Acta Polytechnica CTU Proceedings **41**:66–70, 2023
https://doi.org/10.14311/APP.2023.41.0066

SAFETY ANALYSIS OF THE METHOD OF IMPLEMENTATION OF CRASH CUSHIONS

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Abstract. The topic of the article are vehicle restraint systems. Specifically, the paper focuses on the safety analysis of the way of implementation of crash cushions. Within the safety analysis carried out on the territory of the Ústí Region of the Czech Republic, the most frequently occurring deficiencies in crash cushions and their possible impacts on road safety were identified. The output is the creation of catalogue sheets of crash cushions, which contain the most frequently installed crash cushions on the road network and a summary of methodological requirements for their adequate implementation. The work is intended to serve as an effective tool and a quality source of information for road managers and road safety auditors during their subsequent inspection.

Keywords: Crash cushion, passive safety, traffic accident, road safety systems, safety analysis.

1. Introduction

Road transport is one of the world's most used modes of transport, and the road network is being intensively developed (reconstructed and built) over time. An integral part of this is the increasing degree of automobile use and the higher density of vehicles on the roads. The development of road transport brings a number of positives in the form of more efficient accessibility between territorial units, but also negatives. A typical example is the high number of traffic accidents. Traffic accidents cause both health and economic losses. With the development of modern technology, both active vehicle safety, such as various assistance systems and technical devices aimed at preventing accidents, and passive safety, aimed at mitigating the consequences of accidents, are improving. However, the number of road accidents and accidents with serious consequences is still high and it is necessary to focus on developing [1–3] a safe transport system with socially acceptable levels of safety. In the event of an accident, the aim of passive safety is to mitigate the consequences as much as possible. Among the elements which primarily help to increase passive safety on roads are road restraint systems, such as crash barriers or crash cushions to which this article is devoted. Crash cushions are mainly used to protect isolated obstacles and dangerous places in the vicinity of roads where it is not possible to install crash barriers or other elements [4, 5]. The purpose of the crash cushion is to absorb kinetic energy and safely restrain the vehicle or redirect it back into the lane. The correct effectiveness of a crash cushion occurs provided that it is correctly implemented. Otherwise, the consequences of road accidents could be aggravated or, if not correctly implemented, they can also cause an accident.

2. Crash cushions

Crash cushions are classified as road restraint systems and are placed mainly where for spatial reasons it was not possible to install a crash barrier and the placement of a crash cushion seems to be a more suitable solution. One of the reasons for this may be, that one of the parameters of the barriers, such as the minimum length of the barrier in front of a fixed obstacle, cannot be respected and the solution is to install a crash cushion. Crash cushions are divided into two basic types according to their function, which are gating and non-gating crash cushions. Unlike non-gating crash cushions, gating crash cushions are also tested for side impacts. Their purpose is not only to restrain the vehicle but also to redirect it back into the lane. In the case of side impacts, they perform a similar function as crash barriers. Non-gating crash cushions are placed in places where side impacts are not expected and are designed only for frontal impacts. The resulting choice of crash cushion depends on the type of road where the crash cushion is installed and the type of obstacle or danger point which is supposed to protect. Crash cushions shall comply with the requirements set out in the technical literature specifying the spatial arrangement requirements, their containment level or requirements defining the connection to other road restraint systems. Failure to comply with the requirements defined in the technical literature could result in malfunctioning and possible loss of the ability to restrain the vehicle or negatively affect the accident and its consequences [6].

2.1. Containment level

The basic parameter of crash cushions is the containment level, which is the amount of impact that the crash cushion is able to resist in order to effectively

Speed limit	Minimal containment level
>110 km h^{-1}	110
>90 and ≤110 km h^{-1}	100
>70 and ≤90 km h^{-1}	80, 80/1
≤70 km h^{-1}	50

Table 1. The containment level of crash cushions on roads [7].

restrain or redirect the vehicle. In general, the resulting containment level depends primarily on the speed limit at the location where the crash cushion is installed. The containment levels are divided into several classes, which correspond numerically to the speeds of the vehicles in the performed impact tests [6]. The different containment levels are classified according to the impact tests they must meet for that level. In total, there are 18 types of impact tests, which are defined by several parameters that must be met for a specific impact test. These parameters include the impact track to the crash cushion, the total vehicle mass and the impact speed. In total, five containment levels are defined and the choice of the containment level on the road in a specific location depends on the maximum permitted speed in a specific section [7]. Table 1 shows the individual containment levels for individual maximum permitted speeds on the road.

