation of elements and parameters of the model is presented in table 3. Specific names used below are in accordance with the terms contained in the LS DYNA program [17].

Table 3. Description of the implementation of elements and parameters of the model.

Element	Descriptions
Wire ropes	Beam elements, Belytschko-Szwer resultant beam formulation (ELFORM_2), *MAT_MOMENT_CURVATURE_BEAM (*MAT_166), material parameters determined based on [18,19]
Tensioning elements	Beam elements, discrete beam/cable formulation (ELFORM_6), *MAT_CABLE_DISCRETE_BEAM (*MAT_71), tensile force is 20 kN
Posts	Shell elements, Belytschko-Tsay formulation (ELFORM_2), *MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_24), spacing 2 m
Hooks	Beam elements, Hughes-Liu formulation (ELFORM_1), *MAT_PIECEWISE_LINEAR_PLASTICITY (*MAT_24)
Plastic elements	Shell elements, Belytschko-Tsay formulation (ELFORM_2), *MAT_RIGID (*MAT_20)
Soil	Solid elements, constant stress solid element formulation (ELFORM_1) *MAT_SOIL_AND_FOAM (*MAT_005), material parameters taken from [20]
Motion surface	The vehicle motion surface defined by *RIGIDWALL_PLANAR card
Contact	*CONTACT_AUTOMATIC_SINGLE_SURFACE *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE *CONTACT_AUTOMATIC_GENERAL *CONTACT_INTERIOR only for soil
Damping	*DAMPING_GLOBAL only at the beginning of the calculations *DAMPING_PART_STIFFNESS for wire ropes, tensioning elements, posts, soil

Hourglass	*CONTROL_HOURGLASS, stiffness form of Type 2 (Flanagan-Belytschko)
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3 Numerical simulation

The numerical calculations were performed by using finite element code of LS-DYNA [17] (MPP double precision R8.1.0) on supercomputer Tryton managed by Academic Computer Centre (CI TASK) in Gdańsk, Poland.

3.1 Numerical simulation of crash test

Numerical simulation of the normative TB11 crash test (impact velocity 100 km/h, impact angle 20°, car's mass 900 kg, see table 1) was carried out. For the purpose of the present study this test was named 11_00. Impact point was established at one third of the barrier length, that is 1,3 m after the post no. 8. General view of the numerical model of the crash test is shown in figure 2. The results obtained in this test are presented and compared with the rest tests in the table 4.

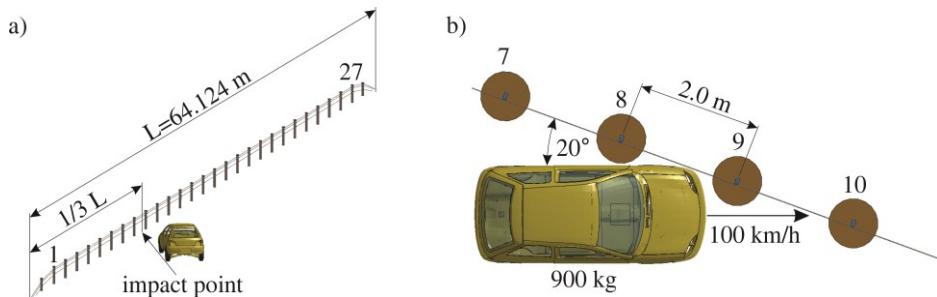


Fig. 2. Numerical model of crash test, a) general view, b) detail of the impact location.

3.2 Influence of selected construction features on the barrier's performance

3.2.1 Barrier's height

In order to investigate the influence of the height of the structure on the crashworthiness of the barrier, two numerical models were created: the first (named 11_01) was 5 cm lower than original model from point 3.1 and the second (named 11_02) was 5 cm higher. The obtained results are presented in point 4.

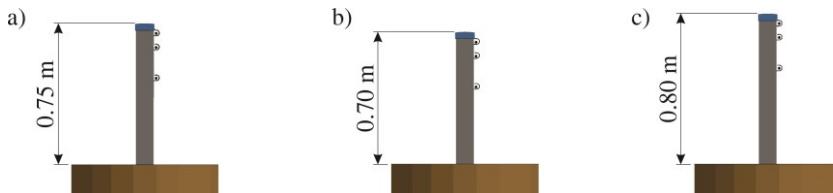


Fig. 3. Barrier's height in a) test 11_00 (based test), b) test 11_01, c) test 11_02.

3.2.2 Tension force in the cable

In this part one of the wire ropes was tensioned with the force lower than the value required by the manufacturer. The tensile force was reduced by 50% (from 20 kN to 10 kN) in the middle wire rope. The simulation named 11_03 was carried out for the purpose of this test. The results from this case are shown in point 4.

3.3 Influence of vehicle motion's parameters on the barrier's performance

3.3.1 Impact angle

In the TB11 test, according to the EN 1317 standard [4], the impact angle should be 20°. The mass of the vehicle and its velocity yield the value of kinetic energy of the impact equal to 40,6 kJ. However, due to the heavier vehicle in numerical simulation (928,7 kg, see table 2) the impact energy in the simulation is 41,9 kJ. For the purpose of study, the effect of vehicle's impact angle on the performance of the barrier, two numerical simulations were conducted. The first simulation (named 11_04) was the test in which the impact angle was set to 10°, the impact energy was then 10,8 kJ, thus the impact energy decreased almost four times. In the second simulation 11_05 the impact angle was 30° and consequently the impact energy increased more than two times and was equal to 89,6 kJ. The results are presented in point 4.

