EXPERIMENTAL CRASH TESTS INVOLVING PASSENGER CARS AND THE PROTOTYPE CONCRETE PROTECTIVE BARRIER

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Abstract

The work describes the experimental test methodology and results obtained during the experimental crash tests involving passenger cars and the prototype concrete protective barrier, which was built according to the original design prepared by the authors of this article. The crash tests involving a vehicle and the protective barrier cover the experiment results in three basic areas: severity of the collision impact on vehicle passengers, the impact on a vehicle and deformation of the road protective system. Applied testing procedures meet the requirements of the national standards, that make the equivalents of the European standards EN-1317-1:1998, EN-1317-2:1998, EN-1317-3:2000. The tests have been performed for selected crash criteria (TB11 and TB32), for a normal restrain level (N2), using three passenger's cars (Dodge Neon and 2 units of Suzuki Swift). Applied testing procedures meet the requirements of the national standards [1-5]. The work presents examples of experimental test results in three basic areas: intensity of the crash impact on the vehicle passengers, the impact on a vehicle and deformation of the road protective system. The test results have been presented in a form of courses of speeds and accelerations along the vehicle body axes x, y, z. Acceleration severity index (ASI), theoretical head impact velocity (THIV), post-impact head delay (PHD), vehicle cabin deformation index (VCDI) and deformation levels of the road protective system (W) have been also defined.

***Keywords**: experimental tests, test track, concrete protective barrier, crash test, experimental verification*

1. Introduction

Global development of the automotive industry results in intense increase of the number of road users and creates various communication problems within a scope of the road infrastructure, new vehicle structures, and most of all a wide scope of traffic safety issues. The basic objective of those various actions is to provide maximum safety for the road users. Many European and world initiatives (programmes) within a scope of safety level improvement e.g. RISER (Roadside Infrastructure for Safer European Road), RANKESR (Ranking for European Roads Safety - UE, AASHTO Roadside Design Guide - USA, Use of Passively Safe Signposts to BS EN 12767 - UK, GAMBIT 2005 (till 2013) - Poland, lead to minimization of the number and results of road accidents. As far as the car manufacturers are concerned, new independent continental institutions have been established to assess the new car safety level e.g.: Euro NCAP - European New Car Assessment Programme, A-NCAP - Australasian New Car Assessment Programme, C-NCAP - Chinese New Car Assessment Programme, NHTSA - National Highway Traffic Safety Administration (USA) and others. According to the existing regulations, all new cars introduced on the market have to undergo the tests to assess driver safety level, passenger (including children) and pedestrian safety levels during frontal, side and rear collisions and during a collision with a post. And as far as the road infrastructure is concerned, a series of standards have been defined in the European Union countries (EN-1317-1:1998, EN-1317-2:1998, EN-1317-3:2000) that have to be fulfilled by the road protective systems [1-3]. Their quality and usability in selected dangerous sections of the roads are defined during the crash tests performed on special test tracks [4, 6, 7]. The crash tests involving a vehicle and the protective barrier [5] cover the experiment results in three basic areas: severity of the collision impact on vehicle passengers, the impact on a vehicle and deformation of the road protective system. Applied testing procedures meet the requirements of the national standards [1-5], that make the equivalents of the European standards EN-1317-1:1998, EN-1317-2:1998, EN-1317-3:2000. The tests have been performed jointly by the test teams from the Research Institute for Roads and Bridges (IBDiM) and the Institute for Motor Vehicles and Transport (IPMiT) of the Military University of Technology. This work presents examples of experimental test results in a form of speed and acceleration courses along the car body axes x, y, z as well as the acceleration severity indexes (ASI) in time function. Theoretical head impact velocity (THIV), post-impact head delay (PHD) indexes, the collision impact on a vehicle and permanent barrier deformation after collision with a car have been also defined.

2. Experimental tests

The tests have been performed with three passenger cars, permitted to the road traffic in Europe, with no technical modifications (repairs or other) and with valid technical inspections. The protective barrier and the test vehicle behaviour are evaluated in each crash experiment, with particular consideration of the crash impact on the vehicle passengers. On the basis of component time acceleration course (longitudinal, transverse and vertical) measured in the car centre of mass, the following parameters are defined:

- theoretical head impact velocity (THIV) [km/h],
- post-impact head delay (PHD) [g],
- acceleration severity index (ASI).

