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Research paper

Safe Lighting Point as a new component of road safety elements

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Abstract: The paper presents the results of research, which included measurements carried out on A dedicated test track of the Road and Bridge Research Institute is related to the improvement of safety of road traffic users, in particular pedestrians, cyclists, scooter users, etc. An in-depth analysis of urban monitoring records of accidents in urbanised areas made it possible to conclude that in the event of a collision between a motor vehicle and a column, the lighting set is fragmented, which has a real impact on the risk to the health and life of vulnerable road users. Research work has therefore been undertaken to develop lighting column designs that fulfil the task of significantly improving safety, particularly for pedestrians and cyclists, in the event of a collision between a motor vehicle and a lighting column. The work was directed at analysing the results of measurements of key parameters of a lighting set structure consisting of a column shaft with movable fittings and a bracket. Based on the research material collected, proprietary design solutions for lighting columns were developed, significantly improving pedestrian safety while meeting the passive safety requirements of vehicle users.

Keywords: crash tests, pedestrian safety, road safety, safe lighting point, street lighting

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1. Introduction

There has been an intensive increase in the number of vehicles on the roads in recent years. This promotes accidents, including collisions between vehicles and road infrastructure components. This is associated with a dense network of components that include road signs, crash guardrails, road lighting, etc. This is accompanied by relatively high vehicle speeds, especially in urbanised areas. In addition, changes to traffic regulations in Poland that change the priority at pedestrian crossings (including the priority of pedestrians who have not yet entered the crossing but intend to), favours accidents or near-accidents. Examples of vehicle collisions with columns or other obstacles, such as signage or roadside trees, are numerous and pose a significant risk to both accident participants and bystanders [1–5] (Fig. 1).

Fig. 1. View of a vehicle fragmented following a collision with a lighting column (source: [6])

Accidents and road incidents were analysed with particular attention to accidents with fixed obstacles such as road infrastructure components. There were 289 accidents involving running into a column/sign in 2023 alone, in which 45 people were killed and 329 injured. Analysing the above data, one can notice a very high number of injuries and a high number of deaths [7–14] (Fig. 2). The response to these incidents is a range of new methods of protecting the vehicle drivers through more modern car safety systems (including vehicle design implementing a controlled crumple zone, seatbelts, airbags) and column design elements implementing speed-appropriate absorption of vehicle impact energy by deforming the column or pulling it from its footing. In terms of requirements for infrastructure, the EN12767 standard for the passive safety of support structures for road equipment has been introduced.

The safety of vehicle occupants can be improved through the appropriate design of support structures, including, among others, lighting columns that take into account the guidelines found in standard EN 12767 [15]. A collision between a car and a column not only results in a risk to the health and life of the driver and passengers but also to other road users - pedestrians, cyclists, scooter users, motorcyclists, passengers, as well as passengers in vehicles with large windows, such as buses.

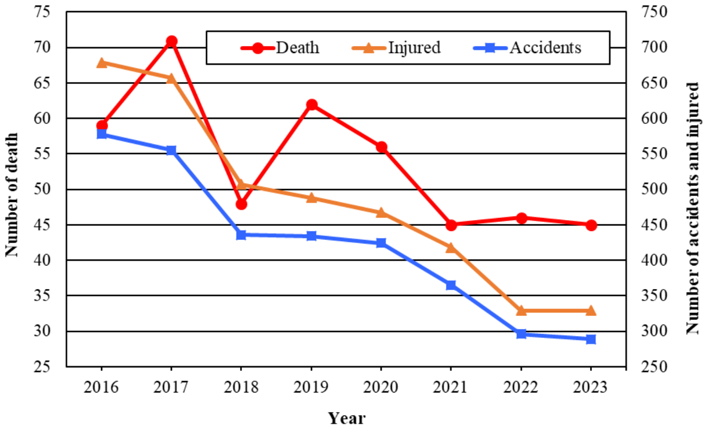

Fig. 2. Accidents involving collision with a column/sign in 2016-2023 (source: [7–14])

The impact of detached column elements, during collisions involving passenger vehicles and lighting columns, on all road users was therefore analysed. An analysis of accidents in urban spaces reveals a high level of risk to people not directly involved in the accident. When a vehicle hits a lighting column, its components are scattered at a considerable distance from the scene. The location of their fall is marked in Fig. 3 (areas 1-3). Most often, these are smaller components of the column and fragments of the luminaire, such as the diffuser, power supply, and components of integrated circuits, which during the fall (mainly due to their sharp shapes), pose a significant risk to other vulnerable road users not directly involved in the incident. This can also include column elements such as the bracket or inspection chamber door.

Fig. 3. Illustration of the position of luminaire components after a vehicle collides with a lighting column in the urban space environment (source: [16])

2. Types of road lighting poles

In the case of lighting poles, it is possible to select both the material and use a pole design that ensures that the energy received from the vehicle during a collision is reduced to a level that ensures the safety of collision participants. In this way, the risk of serious injury can be reduced. It is therefore important that the pole take up some of the energy of the collision, reducing the speed of the vehicle or stopping it completely while maintaining the above condition. The pole should also protect other traffic participants in its vicinity during a crash. The selection of support structures with adequate energy absorption and properties is particularly important in urban areas and along highways, where the presence of road infrastructure increases the risk of collisions [17–20]. Contemporary research in the field points to the need for innovative materials and design solutions, such as deformable or detachable poles, which significantly reduce the force on the vehicle and its occupants. For example, the use of composite poles allows more kinetic energy to be absorbed while reducing the risk of breakaway debris, which could pose an additional hazard [21].