3.3.2 Impact velocity

Two simulations were performed to assess the influence of impact velocity of barrier's performance. In the first simulation 11_06 the impact speed was 50 km/h. This value corresponds to the speed limit in built-up areas in Poland during the day (between 05:00-23:00). At this speed, the impact energy was 10,5 kJ (decreased four times relative to the previous case) and is similar to energy from test 11_04 where the impact angle was set to 10°. In the second simulation 11_07 the impact velocity was 140 km/h which is the speed limit on motorways in Poland. The impact energy for this test was 82,1 kJ thus increased almost two times relative to standard case. The results are presented in point 4.

4 Results

To determine the influence of selected construction features of the barrier and vehicle motion's parameters on barrier's performance, eight numerical simulations were performed. The results from all numerical simulations carried out are presented in Table 4.

Table 4. Results of numerical simulations.

Test	Point	Descriptions	ASI, -	THIV, km/h	W _N , m	Contact length, m
11_00	3.1	base test TB11	0,68	26,9	0,87	8,0
11_01	3.2.1	height decreased by 5 cm	0,75	28,5	0,79	7,5
11_02		height increased by 5 cm	0,75	29,2	1,11	9,0
11_03	3.2.2	50% of initial force	0,66	26,6	0,89	9,0
11_04	3.3.1	impact angle 10°	0,53	20,8	0,60	14,5
11_05		impact angle 30°	1,06	35,3	1,22	7,5
11_06	3.3.2	impact speed 50 km/h	0,49	21,7	0,68	3,5
11_07		impact speed 140 km/h	1,04	30,8	1,33	13,0

Changes in construction features in the analysed cases do not significantly affect the parameters ASI and THIV. However, if the barrier is installed 5 cm higher (test 11_02) than the basic case (test 11_00), the working width increases significantly, which can be very dangerous if there are obstacles such as a road lamp behind the barrier. The height of the barrier installation affects the height of the cables laying on car during the collision. This phenomenon is presented in fig. 4. On the right side of the vehicle, the numbers denote the number of wire ropes at a particular height. In base test 11_00 two wire ropes remained at a height above the wheels and the third the highest wire rope slipped over the hood and then was kept approximately at the level of half of the height of the door's window. In the case when the barrier was installed lower than the original requirement (test 11_01) two cables remained at a height above the wheels and the lower cable was kept at the level of half of the wheel's height. When the barrier was installed higher than it is designed (test 11_02) two cables were at a half of the height of the door's window and the lower cable was kept slightly above the wheel.



Fig. 4. Comparison of cables height in time $T=0,4$ s during tests a) 11_00, b) 11_01, c) 11_02.

The parameters of the vehicle motion's like impact angle and speed have also an effect on obtained result. From the obtained values it can be concluded that larger impact angle or larger car's velocity yield greater severity indices (ASI and THIV) and barrier's deformation (working width). It is worth to notice that the test where the impact angle is 10° (11_04) has similar impact energy to the test with the impact velocity 50 km/h (11_06) and for this two cases the obtained values of ASI, THIV and W_N are comparable. The same relationship can be observed for the two other cases, that is for tests 11_05 and 11_07. Additionally, it is worth noticing that at small angles of impact the length of the vehicle's contact with the barrier has significantly increased, which also affects the size of barrier damages. Fig. 5 shows the comparison of vehicle's trajectory during tests 11_00, 11_06 and 11_07.

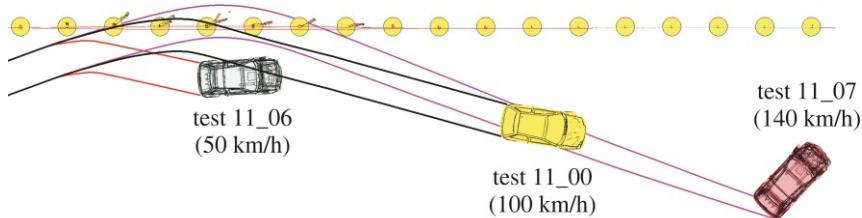


Fig. 5. Comparison of vehicle's trajectory during tests 11_00, 11_06 and 11_07.

5 Conclusions

The work presents the results of the conducted research on the influence of selected construction features on the barrier's crashworthiness, considering the effect of the height of the barrier system and tensile force in the middle wire rope. Also the influence of vehicle motion parameters, that is the impact angle and velocity, on the barrier performance was

examined. Research shows that the above features and parameters affect the behaviour of the barrier during the impact of the vehicle.

The analysed cases revealed that the parameters of the vehicle's impact on the barrier have greater influence on the results than the analysed construction features of the barrier. The impact at an angle or speed greater than EN 1317 standard assume can be dangerous. It should be noted that the speed of 140 km/h is allowed nowadays on motorways in Poland, whilst many drivers are not aware of the fact that the safety barriers for passenger 1500-kg cars are tested at a maximum speed of 110 km/h.

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