Comparison of selected car cabin dimensions before the crash experiment with dimension after the crash made the basis for assessment of the test car cabin deformation.

2.1. Test location

The tests have been performed on the test track of the Research Institute for Protective Systems Sp. z o. o. in Inowrocław, Poland (IBSO) (Fig. 1), which is a part of the Certified Research Laboratory of the Research Institute for Roads and Bridges (Accreditation Certificate no. AB 1025 issued by the Polish Accreditation Centre in March 2009). It is the only research centre in Poland which can perform crash tests involving cars and the concrete barrier according to the existing standards [1, 2]. A short description of the test track is presented in the authors' publication [6].

Fig. 1. Prototype concrete barrier placed on the test track in IBSO in Inowrocław, Poland, ready for crash tests

2.2. Test vehicles

Three passenger's cars have been selected for the crash tests: gross weight of app. 900 kg (Suzuki Swift - 2 units.) and app. 1500 kg (Dodge Neon) that meet the requirements of the standard [1]. During preparation for the crash tests, the vehicle operation fluids have been removed, the vehicles have been cleaned from deposits, mud and washed and the fuel tanks have been filled with water. Selected technical parameters of the test cars are presented in Tab. 1.

Fig. 2. SUZUKI SWIFT 1.3GL test car prepared for the crash test – car no. I at the crash point

Tab. 1. Selected technical parameters of the test cars

Parameter name	**Test cars**		
Vehicle type	I - Suzuki Swift 1.3GL	II - Suzuki Swift 1.3GL	III-Dodge Neon
VIN	JSAEAB35S 00142681	JSAEAB35S 00112748	1B3ES27C1 SD350634
Year of manufacture	1992	1991	1995
Gross weight (measured) [kg]	792.8	794.0	1155.0
Gross weight with extra weight (measured) [kg] *)	864.0	865.2	1439.4
Centre of mass coordinates [mm]: X_{CG}	1016.0	1006.0	1232.0
Y_{CG}	12.0	5.0	4.0
Z_{CG}	504.0	504.0	526.0

**) Extra weight includes: measuring and recording equipment, vehicle steering and emergency braking devices and ballast [1].*

2.3. Protective barrier

A 60m long prototype concrete protective barrier, consisting of 15 identical 4 m segments of symmetrical section (Fig. 1), were used for the tests. The segments were connected by means of special joints the so-called links. Rated height of individual segments amounted to 0.80 m.

2.4. Measurement conditions

The tests were performed in autumn 2009 at ambient temperature of 18°-22°C. Measurement conditions were defined according to the methodology recommended by the standards [1, 2, 5]. Two crash criteria TB11 and TB32 were chosen out of 11 crash test types proposed in the standard [2], including 5 (TB11, TB21, TB22, TB31, TB32) for passenger cars with gross weight of 900–1500 kg, for normal protective barrier restrain level (N2). In each test the cars hit the prototype barrier with left front side (the driver side). Assumed crash test criteria have been supplemented with more requirements: speed and impact angle. Visual recording of the crash tests was provided by means of high-sensitivity and high recording rate cameras (minimum 200 frames per second). Wheel tire pressure of the test cars were defined according to the manufacturer's recommendations. Crash test conditions for the test cars are presented in Tab. 2.

Tab. 2. Test crash conditions (criteria) for the test cars according to PN-EN 1317-2

Test car	**Weight [kg]**	**Collision parameters**		**Test type**	**Restrain level**
		speed [km/h]	angle [^{0}]		
Suzuki Swift 1.3GL (I)	864.0	100	20	TB11	N2
Suzuki Swift 1.3GL (II)	865.0	100	20	TB11	N2
Dodge Neon (III)	1439.4	110	20	TB32	N2

2.5. Test equipment

Instead of a dummy, two ACCINO 2 and 3 systems were used in the test cars for recording the time courses of a collision with a protective barrier. They provide measurements of moment acceleration values in a 3-D Cartesian x, y, z system, by means of two triaxial sets of acceleration sensors (from ± 50 g to ± 100 g) and a self-contained gyro angle velocity sensor (measurement scope up to ≤ 300 ^{0}/s). Apart from that, the ACCINO 2 and 3 systems include microprocessor recorders with recording channels and PC compatible software. The systems were designed by built by the scientific team from the System Control and Engineering Department of the Poznan University of Technology according to the assumptions defined by the test teams (ACCINO2 according to IBDiM and ACCINO3 according to IPMiT). The above systems meet the requirements of the standard [5].