The main factor determining the safety of crash participants is the value of acceleration that acts on the human body at the time of the collision. This acceleration depends on the characteristics of the impact, the direction of impact, and the parameters of the vehicle. Frontal and side collisions are the most common, while rear-end collisions (e.g., vehicle rotation causing a rear-end impact) or angled collisions are less frequent but no less dangerous. Studies show that side crashes generate a higher risk of serious injury due to less structural protection for the sides of the vehicle [22, 23]. In the case of poles with low or zero energy absorption, the vehicle involved in the collision may continue to move, which will pose great risks to pedestrians and cyclists near the collision site.

The different materials used in the construction of poles affect their energy absorption capacity, durability, and maintenance costs. Among the most common types of poles are wooden, concrete, steel and composite poles. Wooden poles are lightweight and relatively inexpensive to manufacture. However, wood is susceptible to degradation by weathering, which shortens its lifespan. Due to their natural flexibility and moderate mechanical strength during a collision, wooden poles absorb some of the impact energy, reducing the risk of serious injury. In studies [17], their relatively low weight has been shown to reduce the force on a vehicle, making them a favorable choice in areas with moderate collision risk. Wooden poles are mainly used in rural areas and small towns, in areas with limited vehicle traffic. Today, most wooden poles have been replaced by other structures.

Concrete poles are commonly used in road infrastructure due to their high strength and corrosion resistance. However, concrete is a very rigid material, which means that during a collision, these poles generate high acceleration acting on the vehicle and its occupants. These columns are most often classified as HE, meaning they absorb a significant amount of crash energy. Research [24] shows that the rigidity of concrete pillars significantly increases the risk of serious injury to the driver and passengers in the event of a crash. At the same time, they do a good job of protecting pedestrians and cyclists off the roadway from speeding vehicles. Due to their lack of energy-absorbing capacity, they are most often used in structures where durability and stability are a priority, such as along highways, in areas with a low risk of collisions.

Steel columns are characterized by high mechanical strength and moderate deformability. Modern structures use breakaway or controlled deformation steel poles, which are designed to undergo controlled damage upon collision. The ability to undergo controlled deformation allows for the reduction of crash energy. Research [21] indicates that steel poles reduce the acceleration values acting on the driver and passengers of the car compared to concrete poles. By using different pole designs and foundations, it is possible to change the level of energy absorption from NE (no energy absorption) to HE (high energy absorption). These types of poles are often used in high-traffic areas, such as cities and highways. Their disadvantage is their higher cost compared to concrete poles.

Aluminum poles are lightweight, corrosion-resistant, and relatively strong. Compared to steel, aluminum has greater flexibility, which increases its ability to absorb crash energy. In addition, the deformed pole structure has a lower tendency to return to its original position, making them safer than steel poles. Lightweight aluminum poles generate lower acceleration values during a collision, which reduces the risk of injury. Research [21] has shown that aluminum poles can be particularly effective in areas with a high risk of collisions. The poles can provide different levels of energy absorption. Due to their higher price compared to steel and concrete, they are mainly used in areas where the safety of traffic participants is a priority.

Composite poles, made of materials such as fiberglass or carbon fiber, are characterized by light weight, high durability and very good ability to absorb crash energy. Compared to other materials, composites are resistant to corrosion and require minimal maintenance. Composite posts are the most effective in terms of traffic participant safety. Research [17] shows that they allow significant reductions in crash participant head velocity (THIV) and head deceleration (PHD), reducing the risk of serious injury to vehicle occupants. They feature relatively low energy absorption and typically appear as NE (no energy absorption) as well as LE (low energy absorption) designs. Due to their low weight and lack of dangerous elements created during a crash, they are most often used in places where the priority is to minimize the risk of injury to so-called vulnerable traffic participants, to which pedestrians and cyclists belong, such as near schools or at pedestrian crossings.

However, the ultimate consequences of a collision depend on several factors, such as the speed of the vehicle at the time of impact, the nature of the impact (frontal, side, etc.), the type of vehicle and its equipment, as well as the personal characteristics of the participants in the collision, including age, weight and overall health [25]. From the point of view of the driver and passengers, particularly vulnerable is the head of the crash participant, which, due to its structure, has relatively little resistance to high acceleration values. Biomechanical studies indicate that serious head injuries are the leading cause of death in traffic accidents [24].

Various biomechanical indicators are used to assess crash risks, including THIV (Theoretical Head Impact Velocity), which determines the theoretical impact velocity of a crash participant's head, and PHD (Post-impact Head Deceleration), which characterizes the deceleration of the head after a vehicle collides with a guardrail. These parameters are calculated based on the results of crash tests and allow for the evaluation of the safety of road infrastructure structures, including pillars, energy barriers, and other elements [24–28].

