Modelling and Simulation of TB11 and TB32 Crash Tests of Two N2 class Barriers on Horizontal Concave Arc Taking into Account Car Speed Limits

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Abstract. In simulation studies of road safety barriers on a horizontal concave arc with small radii, the reliable velocity which should not be exceeded on a given arc is not usually taken into account. In this work, the numerical modelling and simulations of TB11, TB32 crash tests for selected road safety barriers on a horizontal concave arc with a small radius of R=-150 m, at reliable and increased vehicle's velocities, were conducted. The methodology of the numerical modelling and simulation developed and validated in previous works of the authors was applied. The tests include N2 class steel road barriers, codes SP-05/1 (1.00 m post spacing) and SP-05/2 (2.00 m post spacing) (producer Stalprodukt, Bochnia). Suzuki Swift and Dodge Neon vehicle models from the NCAC library were used, accordingly modified. It was demonstrated that road traffic safety on horizontal concave arcs can be ensured while not exceeding the reliable velocity. The compaction of barrier posts or the use of a composite-foam protective overlay added to B guide rails are not recommended.

INTRODUCTION

Numerical modelling of crash tests of road safety barriers began to develop at the beginning of the 21th century [1-3]. Wilde et al. [4] conducted modelling and simulations of TB11 crash tests for a selected steel N2-W4-A class road safety barrier on selected horizontal arcs. The barrier has B guide rails, spacers of a short length and posts interspaced 2.00 m. The simulations were carried out for horizontal concave arcs with radii of -100 m and - 400 m and for convex arcs radii of 100 m and 400 m.

References [5-7] developed the methodology of advanced numerical modelling and simulation of TB11, TB32 crash tests of rectilinear road safety barriers and in horizontal arcs. The simulations were carried out for the SP-05/2 steel barrier, class N2-W4-A [8], on a horizontal concave arc with a radius of 150 m. The test section of the barrier with a length of 40 m, terminated with 12 m long endings was assumed. The impact velocities were 100 and 110 km/h, respectively for the TB11 and TB32 tests, and the velocity of the impact in the TB32 experimental test was 97.7 km/h. It was shown that the barrier does not meet the exit box criterion. In order to meet this criterion, a composite-foam protective overlay was designed for the B guide rail.

The literature review shows that the problem of ensuring road traffic safety can occur only in the case of road safety barriers on horizontal concave arcs with small radii (e.g. R=-150 m), if the driver significantly exceeds the reliable velocity, which should not be exceeded on the given arc [9].

This paper presents the numerical modelling and simulations of TB11, TB32 crash tests for selected road safety barriers on a horizontal concave arc with a small radius of R=-150 m, for reliable and increased vehicle's velocity. The methodology of numerical modelling and simulation developed and validated in Refs. [5-7] was applied. The research concerns steel road barriers of the N2 class, with the codes SP-05/1 (post spacing 1.00 m) and SP-05/2 (post

spacing 2.00 m) (producer Stalprodukt, Bochnia) [8]. Vehicle models from the NCAC library [10] were used, accordingly modified [7].

ANALYSIS OF REGULATION [9] AND FUNCTIONALITY CRITERIA OF ROAD SAFETY BARRIERS

In this work, roads that meet the following conditions are considered: national motorways (S code, at least two carriageways and at least two lanes on each carriageway); roads without curbs; hardened shoulders; location outside built-up areas. The design velocities in these conditions amount to $v_d = 120, 100, 80$ km/h. The reliable velocities on straight sections of the road, corresponding to the above-mentioned design velocities are equal to $v_r = 130, 110, 100$ km/h. On horizontal circular arcs of roads, vehicles must travel at a reduced velocity. The minimum values of the horizontal radius of circular arc *R* for S roads outside built-up areas as a function of the reliable velocity are given in Table 1 (selected cases).

TABLE 1. Minimum values of horizontal circular arc radius for S roads outside built-up areas (road lateral inclination in %) [9]

v_r, km/h	*R*, m			
	4%	5%	6%	7%
100	1000	800	600	500
80	600	450	350	300
60	250	200	150	125

For a horizontal concave arc of an S road outside the built-up area, with a lateral inclination of 6%, the reliable velocity of a car is 60 km/h, and the increased velocity of 80 km/h was adopted.