Fig. 3. Arrangement of the ACCINO 2 and 3 measuring systems and control system components in the test car no. I Suzuki Swift 1.3GL

3. Test results

As a result of performed crash tests, time courses of accelerations and the velocity of the car centre of mass were obtained. They were used to assess the behaviour of the test car and the prototype concrete barrier. Moreover, the indexes defined in the standard [2], such as: acceleration severity index (ASI) calculated according to dependencies (1), theoretical head impact velocity index (THIV) calculated according to dependencies (3) and the post-impact head delay index (PHD) calculated according to dependencies (4) and dynamic deflection (D) and the working barrier width (W) were also used in the assessment. Dependencies listed above are defined in [1].

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

where:

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

$\bar{a}_{x,y,z}(t)$ - acceleration components of the car centre of mass [g],

$\hat{a}_{x,y,z}$ - boundary acceleration values for individual directions amount to 12, 9, 10 g for longitudinal (x), transverse (y) and vertical (z) directions respectively,

δ - movable time interval (δ = 0.05 s).

$$THIV = \sqrt{v_x^2(T) + v_y^2(T)}, \tag{3}$$

where:

v_x - component of theoretical head velocity towards longitudinal car axis (x) [km/h],

v_y - component of theoretical head velocity towards transverse car axis (y) [km/h],

T - shortest time of head hitting one of three possible surfaces (details in [1]).

$$PHD = \max\left(\sqrt{\bar{\ddot{x}}_c^2(t) + \bar{\ddot{y}}_c^2(t)}\right), \text{ for T< t}, \tag{4}$$

where:

$\bar{\ddot{x}}_c^2(t)$ - average value of the maximum acceleration towards the longitudinal car axis [g],

$\bar{\ddot{y}}_c^2(t)$ - average value of the maximum acceleration towards the transverse car axis [g].

Figure 4 presents a course of the acceleration severity index (ASI) in time function, which shows four significant time acceleration dominants for t = 0.1; 0.2; 0.29 and 0.62 s. The index value at the first time dominant (t=0.1 s) corresponds to the first car collision with the barrier.

Table 3 specifies selected parameters and indexes calculated on the basis of the experiment results during the crash tests involving the test cars and the prototype concrete protective barrier. The ASI index allows defining the vehicle passenger danger level during a collision with the protective barrier system. Three danger levels were defined according to the resolutions of the standard: A, B and C. For performed crash tests (Tab. 3) the following ASI index value were obtained: ASI = 1.56-1.57 and they correspond to the lower limit of level C (1.4-1.9). Test car cabin deformation extent (VCDI) was estimated on the basis of comparison of seven internal cabin measurements made before and after the crash test (details in [2]).

Measurement results are specified in Tab. 4.

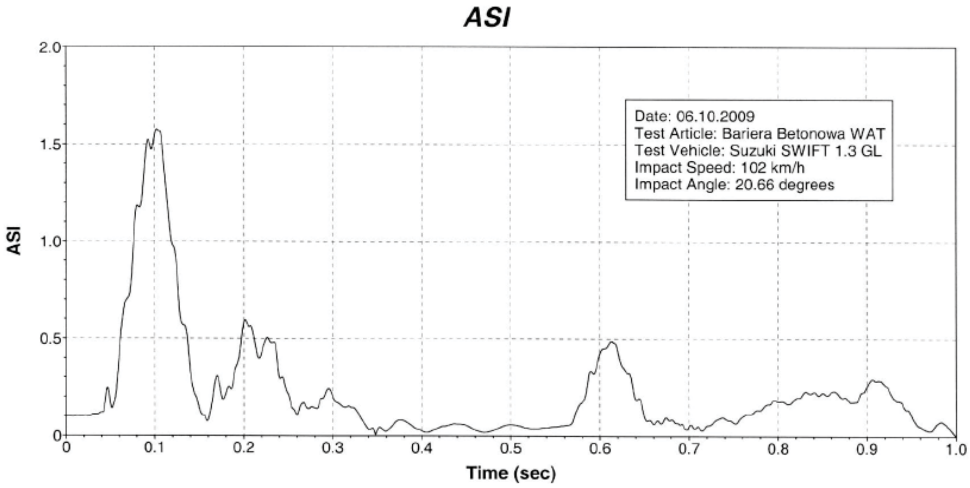

Fig. 4. Selected ASI course in time function for the test car no. I Suzuki Swift 1.3GL