3. Methodology and measurements

3.1. Study methodology

The performance of the detailed research was initiated with an extensive analysis of road incidents recorded by urban monitoring systems, including in particular incidents involving pedestrians, cyclists, and other vulnerable road users. The author's observations, made subsequently, of preliminary and extended polygon tests contributed to a broader approach to the area of road safety and to going beyond the area directly related to drivers and passengers [27–29]. Today, cutting-edge design work in the field of improving driver and passenger safety focuses on the problems of minimizing the impact of a vehicle colliding with a column for a wide range of speeds [30, 31]. However, the impact of the column on other road users, including pedestrians, cyclists, and other users using so-called personal transport devices, is not considered.

The main premise of the detailed research undertaken was to cover all road users, including pedestrians. Based on the foregoing, the new concept of Safe Lighting Point was defined. The Safe Lighting Point, in addition to its functionality to ensure the safety of drivers and passengers, should, by means of the proposed design solutions, prevent or ensure that the effects of the destruction of the components of the column striking the ground or an object during a collision between a vehicle and a column are prevented or limited, and in particular prevent or limit the effects of the detachment of the bracket and prevent or limit the effects of the detachment of the other movable components of the column shaft – including, in particular, the cover of the inspection chamber. At the same time, all of these measures should not limit or reduce the column's ability to keep vehicle drivers and passengers safe.

The project, which included the work described in this paper, was implemented from June 2019 to the end of 2021. It consisted of several stages. The first stage, crucial from the point of view of the expected results of the construction work, involved a detailed analysis of the mechanism and scale of fragmentation of the lighting system components, consisting of the column shaft with the inspection cover and the bracket, resulting from the impact of a vehicle on the column. To complement the project, experimental work was carried out on a crash test station constructed at Elektromontaż. The polygon tests were carried out on the professional crash test track of the Road and Bridge Research Institute (IBDiM) in Inowrocław (Fig. 4).

The Institute is an accredited body for carrying out this type of crash test. After a series of preliminary tests on the test station of Elektromontaż Rzeszów, 19 full-scale crash tests were carried out on the IBDiM crash test track, with an overrun track 350 m long, a system for remote acceleration of vehicles, measurement and testing infrastructure (internal fibre-optic network, power supply backup system, synchronisation system for remote activation of the measuring apparatus), a station for the recording of fast-changing physical phenomena occurring during the impact of the vehicle with the tested objects, a system for the recording of overloads (acceleration/deceleration) affecting the driver during the impact, including with the use of the ATD (Anthropomorphic Test Device) in the form of the Hybrid III dummy and with the participation of real vehicles.

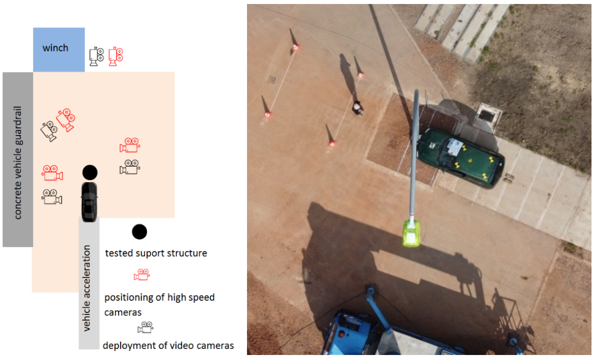

Fig. 4. Schematic diagram of the key elements of the crash test station and top view of a section of the crash track (source: own elaboration)

The research was carried out in two stages. In the first part of the crash tests, all phenomena associated with the fragmentation of the lighting set were analysed, conducting tests for different impact speeds. In the second stage, based on the lessons learned and the proposed structural changes within the column, the effectiveness of the safety improvements, particularly for pedestrians, was assessed.

3.2. Measurement procedure

Passenger cars were used in the study. Their weight of 900 ±40 kg is defined in standard EN12767 [32]. The vehicles were accelerated as required, using a remote acceleration system, over a distance of 350 meters. Figure 5 shows how the overrun occurred during the crash and a sketch of the phase preceding the direct impact of the vehicle on the column shaft. The drawing shows the test vehicle (1), the lighting column (6) with the required impact angle (2), and direction of movement (5) marked. Impact speed measurement zones of 6 m (3) and an impact terminal speed measurement zone of 12 m (4) are also delineated. In addition, the crash zone was equipped with a camera system for video recording and cameras for large-frame recording.

Fig. 5. Illustration of the test vehicle with the column shaft impact procedure (source: own elaboration)

Figure 6, in addition to the diagram discussed, shows actual photographs documenting the preparation of the crash test [33]. Inside the vehicle, a dummy with a weight equivalent to that of a human being (75 kg) was placed on the driver's seat. In addition to the dummy, a measuring apparatus whose measuring range and accuracy must comply with EN 1317-1:2010 was installed.

