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The influence of position of the post or its absence on the performance of the cable barrier system

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Abstract. Road safety barriers are used to increase safety in potentially dangerous places on the roads. They are designed and installed on the roads to prevent any vehicle from getting outside the travelled way or from entering the opposite lane of the road. Barriers, which are used on European roads, have to undergo full scale crash tests according to the EN 1317 standards. Nowadays as a supplement to real crash tests, numerical simulations are commonly used. The work concerns the influence of position of the post or its absence on the crashworthiness of the cable barrier based on numerical study results.

1 Introduction

Nowadays, when a number of new roads and motorways are being built, the issue of proper location of road restraint systems becomes more and more important. These devices are not neutral i.e. vehicle impact with barrier can also be dangerous. Therefore they should be thoughtfully and reasonably installed along the road or in dangerous places. The basic road safety equipment are road barriers. Their main task is to successfully contain the vehicle without breakage of any of its principal longitudinal element and then re-direct the vehicle back on the road at the same time ensuring the lowest possible load on vehicle occupants.

Prior to mass production, safety barriers undergo appropriate crash tests and meet the requirements according to EN 1317 standards [1, 2]. However, these standards do not indicate the type of a safety barrier system to be used on a given road category, leaving these decisions to national or local road authorities.

In Poland, only safety barriers which fulfil the EN 1317 requirements can be used on national roads. The barriers used on national roads should be identical in every aspect to those that have successfully passed the full scale crash tests [2].

The EN 1317 standards consider a limited number of crash test configurations, in addition, they only apply to straight section of the safety barrier, with impact point in its middle section. Whereas in reality there are many different cases, these mentioned standards do not include, like barriers installed on horizontal and vertical road curves

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(concave and convex) [4], variation of vehicle type, velocity and angle of impact, weather or soil conditions (they may not be the same as in the real test) [5], the influence of distance between the barrier and the road or curb [6] or different barrier lengths, in a particular case the barrier may be short, thus not as secure as their full-length parent. In addition, simulations allow to analyse the influence of various obstacles such as truss supporting structure located directly behind the barrier. For these reasons nowadays, in parallel with real crash tests, numerical simulations are commonly used to evaluate and improve the properties of safety barriers. Their great advantage is that their costs are much lower compared to the costs of in-situ tests. They allow for a detailed analysis of the test and to consider many factors, e.g. the change of material properties. Some numerical simulations of crash tests were presented in the papers [7, 8]. It is worth noting that the current standard [9] allows numerical simulations to certify safety barriers modified under certain conditions. In recent years, numerical simulations of crash tests have been significantly developed. In 2012, the standards [10-13] have been published concerning guidelines for numerical simulation of crash test and their verification and validation.

A common problem during the installation of the barrier is a situation when some posts of the barrier have to be mounted in the location of others elements of the road (e.g. drainage wells). In these cases, the posts of the barrier are usually shifted and in this area the post spacing of the barrier is inadequate or simply the posts are not installed. The question remains open about safety of such a structure. Some examples of solutions of this issue are presented in Figs. 1-a, 1-b and 1-c.

In the work the influence of position of the post or its absence on the performance of the cable barrier system was studied. Cable barriers are generally perceived a beneficial construction, usually providing smaller decelerations for people inside the vehicle during the collision than other types of safety barriers. The properties of cable barriers shift the collision population into low-severe type, where occupants are not seriously injured and the vehicle after leaving the barrier can often continue to drive, opposed to the case of steel or concrete barrier [14]. Often road administrators prefer cable barriers instead of others barrier due to their lower cost, ease of maintenance, ease of snow ploughing operations or better see-through appearance and lower crash severity [15]. However, it should be highlighted that cable barriers are not universal devices, in some situations there is a need to use other types of barriers, e.g. where the bridge abutment is adjacent to the road.

In order to assess the influence of the local changes in post spacing, numerical FEM-based simulations of cable barriers were performed.

Fig. 1. An example of a) the local change in post spacing, b) the missing post in cable barrier c) the missing post in steel barrier.