Tab. 3. Experimental test results obtained during the crash tests

Parameter name	**Test cars**		
	I SUZUKI SWIFT 1.3GL	**II SUZUKI SWIFT 1.3GL**	**III DODGE NEON**
Collision velocity [km/h]	102	102	113
Collision angle [^{0}]	20.66	19.32	19.73
Acceleration severity indexes (ASI)	1.58	1.57	1.56
Theoretical head impact velocity indexes (THIV) [km/h]	27	27	25.7
Post-impact head delay indexes (PHD) [g]	10.7	14.6	10.5
Dynamic barrier bending (D) [cm]	27	21	304$^{*)}$
Working barrier width (W) [cm]	82	76	304$^{*)}$
Car-barrier contact length [cm]	500	377	717$^{*)}$

**) special joint was torn*

Fig. 5. The prototype concrete protective barrier after the crash test – visible crash point, impact area and final barrier deformation

The experimental test results presented in Tab. 3 and 4 and on the chart (Fig. 4) make a basis of the quantitative assessment of obtained results.

Tab. 4. Test car cabin deformation extent

Measurement mark*) [cm]	**W – initial state**	**Test cars**		
	T – crash test	**I SUZUKI SWIFT 1.3GL**	**II SUZUKI SWIFT 1.3GL**	**III DODGE NEON**
a – distance between the dashboard and the top of the rear seat	W	180	176	182
	T	180	176	182
b – distance between the roof and the floor plate	W	115	115	114
	T	115	114	112
c – distance between the rear seat and the engine plate	W	111	113	101
	T	110	113	101
d – distance between the bottom part of the dashboard and the floor plate	W	34	37	31
	T	33	37	32
e – interior width	W	130	130	138
	T	130	130	138
f – distance between the lower edge of the right window and upper edge of the left window	W	118	118	112
	T	118	118	112
g - distance between the lower edge of the left window and upper edge of the right window	W	118	118	112
	T	118	118	112
Vehicle cabin deformation index (VCDI) *)		LS0000000	LS0000000	LS0001000

**) Dimensions and description according to the existing recommendations defined in [1] p. A3*

Fig. 6. The test car no. 1 Suzuki Swift 1.3GL after the crash test shown from the driver side and the passenger side

4. Final conclusions

Multivariant simulation tests performed with the use of advanced numerical systems by the finite element method, allowed to assume advantageous dimensions and the segment shape of the prototype concrete barrier. Numerical computation results are presented in the authors' publications e.g. [6, 7]. The crash tests performed on the test track confirmed that the assumed structural concept of the barrier was right. The prototype protective barrier met the requirements imposed on the road protective systems for selected crash criteria TB11 and TB32, at normal barrier restrain level (N2). Tested vehicles underwent deformations caused by the collision with the barrier but each time they were directed by the deformed barrier to the set deflection area. In case of the 900kg cars, the vehicles did not break the barrier, did not go over the barrier, did not fall over in the test track area and they only had some minor deformations in the left front section (Tab. 4, Fig. 6). After braking and stopping on a special prepared aggregate heap, all doors in the test car could be open without using any additional tools (Fig. 6). It is of significant importance for the road accident victims, located inside a car, who need urgent aid given by a paramedic.

Execution of the experimental tests, strictly related to obeying the existing European standards, guarantees the correctness of execution of the experiment and its results make unequivocal assessment of assumed structural concept of the prototype concrete barrier. Obtained experimental test results make a basis for the introduction of changes to the technical design of the prototype concrete protective barrier and they make the reference system for verification of multivariant computation results obtained in the model tests (e.g. 7).

References

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