Fig. 6. View of the measuring apparatus installed inside the test vehicle and the condition of the sample vehicle after the crash test (source: own elaboration)

Verification of the column design for compliance with PN-EN 12767 and the assignment of the column to the appropriate energy absorption class is carried out by crash testing according to the guidelines that are included in the standard and carried out by EN ISO/IEC 17025 by an accredited testing body. During crash track testing, two basic parameters are measured to determine crash severity. Incident severity rates are determined in accordance with EN 1317-1:2010. Two indicators, described below, are measured during each trial. The Acceleration Severity Index (ASI) is a dimensionless value indicating the severity of the accident to the passenger, calculated from the triaxial acceleration values of the vehicle, according to the procedure given in clause 8.1.2 of EN 1317-1:2010. The ASI is calculated using the expression shown below and is dependent on the overload values in all axes, as shown in Fig. 7.

$$ASI(t) = \sqrt{\left(\frac{\overline{a}_x(t)}{12}\right)^2 + \left(\frac{\overline{a}_y(t)}{9}\right)^2 + \left(\frac{\overline{a}_z(t)}{10}\right)^2} \tag{3.1}$$

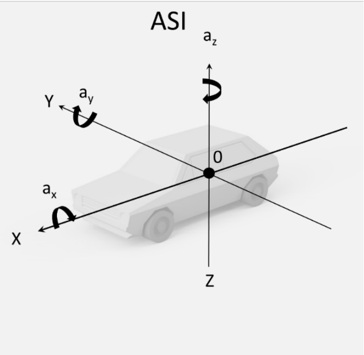

Fig. 7. Defined vehicle axle coordinate system (source: own elaboration)

The second indicator used is THIV (Theoretical Head Impact Velocity), which determines the theoretical impact velocity of the head of an occupant in a crash.

This is the speed at which a hypothetical point of mass of the driver or passenger (e.g., the acceleration-sensitive head of the collision participant) strikes the surface of a hypothetical vehicle cabin. The THIV value is expressed in km/h. This speed shall be calculated in accordance with the procedure given in clause 8.1.3 of the standard EN 1317-1:2010. Surfaces that are theoretically hit by the head in the interior of the vehicle are treated as flat and perpendicular to the x and y axes (Fig. 8). The distance of these surfaces from the initial head position was denoted as D_x in the anterior direction and D_y in both transverse directions.

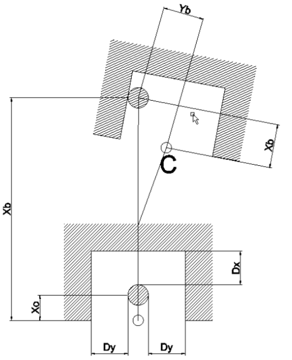

Fig. 8. Illustration describing the theoretical head impact on the left side of the vehicle cabin interior

The head flight time is the time until contact is made with one of the three surfaces, i.e., it is the shortest time T after which one of the three conditions is satisfied:

$$x_b(T) = D_x + x_0 \text{ [m]} \quad \text{and} \quad y_b(T) = D_y \text{ [m]} \quad \text{and} \quad y_b(T) = -D_y [m] \tag{3.2}$$

The standard values adopted are: $D_x = 0.6$ [m] and $D_y = 0.3$ [m].

The theoretical head impact velocity is equal to the head velocity at the moment of T, i.e.:

$$\text{THIV} = \left[V_x^2(T) + V_y^2(T)\right]^{0.5} \text{ [km/h]}, \tag{3.3}$$

where:

$$V_x(T) = \dot{x}_b(T) \text{ [km/h]} \quad \text{and} \quad V_y(T) = \dot{y}_b(T) \text{ [km/h]} \tag{3.4}$$

Ultimately, the formula will take the following form:

$$\text{THIV} = \left[\dot{x}_b^2(t) + \dot{y}_b^2(t)\right]^{0.5} \text{ [km/h]} \tag{3.5}$$

According to Table 1, the passenger safety class can be determined from the measured THIV and ASI parameters. This table includes the permissible values of the ASI and THIV parameters associated with the crash test speeds, ensuring driver and passenger safety [32].

Table 1. Incident severity index [36]

Energy absorption categories	**Occupant safty class**	**Speed**			
		Low speed test 35 km/h		**High speed test 50, 70, 100 km/h**	
		maximum values		maximum values	
		ASI	THIV (km/h)	ASI	THIV (km/h)
HE/LE/NE	E	1	27	1.4	44
HE/LE/NE	D	1	27	1.2	33
HE/LE/NE	C	1	27	1	27
HE/LE/NE	B	0.6	11	0.6	11
NE	A	No test required			

4. Analysis of polygon research results

As a result of a series of polygon tests, parameters relevant to the determination of passive safety, both of driver and passenger, were measured, and the scale of fragmentation of the column elements was analysed. The measurements were carried out in two stages, before the modification of the lighting set structure and after the modification, observing the effects of the structural changes aimed at improving driver and passenger and pedestrian safety.

Based on the analysis of the test results, a relationship was observed between the impact speed and the number and characteristics of the defragmented column elements. The scale of the dispersion of the column elements prior to the structural changes confirmed the occurrence of element detachment, which could also be observed in the crash records captured by the city surveillance cameras. The scale of this phenomenon is large and carries a high degree of danger, especially for vulnerable road users.