Crash cushions are only tested by passenger vehicles. For other motor vehicles, such as trucks, crash cushions are not adapted, as it would be difficult to construct such a crash cushion in terms of space and economic requirements. These crash cushions would have to have a large number of shock absorbing segments, which would significantly affect its size and make it virtually impossible to install on the road network. At the same time, its design would be unsuitable for the impact of passenger vehicles due to the required stiffness it would have to have to restrain trucks, which could exacerbate the consequences of such accidents in the case of an impact.

3. Safety analysis of crush cushions

In order to verify the correctness of the implementation of the crash cushions, a local traffic safety investigation was carried out on 18 crash cushions. Specifically, these are crash cushions located on the road network in the Ústí nad Labem region. As part of the inspection, a detailed check of the technical condition of the crash cushions and a check of the level of road traffic safety in the given locations were carried out. At the same time, it was verified whether the crash cushions were made in accordance with the relevant technical regulations such as EN 1317-2 [8], EN 1317-3 [7], TP 114 [9], TP 158 [6]. Additionally, the potential deficiencies in the construction of the crash cushions were identified.

3.1. Classification of crash cushions defects

Several types of deficiencies that may have an impact on road safety have been identified as part of the safety analysis of selected crash cushions. The most frequently occurring deficiency identified in the monitored crash cushions is the inappropriate placement of the crash cushion in the chevron marking. According to TP 158 [6], it is possible to place a crash cushion in the chevron marking, provided that the specified minimum distances of the crash cushion from the nearest outer edge of the chevron marking are observed. However, from the point of view of road safety it is more appropriate to place the crash cushions outside the chevron marking on the unpaved part of the road, if the spatial conditions allow it. This approach generally preserves more space for possible emergency manoeuvres in the area of the chevron marking, which has the positive consequence of increasing safety on the roads. In the event of a loss of control of the vehicle, the chevron marking serves as an area where the vehicle can be returned to the lane and the manoeuvring space is significantly reduced by placing the crash cushion in this area. Another category of deficiencies that were identified during the analysis is the unjustified placement of the crash cushion, or crash barriers that are connected to the crash cushion. In general, road safety systems are placed, where there is an increased danger in the vicinity of the road and in places where there is an identified risk of collision with other road users. Generally, it is more pleasant for road users that, in the event of loss of control, the vehicle moves into a free space and gradually decelerates, rather than hitting an unjustifiably installed restraint system [10]. In several cases, it was found that crash cushions are installed in places where there are no obstacles or dangerous places that would represent traffic safety risks. On the contrary, their presence can increase the probability of a traffic accident. If the vehicle goes off the road, it may hit the crash cushion and worsen the severity of the accident than if the vehicle were to go into a free space, where it would slow down gradually and thus no collision would occur. Based on the findings, it is recommended to install crash cushions only in situations that pose a traffic safety risk and the installation of a crash cushion will improve the current level of safety. The same is applicable for the crash barriers, which are connected to the crash cushions. The necessity of installation crash barriers behind the crash cushion depends on the type of fixed obstacle or place of danger to be protected. A common shortcoming is placement of crash barriers behind the impact attenuator even if it only protects a separate fixed obstacle. More appropriate solution is to place the impact attenuator immediately in front of the fixed obstacle and deflect the impact attenuator at such an angle that the fixed obstacle is protected on both sides. In this case, the crash barriers do not have to continue behind the crash cushion, because they would not have any protective function at all. As already mentioned, the main parameter of crash cushions is their containment level. Very often it has been found during local road safety inspections that the crash cushion has a higher containment level than is necessary for a specific speed. However, it should be noted that a crash cushion with a containment level than is required at a certain location does not have a negative effect on the level of traffic safety. The detected negative effect on traffic safety is only from the point of view of the spatial arrangement in the vicinity of the crash cushion. Crash cushions with a higher containment level generally have larger dimensions and their part may in some cases restrict the space for possible emergency manoeuvres. It is therefore appropriate in these cases to place the crash cushion at a containment level that corresponds to the local maximum permissible speed and does not interfere with the chevron marking due to its size [6, 7].