2 EN 1317 Standards

The EN 1317 standards [1, 2] define impact test acceptance criteria for crash tests and test methods that should be subjected to safety barriers prior to their use on public roads. In order to pass the crash test, a safety barrier needs to satisfy a series of requirements e.g. the barrier is bound to successfully contain and redirect the vehicle, the vehicle is restrained from rolling over, any elements of the barrier cannot penetrate to vehicle cabin, and after collision, the vehicle must not cross a line parallel to the initial traffic face of the system before impact (exit box). It is emphasized that the standards do not specify conditions for the barrier geometry, dimensions or materials. Instead they describe the performance classes, giving ranges for the three major criteria: containment level, working width and impact severity level. Containment level defines the barrier capacity to contain vehicle impacting the barrier. For example, if a denotes a N2 Containment Level (table 1), two tests, TB11 and TB32, should be conducted (table 2). On the basis of the results from the tests above, the working width and the impact severity level are determined. The working width marks the ability of the barrier to deform during collision, defined as the maximum lateral distance between any part of the safety barrier on the undeformed traffic side and the maximum dynamic position of any part of the barrier or vehicle if its body deforms around the barrier. The impact severity level (table 3) reflects severity of the impact for people inside a vehicle. Two indicators, the acceleration severity index (ASI) and the theoretical head impact velocity (THIV) are required to determine this level. According to [2], severity index is reported for tests with cars and there is no obligation to evaluate this index for tests with heavier vehicles.

Table 1. Containment levels [2].

Containment levels		Acceptance test
Low angle containment	T1 T2 T3	TB21 TB22 TB41, TB21
Normal containment	N1 N2	TB31 TB32, TB11
Higher containment	H1 L1 H2 L2 H3 L3	TB42, TB11 TB42, TB32, TB11 TB51, TB11 TB51, TB32, TB11 TB61, TB11 TB61, TB32, TB11
Very high containment	H4a L4a H4b L4b	TB71, TB11 TB71, TB32, TB11 TB81, TB11 TB81, TB32, TB11

Table 2. Vehicle impact test descriptions [2].

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

Table 3. Impact severity [2].

Impact severity levels	ASI, -	THIV, km/h
A	ASI ≤ 1.0	
B	1.0 < ASI ≤ 1.4	≤ 33
C	1.4 < ASI ≤ 1.9	

3 Numerical model

The calculations were conducted using a finite element code LS-DYNA (MPP double precision R8.1.0) on supercomputer Tryton managed by Academic Computer Centre (CI TASK) in Gdańsk (Poland). The LS-DYNA system is a basic, widespread tool to perform the simulations of crash tests. This system employs a special form of explicit central difference method to integrate the equations of motion [16, 17].

3.1 Numerical model of vehicle

In numerical simulations, a Suzuki Swift (also called Geo Metro) numerical model was used (fig. 2). This model was taken from ROBUST project repository [18], next subjected to minor modifications. The mass of the numerical model is 928,7 kG and consists of 20 089 nodes and 16 291 finite elements. Near the centre of gravity of the vehicle, a special-purpose finite element to measure accelerations and angular velocities has been defined, on this basis severity indices are determined.

Fig. 2. Car Suzuki Swift (left) and its numerical model (right).

3.2 Numerical model of cable barrier

The model of the cable barrier system of a total length of 64.1 m was create for the study. The system overview is shown on figure 3.

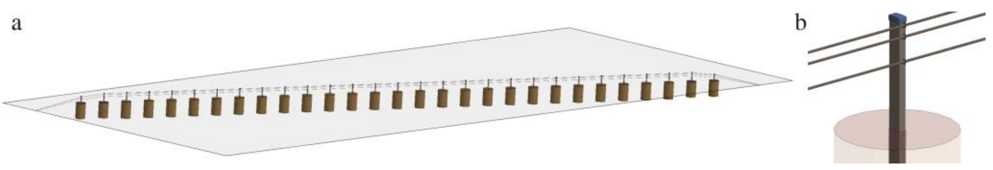

Fig. 3. Cable barrier model: a) general view, b) post and wire ropes view.

The system consists of three wire ropes mounted to the post with steel hooks. The height of the post is 1.7 m, it is embedded 0.95 m in the soil. The spacing between each two posts is 2 m. Two utmost posts at the both ends of the barrier are equipped with additional steel elements to stabilize the post in the soil. A numerical model of the barrier consists of

182 333 nodes and 206 064 finite elements. Since LS-DYNA is used as computational tool, all specific terms used below are described in detail in code theory documentation [16].