During the polygon tests, the deformation of the shaft of the lighting column caused by the impact of the vehicle was recorded, which occurred at all impact speed ranges tested. Its scale is dependent on the strength of the impact. The detachment of the inspection door was recorded at impact speeds of 70 and 100 km/h.

To illustrate the phenomena occurring when a vehicle collides with a column and to illustrate the scale of the collision impact on all road users, a characteristic example of a certified support structure, with a passive safety class NE, was selected for detailed analysis from amongst a series of tests carried out on a crash track. In this case, a proprietary solution of a lighting column, including a bracket and a typical road lighting luminaire, was chosen for the test. The test vehicle was accelerated to a speed of 100 km/h. As a result of the collision, the column structure was detached from the foundation by the attachment dislodging and then thrown at a considerable distance from the point of attachment (approximately 26 m). In its final position, the top of the structure was facing towards the approach. The impact of the vehicle against the structure occurred at a height of 46 cm from the base. A lighting luminaire and bracket were torn away from the column. The luminaire was thrown 3 m from the foundation. The structure did not undergo any additional deformation in the area between the cable cavity, i.e., above the point of impact (height 0.6 m), and the first measuring point on the column shaft, marked with the tape (height 2.0 m). The foundation has not been displaced. The calculated passive safety parameter ASI was 0.5 and THIV was 8 km/h, as shown in Fig. 9.

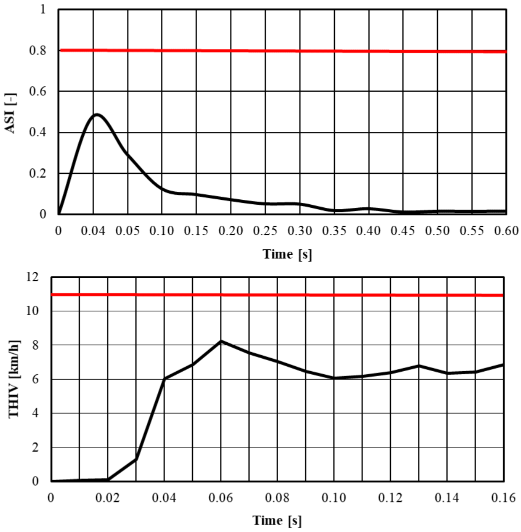

Fig. 9. ASI and THIV diagrams for the 100NE-B-S-SE-SD-0 test

According to EN12767, the passive safety rating of 100NE-B-S-SE-SD-0 has been achieved for the column, guaranteeing the safety of the driver and passengers in the event of a vehicle colliding with the column.

The series of tests carried out also showed the scale of the danger to vulnerable road users in the event of a collision between a vehicle and a lighting column, despite meeting the requirements of the EN-12767 standard for columns with passive safety features. The impact of the car on the column resulted in the detachment of the bracket and the inspection door from the column, as shown in Fig. 10. There was also significant structural damage to the car. The fallen elements of the lighting set were scattered over a wide area, both in the shoulder (sidewalk) lane and the traffic lane of the moving vehicle.

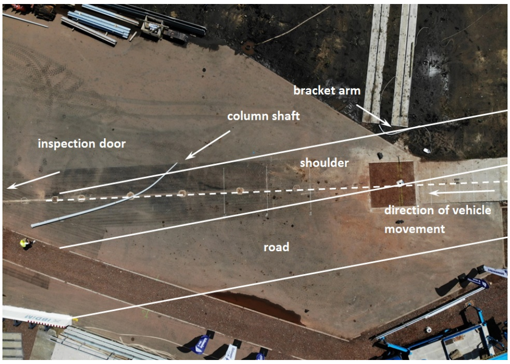

Fig. 10. Scale view of the scatter of the lighting set components following a vehicle collision with a lighting column shaft at a test speed of 100 km/h (source: [33])

A detailed analysis of the condition of the various parts of the lighting set has led to a number of conclusions of a general nature. During the impact of the vehicle, the inspection cover was observed to detach from its shaft on the test station in the course of column displacement. The door has sharp edges along its entire contour. The location of the inspection door, as recommended by the relevant regulations, places it in the centre of the impact forces that cause it to be pushed outwards. An analysis of the fall distance of the doors in the tests carried out shows that, especially at high impact speeds, the distance is significant, reaching up to 60 m, as shown in Fig. 11.

Fig. 11. View of the site of the fallen inspection door and the damage to the column shaft caused when it was pulled out of the ground (source: [33])

The bracket is an important element that transfers stresses from the column shaft to the luminaire. Thus, the two extreme zones of the bracket were analysed, i.e., its mounting area with the column shaft and the bracket mounting area with the luminaire. The bracket is subjected to significant loads during the impact between the vehicle and the column, with two loading phases that can be distinguished. During the first of these, there is a rapid displacement of the top zone of the column shaft caused by the impact of the vehicle. The second phase is usually the impact of the luminaire, attached to the bracket, against the ground. Figure 12 shows an example photo of a bracket separated from the lighting column due to a vehicle impact. As can be seen, the zone of negative impact of the bracket is significant due to its dimensions and weight.