Standards [12, 13] define the functional criteria of straight line road safety barriers, tested by means of crash tests. The main parameters of these criteria are: acceleration severity index ASI; theoretical head impact velocity THIV; working width W; vehicle motion trajectory in the exit box. In the light of standard [16] the following is accepted:

- blocking of the car in the barrier;
- blocking of the car in the barrier and rotation of the car around the vertical axis (skidding);
- skidding and rebounding of the car from the barrier;
- breaking of the right front suspension and destruction of the right front wheel;
- sliding of the car along the barrier without rebounding from the barrier.

DYNAMIC SYSTEMS INCLUDED IN TB11 AND TB32 CRASH TESTS

The subject of numerical tests are the SP-05/1, SP-05/2 N2 class barriers [8]. The barrier consists of B guide rail segments with a total length of 4.30 m and an effective length of 4.00 m, Sigma-100 posts with a length of 1.9 m and spacing of 1.0 m (SP-05/1) and 2.00 m (SP-05/2), trapezoidal spacers and rectangular pads. The barrier elements are made of structural steel S235JR with different chemical composition in particular parts of the barrier, subjected to the hot dip galvanizing process. M16 class 4.6 bolts were used as the fasteners. Barrier SP-05/1 is not offered by the manufacturer and was accepted in this work as a modification of the SP-05/2 barrier.

The length of the barrier test section amounts to L = 40.00 m. Barrier endings with a length of 12.00 m each are modelled by equivalent beam elements in accordance with Ref. [11]. The barrier is in a horizontal concave arc with the radius R=-150 m, measured in the post line. The parameters of the TB11 and TB32 crash tests are as follows: impact from the right side; a 20° impact angle; theoretical point of impact at 0.325L; impact velocity $v = 60, 80$ km/h. 8 crash tests were simulated (two barriers, two tests, two velocities). In the simulations, the dynamic process duration was 1.5 seconds (TB11 test) and 2 seconds (TB32 test), including vehicle impact on the barrier, contact with the barrier and vehicle motion in the exit box.

RESULTS OF SIMULATION OF TB11 AND TB32 CRASH TESTS

The results of the simulated TB11 and TB32 crash tests of SP-05/1, SP-05/2 barriers in a horizontal concave horizontal arc with the radius of R=-150 m are presented in Tables 2 and 3. Depending on the type of barrier, type of test and impact velocity, the following car motion trajectories in the exit box occurred:

- T1: car rebound off the barrier and correct redirecting of the car to the road;
- T2: stopping of the car by the barrier and skidding of the car in the exit box;
- T3: sliding of the car along the guide rail without rebounding;
- T4: car rebound off the barrier and barely correct redirecting of the car to the road;
- T5: car rebound off the barrier, skidding and incorrect redirecting of the car to the road.

TABLE 2. Results of simulated TB11 crash tests of SP-05/1, SP-05/2 barriers on horizontal concave arc with radius of -150m

Barrier	v_c , km/h	v_e , km/h	ASI	THIV, km/h	W, m	Trajectory	Test result
SP-05/1	60	45.7	0.87	13.0	0.18	T1	passed
SP-05/2	60	22.9	0.86	20.5	0.32	T2	passed
SP-05/1	80	45.7	1.10	16.8	0.38	T4	passed
SP-05/2	80	28.9	0.69	17.2	0.49	T4	passed

TABLE 3. Results of simulated TB32 crash tests of SP-05/1, SP-05/2 barriers on horizontal concave arc with radius of -150m

Barrier	v_c , km/h	v_e , km/h	ASI	THIV, km/h	W, m	Trajectory	Test result
SP-05/1	60	34.9	0.62	20.1	0.33	T3	passed
SP-05/2	60	29.9	0.61	13.1	0.53	T3	passed
SP-05/1	80	15.9	0.78	22.1	0.53	T5	failed
SP-05/2	80	41.3	0.61	15.6	0.75	T3	passed