4. Catalogue sheets of crash cushions

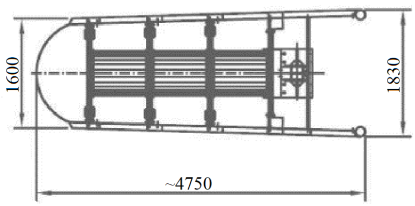
During the safety analysis of the crash cushions it was found that only five of the eighteen locations monitored could be considered to have a socially acceptable design of crash cushions in terms of road safety. These conclusions show that although these are passive safety elements that should contribute to increasing road safety, the placement of crash cushions is not always implemented in accordance with road safety. Based on the resulting knowledge, catalogue sheets of crash cushions have been created, which contain the most frequently occurring types of crash cushions on the road network in the Czech Republic. The catalogue sheets contain an overview of the containment levels of crash cushions, which are their main parameter and are decisive for choosing the type of crash cushion in a specific location [11, 12]. For the correct implementation of crash cushions and maintaining a socially acceptable level of safety, the catalogue sheets also include a summary of methodological requirements according to which it is desirable to implement crash cushions. Furthermore, the catalogue sheets contain the principles of placement of crash cushions, the rules of their spatial arrangement, as well as the design requirements of transitions of crash cushions to crash barriers. In total, the datasheets contain 65 specific types of crash cushions from six companies. (Snoline Spa, HIASA Grupo Gonvarri, Alpina Sicherheitssysteme GmbH, SPS – Schutzplanken GmbH, LUCO Grande Lavori Stradali, Saferoad Holland B.V.). This includes both gating crash cushions, which redirect the vehicle in the event of side impacts, and non-gating crash cushions, which are designed for frontal impacts only. The catalogue sheets divide the crash cushions into groups according to the manufacturing company and similar design features. The crash cushions then differ mainly in their dimensions, and with this their containment level varies, as it is generally the case that the longer the crash cushions are, the higher their containment level increases. Each sheet contains a group of similar types of crash cushions from the same manufacturer and several parameters are given for each specific variant of crash cushion. The first parameter is the containment level of the crash cushion and then the speed for which the crash cushion is adapted. At the same time, the containment level of the crash cushion should correspond to the maximum permissible speed in the section where this safety element is installed. Other parameters are the basic dimensional values of the crash cushions. The length and width of the crash cushion, or for wedge-shaped types of crash cushions, the width at the front of the crash cushion (front width) and the width at the rear of the crash cushion (rear width) are given. The technical drawings of each type of impact cushion with basic dimensions are also an integral part of the resulting catalogue to help visually identify the type of impact cushion. An example of a catalogue sheet for a crash cushion is shown in Figure 1.

5. Conclusion

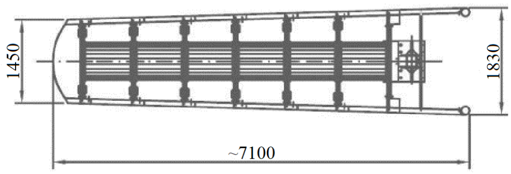
The aim of passive safety systems, which in this case are specifically crash cushions, is to minimise the consequences of road accidents. In order to ensure an adequate level of road safety, it is therefore desirable that all safety systems are implemented not only in accordance with the conditions set out in the technical literature, but also with regard to the specific location, and that the situation is assessed comprehensively in order to maintain a socially acceptable level of safety. For this purpose, for example, a Road Safety Audit or other similar tools may be used, into which the assessment will be integrated. As part of the safety analysis of crash cushions, it was found that crash cushions are often not implemented in accordance with traffic safety assumptions and in some cases not even in accordance with the requirements in the technical literature [6, 7]. In order to increase the safety of traffic, the above-mentioned catalogue sheets of the most frequently installed crash cushions have been created, which also contain a summary of the methodological requirements for implementation of the crash cushions. The catalogue sheets of crash cushions can also be used by road construction designers and road safety auditors, who will be able to distinguish the type of crash cushion according to the sheets and verify the correctness of its implementation. It will also be possible for the professional public to determine the parameters that belong to a specific crash cushion. It will also make it easier to select the type of crash cushion for specific locations according to the parameters that are optimal for the situation in terms of safety. This will provide a broader range of knowledge in the field of road safety systems, which can be used effectively, for example, in the preparation of safety inspections or safety audits and thus contribute to improvement road safety.