Fig. 12. View of the site of the fallen bracket detached from the column shaft (source: [33])

As a result of a series of crash tests, it was determined that the location where the luminaire is mounted to the bracket is subjected to the greatest amount of force, both when the vehicle hits the column and when the lighting set hits the ground.

After careful analysis of the test results obtained, a number of changes were made to the design of the lighting set. This was done based on observations of tests carried out during the first stage of the research. All changes were incorporated into the column design, implemented, and patented [34–36]. They reduce the risk of accidental injury by reducing direct impact losses and also limit the extent of the impact of secondary fragmentation of lighting point components. The developed new design of the solution under study was called the Safe Lighting Point. The fixing of the door within the inspection chamber has also been modified. The effectiveness of the design changes introduced was verified in the second stage of the study during comparative tests, where it was assumed that the impact of the vehicle hitting the column would be reduced for the driver and vehicle occupants, as well as the scatter field and the extent of fragmentation of the dangerous column components.

The tests that were carried out after the modifications included a series of tests of lighting columns dedicated to pedestrian crossings, i.e. areas with high pedestrian traffic. For this reason, limiting the fragmentation of the lighting set was a priority. It was also assumed that a level of protection of HE or LE columns would be achieved, i.e. that impact energy absorbing structures would be achieved. During one of the tests, the test vehicle was accelerated to a speed of 36.1 km/h and then hit a point centrally located on the shaft of the column at a height of 45 cm (height on the column measured vertically from ground level). This caused a dent in the column at a height of 60 cm and its deflection in the ground, over a length of 20 cm (measured in depth, from the ground surface). Eventually, the vehicle reversed after the collision and came to a stop 60 cm in front of the column. The values of the parameters determining the level of safety measured during the test were ASI 0.8 and THIV 27 km/h, respectively, and were lower than acceptable, as can be seen in Fig. 13.

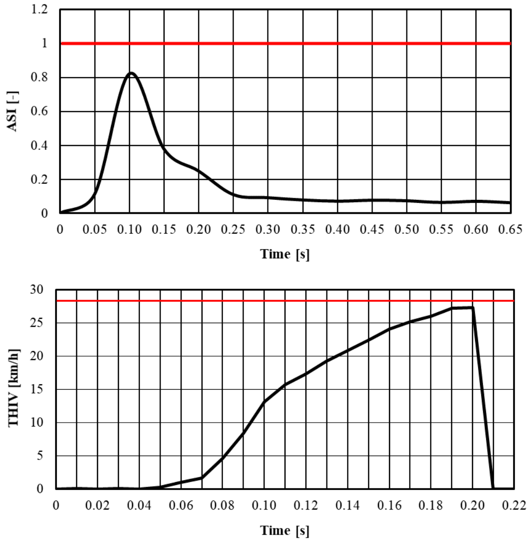

Fig. 13. Diagrams of ASI and THIV values for the impact test at a test speed of 35 km/h

The Safe Lighting Point "behaved" as intended, as it effectively absorbed the energy of the impact, with adequate safety parameters for the driver and passenger and, in addition, the objective of maintaining the full safety of vulnerable road users was met, as there was no fragmentation of the set.

Another test carried out using the same design of the retrofitted lighting set was a crash test using a vehicle at a speed of 68.8 km/h, where the vehicle hit a central test point on a column at a height of 50 cm. The vehicle impact caused the column to deflect 20 cm in the ground and to be completely deformed towards the ground, in line with the direction of the movement of the car. The furthest part of the column lay 7.5 m from where it was installed in the ground. The parameters measured during the test were ASI 1.0, THIV 29 km/h respectively. The Safe Lighting Point "behaved" as expected, as it effectively absorbed the energy of the impact, while maintaining adequate driver and passenger safety parameters. As a result of the impact on the ground, there was only a detachment of the luminaire from the bracket, but it remained attached by wire to the bracket and there was no fragmentation of its components, as shown in Fig. 14.

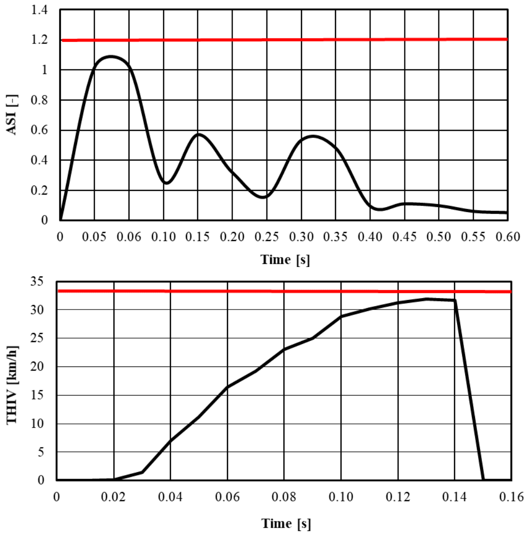

Fig. 14. Diagrams of ASI and THIV values for the impact test at a speed of 70 km/h

Tests were also carried out at the highest test speed of 100 km/h. The vehicle was accelerated to a speed of 103.3 km/h and then hit a central test point on a column at a height of 50 cm from ground level. The vehicle then clipped the column as a result of the collision and eventually came to a stop 37 m from the original location of installation. The column became detached from its foundation base and was displaced from its original location. The deformation of the column was significant due to the force of impact at such a high speed. The proprietary system for mounting the inspection door and the corresponding bracket mounting system passed the crash test. The parameters measured during the test were ASI 1.1, THIV 32 km/h respectively, as shown in Fig. 15. The maximum permissible values for both parameters are indicated by a horizontal red line in the diagrams. The measurements taken indicate that the Safe Lighting Point meets the requirements relating to driver and pedestrian safety.