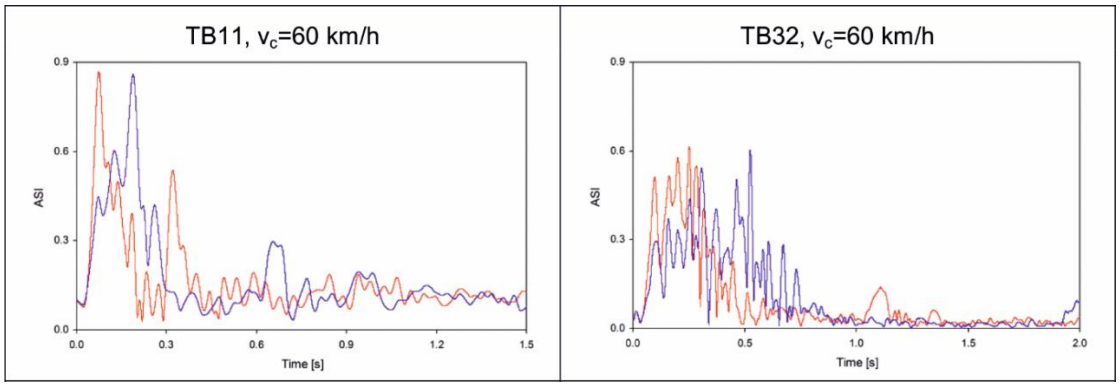

FIGURE 1. Acceleration severity index ASI(t) graphs for barriers SP-05/1 (red), SP-05/2 (blue)

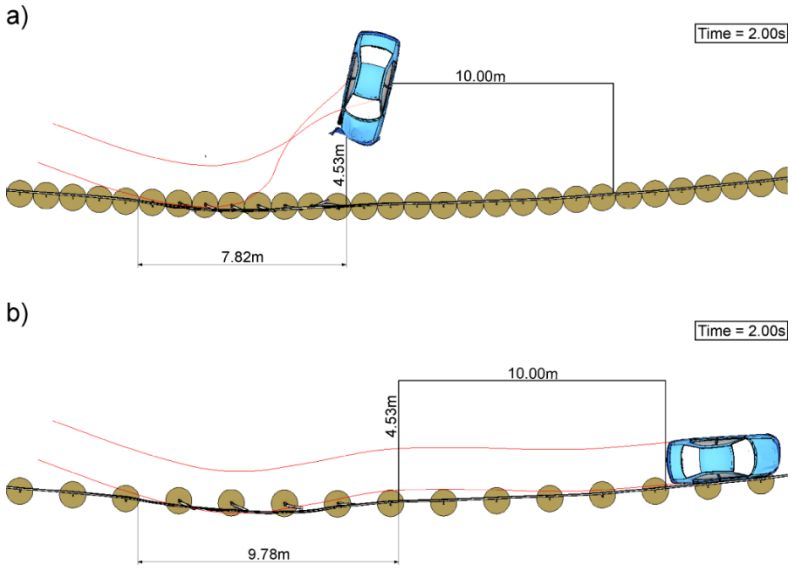

FIGURE 2. Dodge Neon car motion trajectory at impact velocity of 80 km/h: a) SP-05/1 barrier, b) SP-05/2 barrier

Diagrams of function ASI(t) for crash tests at 60 km/h are presented in FIG. 1. The results of the crash test simulations are also presented in FIG. 2, in the form of the final position (for adopted end times) of the Dodge Neon car from the top view, with marking the rear wheel motion trajectory, length of contact with the barrier and exit box.

CONCLUSIONS

The final conclusions from the road crash test simulations performed in this study are as follows:

1) Tests TB11, TB32 of road safety barriers on horizontal concave arcs with small radii should be carried out at the reliable velocity for a given barrier arc.
2) The functional criteria regarding ASI, THIV, *W* for barriers SP-05/1, SP-05/2 on a horizontal concave arc with the radius of $R = -150$ m are fulfilled for an impact velocity equal to the reliable velocity of 60 km/h and the increased velocity of 80 km/h.
3) The vehicle motion trajectories in the exit box vary widely depending on the type of barrier, car type and impact velocity. The exit box criterion is met in all the tested cases except the TB32 test for the SP-05/1 barrier at the increased velocity of 80 km/h.
4) A two-fold reduction in post spacing in SP-05/2 barriers on a horizontal concave arc with a small radius is not recommended.
5) The use of a composite-foam protective overlay on guide rail B of the SP-05/2 barrier is not recommended.

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