TAU Medium

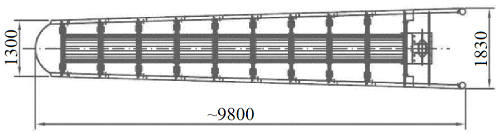
	Containment level	Speed limit [km/h]	Length [m]	Front width [m]	Rear width [m]
TAU 60 M	50	≤ 70	4,750	1,600	1,830
TAU 80 M	80	≤ 90	7,100	1,450	1,830
TAU 100 M	100	≤ 110	9,800	1,300	1,830
TAU 110 M	110	> 110	9,800	1,300	1,830



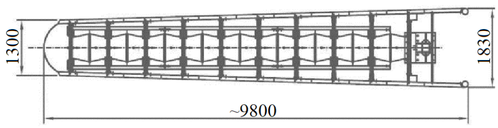
TAU 60 M



TAU 80 M



TAU 100 M



TAU 110 M

Figure 1. Catalogue sheet of crash cushion for TAU Medium.

References

[1] H. İbrahim Yumrutaş, Z. Othman Ali. Experimental performance evaluation of an innovative hybrid barrier system filled with waste materials. *Construction and Building Materials* **316**:125231, 2022. https://doi.org/10.1016/j.conbuildmat.2021.125231

[2] T. Silva, J. Neves. Ascendi's safety barriers upgrading program. In A. Akhnoukh, K. Kaloush, M. Elabyad, et al. (eds.), *Advances in Road Infrastructure and Mobility*, pp. 335–344. Springer International Publishing, Cham, 2022. https://doi.org/10.1007/978-3-030-79801-7_23

[3] T. Micunek, Z. Schejbalova, D. Schmidt. Access bridge design measures for safety increase of the road infrastructure. *Promet – Traffic & Transportation* **25**(6):543–554, 2013. https://doi.org/10.7307/ptt.v25i6.436

[4] M. Budzynski, K. Jamroz, L. Jelinski, et al. Assessing roadside hybrid energy absorbers using the example of safeend. *Materials* **15**(5):1712, 2022. https://doi.org/10.3390/ma15051712

[5] P. Hála, L. Nouzovský. Crashworthiness of brittle blocks as cushioning elements for fixed objects around traffic lanes. *Transportation Research Procedia* **55**:1042–1049, 2021. 14th International scientific conference on sustainable, modern and safe transport. https://doi.org/10.1016/j.trpro.2021.07.076

[6] TP 158 – Tlumiče nárazu, 2014.

[7] ČSN EN 1317-3 – Silniční záchytné systémy – Část 3, 2011.

[8] ČSN EN 1317-2 – Silniční záchytné systémy – Část 2, 2011.

[9] TP 114 – Svodidla na pozemních komunikacích, 2020.

[10] Road safety manual, recommendations from the world road association PIARC, (Příručka bezpečnosti provozu na pozemních komunikacích, doporučení Světového silničního sdružení PIARC), 2004.

[11] J. Nováček, T. Kohout, P. Vrtal, et al. Application of RSA principles to improve the BIM in the road design process with focus on the road restraint systems. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **XLVI-5/W1-2022**:159–164, 2022. https://doi.org/10.5194/isprs-archives-XLVI-5-W1-2022-159-2022

[12] Z. Svatý, K. Kocián, T. Mičunek. Integration of safety assessment in BIM for transportation infrastructure. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* **XLII-5/W3**:143–148, 2019. https://doi.org/10.5194/isprs-archives-XLII-5-W3-143-2019