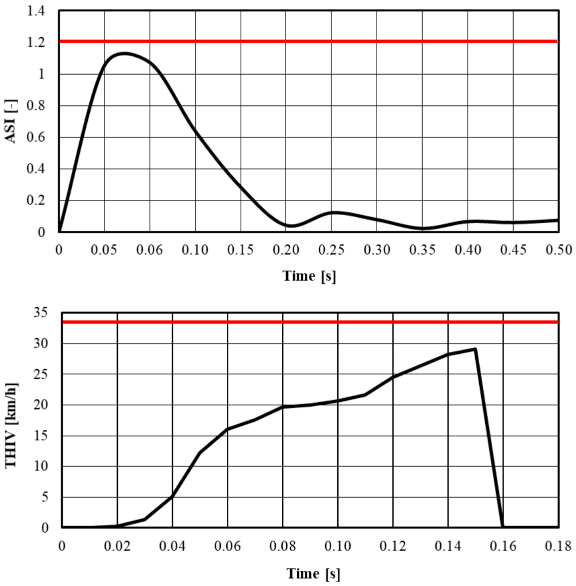

Fig. 15. Diagrams of ASI and THIV values for the impact test at a test speed of 100 km/h

During the tests, at impact speeds of 100 km/h, there was partial fragmentation of the lighting set at the mounting point of the luminaire holder with the bracket, which were subject to the highest loads and accelerations. The luminaire detached, but there was no significant displacement or secondary fragmentation. To ensure the safety of the driver and vehicle occupants, some of the energy was absorbed by the column upon crash with the column shaft.

There was dislodgement of the column from the footing and displacement in the direction of vehicle movement. The site of the column fall includes a section of the shoulder (sidewalk) lane, however, no enlargement of the pedestrian danger zone was observed as a result of the column shaft moving along the ground when dislodged from the footing. Similarly, no significant displacement of the column elements into the vehicle traffic lane was observed, which would have an impact on possible safety hazards, e.g. motorcyclists. It is worth noting that in urbanised areas, speeds of 100 km/h are not allowed, and outside these areas, other protection elements, such as crash barriers are implemented.

5. Summary

As a result of the completed research and development work, an innovative lighting set has been developed that improves the safety not only of the driver and passengers of a vehicle hitting a column, but also the safety of other road users who may be exposed to dangerous, life-threatening impacts of the lighting set components detached from the column shaft. The final structure of the Safe Lighting Point includes five new design solutions, which have been filed with the Polish Patent Office [34–38]. In this respect, the Safe Lighting Point goes beyond the standard column solution with passive safety features. The Safe Lighting Point is an innovative solution for broadly understood road lighting. The developed structure should, on the one hand, retain all its functionalities ascribed to the lighting column and, on the other hand, be structurally modified to provide its new functions. It should be borne in mind that the impact of a speeding vehicle on a column generates complex mechanical loads throughout the column structure, particularly in the region of the end section of the bracket. A detailed analysis of this type of phenomena made it possible to implement a several-stage mechanism to dampen the mechanical forces acting on the column components. The developed Safe Lighting Point fulfils two tasks – it reduces, where needed, the phenomenon of fragmentation of the lighting set and minimises the destructive impact of detached elements on the close vicinity of road users, especially pedestrians and cyclists.

The completed crash test programme allowed a range of structural behaviours to be observed at different test vehicle speeds and energy absorption classes. This made it possible to formulate conclusions, which were included in the proposal for guidelines for the design of road lighting equipment submitted to the Ministry of Infrastructure of the Republic of Poland. The proposed guidelines take into account not only the safety of drivers and passengers but also other road users, including pedestrians. A package of recommendations has been developed for columns with passive safety features that are not shielded by safety barriers. The formulated solutions refer to the speeds allowed on a given section of the road, without distinguishing between the class of road, as crash tests according to EN12767:2019 are performed for specific speed classes and not for road classes. The proposal of guidelines is included in Table 2.