Steel posts are discretized by shell elements of Belytschko-Tsay type (characteristic dimensions ~13-15 mm), defined with Mat Piecewise Linear Plasticity material model. Hooks that keep the wire ropes at the correct height are discretized as beam elements. In order to discretize the wire ropes the beam elements with Belytschko-Schwer resultant beam formulation were used. The Mat Moment Curvature Beam material model was assigned to wire ropes. This method was successfully applied in the paper [19], which compares the simulation results to the experimental ones. The length of a single finite element of the wire rope is 25 mm. In order to perform pretension of the wire ropes, the beam elements are applied with discrete cable formulation and with Mat Cable Discrete beam material model. The soil was modelled in the form of cylinders, forming a background for post embedding. Similar solution was used in files available on NCAC public library [20]. The soil is represented by means of Mat Soil And Foam material model.

4 Numerical simulations description

In order to evaluate the influence of the position of the post or its absence on the performance of the cable barrier system, the following research protocol was effected:

1. determination of the most unfavourable impact location of the vehicle on the barrier,
2. change of the location of posts followed by the study of its influence on the results,
3. local removal of posts and its influence on the results.

In order to conduct the above plan, a series of simulations of TB11 crash test was carried out to determine critical impact location. In the TB11 crash test, the 900-kg vehicle impacts the barrier with the velocity of 100 km/h and the impact angle is 20° (table 2). The impact points were set between the posts 10 and 11 every 0.2 m. The test with the highest value of parameter ASI was then assumed as the most unfavourable configuration. After determining the final impact point further simulations were carried out, here the posts no. 10 and 11 were firstly shifted, next removed. The influence of the location change of the post or its absence was determined on the basis of these simulations.

5 Results

5.1 Determination of the impact location

The ASI results obtained for variable impact position are shown in fig. 4. The impact location has a slight influence on the ASI value. In all cases the indicators make it possible to qualify barrier to class A of impact severity level. Based on this results, the impact location was assumed 0.2 m measured from the post no. 10. and for the purpose of further analysis this simulation will be named tb11_00.

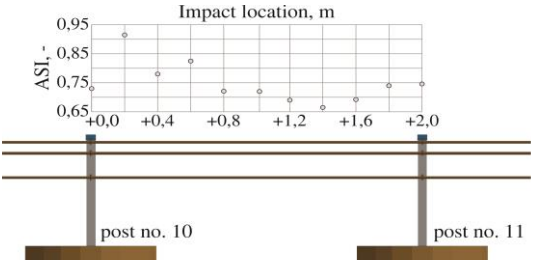

Fig. 4. ASI depending of the impact location.

5.2 The influence of position of the post

In order to determine the influence of the local shift of the post no. 10 (the first post before the impact point) the following values of displacement along the barrier of the post were analysed: -1.0 m, -0.5 m, +0.5 m, +1.0 m. The post after the impact point (no. 11) was analysed in the same way as the post no 10, thus it was also moved: -1.0 m, -0.5 m, +0.5 m and +1.0 m. The results are presented in table 4.

Based on the obtained results, it was found that the change in the location of the post shows a small influence on impact severity indices. In all considered cases, the values of ASI and THIV parameters are lower than for the base test tb11_00 (exception: ASI for the tb11_10_-10 test is higher). The obtained values are also comparable to parameters from the analysis of the determination of the impact location (section 5.1). The local post shift also affects the working width, as is shown in table 4. In the cases where the post before the impact point was moved -0.5 m and -1.0 m, and where the post after the impact point was moved +0.5 m and +1.0 m, the working width was determined by the element of the barrier. The same effect was observed in basic test tb11_00. In these tests deformation of the wire ropes was not significant. The post, which was bent by the car at the level of the ground, determines the working width. In other tests (tb11_10_+05, tb11_10_+10, tb11_11_-10, tb11_11_-05) the working width was determined by the front wheel of the vehicle. Figure 5 shows the comparison of the decisive moments for working width between the tests tb11_00 and tb11_10_+05. For a clearer appearance, the figure shows only the barrier elements above the ground and the vehicle tire, the visibility of other elements of the numerical model has been turned off. It can be noticed that the difference between working widths in these two test is not large, yet in tb11_00 test (dark colour) the vehicle was much closer to the traffic side during the impact (smaller displacement of the wire ropes) and in tb11_10_+05 (bright colour) the vehicle significantly penetrated the barrier. This is presented in fig. 5 which shows the deformation of the wire ropes and the position of the wheel. This fact may be very important if road accident occurs to cause local change in post spacing, e.g. when at a distance slightly greater than the working width determined from the base test tb11_00 (0.84 m), the road lamp will be installed.

