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DYNAMIC TESTS OF THE PROTECTIVE AND SECURITY BARRIER SYSTEM PROBAR

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Abstract. The purpose of this paper is to present a series of dynamic tests for testing the protective and security barrier of the PROBAR system, developed by STRIX Chomutov, a.s., according to the PAS 68:2013 standard. The goal of the tests was to assess how the obstacle resist impacts and whether it can absorb the energy exerted on it. Verification of the mechanical properties of the device was performed in two types of impact configurations. Emphasis was placed on the behaviour of both the obstacle and the vehicle during the impact and in the short time interval after the collision. In terms of criteria for evaluating the impact tests, it can be stated that Test 2 exceeded the Theoretical Head Impact Velocity (THIV) criterion by $20\,\mathrm{km\,h^{-1}}$, while Test 1 did not exceed the limit value. However, all values for other criteria (ASI, PHD, HIC, 3ms) were within the specified limits, and the safety barrier met the required criteria which allows to be certificated.

Keywords: Ressistant systems, accident reconstruction, road safety, crash tests, security barrier.

1. Introduction

Security devices and barriers that allow the prevention of unauthorised entry of cars into areas with a high density of people are now taken as standard. They can be found in various forms, ranging from simple barriers in the form of concrete blocks to architecturally modified objects, PAS68 800 mm Road Blocker (Heald Ltd., UK) and Anti-Terrorist Security Planters (Safetyflex Barriers, UK). The purpose of these structures is mainly to prevent the intrusion of trucks, which by their weight and resulting momentum exceed passenger vehicles and can cause high damage. Their correct functionality and effectiveness must be individually tested. It is essential that the manufacture of these devices meets the necessary safety criteria to assess and evaluate the resistance of the obstacle. At the same time, the effect of the safety barrier on the driver of the vehicle or on the surrounding area must also be assessed. The subject of this paper is to present a series of dynamic tests (crash tests) in testing the protective and security barrier of patented (Patent No. 308880) PROBAR system, which was provided by STRIX Chomutov a. s., Czech Republic.

2. Legislative provisions

One of the best known documents dealing with safety assessment is the Public Available Specifications standard, PAS 68:2013, provided by the British Standards Institute. In 2005, it became the first British Standard to assess the specification of impact tests and these findings are now incorporated in the European Standard EN 1317-1:2010. This standard is also the adopted Czech technical standard ČSN EN 1317 (737001). The determination of all standards from this publication is essential to properly evaluate the functionality and reliability of a given security barrier. This case study makes full use of all the requirements that should be followed in evaluating each criterion against the requirements and all the safety procedures of the PAS 68:2013 standard.

3. Crash tests

The objective of the tests was to verify the mechanical properties of the subject device with emphasis on the behaviour of the barrier and the vehicle during and in a short interval after the impact. At the same time to determine whether the objects in consideration meet the requirements defined in the mentioned standards and can be implemented in practice.

The installation of the tested barrier was on a flat and dry asphalt surface and the overall impact behaviour was analysed using high-speed cameras. Their application was mainly to determine the impact velocity into the test objects, but also to document details and determine the deformations of the individual objects. Cameras A6300 – i-SPEED 720 (Sony, Japan) with frame rates ranging from 100 fps up to 15 000 fps from several shooting angles were used. Two unmanned aerial vehicles were also used to capture the collision. At the same time, measurement methods using total stations were utilized in order to precisely target individual objects for subsequent reconstruction of the accident scene.

Two types of crash tests, each with a slightly different crash configuration, were performed to verify the functionality of the objects. The aim of the different configurations was mainly to verify the full functionality of the tested devices in their entirety. Test No. 1

was assumed to impact into the steel column, while Test No. 2 was assumed to impact into the steel cables.

One of the test conditions is that the vehicle should not be braked except when the safety situation requires it. Thus, after the impact, the vehicle moved to its final position by inertia and without deceleration produced by the braking system.

3.1. Technical parameters of the tested security barrier

The construction of the barrier consists of a set of identical steel columns interconnected by two steel cables (Figure 1). The columns are made up of 324 mm/12.5 mm (outside diameter/width of material) seamless thick-walled steel tubes, with a column height of 918 mm and a weight of approximately 120 kg. Each column is fixed to the subgrade using 4 anchors (IBO32, 2 m long, fixed with grout). The method of anchoring may vary according to the specific geological investigation of the subsoil, always in relation to the required strength of the anchoring connection. The axial distance between two columns is 3.5 m. The technical parameters of the wire ropes used to connect the columns to each other are 20 mm 6x36WS-IWRC with a weight of 1.64 kg m^{-1}. The bottom rope is located at a height of 550 mm, the top rope at a height of 800 mm.