Table 2. Proposal for recommendations for columns with passive safety features

Permissible speed	**Property requirements according to EN 12767:2019**		
	Speed class (km/h)	**Energy absorption category**	**Selection preference**
100 km/h ≤ Vperm ≤ 140 km/h	100	NE1, 2 LE1, 2	a) 100 NE b) 100 LE
70 km/h ≤ Vperm ≤ 100 km/h	70	NE1, 2, 3 LE1, 2, 3	a) 70 NE b) 100 NE c) 70 LE d) 100 LE
50 km/h ≤ Vperm ≤ 70 km/h	50	NE1, 2, 3 LE1, 2, 3 HE	a) 50 HE b) 70 HE c) 50 LE d) 70 LE e) 50 NE f) 70 NE
1 – in the median strip between carriageways, without the use of guardrails, HE columns are used, 2 – on flyovers and bridges, HE columns are used where there is a risk of a column element falling onto the main carriageway, 3 – for column locations where there is a risk of a column element falling into the area of unprotected traffic users, HE columns are used, a)–f) – correspond to the order of preference for selection, determined by the availability of products meeting the requirements described.			

Another proposal developed for the Ministry of Infrastructure was a recommendation on pedestrian crossings [39]. In this respect, it is recommended that high energy absorbing (HE) or low energy absorbing (LE) lighting columns are used in pedestrian crossing areas – for speed levels of 50 or 70 km/h, with a recommended column height of $h \geq 6$ m. The columns should be buried in the ground or mounted on prefabricated foundations, providing a distance of min. 1.5 m from the edge of the road, outside the pedestrian crossing waiting area. The proposed solution of using low- or high-energy absorbing columns can not only be a safe element of the road infrastructure, but can also, from an environmental point of view, have a significant impact on reducing the negative effects of accidents.

In addition, the use of Safe Lighting Points has been proposed for roads where the speed limit is 100 km/h or less, in particular to illuminate areas of heavy vehicular traffic (street lighting, motorway interchanges, traffic slowdown zones) and in the areas of pedestrian crossings, pavements, bus stops, etc., which are an integrated form of a safe lighting column, together with a luminaire dedicated to it, designed to reduce the negative effects of a vehicle impact.

It is proposed that changes and additions be made to the crash test procedures. It is proposed that, as part of the crash tests, luminaires should be installed on the brackets with a weight equivalent to the maximum weight expected for luminaires dedicated to the type of column. There is currently one standardised luminaire weight. It is proposed to introduce new – complementary procedures for assessing the impact zone of a lighting set on the ground. This procedure will provide an answer as to which group of road users will be exposed to the direct impact of the luminaire. It is therefore proposed to run a line of separation perpendicular to the axis of the bracket on the test field. In this arrangement, the half-plane lying to the left of the separation line (which, in fact, is the zone of the carriageway with the two-track vehicles moving) is the zone where the column element is expected to fall. The next zone is the area close to the curb (assumed to be 0.5 m to the right of the separation line; This corresponds to a zone where pedestrian density is usually slightly lower due to the proximity of the carriageway). The third zone is a half-plane 0.5 m or more away, located to the right of the line of separation. This corresponds to a zone with intensive pedestrian traffic (although the sidewalk is often about 2 m wide, the impact of a luminaire on, for example, a building façade will cause it to eventually fall onto the sidewalk. Solutions are postulated to ensure that the column elements do not detach. For higher speeds, it is expected that the extent of the fall area of detached elements will be as small as possible. This could be prevented, for example, by additional structural changes to the column that were applied during the crash tests.

In December 2022, new guidelines were published by the Ministry of Infrastructure of the Republic of Poland regarding the design of equipment for the lighting of non-urban roads and streets, including basic and detailed requirements and a catalogue of typical solutions [40, 41]. Some of the above-mentioned author's proposals have been included in the developed regulation.

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Bezpieczny Punkt Oświetleniowy jako nowy składnik elementów bezpieczeństwa ruchu drogowego

Słowa kluczowe: bezpieczny punkt oświetleniowy, bezpieczeństwo pieszych, bezpieczeństwo ruchu drogowego, oświetlenie uliczne, testy zderzeniowe

Streszczenie:

W artykule przedstawiono wyniki zrealizowanych badań, których elementem były pomiary zrealizowane na dedykowanym torze badawczym, związanych z poprawą bezpieczeństwa uczestników ruchu drogowego, w szczególności pieszych, rowerzystów, użytkowników hulajnóg itp. Dogłębna analiza zapisów monitoringów miejskich w zakresie rejestrowanych wypadków w terenach zurbanizowanych pozwoliła stwierdzić, iż w przypadku zderzenia pojazdu mechanicznego ze słupem dochodzi do rozczłonkowania zestawu oświetleniowego, co realnie wpływa na zagrożenie zdrowia i życia niechronionych uczestników ruchu drogowego. Podjęto w związku z tym prace badawcze, mające na celu opracowanie konstrukcji słupów oświetleniowych, spełniających zadanie istotnej poprawy bezpieczeństwa, szczególnie pieszych i rowerzystów, w przypadku zderzenia pojazdu mechanicznego ze słupem oświetleniowym. Prace ukierunkowane zostały na analizę wyników pomiarów kluczowych parametrów konstrukcji zestawu oświetleniowego złożonego z trzonu słupa z ruchomymi elementami wyposażenia oraz wysięgnika. W oparciu o zebrany materiał badawczy opracowano autorskie rozwiązania konstrukcyjne słupów oświetleniowych, znacząco poprawiające bezpieczeństwo pieszych, przy równoczesnym spełnieniu wymogów bezpieczeństwa biernego użytkowników pojazdów.

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