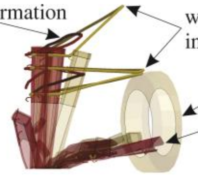

Fig. 5. Comparison of working width between tests tb11_00 and tb11_10_+05.

Table 4. Results of the influence of position of the post.

Post	Shift, m	ASI, -	THIV, km/h	W_N, m	nomenclature
Base test		0.92	28.3	0.84	tb11_00
10	- 1.0 - 0.5 + 0.5 + 1.0	0.93 0.83 0.79 0.83	26.8 27.7 26.6 27.0	0.92 0.89 0.95 0.89	tb11_10_-10 tb11_10_-05 tb11_10_+05 tb11_10_+10
11	- 1.0 - 0.5 + 0.5 + 1.0	0.80 0.79 0.86 0.89	27.3 25.9 26.8 25.5	0.81 0.77 0.86 0.75	tb11_11_-10 tb11_11_-05 tb11_11_+05 tb11_11_+10

5.3 The influence of absence of the post

In order to assess the influence of the local absence of the barrier post, two numerical simulations were carried out, the first in which the post no. 10 was removed, the second in which the post no. 11 was removed. Table 5 shows the obtained results.

Table 5. Results of the influence of absence of the post.

Post absence	ASI, -	THIV, km/h	W_N, m	nomenclature
Base test	0.92	28.3	0.84	tb11_00
10	0.84	25.9	0.89	tb11_10
11	0.79	23.5	0.77	tb11_11

The values of ASI and THIV in the considered cases are slightly lower than for the base test tb11_00. The working width for the tb11_10 was greater than the value obtained from the base test tb11_00, while for the test tb11_11 the working width is smaller. In these both considered cases the car element (front left tire) is decisive upon the working width. Additionally, the obtained values of the analysed parameters are similar to those obtained in the section 5.2. Figure 6 shows the selected result of test tb11_11.

Fig. 6. View of the vehicle during collision in the test tb11_11 (0.14 s after impact).

6 Conclusions

The aim of the study was to investigate how the position change of the post or its absence affects the performance of the cable barrier. This type of problem often appears during the installation of barriers on roads or highways, where the road elements which has been already built impede the correct installation of the barrier.

Numerical simulations show that in the case of the analysed cable barrier the influence of local change of location of the post or its removal is insignificant for the values of the ASI, THIV and W_N parameters. However, it was noticed that variation of the post position (or the post missing) makes the working width increase, so this value might not be already determined by the element of the barrier but the vehicle element may be the most distant part that determines the working width value. This situation can be especially dangerous if there is an existing obstacle e.g. road lamp or some kind of supporting structure for road signs at the distance slightly exceeding the barrier's working width. The obtained results suggest that, when it is not possible to keep the basic spacing of the posts, the elements of road equipment such as street lamps should not be placed, even if their installation is designed at a distance greater than the working width of the barrier.

It should be emphasized that the posts in the cable barrier play a different role than in the steel barrier. In the steel barrier, posts cooperate with the longitudinal rail, whereas in the cable barrier the main role of the posts is to keep the wire ropes at an appropriate height. When the road accident occurs, the wire ropes should be easily detached from the posts. Additionally, as in [17], it is suspected (though it remains unknown) that longer spacing between the posts in cable barrier may cause a vehicle to underride or to pass between the wire ropes. However, these phenomena did not take place in the considered cases. When the vehicle impacted the barrier, the two wire ropes remained at a height above the wheels and the third highest wire rope slipped over the car's hood and then was kept approximately at the level of half of the height of the door's window (see fig. 6).

Numerical simulations were made using the Finite Element Method. This work presents a practical method of analysing the issue that can often be found on roads and highways. The performed simulations confirm the usefulness of numerical simulations to solve this kind of problems. It is noted that these analysis are only predictions and no real full scale crash test has been performed to confirm the numerical calculations.

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