Figure 1. PROBAR system – test layout

3.2. Testing vehicles

Ford vans (Transit 85 T280 and Transit T 300) were chosen for the crash tests, imported to a total weight of 3.5 t. According to PAS 68:2013, these vehicles are in category N1 (day cab vehicles). The impact speed was determined to be 50 km h^{-1} (±3 km h^{-1}) in the form of a perpendicular collision, with the support of a guided vehicle. The vehicles were equipped with tri-axial accelerometers recording the crash scenario at two measuring points (front and side wall of the vehicle). In order to assess safety within the biomechanical criteria, a Hybrid III 50$^{\text{th}}$ Male Dummy (Humanetics Innovative Solution, USA) equipped with its own sensors was fitted in the driver's seat of the vehicle for test 1. The positions of the sensors fitted in the dummy were located on the head, chest and pelvis. These devices have a range of 1 500 g and are capable of measuring upper and lower neck force and moment, chest compression, lumbar force and moment, and knee deflection. The weight of the dummy is 77.7 kg and the sitting height is 884 mm.

3.3. Assesing criteria

During impact tests, several criteria used for evaluating the safety of barriers according to the standard ČSN EN 1317 and also by PAS 68:2013 were assessed. The criteria assessed are aimed at evaluating the effect of kinetic energy on the vehicle occupants [1–3].

Acceleration Severity Index (ASI) is the first defined criterion which defines the impact severity index. It is one of the main criteria used to evaluate road restraint systems. The ASI criterion is calculated from the measured acceleration on the car body. The criterion should not exceed a value of 1 in a given case and can be expressed mathematically:

$$\mathrm{ASI}(t) = \left[\left(\frac{\bar{a}_\mathrm{x}}{\hat{a}_\mathrm{x}} + \frac{\bar{a}_\mathrm{y}}{\hat{a}_\mathrm{y}} + \frac{\bar{a}_\mathrm{z}}{\hat{a}_\mathrm{z}}\right)^2\right]^{\frac{1}{2}}, \tag{1}$$

where $\hat{a}_\mathrm{x}$, $\hat{a}_\mathrm{y}$, and $\hat{a}_\mathrm{z}$ are limit values for particular acceleration components and can be interpreted as a value of applied acceleration during which the risk of a grave injury of the passenger is minimized (max. light injuries). For a fastened passenger the limits are generally used $\hat{a}_\mathrm{x} = 12\,\mathrm{g}$, $\hat{a}_\mathrm{y} = 9\,\mathrm{g}$ and $\hat{a}_\mathrm{z} = 10\,\mathrm{g}$. The magnitudes $\bar{a}_\mathrm{x}$, $\bar{a}_\mathrm{y}$ or if you like $\bar{a}_\mathrm{z}$ are filtered components of the acceleration. ASI is set as maximum of the range ASI(t) [4].

Theoretical Head Impact Velocity (THIV) is the another considered criterion. The THIV concept has been developed to determine the impact severity of a vehicle occupant in a collision with a restraint system. The magnitude of the THIV is considered to be a measure of the severity of the impact of the vehicle on the restraint system. It is calculated as:

$$\mathrm{THIV} = \left[\dot{x}_\mathrm{b}^2(t) + \dot{y}_\mathrm{b}^2(t)\right]^{\frac{1}{2}}, \tag{2}$$

where $\dot{x}_\mathrm{b}^2(t)$ and $\dot{y}_\mathrm{b}^2(t)$ are the coordinates of the theoretical head speed in relation to the vehicle coordinate system. This criterion is chosen when the vehicle is not equipped with biomechanical dummies. The limit of this criterion is set by EN 1317 at 33 km h^{-1} [4].

Post-Impact Head Deceleration (PHD) criterion was another criterion used to assess the impact severity. The PHD criterion was an additional criterion. After the revision of the Czech standards, it is no longer monitored.

$$\mathrm{PHD} = max\left[\dot{x}_\mathrm{c}^2(t) + \dot{y}_\mathrm{c}^2(t)\right]^{\frac{1}{2}}, \tag{3}$$

where $\dot{x}_\mathrm{c}^2(t)$ and $\dot{y}_\mathrm{c}^2(t)$ is the theoretical head acceleration after first contact with the structure. The PHD should not exceed 20 g.

Another criterion considered is the Head Injury Criterion (HIC). This criterion can be seen as a measure of the probability of head injury in an impact. It is calculated as the maximum of the resultant acceleration function $a(t)$.

$$\mathrm{HIC} = \left[\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a(t)\,\mathrm{d}t\right]^{2.5}, \qquad (4)$$

where $a(t)$ is the resulting acceleration [g] and t_1, t_2 are the time instants during the impact determining the beginning and end of the interval for which the HIC value is the highest. The length of the interval $(t_2 - t_1)$ is 36 ms in the case where no contact with a solid structure has been detected. For a "hard" impact, a time interval of 15 ms (HIC15) is considered to calculate the maximum value. The limit value of the HIC criterion is 1 000 – the limit indicates a 50 % probability of severe head injury [5, 6].

The last criterion assessed was the 3ms criterion. Unlike the previous criterion (THIV), it is applicable not only to head injuries. Its threshold value determines the tolerance for the occurrence of severe injury. The limit value for the head is 80 g (accelerations greater than 80 g must not act for more than 3 ms) [4, 7].

4. Results of the tested barrier

The test results can be divided into two parts. In the first part, the accident site was back-tracked and reconstruction of the accident was performed using laser scanning and high-speed camera footage. The second phase focused on the evaluation of accelerometer data and performed calculations according to the above mentioned standard. The results of the tests are summarised in the following Table 1.

	Crash Test No 1	
	Measured value	**Limit value**
ASI [-]	0.75	1
THIV [$\mathrm{km\,h^{-1}}$]	33	33
PHD [g]	11.8	20
HIC36 [-]	32.23	100
3ms [g]	16.61	80
	Crash Test No 2	
	Measured value	**Limit value**
ASI	0.89	1
THIV	53	33
PHD	14.5	20
HIC36	Unmeasured	100
3ms	Unmeasured	80

Table 1. Crash Tests Results

4.1. Crash test into steel column (test No. 1)

During the impact to the barrier, the column was uprooted, but it was not completely ripped out of the ground (it remained anchored in the bedrock at two points). The vehicle was therefore restrained by the system. The surrounding posts were slightly deformed at their fixing points (in the base plates) as a result of the impact. However, in no other case was the column dislodged. The lower steel cable was also broken at the point of impact, but the others remained intact.

When the nose of the car hit the barrier, the right support strut of the car was bent towards the engine compartment, where it damaged the engine of the car. In addition, the right front axle was deformed by contact with the barrier post. This part of the car was pushed up to the point where it came into contact with the body section. This caused a transfer of deformation to the side and upper parts of the bodywork and damage to the windscreen. The right door was deformed and the passenger side space was distorted. The steel cables of the barrier collided with the height above the bumper reinforcement and therefore caused damage in the upper part of the engine compartment. Contact with the steel cables caused deformation of the engine compartment lid including the headlights and both front fenders. The impact with the barrier caused the separation of some parts of the vehicle, e.g. headlight, turn signal, radiator grille, fragments of plastic from the bumper, etc.

4.2. Crash test into steel cable (test No. 2)

In the case of impact with the steel cable, the damage was more pronounced than in the previous test. In this case, two columns were uprooted. However, these again remained anchored to the ground in two places and the vehicle was restrained. The other columns also showed more pronounced deformation, being deformed at the point of attachment and also tilted by the pull of the steel cables during the impact. In addition, the steel wire rope was distorted, but not completely severed as in the previous test.

After the impact of the bow on the steel cables, the bumper cover above the bumper reinforcement was damaged. The areas of the bonnet cover and both headlamps were deformed. The subsequent penetration of the barrier into the engine compartment caused deformation of both fenders, pressing of the radiator wall against the engine and subsequent complete deformation of the engine compartment, with damage to the windscreen and the crew compartment. Some parts of the vehicle were separated, e.g. headlight, turn signal, radiator grille, fragments of plastic from the bumper, etc.

5. Conclusions

The overall evaluation shows that the tested barrier was able to absorb and resist the energy produced by the vehicle during the impact. In terms of the vehicle occupant injury assessment criteria, it can be concluded that Test No. 1 did not exceed any threshold values. Test No. 2 exceeded the THIV criterion by 62 % above the threshold and it is likely that the driver of the vehicle would have been injured. However, the functionality of the safety barrier was assessed as effective and filled all the requirements defined by PAS 68:2013.

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References

[1] United Nations Economic Commission for Europe. Regulation No 21 of the Economic Commission for Europe of the United Nations (UN/ECE) – Uniform provisions concerning the approval of vehicles with regard to their interior fittings, **188**:32–70, 2008. [2023-06-22]. http://data.europa.eu/eli/reg/2008/21(2)/oj.

[2] United Nations Economic Commission for Europe. Uniform provisions concerning the approval of head restraints (headrests), whether or not incorporated in vehicle seats, **258**:30–50, 2020. [2023-06-22]. http://data.europa.eu/eli/reg/2020/1169/oj.

[3] United Nations Economic Commission for Europe. Regulation No 94 of the Economic Commission for Europe of the United Nations (UN/ECE) – Uniform provisions concerning the approval of vehicles with regard to the protection of the occupants in the event of a frontal collision, **254**:77–135, 2012. [2023-06-22]. http://data.europa.eu/eli/reg/2012/94/oj.

[4] L. Nouzovský, T. Kohout, P. Vrtal, J. Nováček. Dynamic tests of the culvert face within crashtests. *Acta Polytechnica CTU Proceedings* **39**:41–48, 2022. https://doi.org/10.14311/app.2022.39.0041

[5] N. Yoganandan, A. M. Nahum, J. W. Melvin (eds.). *Accidental Injury*. Springer New York, 2015. https://doi.org/10.1007/978-1-4939-1732-7

[6] K.-U. Schmitt, P. F. Niederer, F. Walz. *Trauma Biomechanics*. Springer Berlin Heidelberg, 2004. https://doi.org/10.1007/978-3-662-05448-2

[7] C. Got, A. Patel, A. Fayon, et al. Results of experimental head impacts on cadavers: The various data obtained and their relations to some measured physical parameters. In *SAE Technical Paper Series*. SAE International, 1978. https://doi.org/10.4271/780887